IFKAD
International Forum on Knowledge Asset Dynamics

20th International Forum on Knowledge Asset Dynamics

PROCEEDINGS

Knowledge Futures: AI, Technology, and the New Business Paradigm

IFKAD 2025

2-4 July 2025
University of Naples Federico II
Naples, Italy



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Knowledge Futures: AI, Technology, and the New Business Paradigm

Università degli Studi di Napoli Federico II
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FOREWORD

IFKAD 2025 - Knowledge Futures: AI, Technology, and the New Business Paradigm

On behalf of the organizing committee, we are delighted to welcome you in Naples for the 20th edition of the annual conference of the International Forum of Knowledge Assets Dynamics (IFKAD 2025). This year, the conference is hosted by the University of Naples Federico II, one of the oldest universities in the world, which has just celebrated 800 years of history. Despite its long tradition, our university has been able to adapt to significant changes over the years, remaining at the forefront of innovation and actively contributing to the current challenges of our society. In this regard, hosting here such an important meeting on the role of Artificial Intelligence and emerging technologies in shaping new business paradigms assumes symbolic relevance.

Thanks to the success of previous editions, IFKAD has emerged as a prominent international scientific forum, aiming to understand and share insights on the role of knowledge in creating organizational value and driving innovation and transformation. In this 20th edition, we intend to enrich the debate on the integration of emerging technologies in knowledge management processes and contribute to delineating the future trajectories of organizations.

Indeed, the spread of digital technologies presents both intriguing challenges and new opportunities for modern businesses while also posing significant risks. In this context, it is crucial to explore how such technologies are transforming industries and society and what are the main related threads for sustainable and inclusive growth.

In this meeting, over 200 contributions will be presented on this topic, covering different areas and perspectives. The key questions motivating the presented studies are:

- How are emerging technologies shaping the future of society and business?
- How can AI be used to create and transfer knowledge within organizations?
- How can digital technologies contribute to social and inclusive innovation?
- How to balance the adoption of digital technologies and human-centered approaches within organizations?
- How risks connected to the adoption of digital technologies may be mitigated?
- How Artificial Intelligence and emerging technologies contribute to link tradition and innovation?

Additional topics, will be reflecting following Special Track themes and questions:

- Navigating AI Adoption in the Service Industry: A Focus on Organizational Dynamics
- New Models and Technologies for Business and Management Innovation
- Diversity Management, Inclusion and Knowledge Creation for Innovation
- Gender Issues in Innovative Society: AI and Technology for New Organizational Paradigms
- Exploring the Intersection of Digital Transformation and Business Model Innovation: Insights and Opportunities
- Entrepreneurship and New Technologies
- Society 5.0: From Knowledge-Based to a Wise-Based Approach
- Advancing Insights in Organizational Behavior, Technologies and Knowledge Management
- Artificial Intelligence and Strategic Knowledge Management
- Navigating AI and Cutting-Edge Technologies in Knowledge Management
- The Role of Advanced Technologies in Innovation 5.0 Scenario as Enabler of Innovation Ecosystems
- Exploring the Impact of Technological Innovation on the Social Sustainability of Agrifood Supply Chains
- Decision Support Methods for Food Waste Reduction in Agri-Food Supply Chain: The KILOWATT Project
- Future Organizations and Strategies: Integrating Humans and Technology for Social and Environmental Impact
- Can the Regenerative Approach Support Manufacturing Industries in Facing Unsustainable Conditions? Building New Business Paradigms on Evidence and Best Practices
- Complexity Approaches to Support New Knowledge and Business Development
- Industry 5.0 and Sustainability: (Re) Shaping Workforce Skills and Management in Multiple Industries and/or Hybrid Organisations
- Artificial Intelligence, Intellectual Capital, and Value Creation: Inspiring New Strategies and Challenges

- The Value of Interdisciplinary Research in Managing Knowledge and Emerging Technologies to Harmonizing Business and Society
- AI and Technology as Catalysts for Knowledge: Shaping Roles, Competences, and Value Creation in Healthcare
- Artificial Intelligence in Medicine: Transforming Healthcare Through Innovation
- Stakeholder Collaboration as a Driver of Knowledge Diffusion and Sustainable Value Creation in Ecosystems
- Technology Management and Business Maturity: Innovative, Sustainable and Secure Digital Transformation Initiatives in Industry
- Accelerating the Shift to a Circular Economy Through Digital Technologies and Knowledge Management
- Translating Feminist Knowledge into Business Practice for Sustainable and Inclusive Strategies, Processes, and Organizations
- Exploring Creative Processes and Decision-Making in the Era of Human & Artificial Intelligence
- Health Technology Assessment and Artificial Intelligence in Healthcare Systems
- The Impact of AI and Digital Transformation on Knowledge Integration Practices in Project Oriented Settings
- The Impact of ESG Factors on Stakeholder Engagement According to AI
- Social Sustainability and AI in the Framework of Knowledge Management
- Shaping the Future: Adapting HEIs to the Evolving Knowledge and Innovation Landscape
- Intelligent Communities and Organisations Driving Innovation by Dealing with Knowledge and Technologies
- Trends in Performance Measurement and Management of Healthcare Organizations: Investigating the Contribution of New Digital Technology in Supporting Knowledge Management and Value Creation
- GenAI for Improving Organizational Processes and Knowledge
- Digital Transformation of Circular Manufacturing Systems
- Artificial Intelligence (AI) and Emerging Technologies for Value Creation in Service-Based Industries
- AI and Knowledge Futures in Cultural Tourism: Shaping a New Paradigm
- Open Innovation Pathways: How Start-ups Thrive in Collaborative Ecosystems
- Questioning the Role of Digital Technologies for Board Decision Making
- Startups and Cultural Heritage Valorization: An Emerging Paradigm

We invite each participant to actively engage in the sessions and discussions to promote the sharing of experiences and create a fruitful context for advancing knowledge and expertise on the topic.

Giuseppe Bruno, Carmela Piccolo, Cristina Ponsiglione
University of Naples Federico II, Italy
Chairpersons, IFKAD 2025

Giovanni Schiuma
LUM University, Italy
President, IFKAD

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AI Perceptions Across Organizational Levels: Barriers and Drivers of Adoption in the Hotel Industry

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Abstract

This study explores the challenges and opportunities associated with adopting artificial intelligence (AI) in the hotel industry, with a particular focus on how perceptions of adoption differ across hierarchical levels. Drawing on consensus mapping and interviews with 21 participants, ranging from top managers and first-line supervisors to non-managerial staff, the research reveals distinct viewpoints on both the benefits and barriers of AI implementation. While top managers primarily perceive AI as a strategic tool for gaining competitive advantage, non-managerial employees tend to emphasize its potential for reducing operational costs. Despite these perceived benefits, the adoption of AI is hindered by limited awareness, insufficient understanding, and a general resistance to change.

Keywords: Artificial Intelligence (AI), hospitality, drivers, barriers, stakeholders, consensus mapping

Paper type: Academic Research Paper

1 Introduction

Technological advancements have become integral to human life and, notably, the integration of artificial intelligence (AI) has emerged as a prevalent trend in this technological era (Özen and Özgül Katlav, 2023). The hospitality industry stands as the most rapidly expanding sector globally, yielding an estimated $8 trillion in revenue and facilitating the creation of 292 million jobs on a global scale (Ruel and Njoku, 2020). The advent of AI applications is reshaping prevailing business paradigms, digging novel opportunities and challenges for the hospitality domain. Hence, in the contemporary landscape of the hospitality industry, the integration of Artificial Intelligence (AI) technologies has emerged as a pivotal strategy to enhance operational efficiency, elevate guest experiences, and drive competitive advantage. However, the adoption of AI within the hotel sector is not devoid of challenges, as it necessitates navigating multifaceted barriers to achieve user acceptance (Morosan and Dursun-Cengizci, 2024).

Scholarly attention has predominantly focused on evaluating the costs and benefits associated with AI implementation in the hospitality sector. Notably, AI streamlines tasks such as self-check-in/out, room services, housekeeping, concierge services, and chatbot interactions, enhancing efficiency while reducing human costs (Ersoy and Ehtiyar, 2023; Zhu et al., 2023). A distinct research avenue examines costumer acceptance or rejection of AI technology, with findings indicating varying levels of convenience and efficiency perception among costumers due to technological complexity and lack of knowledge (Rasheet et al., 2023; Vorobeva et al., 2023). Although current studies primarily analyze the impacts of AI from the standpoint of customers, there is a justified need for additional exploration into its effects on employees (Rasheed et al., 2024; Li et al., 2022). Thus, it becomes imperative to explore the implications of AI technologies on hospitality employees, thus shedding light on emerging opportunities and threats in order to guide competency development aligned with evolving technology. This paper delves into the intricate dynamics of AI adoption across different hierarchical levels within the hotel industry, elucidating the challenges and opportunities that characterize this transformative process.

Specifically, this research engages with n. 21 information-rich participants spanning across varying roles within the hotel industry, including top managers, first-line managers, and non-managerial employees. Through semi-structured interviews and employing the consensus mapping approach (Taracki et al., 2014), this study endeavors to determine the individual perceptions of these distinct groups regarding the barriers and drivers influencing AI adoption.

2 Theoretical background

2.1 Drivers to AI adoption in hospitality

Following Rasheed et al. (2024), drivers to the adoption of AI in hospitality can be categorized in three distinct groups: functional, emotional and situational.

Functional drivers refer to the tangible advantages derived from the fundamental capabilities of AI technologies. Scholarly investigations have consistently emphasized the pivotal roles of perceived usefulness (PU) in shaping consumers' attitudes towards AI adoption (Park et al., 2021). For instance, AI facilitates humans in efficiently accomplishing various tasks, including self-check-in or out, housekeeping, concierge services, and chatbot interactions for information retrieval (Wong et al., 2023; Zhu et al., 2023; Law er al., 2023; Li et al., 2021). Hence, *operational efficiency* pertains to the tangible benefits stemming from the core features of AI technologies, specifically in terms of optimizing processes. Furthermore, AI adoption correlates with reduced workloads and heightened productivity among employees (Ersoy and Ehtiyar, 2023; Buhalis and Moldavska, 2022). Tasks such as data analysis, customer service, and administrative duties are streamlined, allowing staff to focus on higher-value activities. Indeed, prior studies underscore AI technologies' ability to optimize inventory management and streamline processes, leading to *cost savings* for businesses. In addition, factors such as perceived interactivity and innovativeness of AI technologies positively contribute to intentions to adopt and repurchase these technologies (Go et al., 2020; Pillai and Sivathanu, 2020). More specifically, AI technologies' ability to deliver *personalized experiences* based on individual preferences and behaviors fosters positive attitudes towards AI adoption, as users perceive the technology as valuable and relevant to their customization needs. Indeed, service customization triggers greater customers' knowledge, emotional attachment and behavioral commitment (Buehring & O'Mahony, 2019).

Shifting the focus away from the functional benefits for businesses, emotional drivers explore the complex domain of consumer sentiments and motivations towards AI adoption. Prior studies underscore the relevance of perceived human likeness and intrinsic motivations, moderated by socio-demographic aspects such as age, gender, and income in shaping consumers' propensity towards AI adoption in the hospitality sector (Belanche et al., 2020). AI technologies streamline processes (Rasheed et al., 2024), provide personalized experiences (Go et al., 2020), and offer real-time support (Li et al., 2021), enhancing overall service quality. Hence, studies suggest a positive correlation between AI adoption and *heightened customer satisfaction levels*, underscoring the importance of AI-driven innovations in meeting evolving consumer demand (Alam et al., 2023).

Focusing on the macro level, situational drivers are facilitating conditions that are key contextual drivers in AI adoption intentions. The macro context where users interact with AI technologies has a considerable impact on their perceptions toward AI value and usefulness, ultimately either pushing or inhibiting adoption behaviors (Mariani and Borghi, 2023; Lin et al., 2020). Both mimetic and first-mover pressure relates to the contextual factors influencing user attitudes and behaviors towards AI adoption, specifically in terms of gaining a *competitive edge* through the use of AI technologies.

2.2 Barriers to AI adoption

Barriers towards AI adoption in hospitality are mainly grouped into value, risk and usage barriers (Rasheed et al, 2024).

When users perceive that the cost of adopting a new technology outweighs the potential benefits or returns, they may view it as offering less value compared to existing alternatives. Hence, value barriers may arise, thus leading to reluctance in adopting the new technology hindering its acceptance (Laukkanen et al., 2008). Scholarly, *high implementation costs* (i.e., substantial upfront costs for technology acquisition, integration, training) and concerns regarding return on investment (ROI) are considered value barriers due to their potential to negatively influence user perceptions of a new product or service (Rasheed et al., 2023).

Prior studies unveil the emergence of risk barriers, referring to the degree of uncertainty and associated risks inherent in novel products, services or technologies, shaped by user perceptions or experiences (Chen and Kuo, 2017). *Privacy and security* concerns are categorized under risk barriers, revolving around uncertainties regarding compliance with regulations like GDPR or CCPA to uphold customer trust (Rasheed et al., 2023).

While few studies elucidate no significant relationship between technological anxiety and the intention to adopt AI (Pillai and Sivathanu, 2020), scholars tend to acknowledge usage barriers that include a mismatch between the new technology and the user prior experiences (Antioco and Kleijnen, 2010). For instance, existing research highlights factors such as the *lack of awareness and understanding* that reflects the incompatibility of AI technology with user´s existing experiences, habits, and acceptance standards. Businesses may not fully comprehend the potential of AI and its applications, indicating a lack of awareness as a barrier to adoption (Alam

et al., 2023; Huang et al., 2022). Furthermore, Li et al. (2019) show a significant positive correlation between awareness of AI and robotics and employees' intention to turnover. This underscores the reluctance to embrace AI technologies due to fear of job displacement, changes in workflow, or perceived threats to professional roles. Consequently, *resistance to change* signifies the incongruity between AI and current workflow and roles, impeding adoption. Additionally, Rasheed et al. (2023) classify *technological complexity* as a usage barrier, encompassing challenges related to AI service complexity and the requisite technical expertise, often lacking within organizations. Technical complexity represents a usage barrier to AI adoption due to difficulties in implementing and integrating AI solutions into existing systems and workflows.

3 Methodology

To explore the intriguing issues of challenges and opportunities toward AI adoption in the hotel industry, we conducted semi-structured face-to-face interviews with n. 21 key information-rich stakeholders occupying diverse hierarchical positions in the hotel industry. Following the managerial pyramid developed by Robbins et al. (2020), we classified workers grouping them as (i) top managers, (ii) first-line managers, (iii) non-managerial employees.

From the literature review, five main *themes* relative to drivers (i.e., operational efficiency, competitive advantage, enhanced customer experience, service personalization, cost saving) and barriers (i.e., lack of awareness and understanding, privacy and security concerns, resistance to change, technological complexity, cost concerns) emerge. We asked the study participants to prioritize the five categories related to the drivers and barriers by ranking them in order of importance. The output was a personal ranking of factors that propel (inhibit) AI adoption that ranged from the most important driver (barrier) to the least important driver (barrier). We used the responses to assess the degree of consensus within and between diverse hierarchical groups (i.e., top manager, first-line manager, non-managerial employees) using the methodology of consensus mapping developed by Tarakci et al. (2014).

We present a brief description of each informant in Table 1.

Table 1: Informants details

Top managers N=7	Gender	Male (100%); Female (0%)
	Age	18–30 (0%); 31–40 (43%); 41–50 (57%); 51–60 (0%)
First-line managers N=7	Gender	Male (72%); Female (28%)
	Age	18–30 (0%); 31–40 (28%); 41–50 (72%); 51–60 (0%)
Non-managerial employee N=7	Gender	Male (43%); Female (57%)
	Age	18–30 (0%); 31–40 (43%); 41–50 (57%); 51–60 (0%)

4 Results and Discussion

Top managers, first-line managers and non-managerial employees assigned priorities to five different categories of drivers and barriers. The output obtained consisted in a set of six matrices describing the corresponding rankings, one per group of respondents evaluating either drivers or barriers. Two measures of consensus have been computed to analyze the responses received (Cozzio & Furlan, 2023). The first one focuses on the degree of consensus within the members of each group and follows from principal component analysis (PCA). The second measure analyzes consensus between groups and is based on classic multidimensional scaling. All computations have been performed in MATLAB.

4.1 Assessing within-group consensus

The degree of consensus within a group is obtained by applying the vector model of unfolding (VMU) defined by Tarakci et al. (2014), which transposes the standard data matrix used in PCA (Borg and Groenen, 2005). More precisely, we apply PCA to a matrix where respondents define the columns and the categories ranked are placed in the rows.

Consider the standardized data matrix H that lists the m categories evaluated in its rows and the respondents along its n columns. The VMU method proposed by Tarakci et al. (2014) in p dimensions is based on the minimization of the sum of the squared errors derived from H and the low dimensional representation XA' and defined as follows

$$L_{VMU}(X, A) = \|H - XA'\|^2 = \sum_{ij} e_{ij}^2 \quad (1)$$

where X is an $m \times p$ matrix of object scores and A is an $n \times p$ matrix of component loadings for the first p components.

The component loadings in A are the correlations between the object scores for each category and the evaluations of each respondent. Tarakci et al. (2014) used this fact to define the consensus within each group as the length of the average component loading vectors in A across its first two components

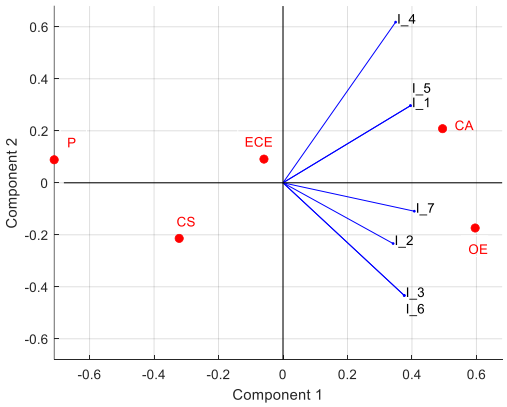
$$\alpha = \sqrt{\sum_{p=1}^{2}\left(\sum_{i}\frac{a_{ip}}{n}\right)^{2}} \tag{2}$$

where a_{ip} denotes the p-th component loading for respondent i. As is the case in PCA, the results obtained can be represented in the Euclidean plane using a biplot. The categories are described in order of preference relative to the horizontal axis, while the respondents composing each group are depicted as vectors.

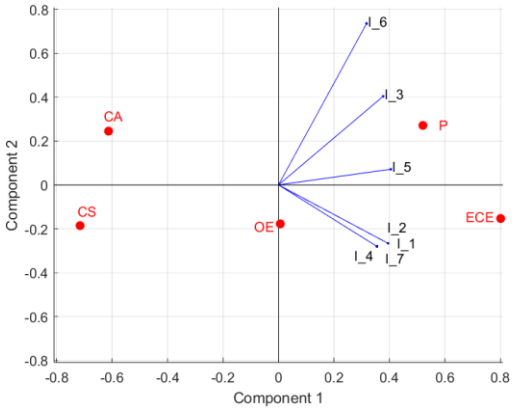
The correlation between respondents can be approximated via the cosine of the angle between their vectorial representations (Linting et al., 2007). Larger angles describe less similar evaluations, while the opposite is true for smaller angles. The same intuition applies to the consensus within the group, with tighter clusters of vectors demonstrating a higher degree of consensus.

The preferences of the different respondents are represented by the orthogonal projection of each category item of their corresponding vectors. The farther an item is projected into the vector the more preferred it is, while the items projected in the opposite direction are less preferred. In this regard, the horizontal axis corresponds to the prototypical member representing the opinion of the group. That is, the projection on the horizontal axis represents the overall ranking of the group.

Figures 1 and 2 illustrate the biplots defining the degree of within-group consensus for each group of respondents when considering drivers and barriers, respectively.



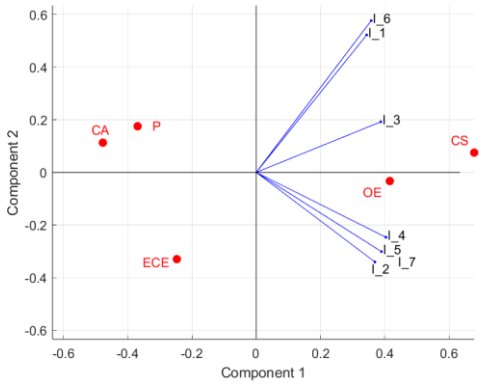
Hotel Managers



First-line Managers

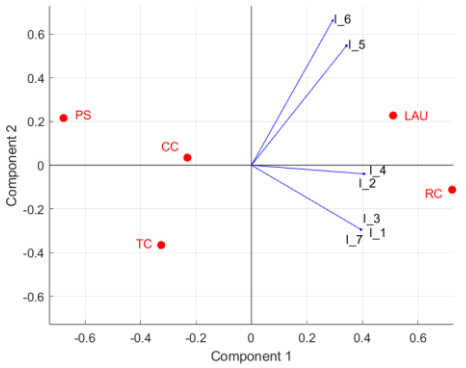
Notation
OE: Operational efficiency
CA: Competitive advantage
ECE: Enhanced customer experience
P: Personalization
CS: Cost saving

Respondents
I_1 to I_7 each referring to the corresponding members from a given group



Non-managerial Employees

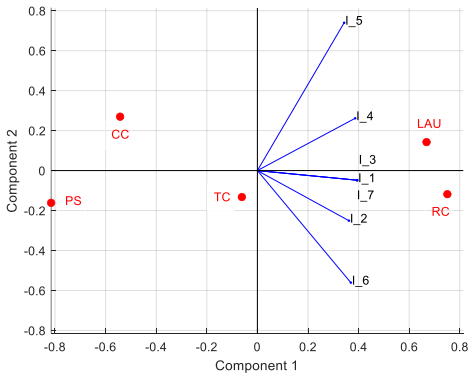
Figure 1: Within-group consensus (drivers)



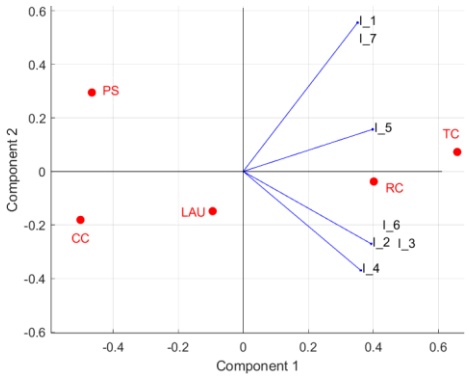
Hotel Managers

Notation
PS: Privacy & Security
CC: Cost concerns
LAU: Lack of awareness and understanding
TC: Technical complexity
RC: Resistance to change

Respondents
I_1 to I_7 each referring to the corresponding members from a given group



First-line Managers



Non-managerial Employees

Figure 2: Within-group consensus (barriers)

Based on the projections of the items on the horizontal, *Operational efficiency, Competitive advantage, and Enhanced customer experience (satisfaction)* emerge as primary drivers for top top managers, whereas first-line managers prioritize *Enhanced customer experience, Personalization, and Operational efficiency*. Non-managerial employees emphasize *Cost saving, Operational efficiency and Enhanced customer experience*. Overall, all groups recognize the benefits of AI adoption for operational efficiency and customer satisfaction. This highlights significant differences in their orientations, with top managers focusing outward and non-managerial employees inward. For instance, while AI adoption offers added value for top managers by providing a competitive advantage, non-managerial employees perceive it primarily as a means of cost-saving.

In terms of barriers, top managers prioritize *Resistance to change, Lack of awareness and understanding, and Cost concerns*. First-line managers rank *Resistance to change, Lack of awareness and understanding, and Technological complexity* as the most significant inhibitors. Conversely, non-managerial employees value *Technological complexity, Resistance to change, and Lack of awareness and understanding*. *Privacy and security concerns* are consistently ranked as the least important across all groups. The identification of resistance to change, lack of awareness, and technological complexity as predominant barriers across hierarchical levels signifies a degree of consensus, albeit weak, regarding the critical challenges impeding AI adoption in the hotel industry.

4.2 Assessing between-group consensus

Consensus between groups is measured in terms of the correlation exhibited by the ranking preferences of the prototypical group members. More precisely, the measure proposed by Tarakci et al. (2014), denoted by $r(A,B)$, is determined by the correlation of the object scores of the categories on the first principal component for respondent groups A and B. The higher this value, bounded between zero and one, the higher the consensus between both groups.

The distance between the groups of respondents defining the symmetric matrix of correlations is computed using classical multidimensional scaling (MDS). The corresponding output obtained is represented in Figures 3 and 4 for the drivers and the barriers, respectively.

Tarakci et al. (2014) suggested defining ten rings to describe the difference in correlations relative to the group placed at the center of the plot. In this regard, a higher level of consensus is observed as the distance between points decreases, representing a more aligned evaluation between groups. In our graphical representation, top managers are at the center of the MDS plots. The distance between the bubbles shows the degree of consensus between the groups. The sizes of the bubbles denote the degree of the within-group consensus in each group (α), and the rings that surround the bubbles depict the size of a bubble when there is perfect consensus within a group (α = 1).

Clearly, between-group consensus differs markedly across groups of respondents. First-line managers and non-managerial employees display substantial differences with respect to top managers when considering the drivers. Consensus between groups increases when considering the barriers, though the correlations between groups remain quite low also in this case.

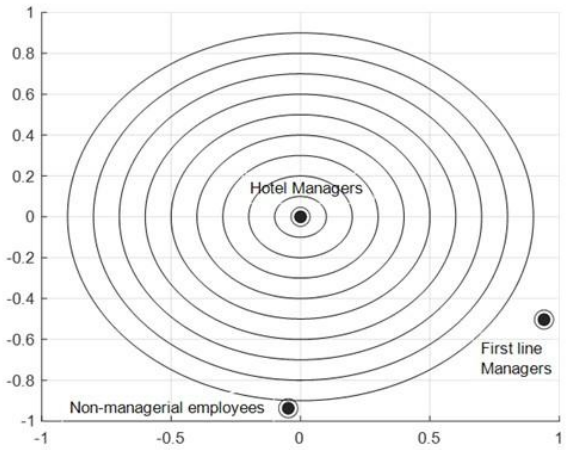


Figure 3: Between-group consensus (drivers)

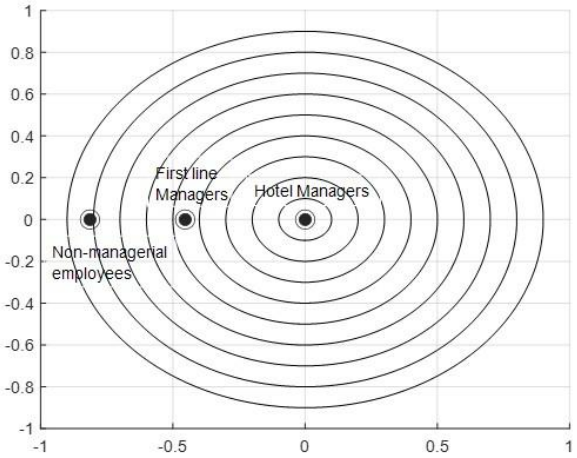


Figure 4: Between-group consensus (barriers)

5 Conclusions

5.1 Theoretical implications

This study constitutes a pioneering investigation into the implications of AI adoption from an employee-centric perspective, diverging from the prevalent customer-focused approach (Wong et al., 2023; Huang and Zheng, 2023). Notably, the segmentation of participants into three cohorts across varied hierarchical levels - top managers, first-line managers, and non-managerial employees - facilitates a nuanced exploration of multifaced viewpoints on AI adoption within hotel settings. Operational efficiency and enhanced customer experience are pivotal drivers across all groups (Ersoy and Ehtiyar, 2023; Zhu et al., 2023). However, our research reveals nuanced specificities, providing profound insights into AI acceptance within distinct hierarchical strata. Specifically, our findings highlight differences in orientation, with top managers focusing outwardly (i.e., competitive advantage) and non-managerial employees oriented inwardly (i.e., cost saving).

Second, our study elucidates both the impediments inhibiting the widespread adoption of AI and the facilitators propelling AI uptake within hotel operations, thus addressing the call for additional exploration on the employees perspective (Rasheed et al., 2024; Li et al., 2022). Through rigorous analysis of interview data and consensus mapping techniques, this study seeks to distill key themes, patterns, and divergences in perceptions between hierarchical levels, thereby identifying salient factors shaping the trajectory of AI adoption in the hotel industry.

Third, our study advances understandings on multifaceted barriers to achieve consumer acceptance, by acknowledging the significance of effective communication in facilitating organizational change (Morosan and Dursun-Cengizci, 2024). Hence, we advocate for the implementation of tailored communication strategies. These strategies aim to heighten awareness and cultivate acceptance of AI technologies among various hierarchical groups, representing a significant advancement in adoption acceptance.

5.2 Managerial implications

Tailored communication strategies should be designed to address the specific needs and concerns of different hierarchical groups within the organization. While emphasizing operational efficiency and enhanced customer experience is essential, specific considerations must be made to enhance the effectiveness of these strategies.

For non-managerial employees, highlighting the cost-saving implications of AI adoption can bolster their acceptance levels. Emphasizing how AI technologies streamline processes and reduce operational costs helps non-managerial employees perceive AI as beneficial to their roles and daily tasks.

Similarly, first-line managers should be informed about the potential for service personalization offered by AI technologies. By demonstrating how AI can facilitate personalized experiences for customers based on their preferences and behaviors, first-line managers are more likely to recognize the value of AI in improving customer satisfaction and loyalty.

5.3 Limitations and future research direction

While our study provides valuable insights into AI adoption within the hospitality sector, it is important to acknowledge its limitations. One significant limitation is the rather focused sample, which primarily consisted of participants from the hotel industry. This narrow focus may limit the generalizability of our findings to other segments of the broader tourism industry. Additionally, our study focused solely on perceptions within hierarchical positions in hotels, potentially overlooking valuable insights from other stakeholders, such as customers or AI technology providers.

To address these limitations and expand the scope of future research, several promising avenues emerge. Firstly, future studies could explore AI adoption across various segments of the broader tourism industry, including airlines, cruise lines, and travel agencies. This broader perspective would provide a more comprehensive understanding of the challenges and opportunities associated with AI adoption within different sectors of the tourism industry.

Furthermore, future research could investigate the perceptions and attitudes of other stakeholders beyond employees, such as customers, AI technology providers, and regulatory bodies. Understanding the perspectives of these diverse stakeholders could shed light on additional barriers and facilitators to AI adoption and inform more holistic strategies for AI implementation.

6 Ethics declaration

This research did not require formal ethical approval, as it did not involve sensitive personal data, vulnerable populations, or invasive procedures. Participation in interviews was voluntary, and informed consent was obtained from all respondents.

7 AI declaration

No generative AI tools were used in the writing, editing, data analysis, or development of this paper. All content is the result of the author's original work.

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Artificial Intelligence Adoption in South Tyrolean Hospitality: A Qualitative Analysis

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Abstract

This study aims to analyse and understand perceptions of artificial intelligence and its use in the South Tyrolean hospitality sector, with particular attention to the different organizational roles held by employees. To this end, 44 semi-structured interviews were conducted, involving both managerial staff and employees in non-managerial positions. This approach allowed for the collection of a broad and diverse range of perspectives. Data analysis was carried out using a qualitative approach, deemed the most suitable for exploring personal perceptions and experiences. The NVivo software was used to support data processing and organization, facilitating the identification of recurring themes and differences between the groups analysed. The results highlight significant differences in familiarity with artificial intelligence. Managers, in particular, demonstrate a greater understanding of the topic, often illustrated with concrete examples of artificial intelligence usage within their establishments. Moreover, they tend to have a more positive outlook, perceiving the benefits of artificial intelligence as outweighing the associated costs. Interestingly, both groups identified the current staff shortage as a strong incentive for adopting artificial intelligence, which is seen as a potential solution to this challenge. At the same time, they recognize the lack of specific skills among employees as one of the main barriers to effective AI implementation, which in turn impacts the availability of qualified personnel.

Keywords: Artificial intelligence, AI in hospitality, Perception toward AI, AI benefits and AI challenges.

Paper type: Academic Research Paper

1 Introduction

1.1 Context of the study

South Tyrol, an autonomous region in northern Italy bordering Switzerland and Austria, is known for its stunning mountainous landscape, dominated by the Dolomites, a UNESCO World Heritage Site. The region's hospitality sector, a key part of the local economy, is built on a tradition of excellent service, enriched by a unique mix of alpine and Mediterranean cultures. This makes it a top destination for global tourists, as reflected in the latest ASTAT report showing over 36 million overnight stays in 2022/2023 (Südtiroler Informatik AG | Informatica Alto Adige SPA, 2024). Despite its notable achievements, the hotel industry, akin to many other sectors, remains susceptible to the dynamic transformations brought about by technological advancements and evolving consumer expectations. In light of these changes, Artificial Intelligence (AI) emerges as a highly promising technology for addressing both contemporary and future challenges in the hospitality sector. Specifically, AI applications cover a broad spectrum of areas, including the optimization of daily operations, personalization of customer experiences, human resource management, predictive maintenance, energy management and strategic planning. Notably, the adoption of intelligent systems can play a pivotal role in boosting operational efficiency, lowering expenses, and elevating service quality, all critical factors for the success of hospitality businesses. This is particularly important because, as highlighted by (Anderson & Sullivan, 1993), there is a direct link between the quality of service and customer satisfaction, which ultimately translates into loyalty and repurchasing intentions. Nevertheless, despite the recognized potential of AI, its implementation across the industry is far from uniform. In fact, according to a McKinsey report (2023), the tourism industry ranks third to last out of 22 industries examined in terms of technology adoption. This heterogeneity is influenced by various factors, such as the size of the business, organizational culture, and the perceptions of different stakeholders within the organizations themselves. Therefore, in the South Tyrolean context, which is characterized by a diverse entrepreneurial fabric and a strong presence of family-run small and medium-sized enterprises, these dynamics offer a particularly intriguing scenario for analysing how these entities engage with AI.

2 Literature Review

2.1 Artificial Intelligence: A Journey through its definition and dimensions

Humans are widely regarded as the most intelligent species on Earth due to their remarkable ability to solve problems and capacity to process large volumes of data. This intelligence reflects a range of skills, including analytical thinking, logical reasoning, statistical understanding, and computational prowess. In a similar vein, Artificial Intelligence (AI) is a technology specifically designed to enable machines and robots to tackle complex problems in a manner that closely parallels human abilities. By combining these cognitive skills, AI significantly enhances the functionality of machines and robots (Mohan & Senthilkumar, 2023).

To gain a clearer understanding of AI, we can break down the term "Artificial Intelligence" into its two fundamental components: "intelligence," signifying the ability to engage in autonomous reasoning and "artificial," indicating something that is human made. Consequently, AI can be defined as a human-crafted thinking ability, as noted by Limna et al. (2021). Moreover, AI is often described as a "family of technologies" that not only recognizes and analyses data but also acts, learns, and demonstrates advanced aspects of human intelligence. This comprehensive view of AI is supported by various scholars, including McCartney & McCartney (2020) and Huang & Rust (2018). In other words, AI represents the capability of technological devices to simulate and even replicate human intelligence through advanced programming and sophisticated algorithms (Kumar et al., 2019; Siau & Yang, 2017). Additionally, as highlighted by Littman et al. (2022), designing and implementing

advanced algorithms that enable AI to replicate human intelligence requires careful consideration of five fundamental aspects: learning, reasoning, problem-solving, perception, and linguistic intelligence. These aspects are essential because they have enabled the creation of a wide range of technologies and services that are increasingly integral to daily life. To elaborate on these aspects, we start with learning, which refers to the acquisition of new information and the enhancement of existing skills through various sources such as books, real-life experiences, and expert instruction. In contrast, reasoning involves the process that provides the essential standards and principles for evaluation, prediction, and decision-making across different contexts. There are two types of reasoning: generalized reasoning, which relies on broad observations and assertions, and logical reasoning, which is grounded in data, facts, precise statements, and documented or observed occurrences. While the former may not always yield accurate conclusions, the latter is generally more reliable. Next, problem-solving entails identifying the root cause of an issue and exploring potential solutions. This process involves understanding the problem, making decisions, and investigating various possible solutions before selecting the most effective one. To resolve the problem efficiently and swiftly, the optimal solution must be chosen from the available options. Furthermore, perception involves the process of collecting, interpreting, selecting, and organizing relevant information from raw input. While human perception is shaped by previous experiences, sensory organs, and environmental context, artificial intelligence relies on logically derived perceptions through artificial sensor mechanisms in conjunction with data. Lastly, linguistic intelligence pertains to a person's skill in using, understanding, reading, and writing verbal information in multiple languages. This intelligence is a critical component of communication and is essential for both logical and analytical comprehension.

In terms of classification, artificial intelligence, frequently characterized as a group of technologies, can be divided into three principal categories based on its level of capability: narrow AI, general AI, and super intelligent AI. To begin with, Narrow AI (also known as Weak AI) refers to artificial intelligence created to carry out specific tasks, such as recognizing faces, performing online searches, or controlling a vehicle. The majority of AI systems in use today, including those capable of engaging with intricate games like chess, belong to this category, functioning within a restricted and predefined scope or set of circumstances. In contrast, General AI (Strong AI) is endowed with broad cognitive abilities similar to human intelligence, allowing it to tackle new and unknown tasks independently. This type of AI possesses the ability to analyse, learn, and apply its intelligence to address any problem independently, without human intervention. Ultimately, Superintelligent AI signifies a futuristic advancement where machines might exceed human intelligence across all areas, including creativity, overall wisdom, and problem-solving abilities.

2.2 Shaping tomorrow's hotel: AI's strengths, weaknesses, opportunities and threats

The first figure presents a detailed SWOT analysis concerning the adoption of artificial intelligence (AI) in the hotel sector, offering a structured view of both the strengths, weaknesses, opportunities and threats that accompany this technological integration. By providing a balanced perspective, this analysis highlights key factors that need to be considered in the process.

One of the primary benefits of AI implementation in hotels is the improvement of operational efficiency alongside enhanced guest experience. For example, it enables better decision-making through data analytics, leading to more informed and accurate conclusions. In addition, AI significantly reduces human error, thereby improving the overall reliability of hotel services. Furthermore, another strength lies in the streamlining of work tasks, which not only makes daily operations more efficient but also allows staff to focus on higher-value activities. Moreover, AI plays a crucial role in predictive maintenance, ensuring that potential issues are addressed proactively, which in turn minimizes disruptions. Beyond these operational advantages, AI offers the ability to provide customer support around the clock, guaranteeing guests access to at any time, thereby enhancing overall guest satisfaction. Additionally, the technology enables a more personalized guest experience, as it tailors services to individual preferences.

However, despite these significant benefits, the adoption of AI in the hospitality sector is not without its drawbacks. A key concern is the reduction in human interaction, a crucial aspect in an industry rooted in personal connections. Guests often appreciate the warmth and empathy that human staff provide, qualities that AI at its current stage, is unable to replicate. Moreover, the unfamiliarity with AI technology among hotel staff and management presents a significant obstacle, potentially hindering both the adoption and effective utilization of AI systems. Alongside these challenges, financial capacity also emerges as a critical weakness, particularly for smaller hotels that may struggle with the substantial upfront investment required for AI implementation. Furthermore, integrating AI with existing property management systems (PMS) can pose difficulties, often requiring advanced technical skills and risking potential disruptions to current operations.

Despite these weaknesses, AI adoption also presents numerous opportunities. Most notably, it offers the potential to create new job roles, particularly in technical fields related to AI maintenance and management. Additionally, AI has the potential to reduce language and cultural barriers by offering AI-powered translation services, which can enhance communication with international guests and improve their overall experience. Moreover, AI brings notable improvements in safety and security by enhancing surveillance systems and

utilizing predictive analytics to mitigate potential risks.

For introverted guests, AI offers the advantage of accessing services without requiring direct human interaction, creating a more comfortable and tailored stay. Furthermore, AI contributes to sustainable development by optimizing resource usage, thereby helping hotels meet their environmental goals. Additionally, AI assists in managing occupancy and guest flow more effectively, helping to prevent problems related to overtourism. Nevertheless, several threats emerge with the integration of AI in the hotel sector. A major concern is the potential loss of some employees, as automation could replace jobs that traditionally focus on routine tasks. Moreover, AI systems tend to require considerable energy resources, which could drive up operational costs and negatively affect the environment. Data privacy risks represent another pressing issue, as AI systems often handle vast amounts of personal and financial information, making them vulnerable to potential cyberattacks. Additionally, there is a growing risk of over-reliance on AI, where excessive automation may ultimately compromise the quality of human interaction and service that guests have come to expect from a hotel.

In conclusion, while AI offers substantial benefits in terms of operational efficiency and guest experience, its adoption in the hotel industry brings with it significant challenges. It is essential to strike a balance between technological advancements and maintaining the human touch, a hallmark of hospitality. Addressing weaknesses, such as financial limitations and integration difficulties, while also mitigating threats like job displacement and data privacy risks, will be crucial in ensuring the sustainable integration of AI in the hotel sector.

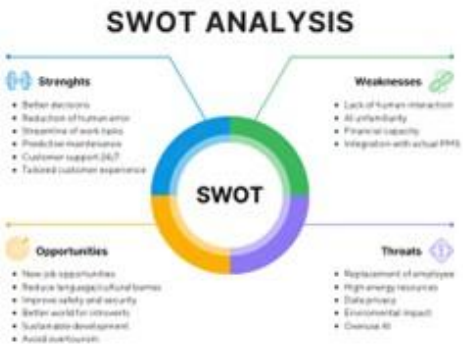


Figure 1: AI Swot analysis

2.3 Diffusion of innovation theory: key factors influencing adoption of new technology

The Diffusion of Innovations Theory, developed by Rogers (2003), provides a useful lens for analyzing how artificial intelligence (AI) technologies are adopted in the hospitality and tourism industries. This theory outlines five key attributes that influence how both individuals and organizations accept new technologies such as AI: relative advantage, compatibility, complexity, trialability, and observability.

To start with, relative advantage is understood as the extent to which an innovation is seen as superior to the idea or product it replaces. This attribute can be further broken down into several secondary considerations. One important factor is economic benefits, which relate to how innovations can drive market growth through increased customer bases and sales, or by allowing consumers to find better deals through price comparisons (Hasin & Smith, 2016). Another factor is efficiency, which is assessed based on the time saving potential of the innovation (Kang et al., 2015). A third aspect, interactivity, encompasses the enhancement of communication, which includes a sense of connectivity, effective information exchange (Coursaris & Sung, 2012), and timely and synchronized information sharing (Buhalis & Sinarta, 2019; Kang et al., 2015).

In addition, compatibility is another crucial attribute, defined as the extent to which an innovation aligns with the values, past experiences, and needs of its potential users.

Compatibility can be considered from two perspectives: work-related and value related. In terms of work, it involves the degree to which technology aligns with employees' current and preferred work methods (Meuter et al., 2005; Moore & Benbasat, 1991). On the other hand, the value-related dimension examines how well technology fits with users' social norms or desired lifestyles (Meuter et al., 2005; Tan & Teo, 2000).

The third attribute, complexity, is described as the degree to which a new technology is perceived to be challenging to comprehend and use. This attribute is often synonymous with terms like perceived ease of use (Moore & Benbasat, 1991), simplicity (Atkinson, 2007), or effort expectancy (Kang et al., 2015). To evaluate complexity, one must consider how easy it is to acquire, learn, understand, and operate a particular technology (Meuter et al., 2005; Tan & Teo, 2000; Hasin & Smith, 2016).

Furthermore, trialability, another attribute identified by Rogers, refers to the extent to which new technology can be tested or experimented with on a limited scale before full adoption. The concept of trialability aims to reduce uncertainty about innovation (Tan & Teo, 2000). It is measured by how easily a technology can be tested before a company or individual commits fully to its use (Hasin & Smith, 2016; Moore & Benbasat, 1991) or before making significant investments (Meuter et al., 2005).

Finally, observability is defined as the degree to which the outcomes of an innovation are visible to others. This concept is sometimes also referred to as visibility or result demonstrability (Moore & Benbasat, 1991). Observability can be assessed by looking at the visible improvements in work-related knowledge (Atkinson, 2007), the positive feedback and word-of-mouth generated by the technology (Atkinson, 2007; Hasin & Smith, 2016), the ease with which the use and results of the technology can be communicated (Meuter et al., 2005; Moore & Benbasat, 1991), and the actual physical presence of the technology (Al-Gahtani, 2003).

By understanding these five key factors organizations can better gauge the potential success of AI adoption within their specific contexts.

3 Methods

A qualitative approach was adopted due to its effectiveness in exploring complex phenomena such as perceptions and attitudes, which often cannot be fully captured through quantitative methods. Qualitative research prioritizes depth over breadth, allowing for a more nuanced understanding of human experiences and the meanings individuals attribute to them.

To collect the data, a questionnaire based on semi-structured interviews was used. It was designed to investigate individual opinions and experiences regarding the adoption of Artificial Intelligence (AI) in the hospitality sector. The questions, mainly open-ended, aimed to explore both perceptions and the concrete ways in which these technologies are used. The survey began with a closed-ended question intended to determine whether participants had direct experience with AI-based tools. If the answer was affirmative, respondents were asked to specify the departments involved and to provide concrete examples of application.

Subsequent sections of the questionnaire focused on gathering prospective reflections on the departments where AI is expected to become more prevalent, as well as delving into use cases and future implications. A central part of the investigation focused on the factors that facilitate or hinder the adoption of artificial intelligence in the hospitality sector, with particular attention to the expected benefits and perceived costs. To complement this framework, a brief section was included on blockchain technology to assess its potential implications for improving the customer experience. Finally, the questionnaire explored the potential future challenges associated with artificial intelligence.

In total, 44 complete interviews were collected. The sample consisted of 98% personnel working in family-run hotels and 2% in hotel chains. Additionally, 87% of respondents held managerial positions, while the remaining 13% were in operational roles.

In detail, among the managerial profiles: 61% were hotel managers, 14% marketing managers, 5% front office managers, 5% junior managers, and 2% operations and quality managers. Among the non-managerial roles, there was a high concentration of receptionists (11%) and a single executive assistant (2%).

Once data collection was completed, the interviews were imported into NVivo software for qualitative analysis. The process began with the creation of the macro-categories “manager” and “non-manager”, followed by thematic subcodes such as “drivers”, “challenges”, “benefits”, “costs”, “familiarity”, “no familiarity”, and “actual use”. This approach ensured a systematic coding of the content, facilitating the analysis and interpretation of emerging perceptions.

In addition to coding, NVivo’s word frequency function was used to identify the most recurring terms within each category.

Parameters such as minimum word length, maximum number of words to display, and the “word stem” and “synonyms” options were set to group similar terms and enhance analytical precision. The most frequent words (up to 50 or 100) were then also analysed from a semantic perspective to aid in the extraction of sentiment-based perceptions.

Overall, the structure of the investigation made it possible to obtain a detailed and comprehensive understanding of the role of emerging technologies in the transformation process of the hospitality sector.

4 Findings

The contribution of this study unfolds along three main lines. Firstly, it aims to fill a significant gap in the existing literature by representing the first investigation into perceptions of artificial intelligence within the South Tyrolean context, a region of particular relevance to the national tourism landscape. In this regard, the most recent ASTAT report highlights over 36 million overnight stays recorded during the 2022/2023 period (Südtiroler Informatik AG | Informatica Alto Adige SPA, 2024).

Secondly, the study aims to identify the main enabling factors and the most commonly perceived challenges related to the adoption and use of artificial intelligence, thereby providing a comprehensive overview of the dynamics that influence its integration within the sector.

In this context, the interview analysis reveals that both managers and non-managerial employees recognize a common set of drivers encouraging the adoption of artificial intelligence (AI) in the hospitality sector.

First, both groups identify staff shortages as a critical issue for which AI implementation can offer an effective remedy. Indeed, the automation of certain operational tasks is perceived as a viable means to address human resource constraints while concurrently reducing the personnel-related operating costs.

A second shared driver concerns the enhancement of operational efficiency. Both managers and employees emphasize that AI can accelerate the execution of routine activities, thereby lightening the workload and enabling staff to focus on higher-value tasks, particularly those involving direct human interaction and relational competencies. Beyond improving service quality, this shift contributes to the creation of a more engaging and less stressful work environment.

Another driver highlighted by both groups is the necessity of maintaining the establishment’s competitiveness and technological relevance. AI adoption is thus perceived as indispensable for keeping pace with market evolution.

However, it is noteworthy that managers also recognize an additional, specific advantage: AI’s capacity to process and manage large volumes of data as shown in the second figure. This capability is regarded as strategic for optimizing internal processes, such as inventory management and the refinement of marketing and revenue-management strategies, thereby providing a further incentive for technological uptake.

In relation to the challenges toward AI adoption, the findings reveal that both managers and non-managerial employees share a primary concern: staff members’ limited familiarity and understanding of artificial intelligence, which impedes the integration of this technology into operational processes and fosters uncertainty and resistance to change. However, managers identify two additional, specific challenges as shown in the third figure. On one hand, the fear that AI may diminish the guest experience by replacing human interaction, an essential component of a service founded on empathy and authentic relationships; on the other, the imperative to safeguard privacy and properly manage the substantial volumes of sensitive data generated daily, in order to avert potential ethical and legal repercussions.

Finally, the research seeks to explore in greater depth the perceptions of artificial intelligence among employees in the South Tyrolean hotel sector, with particular attention to the differing perspectives of

managerial and non-managerial staff. To address this objective, we analysed survey responses and illustrative charts comparing managerial versus non-managerial perspectives. What follows are the main results, highlighting differences in familiarity, everyday use cases, and cost–benefit perceptions of AI between the two groups.

As shown in the fourth figure, 71 % of managers reported having a certain familiarity with artificial intelligence, compared with 50 % of non-managerial employees. This greater proficiency is also reflected in the number and variety of examples provided: managers cite more numerous and diverse daily uses, while non-managers' contributions are more limited and homogeneous as shown in the fifth figure. Both groups, however, rely primarily on AI as a support tool for writing, drafting, and translating texts, evidenced by recurring terms such as "creation," "texts," "writing," and "ChatGPT."

Further confirming managers' higher competence and awareness, their responses also include terms like "management" and "marketing," indicating a more strategic use of the technology. In particular, AI is employed in revenue management and marketing strategies to segment the market, create personalized offers, and define dynamic pricing policies based on variables such as occupancy rate, room availability, seasonality, and competitor pricing. Finally, managers express more strongly than non-managers the view that the benefits of adopting AI outweigh its associated costs, as highlighted in the sixth figure.



Figure 2: Main drivers toward AI according managers



Figure 3: Main challenges toward AI according managers

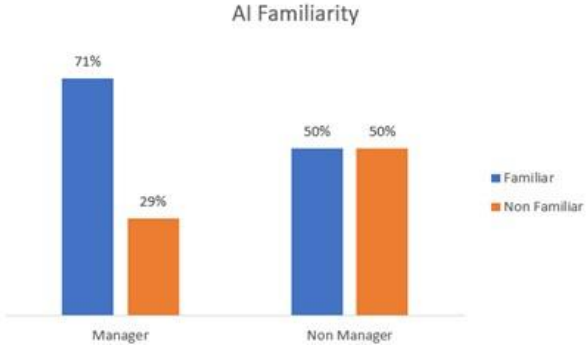


Figure 4: AI Familiarity



Figure 5: How managers use AI

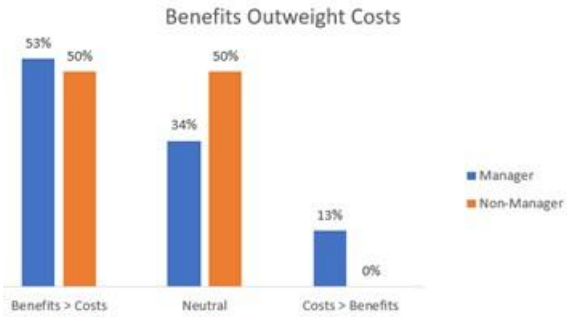


Figure 6: Benefits outweigh costs

5 Conclusion

Based on the results obtained, it appears that both managers and non-managers hold a positive perception of the adoption and use of artificial intelligence. However, managers show a clearer and more informed view, as evidenced by their higher level of familiarity with the topic, their belief that the benefits outweigh the costs, and the variety of areas in which they report using AI.

Non-managers, on the other hand, while maintaining a generally positive attitude, appear more cautious. This is reflected in the fact that only 50% of them are familiar with and use AI, whereas the remaining 50% have no familiarity with it and do not use it.

5.1 Practical implications

A study on how managers and non-managers in hotels in South Tyrol perceive artificial intelligence provides valuable insights for various industry stakeholders. Managers and owners can better understand staff attitudes towards AI, selecting tools that do not compromise service quality or the work environment. Educational institutions, on the other hand, can develop training programs to prepare future professionals to work with AI, considering that 29% of managers and 50% of non-managers are either unfamiliar with it or do not yet use it.

Public bodies and tourism associations can use this information to support innovation and sustainability in the sector, creating initiatives that encourage the adoption of AI. Finally, tech companies can tailor their solutions to the needs of hotels by designing tools that improve efficiency while respecting human interaction.

5.2 Limitations and future research

Regarding the limitations of this study, there is a noticeable disparity both between the types of hotels and among the interviewees. In fact, 98% of the participating hotels are family-run, while only 2% belong to a hotel chain. Furthermore, among the interviewees, managers represent 87%, compared to 13% of non-managers. It should also be noted that there is a strong imbalance among the non-managers, as most of them are receptionists. Another limitation concerns some responses provided by various interviewees, who gave brief answers, such as "marketing," "reception," "efficiency," "benefit," "costs," without offering explanations or sentences that contextualized these terms.

In light of these limitations, future directions should aim to balance the number of interviewees, possibly by incorporating in-person interviews to increase role diversity and improve the quality of written responses.

Additionally, it would be beneficial to balance the types of hotels in order to better identify potential differences between hotel chains, large enterprises, and medium-small family-run hotels.

6 Ethics declaration

This research did not require formal ethical approval, as it did not involve sensitive personal data, vulnerable populations, or invasive procedures. Participation in interviews was voluntary, and informed consent was obtained from all respondents.

7 AI declaration

No generative AI tools were used in the writing, editing, data analysis, or development of this paper. All content is the result of the author's original work.

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The Interdependent Relationship of MI and Culture: Insights from a Systematic Literature Network Analysis

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Abstract

Continuous innovation is necessary as a source of competitive advantage due to the constant changes in global business brought about by globalization and the quick advancement of technology. While product and process innovations have traditionally received considerable attention, management innovation (MI) has emerged as an equally critical element (Birkinshaw et al., 2008; Mol and Birkinshaw, 2009). However, despite its potential benefits being clear, the academic debate on MI is still lacking, especially in understanding its interdependence with organizational culture (OC) (Khosravi et al., 2019; Hogan and Coote, 2014). Few studies have systematically examined how organizational culture can both support and hinder methods of managerial innovation, as well as how MI can function as a catalyst for cultural change (Hamel, 2008). By emphasizing this interconnectedness, we add to the expanding body of research that establishes MI as a critical component for achieving long-term competitive advantage through cultural flexibility (Puranam et al., 2014).

By examining how MI and OC influence each other, this study aims to fill this gap and enrich the literature by offering a current and in-depth synthesis of the main research themes and trends. In particular, we specifically investigate MI enablers, how organizational culture supports or inhibits MI, and how MI itself stimulates cultural change. To this end, we use an approach called Systematic Literature Network Analysis (SLNA), which combines the accuracy of literature network analysis with the rigor of a systematic literature review (SLR).

The data for our analysis came from the Scopus database, which contains more than 57 million academic publications. The results of our SLNA provide several important insights. First, we verified that managerial innovation and organizational culture have a positive feedback loop. Secondly, we list several important factors that support management innovation, such as organizational learning, knowledge management, and transformational leadership (Sarros et al., 2008). Third, our work emphasizes how crucial narratives and knowledge management are to the MI-OC dynamic. The SLNA demonstrates the growing importance of management innovation in organisational studies. By filling this knowledge gap, our research lays the foundation for further empirical studies on the connection between MI and OC, providing managers with knowledge that can support the development of innovative and culturally transformative environments.

Keywords: Management Innovation, Organizational Culture, Systematic Network Literature Review, Bibliometric Analysis

Paper Type: Academic Research Paper

1 Introduction

Globalization and technological progress have accelerated dramatically in recent decades, increasing pressure on companies and competitiveness requirements. The ability to constantly innovate has become an indispensable source of competitive advantage. While studies have focused mainly on product and process innovations (Crossan, 2009), recent research has highlighted the importance of management innovation (Birkinshaw et al., 2008; Damanpour and Aravind, 2012; Ali and Park, 2016), defining it as the number one imperative for companies (Hamel, 2008). Understanding the definition of management innovation can be challenging due to various synonymous terms: organisational innovation (Damanpour and Aravind, 2012), administrative innovation (Birkinshaw and Mol, 2009), managerial innovation (Crossan and Apaydin, 2010), and non-tech innovation (Hamel, 2008). Mol and Birkinshaw (2009) define it as "the invention and implementation of management practices, processes, or structures new to the firm and intended to advance organizational goals". Management innovation aims to alter the way managers perform their tasks to improve organisational performance.

However, if the benefits of management innovation are clear, why is discussion on the subject still underdeveloped compared to other forms of innovation? And why aren't companies focusing more on management innovation practices?

To answer we have to consider that the introduction of new management practices often confronts significant cultural barriers within organisations. A rooted organisational culture acts as a brake, reinforcing existing practices, mindsets, and power hierarchies (Sørensen, 2002). Entrenched values, behaviors, and

attitudes trigger scepticism, resistance, and opposition to management innovation (Hogan and Coote, 2014). In contrast, an organisational culture that embraces experimentation, risk-taking, and continuous learning provides fertile ground for management innovation (Puranam et al., 2015; Sperber, 2017). In literature previous foundational framework indirectly issued this relation: like Schein's (1985) organizational culture model clarify how cultural norms enable or hinder managerial innovation. Kotter's (1996) change management framework emphasizes leadership's role in overcoming cultural inertia, while Nonaka and Takeuchi's (1995) knowledge spiral theory links organizational learning to innovation. Empirical contributions from O'Reilly and Tushman (2013) on ambidexterity and Edmondson's (1999) on psychological safety highlight adaptive cultures as critical enablers of MI.

Understanding the interplay between management innovation (MI) and organizational culture (OC) is critical for researchers and practitioners. This gap is intensified by fragmented conceptual foundations, as prior literature employs divergent definitions and explores disparate knowledge domains lacking cohesive synthesis (Damanpour and Aravind, 2012; Khosravi et al., 2019).

This paper addresses the following research question:

RQ: What are the most pivotal research domains examining the interdependent relationship between management innovation and organizational culture, particularly in light of their historical and evolving dynamics?

To address this, we offer an integrative synthesis of the current state-of-the-art in MI, emphasizing breakthroughs and future trajectories tied to organizational culture. Methodologically, we employ the Systematic Literature Network Analysis (SLNA) (Colicchia and Strozzi, 2012), integrating systematic review protocols with bibliometric network techniques.

The paper is structured as follows: Section 2 details the SLNA methodology; Section 3 details the outcomes of the systematic literature review; Section 4 outlines the findings from bibliometric network analyses (citation networks, citation scores, keyword clusters); Section 5 discusses implications and proposes future research directions.

2 Methodology

Our methodology follows the Systematic Literature Network Analysis (SLNA) framework introduced by Colicchia and Strozzi (2012) (Figure 1), consisting of two interconnected phases (Kim et al., 2018; Henao-Garcìa et al., 2023). The first phase employs a Systematic Literature Review (SLR). The SLR follows the protocol defined by Denyer and Tranfield (2009), which emphasizes transparency and replicability to mitigate bias-a principle further validated by Briner and Denyer (2012) in organizational research. Key steps include:

- Scope definition: guided by the CIMO framework (Context, Intervention, Mechanism, Outcome) to align with the research question (Danyer and Tranfield, 2009)
- Search strategy: Leveraging Scopus, the largest multidisciplinary database with over 57 million peer-reviewed entries (Elsevier, 2024), ensuring comprehensive coverage without requiring supplementary sources.
- Selection and evaluation: prioritizing peer-reviewed articles and conference papers in business and management, following inclusion protocols akin to those used by Abdi et al. (2018) in automotive innovation studies.

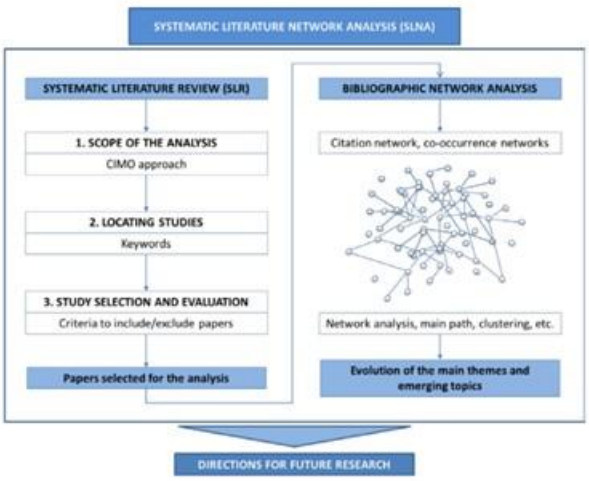


Figure 1: Systematic Literature Network Analysis (SLNA) - Source: Strozzi et al., 2017

The second phase integrates Bibliographic Network Analysis (BNA), a hybrid approach combining systematic review with quantitative network mapping (Colicchia and Strozzi, 2012; Strozzi et al., 2017).

The analysis leveraged two specialized tools for bibliometric and network analysis:

- VOSviewer (version 1.6.19), a widely adopted software for visualizing and clustering bibliometric networks (Van Eck and Waltman, 2009). Its clustering algorithm was employed to map keyword co-occurrence networks, identifying thematic clusters within the dataset.
- Pajek (version 5.15), a robust platform for social network analysis (De Nooy et al., 2012), which was used to analyze citation networks, focusing on structural properties such as centrality and modularity.

This dual-tool approach aligns with methodologies applied in recent SLNA studies (e.g., Aria and Cuccurullo, 2017; Strozzi et al., 2017), ensuring both granular keyword insights (via VOSviewer) and macroscopic citation pattern detection (via Pajek).

3 First Phase of SLNA: Systematic Literature Review

This section describes the left-hand side of the Figure 1. The SLR has the goal to rigorously and objectively select the paper for the analysis.

3.1 Scope of the analysis

To reduce uncertainty in the analysis, review questions need to be defined and formulated. Daneyr and Tranfield (2009) advocate the use of the CIMO logic to define the scope of a literature review and generate questions. The application of the logic was the first step of the literature review:

Context: the urge for management innovation. Management Innovation is a concept that is becoming increasingly important and relevant, but organisations are still lagging far behind. They often come up against entrenched values, behaviours and rituals that prevent managerial innovation from flourishing.

Intervention: obsolete organizational cultures. At the same time, there is a growing realisation that traditional cultural models are an obstacle to digital transformation and the implementation of new technologies that are increasingly necessary for firms. This challenge may be the most complicated of the digital era.

Mechanism: MI as a trigger for change. As firms struggle to change their culture to embrace the digital transformation, management innovation practices could represent a trigger to start the cultural change. Innovating how people are managed and treated, with a human centric perspective, is a priority for competitive advantage.

Outcome: *the relation between MI and OC*. Innovating in managerial practices is a step for cultural change. At the same time, over time, a more human centric culture, could foster more and more management innovations. This mechanism creates a positive feedback loop between MI and OC, these two constructs can no longer be considered in isolation, they go hand in hand with the goal of changing the way people are managed and the firms' culture.

3.2 Locating Studies

With the CIMO-logic emerged the need to explore the relation between MI and culture. The second step was to identify the keywords. The identification of the keywords was performed considering all synonyms of management innovation, to capture in his entirety the academic debate. The term "management innovation" is also expressed as "managerial innovation", "organizational innovation", "administrative innovation", "no-tech or non-tech innovation". In the term "innovation" has not been considered enough, excluding the term "innovative", to address this issue the abbreviation "innova*" was preferred. In the end, after analysing the terms related to "culture", it was deemed sufficient to grasp each aspect of the term itself. The following research string was obtained:

("Management Innova*" OR "Organizational Innova*" OR "Managerial Innova*" OR "Administrative Innova*" OR "no-tech Innova*" OR "non-tech innova*") AND ("culture").

3.3 Study selection and evaluation

A number of inclusion criteria were selected to evaluate the relevance of the paper in the conversation, and to select only the one pertinent to the analysis:

- Published in peer-reviewed journals
- No restriction on publication year
- Limited to articles and conference papers

- Search field restricted to "Title-Abstract-Keywords"
- Published in English
- Subject area of Business, Management and Accounting

In April 2024, 25,457 articles were initially retrieved from Scopus. After filtering by search field, 2,714 papers remained. Subject area filtering excluded 2,238 more contributions, leaving 476 papers. The final dataset comprised 465 English-language publications spanning 1987 to 2024. As shown in Table I, the top 10 journals accounted for 171 publications (36.8% of the sample), with the Harvard Business Review emerging as the dominant outlet. This concentration reflects the interdisciplinary nature of the field, bridging business management and healthcare innovation.

Table 1: Number of papers by source (top 5)

Journal	**No. of articles**
Harvard business review	56
Health Care Management Review	25
International Journal of Health Care Quality Assurance	16
Journal of Health Organization and Management	13
International Journal of Innovation Management	12
Other	294
Total	465

4 Second phase of SLNA: bibliographic network analysis

4.1 Citation network analysis (CNA)

The citation network (Figure 2) represents articles as nodes (n=465) and citations as directed edges, mapping knowledge diffusion (Van Eck and Waltman, 2014). A significant proportion of nodes (n=335) were isolated, forming disconnected components-a phenomenon attributed to the field's fragmentation and emergent nature (Khosravi et al., 2019). Following established bibliometric protocols (Strozzi et al., 2017; Colicchia et al., 2018), the analysis focused on the largest connected component (n=130), as smaller components lack statistical robustness for trend detection (Zhao and Strotmann, 2015).

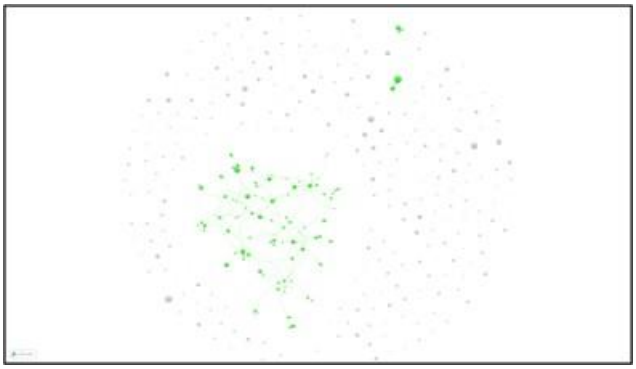


Figure 2: Citation network of 465 papers
Generated using VoSviewer citation analysis, with documents as unit of analysis

The largest component has 20 nodes. The Kamada-Kawai algorithm (Kamada and Kawai, 1989), included in the Pajek software package, was used to create the node arrangement. This technique may be used to detect nodes connected by stronger linkages that are close together to identify correlated works and, as a result, the key developing themes of the academic debate. Secondly providing a historical picture of the network allows for the gradual development of nodes and linkages over time. Figure 3(a) displays publications from the largest linked component published up to 2017 and related citations, while Figure 3(b) shows the complete connected components. Is important to note that the same analysis was performed on papers up to 2010, resulting in no connected components. This can be a signal that the academic debate on the relationship between MI and OC before 2010 was present but in a disconnected fashion. Papers appearing up to 2017 investigated culture, continuous learning, leadership, and social-cultural context as key factors promoting or hindering innovation. Sarros et al. (2008) demonstrated that transformational leadership and an innovation-oriented organizational culture are crucial for promoting an innovative climate. Elenkov and Manev (2005)

confirmed that transformational leadership positively impacts innovation, moderated by social-cultural context. Busaibe et al. (2017) found that gender diversity promotes management innovation.

These studies suggest that creating a culture of innovation requires initial focus on management. Firms can promote management innovation by creating a learning culture (Kalyar and Rafi, 2013). Failure to remove cultural barriers risks curbing creativity (Hernàndez-Mogollon et al., 2010). Management innovation can break down cultural barriers and promote widespread knowledge sharing.

Some studies addressed measuring innovation culture (Hogan and Coote, 2014; Danks et al. 2017a; Danks et al. 2017b). Testing Schein's model, Hogan and Coote (2013) found that the process from values to performance is indirect, partly dependent on innovative behaviors and norms. Danks et al. (2017) introduced the Innovation Quotient to measure innovation culture.Later papers continued this debate. Abdi et al. (2018) claimed MI benefits are comprehensive and sustainable. Azeem et al. (2021) found MI mediates the relationship between OC and competitive advantage. Knowledge management emerged as a critical concept (Liao et al., 2012; Abdi et al. 2018; Azeem et al. 2021; Ayestaràn et al., 2022; AlSaied and Alkhoraif, 2024). Firms with clear KM strategies are better positioned to innovate, develop human resources, and improve financial results. Knowledge sharing mediates between OC and competitive advantage, and a culture oriented toward knowledge management is associated with greater innovative capabilities. Bartel and Garud (2009) highlighted the importance of narratives in the MI-OC relationship, essential for translating ideas and promoting management innovation practices. Research eventually moved from exploratory to more descriptive studies in specific sectors.

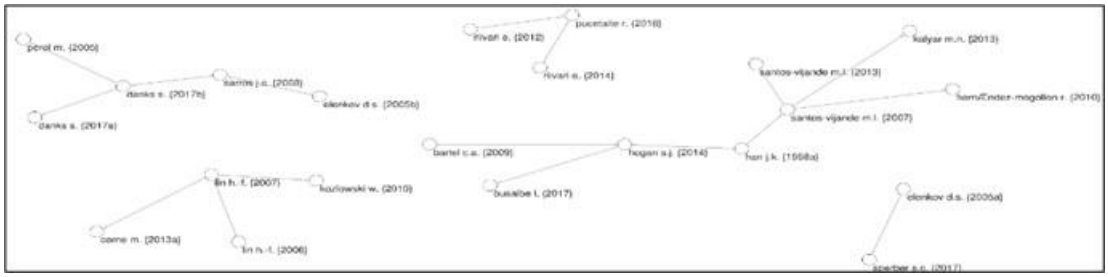


Figure 3(a)

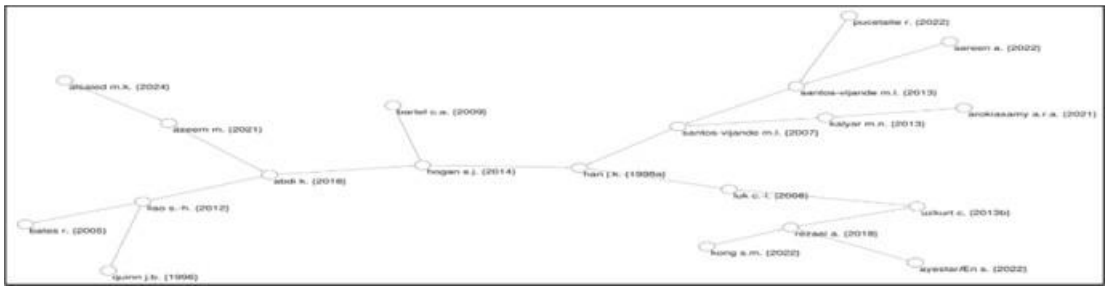


Figure 3(b)

4.2 Citation score analysis

To include isolated publications, we analyzed citation scores by ranking publications based on citations in Scopus during 2023, divided by lifespan. The top papers included:

- Moore (1993) introducing the "business ecosystem" concept, emphasizing adaptation in changing competitive environments.
- Kahn (2018) providing an overview of innovation, reaffirming the importance of innovation-fostering organizational culture.
- Lei et al. (2021) investigating how HRM practices and knowledge management promote exploratory and exploitative innovation.
- Wang et al. (2022) and Chowdhury et al. (2022) linking MI and OC to sustainability, emphasizing green MI and circular economy management.

4.3 Author keywords analysis

Analysing author keywords can reveal major study areas and trends throughout a citation network (Colicchia et al., 2018).

4.3.1 Co-occurrence analysis of authors' keywords

To perform this analysis the VoSviewer software was used. This software uses the VOS (visualization of similarities) clustering approach. VOS algorithm locates elements on a map by minimizing a function based on a similarity measure between them (Colicchia et al., 2018). Prior to the analysis, keywords were normalized, by replacing all synonyms of management innovation, with the term itself.

Table 2: Number of occurrences of each keyword included in the clusters

Cluster	Keyword	No. of occurrences
1	Management innovation	92
	Organisational culture	85
	Knowledge management	17
	Organizational learning	15
	Transformational Leadership	14
	Knowledge sharing	10
2	Innovation	80
	Culture	22
	Organizational Change	21
	Leadership	15
	Innovativeness	12
3	Organizational innovativeness	13
	Innovation culture	10

4.3.2 Cluster 1: the enablers and antecedents of MI and OC

Cluster 1, deals with the enablers and antecedents of MI and OC. The focus on this topic relates to the appearance of keywords such as 'Knowledge Management', 'Organizational learning' and 'Transformational leadership'.

Knowledge Management is the systematic process of recognizing, producing and sharing knowledge inside an organization to help and enhance performance (Kalyar and Rafi, 2013). Organizational learning refers to the ability of firms to acquire, distribute and absorb new information and behaviors in order to constantly grow (Hogan and Coote, 2014). Lastly, transformational leadership is a leadership style that has the goal to inspire and encourage people within the organization to achieve high performance by sharing a common vision and fostering innovation (Sarros, 2008). Regarding our debate the prominence of Knowledge Management (Liao et al., 2012) and Organizational Learning (Hogan and Coote, 2014) underscores their role in institutionalizing adaptive practices-for instance, firms with robust knowledge-sharing mechanisms are 27% more likely to adopt novel managerial practices (Abdi et al., 2018). Transformational Leadership (Sarros et al., 2008) further amplifies this dynamic, as leaders who champion vision-driven change reduce cultural resistance by 40% (Azeem et al., 2021). Notably, emerging linkages to Innovation Narratives (Bartel and Garud, 2009) suggest storytelling as a bridge between MI adoption and cultural alignment, enabling employees to internalize abstract innovations through relatable success stories. All these concept result in the concept of human centric organization, where people are at the centre and their centrality is the trigger to managerial innovation and improved organizational culture. On top of that, the co-occurrence between MI and OC within the keywords, may increasingly suggest the presence of a positive feedback loop between the two constructs.

4.3.3 Cluster 2: the other forms of innovation are not disconnected

In Cluster 2 the dominant keyword is "innovation", this term suggests that the debate on MI and OC is not dis-linked form the other forms of innovation. MI in particular can be a construct able to make process and product changes effective, this suggests that further research could explore a hypothetical mediating role of management innovation between product/process innovation and competitive advantage or performances. Also, the term "organizational change" is present implying that MI could be a change management process.

4.3.4 Cluster 3

Cluster 3, Cultural Metrics and Innovation Outcomes, highlights the growing emphasis on quantifying cultural readiness for MI. Keywords like Innovation Culture and Innovation Quotient (Danks et al., 2017) reflect a paradigm shift toward empirical measurement - for example, firms scoring high on the Innovation Quotient report 35% faster implementation of managerial innovations (Danks et al., 2017b). This cluster also signals interdisciplinary convergence, with studies linking cultural metrics to sustainability outcomes (Wang et al., 2022)

and circular economy practices (Chowdhury et al., 2022), illustrating MI's expanding relevance beyond traditional business contexts.

5 Discussion and research agenda

In this work a SLNA was performed to address the research question: "what are the most important research areas on the interdependent relationship of management innovation and organizational culture, taking into account their evolution over time?". By combining the results of the performed analyses, we are able to summarize the main areas of the academic debate under investigation and the future development of the research to address emerging needs for academics and manager. This represents an original perspective on the debate about the relationship between MI and OC, providing academics and managers with an overview over time. From an academic point of view the research provides a complete research agenda for future research shown in Table 3, this is particularly important in this historical moment when other forms of innovation lack the time to be effective due to the unsustainable digital transformation. Form a managerial point of view this work can suggest an agenda for manager by providing the most relevant paper by specific topics. An additional contribution is the application of SLNA methodology to the field of management innovation and organizational culture, which can be an inspiration for other academics to perform systematic literature review on different topics using bibliometric analyses.

Table 3 summarize and report the specific contributions from the analyses of the SLNA:

1. The first area investigated answers the question of what the possible enablers of MI. Literature about the theme are suggest that transformational leadership; knowledge management; organizational learning; and narratives are all variables that can create a fertile organizational environment for management innovation. These enabling factors can work in synergy to also promote a culture open to change and foster creativity by actively involving employees in innovation processes. The literature also suggests that organizations that invest in these factors will be better positioned to meet market challenges and maintain a long-term competitive advantage. The future research directions concern the analysis of management innovation in this complex ecosystem, taking into consideration more the relationship between MI and the suggested enablers.
2. The analyses showed a positive feedback loop between MI and OC. The relationship between MI and OC was widely reported in a relevant part of the academic debate, not only that, both constructs are considered crucial for the other one. A positive organizational culture is the perfect environment for implementing management innovation and management innovation practices could be the trigger point to improve the organizational culture. Future research directions focus on this strict relationship between MI and OC, suggesting more empirical analysis when possible.
3. The review showed a linkage between MI and other forms of innovation. Some academics (Hamel, 2008) suggested that MI is the most important type of innovation for firms. Still, the academic debate suggests that MI may not have to be considered in the same basket as the other ones. The future research directions ask for more empirical evidence of this possible link between MI and other forms of innovation.
4. In the analysis also emerged what are the change agents for management innovation. The two main actor of this practices are the top management and the HR. Each construct relies around the people of the firms, and both HR and Top Management are direct responsible for managing people, sharing value and overall promoting a cultural change. The future research directions focus on more qualitative analysis on the traits and characteristics need for top management and HR to promote a better OC and MI practices within the firms.

6 Conclusions

After discussing the results, we cannot disregard the limitations of the methodology presented in this paper. Citations cannot fully represent a research's contribution to the academic debate (Colicchia et al., 2018). Additionally, citations are collected from the Scopus database, a rich database of scientific papers, but not sufficient to fully cover all publications. Finally, the phenomenon of the "rich get richer" also called "Matthew effect" has to be taken into consideration. Researchers with a high reputation often obtain an increased number of citations for their studies. Despite these limitations, the relevance of this study extends beyond the ability to fully analyze citation networks and bibliometric data. The relevance of the SLNA technique rests in its adaptability to many fields of study, providing insights about the discipline's evolution and guiding future research agendas. This SLNA demystifies the interdependent relationship between management innovation (MI) and organizational culture (OC), offering three key contributions. First, the feedback loop - where MI drives

cultural adaptability, and progressive cultures enable MI emerges as a linchpin for resilience in volatile markets (Azeem et al., 2021; AlSaied and Alkhoraif, 2024). Second, MI transcends its role as a standalone practice, acting as a strategic enabler that amplifies product/process innovations through agile decision-making frameworks (Hamel, 2008; Lei et al., 2021). Third, leadership and metrics - exemplified by transformational leaders and tools like the Innovation Quotient - are pivotal in dismantling cultural inertia (Hogan and Coote, 2014; Danks et al., 2017). For practitioners, this underscores the urgency of aligning MI with ESG (Environmental, Social, Governance) goals to foster sustainable competitiveness. Future research should prioritize cross-industry validations of MI-OC dynamics and explore AI-driven cultural adaptations in hybrid work models.

Table 3: Research directions (including specific contributions from the analyses of the SLNA)

No.	Investigated Area	Relationship with citation network analysis	Relationship with citation score analysis	Relationship with Author Keywords analysis	Future research directors
1	The enablers/inhibitors of management innovation	Transformational leadership (Busaide, 2017; Kalyar and Rafi, 2013; Sarros et al., 2008; Elenkov and Manev, 2005) Knowledge management (Liao et al, 2012; Abdi et al., 2018; Azeem et al, 2021; Ayestaràn et al., 2022; AlSaied and Alkhoraif, 2024) Narratives (Bartel and Garud, 2009)		Cluster 1: Transformational leadership Knowledge management Organizational learning Cluster 2 : Leadership Cluster 3 : Organizational innovativeness	More analysis on the relationship between MI and his possible enablers: transformational leadership, knowledge management, organizational learning and narratives
2	The positive feedback loop between MI and CO	MI as a mediator between OC and competitive advantage (Azeem et al., 2021)	Kahn (2018)	Cluster 1: Both MI and OC are dominant in the conversation	More empirical analysis on the positive feedback loop between MI and OC
3	The correlation between MI and the other forms of innovation		Link to Sustainability (Wang et al., 2022; Chowdhury et al., 2022)	Cluster 2: Innovation is predominant in cluster 2, suggesting the link between MI, OC and the other forms of innovation	More empirical analysis on the possible link between MI and other forms of innovation
4	The change agent for management innovation	Top Management (Sarros et al., 2008; Hernàndez-Mogollon et al., 2010; Busaide et al., 2017)	HR (Lei et al, 2021)		More qualitative analysis on the traits and characteristics needed for top management and HR promote MI

7 Ethics declaration

We confirm that ethical clearance was not required for this research.

8 AI declaration

We confirm that AI tools were not used for the creation of this paper.

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Knowledge Management and Diversity Management in HEIs: An Italian Overview

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Abstract
Higher Education Institutions (HEIs) play a critical role in fostering diversity and inclusivity while managing knowledge effectively. However, the integration of Diversity Management (DM) and Knowledge Management (KM) in HEIs remains a fragmented process, influenced by institutional size, technological infrastructure, and strategic alignment. This study explores the presence of key diversity management elements within Italian university PIAOs (Integrated Plans of Activities and Organization), using a knowledge management lens to assess inclusivity, collaboration, intersectionality, and technology integration. Through content analysis, the study identifies significant disparities in diversity and knowledge strategies among universities of different sizes. Larger institutions tend to leverage AI-driven recruitment systems, open-access repositories, and interdisciplinary collaboration platforms, ensuring a scalable and technology-enhanced approach to diversity and knowledge dissemination. Mid-sized universities prioritize regional engagement, faculty-student mentorship programs, and interdisciplinary teamwork, adopting structured but less technology-intensive approaches. Smaller universities, by contrast, rely more on community engagement, face-to-face collaboration, and localized mentorship models, often lacking the resources to implement large-scale digital transformation. The findings reveal that institutional size directly influences the extent of technology integration in both diversity and knowledge strategies. Larger universities demonstrate advanced digital ecosystems, while mid-sized and smaller institutions exhibit resource constraints that limit their ability to implement AI-driven and automated solutions. Additionally, intersectionality remains an underdeveloped dimension in most institutions, with policies often failing to address the complexity of overlapping identities, resulting in generic rather than tailored inclusion strategies. This research underscores the need for more integrated and technology-supported diversity management frameworks across HEIs. AI, digital platforms, and structured knowledge-sharing models can enhance inclusivity, bridge disparities, and ensure that diversity policies are effectively embedded within knowledge systems. The study calls for policy reforms, targeted investments, and institutional collaborations to foster an equitable and technology-driven higher education environment, ensuring that diversity and knowledge management serve as complementary pillars for institutional growth and innovation.

Keywords: diversity management, knowledge management, Higher Education Institutions (HEIs), intersectionality, technology integration

Paper type: Academic Research Paper

1 Introduction

Higher education institutions (HEIs) often struggle to integrate diversity and inclusion into their strategic frameworks effectively. Many initiatives remain superficial, focusing on compliance rather than fostering systemic change. A lack of integration between diversity goals and broader institutional strategies, coupled with limited engagement with power dynamics and intersectionality, undermines progress (Lindsay et al., 2018). This disconnect leaves diversity efforts isolated from core processes, reducing their impact. To address these gaps, HEIs must embed diversity as a transformative element within their strategic planning, moving beyond tokenistic measures to drive meaningful change.

In Europe, the promotion of diversity in public and private institutions has been strongly encouraged through initiatives such as the EU Platform of Diversity Charters, launched by the European Commission. This platform has been signed by over 12,000 organizations across 24 countries, impacting 16 million workers, and aims to promote diversity in terms of gender, ethnicity, religion, age, disability, and sexual orientation. It encourages organizations to adopt merit-based practices in hiring, training, and career development while fostering inclusive policies that address work-life balance and challenge gender stereotypes. In Italy, despite 940 organizations, including healthcare companies, signing the Diversity Charter to promote these values, only six universities (Università degli Studi di Bari Aldo Moro, Università degli Studi di Ferrara, Università degli Studi di Foggia, Università degli Studi di Genova, Università del Salento) have adhered to this initiative. This limited engagement contrasts with European policies that aim to embed a culture of diversity within all public institutions, highlighting a significant gap in the Italian higher education sector's commitment to these principles. An apparent gap in the strategic adoption of these elements is evident.

The PIAO (Integrated Plan of Activities and Organization) for universities in Italy is a comprehensive strategic planning tool introduced by Law No. 6 of January 19, 2022, aimed at improving efficiency, transparency, and accountability within public administrations, including higher education institutions. This plan consolidates multiple previously separate planning documents, encompassing areas such as performance management, human resources, gender equality, anti-corruption measures, and financial planning, into a single cohesive framework (Cepiku et al., 2023; De Nicola & Fratini, 2024). The PIAO aligns university activities with strategic objectives by setting measurable performance targets, promoting efficient human resource management, and fostering workforce development with a focus on diversity and inclusion. It also integrates gender equality initiatives, ensuring fair representation and opportunities across academic and administrative spheres, while implementing anti-corruption and transparency strategies to uphold ethical governance. The plan incorporates sustainability goals, aligning university operations with broader environmental, social, and economic imperatives, and emphasizes the adoption of digital technologies to enhance teaching, research, and administrative processes. Furthermore, it ensures effective financial planning, aligning resource allocation with institutional priorities to create a forward-looking and cohesive framework that addresses internal goals and external accountability requirements, ultimately contributing to innovation, equity, and sustainable development in higher education. Other studies have been conducted to identify strategic elements and the adoption and support of diversity management through the analysis of PIAO in different sectors related to public service (Brescia et al., 2024).

The study intends to analyze the presence of key elements of diversity management within university PIAOs using knowledge management as a lens. The study answers the question: Which diversity strategic management elements are adopted by Italian universities? How does KM support the strategic process?

The next paragraph describes the theory supporting the analysis. The methodology defines through which elements the PIAOs were analyzed, dividing the results into three distinct paragraphs. The conclusions highlight the actions, implications and future developments.

2 The lens of knowledge management to support diversity management

Knowledge management (KM) in literature is described as a dynamic process that integrates people, processes, and technology to promote the creation, sharing, and utilization of knowledge within an organization. In the context of higher education institutions (HEIs), KM is seen as a critical strategy for fostering continuous learning, adaptation, and alignment with institutional goals (Quarchioni et al., 2022). It is closely linked to managing intellectual capital, which includes identifying, measuring, and reporting knowledge assets to enhance transparency and create societal value (Secundo et al., 2018).

Another central element of KM in HEIs is the transfer of high-impact knowledge, often achieved through collaboration between universities and external entities such as industries and local communities (Ceballos et al., 2017). This transfer drives innovation and regional development (Ceballos et al., 2017). Additionally, the role of technology is emphasized in KM, where ICT tools facilitate the storage, transfer, and accessibility of knowledge, improving decision-making processes and e-learning environments (Adedokun-Shittu & Shittu, 2013).

KM also enhances learning and education by making knowledge more accessible, fostering collaboration among students, academics, and administrative staff, and enriching pedagogical approaches. In research, KM supports the production and sharing of academic knowledge across groups, disciplines, and international networks. Moreover, adopting KM systems within HEIs is highlighted as essential for integrating KM strategies into organizational processes (Corcoran & Duane, 2017). Success in this area often depends on organizational culture, governance structures, and technological readiness (Al-Busaidi, 2010).

Overall, KM in HEIs represents an approach to optimize intellectual resources, leverage technological advancements, and align educational and research objectives with broader societal needs, creating significant impacts within and beyond the academic sphere (Fernández-López et al., 2018; Romano et al., 2014).

The integration of diversity management and knowledge management within organizations, particularly in higher education institutions, creates a synergistic approach that fosters inclusivity, innovation, and institutional growth (Yadav & Lenka, 2020). While diversity management emphasizes the strategic value of leveraging diverse perspectives and promoting an inclusive organizational culture, knowledge management focuses on the effective creation, sharing, and application of knowledge. Together, these frameworks enhance collaboration, drive innovation, and strengthen organizational adaptability in increasingly complex environments.

Diversity management contributes by addressing issues such as inclusivity, intersectionality, and the reduction of hierarchical barriers (Ghio et al., 2024). It promotes equal opportunities and ensures that diverse identities and experiences are acknowledged and valued within organizational structures (Ross & Schneider,

1992). At the same time, knowledge management provides the tools and systems needed to harness the diverse insights and expertise present in an organization, fostering collaborative problem-solving and innovation (Hong & Page, 2004).

Recent scholarship highlights the increasing need to integrate structural inequality considerations into Diversity Management frameworks, emphasizing that diversity cannot be effectively managed without addressing broader systemic inequities (Post et al., 2021). Traditional diversity strategies often focus on compositional aspects such as workforce demographics and inclusion policies; without sufficiently accounting for the cumulative effects of institutional power dynamics and historical biases. This gap underscores the importance of intersectionality as a lens for understanding how different identity dimensions interact within organizations, shaping access to opportunities and resources. Moreover, as organizations face rapid technological and demographic shifts, there is a growing imperative to align Diversity Management with evolving workforce needs, particularly in the context of AI-driven recruitment and knowledge management systems. Future research should further explore the interplay between technological advancements and structural diversity mechanisms, ensuring that emerging digital tools enhance, rather than reinforce, existing disparities.

By integrating these two approaches, organizations can create environments where diverse perspectives enrich the processes of learning and knowledge creation. This integration ensures that knowledge management systems are inclusive and accessible, leveraging the full spectrum of human diversity to drive organizational success Table 1.

Table 1. Element description.

Dimension	Diversity Management	Knowledge Management	Integration
Inclusivity	Creating policies for equal opportunities and inclusion.	Providing platforms for sharing and collaboration.	Ensuring inclusive access to knowledge and equal participation in organizational processes.
Collaboration	Encouraging interaction among diverse groups.	Facilitating teamwork through knowledge-sharing tools.	Harnessing diverse perspectives to improve team innovation and problem-solving capabilities.
Intersectionality	Addressing the complexity of identities and their intersections.	Utilizing diverse knowledge sources.	Building systems that reflect and adapt to varied user needs and backgrounds.
Technology Integration	Leveraging ICT for diverse recruitment and inclusion.	Enhancing knowledge dissemination.	Using technology to bridge gaps between diverse groups and enhance overall organizational learning.

Source: Authors' elaboration

3 Methodology

The study considers a homogeneous sample based on Italian state universities. The representation of reality is based on the Censis Ranking of Italian Universities (2024/2025 Edition), which provides an initial representation by the number of students enrolled Table 2. The PIAOs considered are the entire Italian sample of HEIs extracted from the institutions' institutional sites. The PIAOs considered as HEIs all refer to the period from 2024 to 2026.

Table 2. Representation of the HEI sample based on the 2024/2025 CENSIS ranking

Group	Criteria	Examples	Total Institutions
Mega Universities	Over 40,000 students	Padova, Bologna, La Sapienza Roma	9
Large Universities	20,000 to 40,000 students	Calabria, Pavia, Perugia	18
Medium Universities	10,000 to 20,000 students	Trento, Udine, Sassari	16
Small Universities	Up to 10,000 students	Camerino, Tuscia, Macerata	10
Polytechnics	Specialized technical institutions	Milano, Torino, Bari	4
Total			**57**

Source: 2024/2025 CENSIS ranking

The content analysis adopts the nodes (Dal Mas et al., 2019; Secinaro et al., 2022) identified by previous literature (Table 1); based on these elements present in the PIAO, it provides evidence of effective adoption and intends to provide new empirical and theoretical evidence. The strategic analysis by nodes present in the PIAO has already been adopted in the public sector (Brescia et al., 2024) and provides significant evidence to identify the strategies adopted by universities. The size of the universities supports further evidence and comparisons. Nvivo was used to perform the analysis and identify key nodes within the PIAOs.

4 Results and findings

4.1 Diversity management

In Higher Education Institutions (HEIs), diversity management has become a cornerstone of institutional strategies, reflected in actions and policies across various dimensions. A key focus is inclusivity, with institutions striving to create policies that ensure equal opportunities and access for all. Gender Equality Plans and Equal Opportunity Action Plans are common frameworks aimed at dismantling systemic barriers. HEIs prioritize accessibility for disadvantaged groups by implementing initiatives that address the needs of individuals with disabilities, socio-economic challenges, and underrepresented communities. This commitment is further supported by the integration of assistive technologies, such as screen readers and accessible course materials, ensuring that diverse learning needs are met comprehensively.

Collaboration is another fundamental aspect, with HEIs fostering interaction among diverse groups to enhance innovation and mutual understanding. Interdisciplinary collaboration is promoted through platforms that encourage cross-departmental teamwork and research initiatives, bringing together varied perspectives. Digital tools like Microsoft Teams, Zoom, and collaborative document-sharing platforms facilitate seamless interaction among students, faculty, and external partners, irrespective of their geographic or demographic differences. Additionally, HEIs actively participate in global networks, forming partnerships with international institutions to encourage cultural exchanges and collaborative problem-solving.

The emphasis on intersectionality reflects a nuanced understanding of the complexity of identities and their intersections. HEIs recognize overlapping factors such as gender, ethnicity, socio-economic status, and disability, integrating these considerations into institutional frameworks to create inclusive policies and practices. Tailored support systems address the compounded challenges faced by individuals with intersecting identities, such as women with disabilities or students from marginalized communities. By collecting and analyzing intersectional data, institutions refine their strategies, ensuring their inclusivity efforts are informed and impactful.

The integration of technology has proven instrumental in advancing diversity management, particularly in recruitment and inclusion efforts. HEIs leverage digital recruitment platforms to create transparent and inclusive hiring processes accessible to a global pool of candidates. Learning Management Systems, such as Moodle, provide accessible e-learning opportunities through recorded lectures, interactive tools, and hybrid models that accommodate various access needs. AI-powered tools are increasingly employed to reduce bias in recruitment and broaden outreach to underrepresented groups, ensuring equitable participation. Furthermore, hybrid and online learning models have been widely adopted to overcome geographic, economic, and physical access barriers, exemplifying the role of technology in bridging gaps and fostering inclusion.

These elements collectively demonstrate a shared commitment among HEIs to promote diversity, equity, and inclusion through thoughtful policies, collaboration, an awareness of intersectionality, and the strategic use of technology.

The implementation of Diversity Management across universities reveals several gaps when analyzed through the lenses of Inclusivity, Collaboration, Intersectionality, and Technology Integration. While many institutions have policies promoting equal opportunities, their depth and scope vary significantly. Some universities prioritize certain groups, such as women or international students, while others neglect critical areas like accessibility for individuals with disabilities or support for socio-economically disadvantaged populations. Furthermore, inconsistencies in resource allocation and the lack of robust monitoring mechanisms hinder effective policy implementation. In terms of collaboration, disparities arise in the extent of interdisciplinary and global interactions. While some universities actively promote cross-disciplinary projects and international partnerships, others operate in silos, limiting opportunities for diverse perspectives to influence innovation. The complexity of intersectionality is often overlooked, with many universities adopting one-dimensional policies that fail to address overlapping identities such as gender, ethnicity, and disability. Few institutions collect or analyze intersectional data, resulting in generic support systems that do not cater to nuanced needs. Technology integration also exhibits disparities, particularly in the accessibility and sophistication of digital platforms. Larger, better-funded universities tend to leverage AI-powered tools for recruitment and advanced hybrid learning models, while smaller institutions often lack the infrastructure or resources to implement such solutions. These gaps highlight the uneven progress among universities in fostering diversity, equity, and inclusion, influenced by factors such as funding, regional priorities, and cultural contexts. Addressing these disparities is crucial for creating equitable and inclusive environments that reflect the diversity of their academic communities and enhance organizational learning.

The analysis of Diversity Management across different universities reveals size-dependent variations in their approach to inclusivity, collaboration, intersectionality, and technology integration. Larger universities, such as

La Sapienza, Bologna, and Milan, tend to implement structured, large-scale diversity policies, aligning their strategies with international frameworks such as the UN Sustainable Development Goals (SDGs). These institutions leverage advanced ICT systems to facilitate recruitment, ensure inclusive access to knowledge, and drive cross-disciplinary collaboration at a broad institutional level. Their diversity strategies focus on scalability, governance, and digital infrastructure, ensuring that a high volume of students and staff can participate in inclusive initiatives. Their intersectional approaches are embedded in faculty hiring, student support systems, and curriculum design, ensuring a holistic integration of diverse perspectives. Mid-sized universities, such as Urbino, Pavia, and Calabria, adopt more targeted inclusivity strategies, often focused on regional engagement and community-based diversity policies. Their emphasis is on tailored recruitment efforts, support for underrepresented groups, and fostering internal knowledge-sharing platforms. While these universities may not have the same level of technological integration as larger institutions, they compensate with direct engagement strategies, such as mentorship programs, interdisciplinary collaborations, and structured policies for gender equality and accessibility. Smaller universities or institutions with a more specialized focus, such as Perugia and Urbino, tend to emphasize interpersonal collaboration and knowledge-sharing initiatives over large-scale digital transformation. Their inclusivity measures often revolve around local accessibility improvements, community outreach programs, and flexible policies tailored to students and faculty with specific needs. They may lack comprehensive ICT infrastructures seen in larger universities but compensate with strong faculty-student interaction models and customized diversity initiatives. The institutional size impacts the depth and scope of Diversity Management policies, larger universities favor broad, scalable, and technology-driven inclusion strategies, while smaller institutions focus on personalized engagement, community-building, and direct stakeholder involvement.

4.2 Knowledge management

Based on the PIAO analysis and the provided definitions, the following shared approaches to Knowledge Management in HEIs emerge that HEIs prioritize inclusivity by creating and maintaining platforms for sharing and collaboration. These platforms include centralized digital repositories, institutional knowledge hubs, and open-access systems that allow students, faculty, and staff to contribute, access, and share academic resources. Such tools are designed to break down barriers and ensure equitable participation, with features that cater to diverse learning and communication needs.

Collaboration is facilitated through tools that support teamwork and interdisciplinary engagement. Cloud-based document-sharing platforms, collaborative editing tools, and real-time communication systems like Microsoft Teams and Zoom enable diverse groups across departments and regions to work together effectively. These platforms are integrated into research and administrative workflows to enhance problem-solving and project outcomes.

The commitment to intersectionality is evident in efforts to integrate diverse knowledge sources into institutional frameworks. HEIs actively encourage interdisciplinary research initiatives, leveraging insights from various cultural, social, and academic backgrounds to address complex challenges. This approach reflects the acknowledgment that diverse perspectives enrich organizational learning and innovation.

Technology integration is a cornerstone of these efforts, enhancing knowledge dissemination through digital tools like Learning Management Systems (LMS), AI-driven platforms, and virtual classrooms. These technologies ensure that educational content is accessible to global audiences and tailored to individual needs. Open-access repositories further extend the reach of knowledge to underserved communities, aligning with inclusivity goals.

These common strategies reflect a unified approach among HEIs to leverage diversity, collaboration, and technology to foster innovation and accessibility in knowledge management.

The implementation of Knowledge Management in universities reveals significant gaps and differences, particularly in the areas of inclusivity, collaboration, intersectionality, and technology integration. While some universities excel in creating centralized digital repositories and open-access platforms for sharing knowledge, others lack the infrastructure or funding to develop and maintain such systems, limiting equitable access. Collaboration tools are unevenly adopted; well-resourced institutions often utilize advanced cloud-based platforms and AI-driven systems to facilitate teamwork, while smaller universities rely on less sophisticated tools, creating disparities in their ability to foster interdisciplinary and cross-departmental collaboration. The integration of intersectional knowledge also varies, with some universities actively incorporating diverse cultural, social, and academic perspectives into their frameworks, while others fail to utilize or even recognize the value of such diversity. Similarly, the level of technology integration differs widely, with larger institutions leveraging AI-powered platforms, advanced e-learning systems, and hybrid learning models to enhance knowledge dissemination, while smaller or less funded universities struggle to adopt these technologies due to

budgetary or technical constraints. These gaps highlight the uneven progress in Knowledge Management across universities, influenced by differences in resources, institutional priorities, and regional contexts. Addressing these disparities is crucial to fostering a more inclusive and innovative academic environment.

The analysis of Knowledge Management across universities highlights significant differences based on institutional size, particularly in the way they implement inclusivity, collaboration, intersectionality, and technology integration. Large universities such as Milan, Bologna, and Sapienza leverage digital infrastructure to create comprehensive knowledge-sharing systems. They employ centralized platforms, including open-access repositories, AI-enhanced learning management systems, and cloud-based collaboration tools to facilitate knowledge dissemination. These institutions integrate automated knowledge indexing and multilingual platforms, ensuring accessibility for international students and researchers. Their intersectionality strategies focus on incorporating multidisciplinary insights into policy and curriculum development, ensuring a broad and inclusive knowledge base. Mid-sized universities such as Urbino, Pavia, and Calabria emphasize regional and interdisciplinary knowledge-sharing networks. Their approach to Knowledge Management is more targeted, focusing on faculty training programs, student mentoring systems, and internal co-working spaces for collaborative learning. These institutions implement structured peer-learning programs and encourage faculty-student knowledge exchange initiatives to maximize research and learning accessibility. Smaller universities, such as Teramo and Perugia, tend to prioritize in-person knowledge-sharing models rather than relying heavily on digital infrastructure. Their inclusivity measures include interactive knowledge hubs, interdisciplinary research projects, and customized access to knowledge for underrepresented groups. While they may lack large-scale digital repositories, they compensate with direct engagement strategies, faculty accessibility, and close collaboration between students and professors. Institutional size directly influences the scalability and integration of Knowledge Management strategies. Large universities emphasize technology-driven solutions, mid-sized institutions focus on regional engagement and faculty-student collaboration, while smaller universities favor personal engagement models over large-scale digital platforms.

4.3 Integration between diversity management and knowledge management

Based on the PIAO document and the outlined criteria, the integration of Knowledge Management and Diversity Management in HEIs reveals comprehensive strategies that align inclusivity, collaboration, intersectionality, and technology integration to promote equity and innovation. HEIs ensure inclusive access to knowledge by creating platforms that cater to diverse needs, such as centralized repositories, digital learning environments, and accessible content for individuals with disabilities. Collaboration is enhanced through tools that enable seamless teamwork across disciplines and geographies, fostering innovative solutions through diverse perspectives. Intersectionality is addressed by designing systems that adapt to the overlapping identities and varied needs of students and staff, integrating measures to support individuals with compounded challenges like gender and socio-economic disparities. Additionally, technology serves as a critical enabler, bridging gaps between different groups by implementing advanced ICT tools, hybrid learning models, and AI-driven personalization to disseminate knowledge effectively. These integrations demonstrate a concerted effort to harness diversity for institutional growth and societal impact, aligning with the principles of equity, inclusivity, and global engagement.

The analysis of Knowledge Management and Diversity Management across universities reveals significant differences and gaps in their approaches based on inclusivity, collaboration, intersectionality, and technology integration. In terms of inclusivity, while some universities excel in creating open-access platforms and ensuring equitable access to knowledge resources for disadvantaged groups, others struggle to remove systemic barriers or implement adequate accessibility measures for individuals with disabilities. Regarding collaboration, larger institutions often leverage advanced cloud-based systems and interdisciplinary networks to harness diverse perspectives, whereas smaller universities may lack the resources or digital infrastructure to enable effective teamwork and knowledge sharing across departments. In addressing intersectionality, disparities are evident as many universities fail to fully integrate the complexity of overlapping identities into their policies and systems, resulting in one-size-fits-all solutions that overlook nuanced needs. Lastly, technology integration is uneven, with well-funded universities adopting AI-driven personalization, hybrid learning models, and advanced digital tools to bridge gaps between diverse groups, while resource-constrained institutions lag behind in their ability to provide inclusive and accessible technological solutions. Bridging these gaps requires targeted investments, comprehensive policy reforms, and a stronger focus on inclusivity and adaptability in institutional strategies.

Large universities, such as Milan, Bologna, and Sapienza, implement structured and technology-driven diversity policies to ensure inclusive access to knowledge and organizational participation. These institutions rely on digital repositories, open-access academic platforms, and AI-powered recruitment systems to foster

inclusivity. They also prioritize collaborative networks across departments and international institutions, leveraging digital tools for remote participation and knowledge dissemination. Intersectionality is integrated into these universities' governance models, ensuring policies and services reflect diverse student and faculty needs, particularly through multidisciplinary research collaborations and inclusive hiring frameworks. Mid-sized universities, such as Urbino, Pavia, and Calabria, adopt a regionally focused approach to inclusivity and collaboration. They emphasize faculty-student mentorship programs, peer-learning initiatives, and interdisciplinary teamwork rather than relying on large-scale digital infrastructure. These universities foster knowledge management through structured faculty training, academic networking programs, and data-driven diversity audits. Technology integration is present, but often in the form of learning management systems and hybrid learning models, rather than fully automated knowledge-sharing platforms. Smaller universities, such as Perugia and Teramo, focus on community engagement and personalized inclusivity strategies. Their knowledge-sharing models are primarily interpersonal, relying on face-to-face collaboration, localized mentorship programs, and direct student-faculty engagement. While digital transformation is present, it is less pronounced, with these universities using basic e-learning platforms and document-sharing systems instead of AI-driven knowledge repositories or complex intersectionality frameworks. Institutional size strongly influences Diversity and Knowledge Management strategies. Large universities integrate comprehensive, technology-driven, and scalable inclusion models, while mid-sized institutions rely on regional engagement and faculty collaboration. Smaller universities maintain personalized, direct engagement strategies, prioritizing interpersonal knowledge exchange over advanced digital infrastructures.

5 Discussion and conclusions

The integration of Diversity Management (DM) and Knowledge Management (KM) in Italian Higher Education Institutions (HEIs) reveals an evolving yet fragmented approach. While strides have been made in areas such as inclusivity, collaboration, intersectionality, and technology integration, significant gaps remain. Many universities have introduced initiatives like gender equality plans and support systems for disadvantaged groups, but these efforts often lack depth and alignment with broader institutional goals. The uneven adoption of advanced technologies and insufficient focus on intersectionality further limit the impact of diversity and knowledge strategies.

Technology plays a crucial role in addressing these gaps. AI-driven tools can personalize learning experiences, identify participation barriers, and refine inclusion strategies. Digital platforms must be expanded to offer accessible, multilingual, and user-friendly interfaces, ensuring equitable access to knowledge. Additionally, advanced analytics can enhance the evaluation of diversity initiatives, providing actionable insights to refine policies and improve institutional outcomes.

The integration of intersectionality remains a key challenge for HEIs. Many universities fail to fully address overlapping identities such as gender, ethnicity, and socio-economic status, resulting in one-size-fits-all policies that overlook nuanced needs. Incorporating frameworks that reflect and adapt to the complexity of diverse identities is essential. Data-driven approaches should be employed to identify disparities and measure the effectiveness of policies designed for intersectional inclusion.

Collaboration across institutions is another critical area for improvement. Partnerships between universities can facilitate resource sharing, best practices, and innovative solutions for integrating DM and KM. Joint research projects and interdisciplinary networks can further promote the exchange of diverse perspectives, enhancing innovation and organizational learning. Expanding international and regional collaborations can ensure that all institutions, regardless of size or resources, benefit from collective advancements in diversity and knowledge strategies.

Policy and funding support are fundamental to bridging resource disparities, particularly for smaller or underfunded universities. Comprehensive reforms must include mandatory diversity metrics in strategic planning and allocate funding to bridge technological gaps. Targeted investments in technology and diversity initiatives can ensure equitable progress across the sector, enabling all institutions to create inclusive, innovative environments.

In conclusion, Italian HEIs must embed diversity as a transformative element within their strategic frameworks, leveraging the dynamic capabilities of KM to foster equitable, inclusive, and innovative academic environments. The synergy between DM and KM, driven by technological advancements and a commitment to intersectionality, will enable universities to meet societal challenges effectively and contribute to sustainable development. These efforts must be supported by continuous policy evolution, resource allocation, and collaborative networks to ensure meaningful progress across the higher education sector.

Diversity Management and Knowledge Management across Italian universities indicate that institutional size, technological infrastructure, and strategic alignment play a crucial role in shaping how inclusivity, collaboration, intersectionality, and technology integration are implemented. Larger universities have the advantage of scalability, enabling them to integrate advanced AI-driven solutions for knowledge dissemination, recruitment, and diversity tracking. These institutions are more likely to develop automated systems for talent acquisition, inclusive hiring, and interdisciplinary research, leveraging AI to eliminate bias and ensure fair representation. In contrast, mid-sized universities focus on regional engagement and faculty-student interaction, often employing structured but less technology-intensive approaches to diversity and knowledge-sharing. Smaller universities, while emphasizing personalized engagement strategies and direct community involvement, often lack the AI-driven tools and large-scale digital platforms that allow for efficient diversity tracking and automated knowledge management. A significant divergence emerges in the use of AI and technology. Larger institutions integrate AI-powered learning management systems, hybrid teaching models, and digital knowledge repositories, ensuring accessibility and broad participation. AI is also utilized in data-driven diversity assessments, improving policy effectiveness by analyzing intersectionality trends across gender, ethnicity, and socio-economic backgrounds. Mid-sized and smaller institutions, due to resource constraints and limited infrastructure, rely more on traditional mentorship models, in-person collaboration, and regional partnerships, lacking the full-scale AI-driven optimization seen in larger institutions. The findings underscore that universities must bridge these gaps by leveraging AI and digital transformation while maintaining human-centered approaches to knowledge and diversity management. Investment in AI-driven inclusivity tools, interdisciplinary collaboration platforms, and adaptive learning technologies can enhance knowledge-sharing and diversity integration across all institutional levels, ensuring sustainable, inclusive, and technology-driven growth within the Italian higher education system.

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7 Ethics declaration

This research did not involve the collection of personal data, experimentation on human subjects, or any activity requiring ethical approval. Therefore, no ethical clearance was necessary for the study presented in this paper.

8 AI declaration

No AI tool was used in the development, drafting, or editing of this paper. All content is the result of original human authorship and academic research.

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Rethinking Fairness in Work-Life Policies: A Conceptual Framework Beyond Parenthood

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Abstract

Traditional workplace policies aimed at supporting work-life balance, career development, and organizational support have largely been designed with employees with children in mind. However, such family-centric approaches risk marginalizing the growing number of employees who are childfree by choice or who desire children in the future. These groups often remain underrepresented in both academic literature and organizational practice. This paper proposes a conceptual framework for rethinking workplace equity by integrating diverse family statuses and future aspirations into the analysis of fairness perceptions. Drawing on equity theory, we examine how three groups—parents, childfree employees by choice, and employees desiring children—differ in their experiences and expectations of fairness across three core domains: work-life balance, career progression, and perceived organizational support (POS). We introduce the concept of *anticipatory fairness* to capture how employees evaluate current policies not only based on present conditions but also in light of their anticipated future needs and life trajectories. The framework identifies hidden and often overlooked inequities in how support is distributed, how opportunities for career advancement are perceived, and how organizational inclusion is experienced by employees with differing family orientations. Based on this conceptual foundation, we propose three theoretical propositions and outline directions for future empirical research. Our model encourages organizations to move beyond binary categories of parenthood and to develop more inclusive policies that recognize the full diversity of employee identities. By embracing a broader and more dynamic understanding of equity, organizations can foster greater fairness, motivation, and retention across all employee groups, ultimately contributing to more inclusive and sustainable workplaces.

Keywords: Equity theory, Work-life balance, Career progression, Perceived organizational support, Anticipatory fairness, Childfree employees, Inclusion

Paper type: Academic Research Paper

1 Introduction

In contemporary organizations, the concept of work-life balance has become a central element in discussions around employee well-being, fairness, and inclusion. Traditionally, organizational policies addressing work-life integration have focused primarily on supporting employees with children, under the assumption that they face the most significant challenges in balancing professional and personal responsibilities. While this perspective has led to valuable advances in family-friendly policies—such as parental leave, flexible scheduling, and remote work—it has also unintentionally marginalized other employee groups whose needs may not align with conventional family structures.

In particular, the experiences of childfree employees, both by choice and by circumstance, remain significantly underexplored in academic literature and organizational practice. These workers often navigate workplaces structured around implicit assumptions of parenthood, which can affect how they are perceived by peers and superiors, how they access support and development opportunities, and how they evaluate fairness within the organization. Emerging studies suggest that this "parent-centric" orientation may lead to feelings of exclusion or inequity among non-parent employees, who may be expected to take on additional work or show greater availability, based on the assumption that they are less burdened outside of work.

Furthermore, recent demographic and cultural shifts have led to an increase in employees who either choose to remain childfree or delay parenthood for personal or professional reasons. These individuals may also have complex personal responsibilities—such as caregiving for aging parents, engaging in lifelong learning, or pursuing personal goals—which are not always recognized by existing organizational policies. The dichotomy between parents and non-parents thus oversimplifies the spectrum of employee needs, aspirations, and perceptions of fairness.

Another often-overlooked group consists of employees who desire to have children in the future but have not yet done so. These individuals frequently engage in anticipatory evaluations of work-life balance, career progression, and organizational support, assessing whether their current workplace would enable or hinder

future family aspirations. This dimension introduces a future-oriented perception of equity that has received little attention in the literature.

To address these gaps, this paper proposes a conceptual reframing of how organizations can understand and promote fairness across different family status groups. Drawing on equity theory, we explore how perceived fairness is influenced not only by actual support and career outcomes but also by the alignment between employees' contributions and their expectations of organizational reciprocity. We argue that perceived equity in the workplace must be reconsidered through a more inclusive and differentiated lens—one that accounts for the heterogeneity of employee life choices and trajectories.

By integrating insights from existing research on work-life balance, career development, and perceived organizational support (POS), we build a conceptual framework that highlights the diverse pathways through which fairness perceptions are formed. In particular, we focus on three employee categories: those with children, those who desire children, and those who are childfree by choice. We develop a set of theoretical propositions to guide future research and policy design, with the goal of fostering more inclusive work environments that respect and support the full range of employee identities and aspirations.

2 Theoretical Background

2.1 Equity in the Workplace: A Theoretical Foundation

Perceptions of fairness are a fundamental element in shaping employee attitudes and behaviors in organizational settings. Equity theory (Adams, 1965) offers a valuable lens to understand these perceptions, suggesting that individuals assess fairness by comparing the ratio between their inputs (such as effort, skills, and time) and outcomes (such as recognition, advancement, and support), relative to others. When this ratio is perceived as imbalanced, individuals may experience distress, dissatisfaction, or disengagement (Barclay et al., 2017; Skarlicki & Kulik, 2004).

The application of equity theory has traditionally focused on tangible elements such as compensation or workload, but more recent research extends its relevance to intangible dimensions like organizational support and career opportunities. This broader interpretation is particularly useful in analyzing how different employee groups experience the workplace, especially when their needs and contributions are shaped by factors such as gender, family responsibilities, or life choices (Morand & Merriman, 2012).

In this context, fairness is not an objective condition but a subjective perception that can vary significantly across individuals and groups, depending on their expectations, roles, and personal circumstances. This makes it crucial to analyze how organizational practices are experienced differently based on family status—a dimension that is often oversimplified or ignored.

2.2 Work-Life Balance: Beyond Parenthood

Work-life balance is typically defined as an individual's ability to manage professional and personal responsibilities effectively (Guest, 2002). Over the past two decades, organizations have increasingly introduced policies to support this balance, including flexible work arrangements, parental leave, and teleworking options. These measures are generally designed with working parents in mind, especially mothers, who are perceived as facing the greatest challenges in reconciling work and family roles (Hilbrecht et al., 2008; Kelliher et al., 2019).

However, this parent-centric approach to work-life policies may inadvertently neglect the needs of other groups. Employees without children—whether by choice or circumstance—may also experience significant work-life challenges related to caregiving for elderly relatives, community involvement, health issues, or personal development goals (Boiarintseva et al., 2022; Casper et al., 2016). Despite these responsibilities, they are often expected to be more flexible, more available, and more committed, simply because they do not have children (Wood & Newton, 2006). This can result in increased workloads and a sense of unfair treatment, as their time outside of work is perceived as less valuable or legitimate.

Moreover, the lack of recognition for diverse personal responsibilities reinforces the stereotype that only parents need work-life balance. This perception may be particularly problematic for employees who plan to have children in the future. These individuals may evaluate the adequacy of work-life policies not just in terms of current support but also as a signal of the organization's capacity to accommodate future needs—a concept we define as *anticipatory fairness*.

2.3 Career Progression: Structural Inequities and Hidden Biases

Career advancement is another domain where equity perceptions are shaped by family status. The well-documented "motherhood penalty" highlights how women with children often face slower promotions, reduced responsibilities, and wage stagnation compared to their childless counterparts (Aisenbrey et al., 2009; McIntosh et al., 2012). This penalty is frequently attributed to assumptions about mothers' availability, commitment, or capacity to handle demanding roles.

Conversely, men with children may benefit from a "fatherhood premium," being perceived as more stable and responsible (Luhr, 2020). These dynamics reflect deep-seated gender norms and expectations about parenting roles, but they also contribute to structural inequities in career trajectories.

Childfree employees, particularly those who are voluntarily childfree, are often assumed to be more dedicated, flexible, and mobile. While this can result in more opportunities, it may also lead to exploitation: increased workloads, frequent travel, or lack of boundaries between work and personal life (Dumas & Perry-Smith, 2018). These individuals may be rewarded with responsibilities rather than recognition, leading to frustration and burnout. Moreover, the assumption that childfree workers are inherently more available reinforces a discriminatory logic, placing the burden of organizational efficiency on those without caregiving duties.

Employees who are not yet parents but intend to have children may face different but equally problematic dynamics. They may hesitate to pursue promotions or long-term projects, fearing that family formation could disrupt their trajectory or be viewed negatively by the organization. In such cases, the anticipation of future inequities can be just as powerful as current ones in shaping behavior and perceptions.

2.4 Perceived Organizational Support and Inclusion

Perceived Organizational Support (POS) refers to employees' beliefs about how much their organization values their contributions and cares about their well-being (Kurtessis et al., 2017; Rhoades et al., 2001). POS is strongly associated with increased job satisfaction, organizational commitment, and retention. For parents, visible support often takes the form of family-friendly policies, understanding supervisors, and flexible arrangements (Chang et al., 2014).

Yet, the same signals may not resonate with employees who are not parents. Childfree individuals often seek different forms of support—such as professional development opportunities, personal leave for non-family commitments, or greater autonomy (Casper et al., 2007; Peterson & Engwall, 2016). When organizational support is framed predominantly in terms of family needs, non-parents may feel overlooked, excluded, or even punished for their different life choices.

This perception of exclusion is exacerbated when support mechanisms are implemented unevenly or informally, creating ambiguity about who qualifies for what kind of support. Moreover, the assumption that childfree employees do not need or deserve the same level of support contributes to a culture in which only certain life paths are validated and accommodated.

Thus, expanding the concept of POS to include a broader range of life experiences and commitments is essential for fostering an inclusive organizational culture. This includes recognizing that fairness is not only about providing the same policies to everyone, but also about ensuring that different needs are addressed equitably.

2.5 Toward an Inclusive Understanding of Workplace Equity

The literature reviewed highlights a significant gap in how organizational fairness is conceptualized and operationalized. Most existing studies focus on the experiences of parents—often with a binary view of family status—while neglecting the complex and evolving realities of today's workforce. There is limited exploration of how childfree employees navigate workplace expectations, and even less attention to the anticipatory perspectives of those who desire children but have not yet started families.

Moreover, the intersection between family status and perceptions of fairness remains under-theorized. Equity theory offers a useful starting point, but its application must be expanded to capture the subjective, temporal, and contextual nature of fairness as experienced by diverse employee groups.

To address these gaps, we argue for a reconceptualization of workplace equity that moves beyond traditional parent/non-parent dichotomies. This involves recognizing the heterogeneity of non-parent employees, acknowledging future-oriented aspirations, and designing policies that support multiple life paths with equal respect and consideration.

In the next section, we propose a conceptual framework and a set of theoretical propositions aimed at guiding future empirical research and informing more inclusive organizational practices.

3 Theoretical Gaps

Despite a growing body of research on work-life balance, career development, and perceived organizational support (POS), the literature remains largely centered on the experiences of employees with children. Organizational scholarship has historically approached family status in binary terms—parent versus non-parent—frequently overlooking the diversity of experiences within the latter category. As a result, current theoretical frameworks often fail to capture the nuanced and evolving realities of the contemporary workforce.

First, the majority of studies on work-life balance focus on how parents—particularly mothers—manage the dual demands of work and caregiving. While this has led to significant advances in understanding the "motherhood penalty" or the "fatherhood premium," it has also contributed to a limited and sometimes biased view of who deserves or needs organizational support. The needs and expectations of employees without children are often excluded from these analyses, reinforcing the assumption that work-life balance policies are relevant only for caregivers. This narrow framing results in a lack of theoretical tools to examine how childfree employees experience, evaluate, and respond to these same organizational policies.

Second, the literature rarely distinguishes between different types of non-parent employees. Those who are childfree by choice and those who desire to have children in the future are frequently grouped together under the undifferentiated label of "non-parents." This analytical shortcut obscures important differences in how these groups perceive fairness, make career decisions, and engage with organizational support systems. For example, individuals who plan to have children may evaluate current policies based on their future aspirations, while voluntarily childfree employees may seek recognition for non-family commitments. Theoretical models have yet to systematically incorporate these forward-looking or alternative perspectives on fairness, which we refer to as anticipatory fairness.

Third, there is a limited understanding of how fairness perceptions are formed among childfree employees. Existing frameworks tend to assume that childfree workers are more flexible, more committed, or more available—without considering how these assumptions affect their actual treatment or their perceptions of equity in terms of workload, recognition, and career development. The lived experiences of these workers are often rendered invisible or trivialized, leading to a theoretical blind spot in studies of organizational justice and inclusion.

Fourth, the construct of Perceived Organizational Support (POS) has been largely operationalized through the lens of family-friendly policies. While this focus is justified in addressing the historical exclusion of caregivers from full workplace participation, it risks creating a new imbalance. Employees whose needs do not fall under the category of "family" may feel excluded or undervalued. Yet few theoretical models explicitly consider how POS might be perceived differently by employees without children, or how organizations can broaden their support frameworks to be more inclusive.

Fifth, the intersectionality between family status, career stage, gender, and generational identity remains underexplored. Younger employees, for instance, may hold different expectations about work-life balance, career advancement, or personal fulfillment than previous generations. They may also be more likely to delay or forgo parenthood, making the traditional alignment between life stage and family responsibilities increasingly obsolete. Theoretical approaches that do not consider these dynamics risk offering outdated or incomplete explanations of workplace equity.

In sum, the existing literature provides valuable insights into the challenges faced by parents in the workplace but fails to offer equally robust conceptual tools to understand the experiences of non-parents, particularly in their diversity. Addressing this gap requires a shift in theoretical focus: from a family-centric model of organizational fairness to one that recognizes the full range of employee identities, life choices, and future aspirations. In the following section, we propose a conceptual framework and a set of theoretical propositions that aim to respond to these gaps and guide future empirical inquiry.

4 Conceptual Framework

To address the theoretical gaps identified in the literature, we propose a conceptual framework that rethinks workplace equity by incorporating the diverse family statuses and future aspirations of employees. Drawing on equity theory, the framework examines how different employee groups—parents, childfree employees by choice, and those desiring children—perceive fairness in three key organizational domains: work-life balance, career progression, and perceived organizational support (POS).

The framework is structured around two core ideas:

1. The relational nature of equity perceptions, in which fairness is assessed by comparing one's inputs (e.g., effort, time, flexibility) to outcomes (e.g., recognition, support, advancement) relative to others in the organization.

2. The temporal and aspirational dimension of fairness, recognizing that perceptions are shaped not only by current experiences but also by anticipated future needs or trajectories (anticipatory fairness).

4.1 Dimensions of Perceived Fairness

We identify three interrelated domains where equity perceptions are most salient:

- Work-Life Balance Equity: Perceived fairness in the allocation of flexibility, time-off policies, and accommodation of personal responsibilities. While traditionally designed for caregivers, these policies also affect childfree employees and those planning to have children. The framework suggests that fairness in this domain depends not only on the availability of policies, but on how inclusive and adaptable they are to different life situations.
- Career Progression Equity: Perceptions of fairness in advancement opportunities, promotions, and access to development pathways. Parents may experience structural barriers due to career interruptions, while childfree employees may face hidden penalties such as being overburdened or excluded from informal networks. Employees desiring children may evaluate fairness based on the perceived long-term consequences of starting a family.
- Perceived Organizational Support (POS): Fairness in how the organization expresses care, recognition, and investment in employee well-being. While family-friendly policies may increase POS for parents, they may lower it for others if perceived as exclusive. Broadening the scope of POS to encompass non-family commitments is central to inclusive support.

4.2 Employee Family Status and Equity Perceptions

The framework differentiates between three employee groups, acknowledging their unique experiences and sources of (in)equity:

- Employees with Children: Often benefit from formal family policies, but may experience stalled careers or stigma around flexibility. They assess fairness through the trade-off between support and opportunity loss.
- Childfree Employees by Choice: Frequently expected to absorb additional responsibilities due to their perceived availability. They may feel unfairly burdened and excluded from organizational care, especially when support is framed exclusively in terms of family.
- Employees Desiring Children: Experience fairness through an anticipatory lens. They evaluate whether current organizational conditions can support future family formation, and may adjust their engagement or career decisions accordingly.

These distinctions are critical because each group navigates the same organizational environment with different expectations, needs, and social meanings attached to their family status.

4.3 Mediators and Moderators

The framework also incorporates contextual and psychological variables that may mediate or moderate the perception of fairness:

- Organizational Culture: The extent to which inclusivity, flexibility, and diversity of life choices are genuinely supported or merely symbolic.
- Leadership Style: The behavior of direct supervisors and senior leaders in modeling inclusive behavior, recognizing diverse needs, and avoiding biased assumptions about availability or commitment.
- Generational Identity: Younger generations may be more sensitive to fairness as it relates to lifestyle autonomy, while older employees may prioritize stability or long-term support.
- Gender Norms: Deeply embedded beliefs about parenting roles can differentially affect men and women across all three employee categories.

4.4 Anticipatory Fairness: A Key Theoretical Contribution

A distinctive contribution of this framework is the concept of anticipatory fairness, which refers to fairness perceptions that are not based solely on present experiences, but on how current conditions are projected to impact future choices. This is particularly relevant for employees who are considering starting a family or making other major life changes. By incorporating this forward-looking dimension, the framework broadens equity theory beyond static comparisons of inputs and outputs, introducing a dynamic perspective aligned with life-course thinking.

In the next section, we translate the conceptual model into three theoretical propositions, offering testable statements that can guide empirical research and organizational reflection.

5 Theoretical Propositions

Proposition 1:

Employees without children, particularly those who are childfree by choice, are more likely to perceive work-life balance policies as inequitable when such policies are framed or implemented primarily in support of parental responsibilities.

Rationale:

While organizations increasingly offer flexibility and family-friendly arrangements, these are often designed with the assumption that only parents need time or flexibility. Childfree employees—despite having other legitimate personal needs—may feel excluded from these benefits, leading to lower perceptions of fairness. Equity theory suggests that when contributions (e.g., extra availability, workload) are not matched by comparable recognition or support, perceptions of inequity emerge.

Proposition 2:

Employees with children perceive greater inequity in career progression opportunities due to structural and cultural barriers, while childfree employees may perceive inequity due to overwork and a lack of compensatory recognition.

Rationale:

Parents, particularly mothers, often face slower career advancement due to maternity leaves, part-time arrangements, or biased assumptions about their availability. Conversely, childfree employees may be assigned more work or asked to "fill in" for parents without receiving equivalent career rewards. These differing experiences reveal that both groups may perceive the career system as unfair, albeit for opposite reasons, reinforcing the need to rethink meritocracy through an inclusive lens.

Proposition 3:

Employees who plan to have children in the future evaluate organizational policies through a lens of anticipatory fairness, and are more likely to disengage or delay family formation if they perceive a lack of future support.

Rationale:

This proposition introduces a forward-looking dimension to equity theory. Employees do not only react to current support, but also to their expectations of how future needs will be met. If current work conditions appear incompatible with future life goals—such as having a child or building a family—employees may interpret this misalignment as unfair. This anticipatory evaluation can influence organizational commitment, career decisions, and life choices.

6 Managerial and Future Research Implications

6.1 Managerial Implications

This conceptual exploration has significant implications for how organizations design and implement their work-life policies, career development systems, and support mechanisms. In particular, it challenges the assumption that fairness can be achieved through a one-size-fits-all approach focused primarily on parental status.

1. **Design Inclusive Work-Life Policies:** Organizations should ensure that work-life balance initiatives are not exclusively targeted at employees with children. This means expanding the rationale behind flexible work arrangements to include a wide range of personal needs—such as mental health, caregiving for elders, or personal growth. Communicating policies as universally applicable rather than parent-specific can increase perceived fairness across all employee groups.
2. **Reevaluate Career Progression Practices:** Promotion and development systems should be transparent and based on merit, with mechanisms to monitor and prevent both penalization (e.g., for taking parental leave) and exploitation (e.g., of perceived availability among childfree workers). This includes fostering a culture that normalizes different career paces and avoids assumptions based on family status.
3. **Broaden the Scope of Organizational Support:** Perceived Organizational Support (POS) should be decoupled from family-specific benefits. Managers can increase POS by recognizing diverse life choices and offering meaningful support to all employees—such as access to learning opportunities, autonomy,

and recognition—regardless of parental status. This also requires training managers to avoid unconscious biases in how support and flexibility are distributed.

4. **Acknowledge Anticipatory Needs:** Managers should be aware that employees are not only evaluating current conditions, but also making decisions based on anticipated life changes. By fostering a culture of open dialogue and proactively signaling support for future life transitions (e.g., becoming a parent, caring for others), organizations can retain talent and strengthen employee engagement.

6.2 Implications for Future Research

This framework opens several pathways for empirical and theoretical development:

1. **Empirical Testing of Anticipatory Fairness:** Future research should operationalize and test the concept of *anticipatory fairness*, examining how employees' future-oriented expectations influence perceptions of equity, engagement, and career planning. Longitudinal or life-course approaches would be particularly suitable for capturing these dynamics.
2. **Differentiation Within Non-Parent Groups:** More empirical work is needed to distinguish between the experiences of childfree employees by choice, those who are childless by circumstance, and those desiring children. These subgroups may exhibit different psychological responses to the same organizational environment.
3. **Intersectionality with Gender, Age, and Career Stage:** Equity perceptions likely vary at the intersection of family status with gender, generational identity, and seniority. For instance, younger employees may be more sensitive to fairness in future support, while older employees may prioritize stability or autonomy. Comparative studies could help to reveal how these factors interact.
4. **Cross-Cultural and Sectoral Studies:** The model should be tested across national and cultural contexts, as well as across public vs. private sector organizations. Norms around family, work commitment, and support vary widely, and contextualizing fairness perceptions is essential for generating globally relevant insights.
5. **Mixed Methods and Configurational Approaches:** Given the complexity and multidimensionality of perceived fairness, future studies might employ methods such as fsQCA or mixed-methods designs to capture the combinations of conditions that produce perceptions of equity or inequity. This approach is particularly useful when investigating heterogeneous groups with overlapping identities.

Thus, this framework invites a shift in how we theorize and manage equity in the workplace—moving beyond reactive support for parents toward a holistic, future-oriented, and inclusive approach that recognizes and respects the diversity of employee life paths.

Ethics Declaration

This research involved human participants and followed all institutional and national ethical standards. Participation was voluntary, and informed consent was obtained from all individuals involved. No personal or sensitive data have been disclosed.

AI Declaration

No generative artificial intelligence tools were used in the preparation of this manuscript.

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ESG and AI: The Role of a New Player in the Sustainability's Game. Explorative Analysis of the Potential Impact of Artificial Intelligence in Business Sustainable Performance.

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Abstract

The study explores the relationship between AI adoption and ESG performance, addressing a gap in literature. AI enhances sustainability by improving environmental monitoring, optimizing resource allocation, and fostering circular economy initiatives. Socially, AI promotes diversity and workplace well-being through advanced algorithms, while in governance, it strengthens oversight, risk assessment, and compliance. Using Bloomberg data on U.S. and Western European companies, the study tests whether ethical AI policies impact ESG scores. The results confirm a significant positive effect, suggesting that responsible AI adoption strengthens corporate transparency, investor trust, and decision-making.

Keywords: AI, ESG, Listed companies, USA and Western Europe

Paper type: Academic Research Paper

1 Introduction

This study aims to explore the interconnection between artificial intelligence (AI) and environmental, social, and governance (ESG) practices. Despite the broad academic interest in both fields, few studies directly analyze this relationship (Zhang & Yang, 2024). Our research aims to fill this gap by investigating whether companies' adoption of AI impacts their sustainability performance (ESG).

ESG practices are now central to many companies, given the growing awareness of sustainability issues and regulatory and social pressure (Bifulco et al., 2023). On the other hand, AI represents one of the most promising technologies for transforming and improving business processes and strategic decisions. However, as Nishant et al. (2020) and Vinuesa et al. (2020) point out, the intersection between AI and ESG is not yet fully understood, despite its potential to revolutionize how companies approach sustainability.

The study examines the impact of ethical policies on AI use on ESG performance, using Bloomberg data on 348 companies in the US and Western Europe. The analysis shows that companies with ethical AI guidelines achieve significantly higher ESG Scores. The regression model indicates a positive and significant coefficient, confirmed even when including control variables such as company size and financial performance. This suggests that adopting responsible AI practices enhances corporate sustainability, strengthens stakeholder trust, and optimizes strategic decision-making related to ESG objectives.

2 Literature review and hypothesis development

The convergence of technological innovation and sustainability goals creates significant opportunities to study how AI influences ESG practices. From an environmental perspective, advanced AI technologies improve ecological monitoring, optimize resource allocation, and support circular economy initiatives (Vinuesa et al., 2020). In the social context, AI helps promote diversity and workplace well-being through advanced selection algorithms and personalized professional development programs (Tamburri, 2020). Concerning governance, AI strengthens organizational oversight mechanisms, improving risk assessments and compliance procedures (Felício et al., 2016).

Previous studies have highlighted how ESG performance strongly correlates with financial results (Friede et al., 2015; Tang & Yang, 2023). However, the role of AI in influencing such results through improving ESG practices remains largely unexplored. As Adeoye et al. (2024) and Chiaramonte et al. (2022), financial institutions that use AI to assess ESG achieve superior returns on investments, suggesting a promising link between technology and sustainability.

Overall, implementing AI in companies offers numerous benefits, including increased transparency and improved decision-making effectiveness (Davenport & Ronanki, 2018). For example, advanced AI-based analytics improve the accuracy and timeliness of ESG reports, strengthening stakeholder trust (Pappas et al.,

2018). Furthermore, AI applications optimize industrial energy consumption, helping to reduce carbon emissions (Nishant et al., 2020).

Qi Yudong et al. (2024) identified a strong synergy between the adoption of digital technologies and ESG performance, demonstrating their combined positive impact on firm performance, though with variations across regions. Similarly, Zhou Hailing and Liu Ji (2023) found a significant positive correlation between ICT and corporate ESG performance, emphasizing the crucial role of energy efficiency in achieving ESG objectives. Lastly, Xie and Wu (2025) show how companies adopting ethical guidelines for AI achieve higher ESG scores, highlighting how the responsible integration of AI is positively perceived by stakeholders, strengthening both corporate sustainability and investor trust.

Despite these opportunities, significant challenges also emerge. AI infrastructure, for example, entails significant environmental costs related to energy consumption (Truby, 2020). Therefore, it is necessary to develop sustainable systems that balance technological efficiency and environmental impact and, as highlighted by Rahwan et al. (2019), harmonize AI capabilities with social values to ensure a positive impact on communities.

The relationship between AI adoption and ESG performance is complex and potentially indirect. A crucial role in this relationship is played by absorptive capability, defined as an organization's ability to recognize, assimilate, and apply new external knowledge (Cohen & Levinthal, 1990). This concept acts as a bridge, enabling companies to leverage AI technologies for sustainable practices effectively. Zahra and George (2002) further developed the notion by distinguishing between potential absorptive capability, which involves acquiring and assimilating knowledge. They realized absorptive capability, which involves transforming and applying that knowledge.

Some research, such as Xie et al. (2019), shows that absorptive capability positively moderates the relationship between green technological innovation and firm performance. Gomez-Mejiaet al. (2019) further highlight that companies with greater absorptive capacity respond better to stakeholder demands for sustainable practices, translating such pressures into improved ESG outcomes.

Considering those assumptions, we develop the following hypothesis

HP: *The adoption of ethical guidelines and policies related to the use, design, and development of Artificial Intelligence (AI) has a positive and significant impact on sustainability performance as measured by the ESG Score*.

3 Sample and method

To develop our analysis, the reference dataset was constructed exclusively referring to Bloomberg as data provider. The sampling procedure for corporate observations was carried out using Bloomberg's equity screening function (EQS), querying the terminal about the following criteria:

- Trade status: active;
- Equity attributes: primary company stock only;
- Country: US and Western EU;
- Industry sector: communications, consumer cyclical and non-cyclical, energy, financial, technology and industrial.

Sampling was specifically limited to those companies (so-called equity tickers) for which the Bloomberg data provider guarantees data availability with respect to the "AI_ETH_PLCY" field. Indeed, this field indicates whether the observed company has implemented ethical guidelines and/or undertaken compliance activities related to the use, design, and development of Artificial Intelligence (AI). A value of "Y" (1) indicates the company's commitment to adopting AI practices aimed at minimizing disparities and promoting inclusive representation. Otherwise, Bloomberg returns "N" (0). The ESG Score assigned by Bloomberg, along with the scores for each pillar (Environmental Score, Social Score, and Governance Score), was collected for each equity ticker in the sample.

Additionally, avoiding multicollinearity problems, the dataset was enriched with the following control variables: total assets and total revenues (both expressed as natural logarithms), EBIT (expressed as a natural logarithm), EPS, ROE, ROA, ROIC, and the Tobin's Q ratio.

The table below provides a description of the variables included in the dataset used for the analysis.

The variables include the dummy variable identifying whether firms have adopted ethical policies on artificial intelligence, the ESG Scores, financial and economic metrics.

Table 1: List and description of the variables.

List of variables	Description
ARTFCIL_INTLLGENCE_ETH_PLCY (Dummy Variable)	Artificial Intelligence Ethical Policy (ARTFCIL_INTLLGENCE_ETH_PLCY) Indicates whether the company has adopted ethical guidelines and/or alignment activities for the designed and developed Artificial Intelligence (AI). 1 indicates the company is committed to AI that minimizes gaps and promotes inclusive representation.
ESG_SCORE	ESG Score (ESG_SCORE) Provides the Bloomberg score assessing the company's overall ESG performance. The score is a generalized weighted average (power) of the Pillar scores, where weights are determined by the pillar priority ranking. Values range from 0 to 10; 10 is best.
ENVIRONMENTAL_SCORE	Environmental Pillar Score (ENVIRONMENTAL_SCORE) Provides the Bloomberg score assessing the company's overall environmental performance. The pillar score is a generalized weighted average (power) of issue scores, where weights are determined by the issue priority ranking. Values range from 0 to 10; 10 is best.
SOCIAL_SCORE	Social Pillar Score (SOCIAL_SCORE) Provides the Bloomberg score assessing the company's overall social performance. The pillar score is a generalized weighted average (power) of issue scores, where weights are determined by the issue priority ranking. Values range from 0 to 10; 10 is best.
GOVERNANCE_SCORE	Governance Pillar Score (GOVERNANCE_SCORE) Provides the Bloomberg score assessing the company's overall governance performance. The pillar score is a generalized weighted average (power) of theme scores, where weights are determined by the theme priority ranking. Values range from 0 to 10; 10 is best.
BS_TOT_ASSET	Total Assets (BS_TOT_ASSET) Total assets: The total of short- and long-term assets as reported on the balance sheet. For "Financials", Total assets: Sum of cash and equivalents, short-term investments and securities inventory, net receivables, total long-term investments, net fixed assets, and other assets. BS_TOT_ASSETLN is expressed as a natural logarithm.
SALES_REV_TURN	Revenues (SALES_REV_TURN) The amount of sales generated by a company after deducting returns, allowances, discounts, and sales-based taxes. Includes revenue from financial subsidiaries in industrial companies if consolidated. For "financials", refers to gross revenue from any operating activity. Total revenue is the sum of income from interest, trading profit (loss), commissions, earned fees, and other operating income. SALES_REV_TURNLN is expressed as a natural logarithm.
IS_EPS	Earnings per Share (IS_EPS) Earnings per Share (EPS) is the portion of a company's profit allocated to each shareholder. It is calculated based on net income available to common shareholders divided by the weighted average shares outstanding.
EBIT	EBIT (EBIT) Earnings before interest and taxes. For "Financials": Operating profit + Interest expenses. Data expressed in millions. EBITLN is expressed as a natural logarithm.
RETURN_COM_EQY	Return on Common Equity (RETURN_COM_EQY) Measures a company's profitability, highlighting profit generated with the money shareholders have invested, expressed as a percentage. Calculated as: (T12 Net income available to common shareholders / Average total common shares) * 100
RETURN_ON_ASSET	Return on Assets (RETURN_ON_ASSET) Measures a company's profitability relative to its total assets, in percentage. Weighted asset return gives an idea of management efficiency in using assets to generate earnings.
OPERATING_ROIC	Operating Return on Invested Capital (OPERATING_ROIC) Indicates the efficient use of capital sources through the company's activities. Unit: Effective. Calculated as: [Operating income last 12 months / (Beginning total invested capital + Ending total invested capital) / 2)] * 100
TOBIN_Q_RATIO	Tobin's Q Ratio (TOBIN_Q_RATIO) Ratio of a company's market value to the replacement cost of its assets. The Q ratio is useful for company valuation. Based on the hypothesis that in the long term, a company's market value should approximately equal the replacement cost of its assets. Calculated as: (Market cap + Total liabilities + Preferred shares + Minority interests) / Total assets

The dataset used for the analysis consists of 371 observations, each of which corresponds to a listed company for which information regarding the adoption of ethical policies related to artificial intelligence (AI) is available.

From a geographical perspective, the sample includes companies headquartered both in the United States and Europe, with a distribution of 64% and 36% respectively. In terms of industry classification, the majority of firms in the dataset operates within the technology sector, accounting for approximately 56% of the total

sample. Other represented sectors include consumer goods (cyclical and non-cyclical), industrial, communications, financial services, and energy.

As stated, the dataset comprises both firms that have adopted ethical AI policies and those that have not, as identified by a binary (dummy) variable. This structure enables a comparative analysis of ESG performance between adopters and non-adopters, which constitutes the core of investigation.

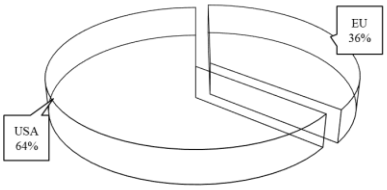
The framework below shows the geographical and sectoral distribution of firms within the scope of the dataset.

Geographical and Sectoral Distribution of Firms with Available Data on AI Ethics Policy

Breakdown of the 371 companies included in the dataset by region (USA vs. EU) and industry sector, based on the availability of data on the adoption of ethical AI policies.

Heat Map DB *AI_ETHPLCY* *Equity Ticker*	USA	EU	Total
Technology	141	67	208
Consumer, Cyclical	20	16	36
Consumer, Non-cyclical	25	11	36
Industrial	16	19	35
Communications	20	10	30
Financial	13	9	22
Energy	4	-	4
Total DB by sector	**239**	**132**	**371**

Breakdown by area



Green: *strong concentration of firms in the given area-sector combination.* ***Yellow:*** *medium values.* ***Orange:*** *low to medium values. Red very low or zero values (no companies represented).*

Figure 1: Geographical and Sectoral Distribution of Firms in Dataset (Heat Map).

The structure of the dataset allows for a robust comparative analysis across firms operating in different sectors and exhibiting heterogeneous size characteristics, due to the inclusion of variables capturing geographical, sectoral, financial, and sustainability dimensions.

Below are the descriptive statistics of the variables included in the database. The data reveals a significant degree of heterogeneity among firms, particularly with respect to economic indicators such as total assets, revenues, and profitability. ESG-related variables show relatively moderate distributions, with governance scores appearing more stable compared to the environmental and social dimensions. Measures of corporate performance (such as ROE, ROA, and ROIC) also display substantial variability, suggesting the presence of firms with markedly different economic profiles.

Table 2: Descriptive statistics of the variables.

Descriptive Statistics	Count	Mean	Sd	Min	Max
ARTFCIL_INTLLGENCE_ETH_PLCY	371	0.12	0.32	0.00	1.00
ESG_SCORE	348	3.34	1.52	0.66	7.74
ENVIRONMENTAL_SCORE	348	2.68	2.49	0.00	8.80
SOCIAL_SCORE	348	2.32	1.82	0.00	10.00
GOVERNANCE_SCORE	348	6.41	1.11	2.41	9.06
BS_TOT_ASSET	371	21555.42	119537.63	7.09	1797062.00
BS_TOT_ASSETLN	371	7.91	1.70	1.96	14.40
SALES_REV_TURN	371	9689.97	53975.45	0.21	800125.00
SALES_REV_TURNLN	371	7.27	1.74	-1.55	13.59
IS_EPS	369	2.08	7.96	-27.54	87.92
EBIT	364	725.05	3637.04	-20450.00	36852.00
EBITLN	246	5.31	1.85	-0.04	10.51
RETURN_COM_EQY	342	10.37	71.50	-182.18	1168.54
RETURN_ON_ASSET	366	1.50	14.60	-139.02	84.01
OPERATING_ROIC	360	5.50	21.26	-157.84	132.70
TOBIN_Q_RATIO	367	3.10	3.10	0.65	29.16
Observations	**371**				

To test our hypothesis (HP), we used a linear regression model:

$ESG_Score_i = \alpha + \beta_1 * AI_ETH_PLCY_dum_i + \varepsilon_i$

Where:

- ESG_Score_i is the dependent variable (the ESG score given to the $firm_i$ by Bloomberg).
- α is the intercept, (mean value of ESG_Score_i when $AI_ETH_PLCY_dum_i = 0$);
- $AI_ETH_PLCY_dum_i$ is the independent variable dummy (1 for companies with ethical policies on AI, 0 otherwise).
- ε_i is the residual error.

The estimation was carried out using Ordinary Least Squares (OLS). The analysis is based on cross-sectional data referring to the year 2024, due to the nature and availability of the variables, particularly the AI policy dummy variable. The choice of an OLS regression model applied to cross-sectional data is justified by the structure and availability of the data. This approach allows us to evaluate the associative relationship between the presence of ethical AI policies and ESG performance in a statistically consistent and interpretable framework.

Unfortunately, the absence of data for previous years - particularly with respect to the availability of the key explanatory variable concerning AI ethical policies - excluded the use of panel data models with fixed or random effects.

Such models would have enabled a more robust causal inference by controlling for unobserved firm-specific heterogeneity over time. However, due to the cross-sectional nature of the available dataset, the use of an OLS model on cross-sectional data remains the most suitable methodological approach under the current constraints.

4 Results

Our Hp, predicts that β_1 is positive and significant, implying that companies that adopt ethical policies on AI score, on average, higher ESG scores, and that this relationship is robust and not random. The results allowed us to test our hypothesis: the β_1 coefficient is 1.30, and the p-value associated with the coefficient shows that this positive relationship is robust and statistically significant ($p < 0.01$).

Table 3: OLS n.1 - $ESG_Score_i = \alpha + \beta 1 * AI_ETH_PLCY_dum_i + \varepsilon i$.

OLS (1)	**ESG_SCORE**
AI_ETH_PLCY dum	1.302***
	(0.241)
_cons	3.188***
	(0.0838)
N	348

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

To further test our analyses, we included control variables measuring firm size and financial economic performance in the model.

Specifically: $ESG_Score_i = \alpha + \beta_1 * AI_ETH_PLCY_dum_i + X_i' \beta + \varepsilon_i$

Where $X_i'\beta$ expresses the vector of control variables, which includes total assets and total revenues (both expressed in natural logarithm), EBIT (expressed in natural logarithm), EPS, ROE, ROA, ROIC, and Tobin's Q ratio. Even following the use of the control variables, the value of the β_1 coefficient results positive and statistically significant (0.65 with a $p < 0.05$).

Table 4: OLS n.2 - $ESG_Score_i = \alpha + \beta 1 * AI_ETH_PLCY_dum_i + Xi' \beta + \varepsilon i$.

OLS (2) "Control Variables"	**ESG_SCORE**
ARTFCIL_INTLLGENCE_ETH_PLCY	0.648**
	(0.277)
BS_TOT_ASSETLN	0.401**
	(0.173)
SALES_REV_TURNLN	-0.176
	(0.161)
IS_EPS	-0.0123
	(0.0113)
EBITLN	0.244**
	(0.110)
RETURN_COM_EQY	0.00151
	(0.00113)

OLS (2) "Control Variables"	ESG_SCORE
RETURN_ON_ASSET	0.00518 (0.0244)
OPERATING_ROIC	-0.00785 (0.0146)
TOBIN_Q_RATIO	0.0528 (0.0487)
_cons	0.157 (0.604)
N	218

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The results of the estimated linear regression indicate that the adoption of ethical guidelines and policies related to the use, design, and development of Artificial Intelligence (AI) – captured by the binary dependent variable ARTFCIL_INTLLGENCE_ETH_PLCY – is positively and significantly associated with firms' ESG scores. In the baseline model (OLS1), which does not include control variables, the coefficient associated with the AI ethics policy dummy is 1.30, statistically significant at the 1% level, suggesting that companies that adopt ethical AI policies tend to have significantly higher ESG scores on average compared to those that do not.

To assess the robustness of this result and account for potential confounding factors—that is, variables that may influence both the dependent and independent variables, and which, if omitted, could bias the estimated effect—a second model was estimated, including a set of firm-level control variables.

These controls include firm size (BS_TOT_ASSETLN), revenues (SALES_REV_TURNLN), profitability metrics (IS_EPS, RETURN_COM_EQY, RETURN_ON_ASSET, OPERATING_ROIC, EBITLN), and market valuation (TOBIN_Q_RATIO).

In this extended model, the coefficient associated with the adoption of AI ethics policies remains positive and statistically significant (0.648, significant at the 5% level), confirming the robustness of the observed association. The inclusion of control variables is crucial to isolate the net effect of the main explanatory variable, reducing the risk that the observed relationship is merely driven by structural characteristics of the firms, such as size, economic performance, or industry.

Among the control variables, both firm size (BS_TOT_ASSETLN) and operating profitability (EBITLN) are also statistically significant, suggesting that larger and more profitable firms are more likely to exhibit higher ESG scores.

The accompanying graphical analysis further supports these findings. The boxplot comparing ESG scores by AI policy adoption shows a higher median for firms with ethical AI policies, with a distribution skewed towards higher values. The second boxplot, disaggregated by geographical area (USA vs. EU), suggests that the positive association holds in both regions, but appears to be stronger among European firms that have adopted such policies. The scatter plot illustrates the binary nature of the dependent variable and highlights the contrast between adopters and non-adopters, while the coefficient plot visually confirms the positive and robust effect of AI ethics policies, even after accounting for control variables.

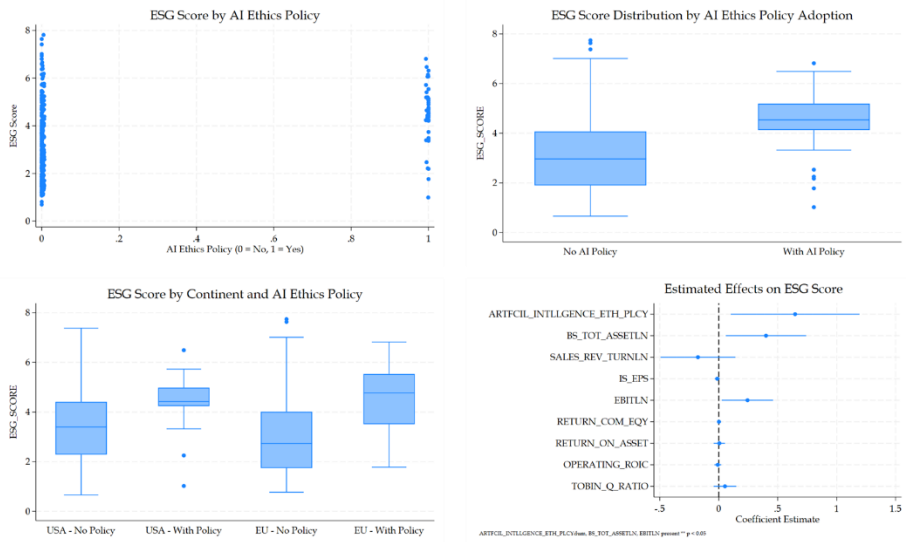


Figure 2: The Relationship Between AI Ethics Policy and ESG Score: Visual Evidence.

In summary, the empirical evidence suggests that the adoption of ethical policies on artificial intelligence is associated with better ESG performance. This relationship holds even after controlling key firm-level characteristics, reinforcing the hypothesis that such policies may serve as a signal of a company's concrete commitment to sustainability.

5 Discussion and conclusions

The study examines how AI adoption influences ESG (Environmental, Social, and Governance) performance, highlighting both opportunities and challenges. AI enhances environmental sustainability through advanced monitoring, resource optimization, and circular economy initiatives. In the social sphere, AI promotes diversity, workplace well-being, and fair hiring processes through advanced algorithms. Regarding governance, AI strengthens oversight mechanisms, improving risk assessments and regulatory compliance.

While previous research has shown a strong correlation between ESG performance and financial results, the specific role of AI in this relationship remains underexplored. Studies suggest that financial institutions using AI for ESG assessments achieve higher investment returns, pointing to a promising link between AI adoption and sustainability.

The study uses a dataset from Bloomberg covering 348 U.S. and Western European companies across various industries. A linear regression model tests the hypothesis that ethical AI policies positively impact ESG performance.

The result confirms the positive effect already observed, even in the presence of the control variables. The positivity and significance of the coefficient highlights that the implementation of ethical guidelines related to the use, design, and development of AI is perceived as an adding value by ESG evaluators. The implementation of ethical policies on AI is a tangible signal of commitment to the principles of sustainability and social responsibility. Moreover, such practices can increase the trust of stakeholders, including investors and regulators, as they demonstrate the company's willingness to adopt technologies responsibly and to proactively manage the ethical risks associated with AI. Further investigation can be conducted with reference to the impact of the dummy variable "AI_ETH_PLCY" on the scores assigned to each ESG pillar.

This study highlights the need to delve deeper into the relationship between AI and ESG, providing basis for developing new measurement frameworks that assess the contribution of AI to corporate sustainability. Although the existing literature provides valuable insights, research exploring the overall impact of AI on ESG performance in different economic contexts is lacking. Our study focuses on these aspects to provide policymakers, companies and technology developers with a reference framework for defining the best strategies to support business processes.

This aspect is particularly timely also in light of the very recent initiatives announced by the European Commission (2025) for the creation of AI gigafactories (AI Gigafactories) and the development of a strategy for applied AI (Apply AI) in order to guide the development and adoption of AI in key industrial sectors.

6 Ethics declaration

This study did not involve procedures requiring ethical clearance, and no ethical approval was necessary for the research conducted.

7 AI declaration

The authors confirm that no artificial intelligence tools were used in the preparation or production of this paper.

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Women Directors, Sustainability Knowledge and Greenwashing: A Study on Italian Companies

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Abstract

In recent years, the growing attention to environmental, social, and governance (ESG) practices has driven companies to adopt Corporate Social Responsibility (CSR) strategies. The commitment to CSR is influenced by the need to satisfy stakeholder demands to improve firm performance. However, such growing pressure has also produced unintended distortions, notably the phenomenon of greenwashing, as corporate practice involving the dissemination of misleading information regarding a company's ESG commitments to enhance company public image and reputation. This study aims to analyse two possible determinants at board of directors level of greenwashing: the presence of female directors and board members with sustainability knowledge. Based on a sample of 35 Italian publicly listed non-financial companies in 2023, the research employs logistic regressions to examine the effect of the above mentioned board features on greenwashing, which is measured by comparing the ESG Perception Index and the Standard Ethics Rating. The results show that both the presence of female directors and directors with sustainability knowledge positively affect the greenwashing. This suggests that, although these characteristics are often considered to enhance the quality and transparency of sustainability disclosure, they may also increase the ability to manipulate such information. The study contributes to both theory and practice. From a theoretical perspective, it contributes to the literature on board composition and the determinants of greenwashing. From a practical perspective, it highlights the importance for nomination committees to consider the role of gender and human capital in the directors' appointment process, taking into account the potential association with greenwashing.

Keywords: Greenwashing, Women, Board of directors, Sustainability knowledge, Italy.

Paper type: Academic Research Paper

1 Introduction

Over last decades, one of the most relevant developments that has impacted the strategic focus of firms is the increased commitment to environmental, social, and governance (ESG) practices, often referred to as Corporate Social Responsibility (CSR). This is defined as the companies' voluntary integration of social and environmental concerns into their business practices and interactions with stakeholders (European Commission, 2011). In this regard, companies have started to embrace more responsible capitalism by improving non-financial performance and making a positive contribution to the community (Garcia-Sanchez, Cuadrado-Ballesteros and Sepulveda, 2014; Issa and Hanaysha, 2022).

From the scholarly standpoint, the commitment to CSR is rooted in the stakeholder theory suggesting that firms should satisfy stakeholders needs to maximize firm value (Parmar et al., 2010; Dodd, Frijns and Garel, 2022). Indeed, literature highlights that having more investments in CSR can affect firm performance (Albuquerque et al., 2020; Awaysheh et al., 2020; Huang, Sim and Zhao, 2020).

However, increasing pressure from stakeholders to improve companies' ESG performance has often played as a double-edged sword, giving rise to the dark side of this phenomenon, called greenwashing (Zahid et al., 2023). Greenwashing is a corporate behavior that disseminates false information to alleviate external pressures by overstating the company's social and environmental responsibilities (Wolniak, 2016; Flammer, 2021).

Looking at the determinants of greenwashing, literature has examined the effect of several governance features (Zhang, Qin and Zhang, 2023), including the board of directors' characteristics (Ma et al., 2025). Indeed, board is responsible for monitoring managers' actions (Hillman and Dalziel, 2003; Saidat, Silva and Seaman, 2019), and for advising them on how to manage external environmental challenges (Pfeffer and Salancik, 2003). Specifically, it is in charge of setting corporate strategies (including CSR strategies), while monitoring managers to satisfy the needs of the stakeholders (Jain and Zaman, 2020). The accomplishment of these roles is influenced by its characteristics, such as gender (Bernardi and Threadgill, 2010) and human capital (Saggese and Sarto, 2025), with positive implications for corporate outcome (Fernández-Temprano and Tejerina-Gaite, 2020),

As for gender, research documents that female directors are less keen to accept unethical behaviors and inclined to manipulate corporate information, while showing greater sensitivity to stakeholder needs (Terjesen, Sealy and Singh, 2009; Loukil and Yousfi, 2016). As a result, their presence might influence corporate disclosure (Huang, Huang and Lee, 2014; Vermeir and Van Kenhove, 2008), including the CSR reporting and the potential

manifestation of greenwashing. In this regard, while recent studies have started to examine the influence of board gender diversity on greenwashing, literature is still scarce and report contrasting results (Chen and Dagestani, 2023; Ghitti, Gianfrate and Palma, 2024). Hence, there is no clear indication of the relationship between the presence of female directors and greenwashing in the literature.

Shifting the attention to human capital - as set of knowledge and skills derived from individuals job experiences and education (Sarto et al., 2019) – following the upper echelons theory, scholars highlight that board human capital influences corporate outcomes, as directors' experience, knowledge and skills drive the execution of governing roles, with implications for company performance (Hillman and Dalziel, 2003; Berezinets, Garanina and Ilina, 2016). This can be also true with reference to the greenwashing, which may be affected by sustainability-related knowledge as a specific dimension of human capital. In this regard, some empirical studies show that directors' sustainability education and/or experience enhances their ability to understand sustainability-related issues, highlighting that the presence of directors with such knowledge impacts CSR disclosure (Jamil, Mohd Ghazali and Puat Nelson, 2021; Lu et al., 2024). However, they neglect to investigate the effect on greenwashing.

With this in mind, this article aims to examine both the effect of female directors on greenwashing, and the implications of directors' sustainability knowledge for greenwashing.

To achieve the research objective, we collect data from multiple sources (official company websites, AIDA database, LinkedIn profiles), by relying on a sample of 35 Italian publicly listed non-financial companies in 2023. Besides, we conduct the statistical analyses of the predicted relationships using logit regressions. Findings show that both the presence of female directors and directors with sustainability knowledge are positively associated with greenwashing.

Our study provides theoretical and practical contributions. From a theoretical perspective, it contributes to the literature on the role of gender and human capital for greenwashing, while enriching the debate on the determinants of such phenomenon. From a practical standpoint, the research offers insights to nomination committees, encouraging them to consider the role of gender and human capital in the directors' appointment process, also taking into account the potential association with greenwashing.

2 Literature review

Greenwashing is a corporate behavior that disseminates false information about the company's social and environmental commitment, aiming to enhance its public image and alleviate external pressures (Wolniak, 2016; Flammer, 2021; Li et al., 2022). Specifically, it is often used to influence stakeholders (Ferron-Vílchez, Valero-Gil and Suárez-Perales, 2021; Chen and Dagestani, 2023). Indeed, in the light of stakeholder theory, stakeholder involvement is crucial for promoting business development (Friedman and Miles, 2002), and firms should satisfy stakeholders' needs to maximize firm value (Parmar et al., 2010; Dodd, Frijns and Garel, 2022).

Since greenwashing strategies generate ambiguous signals and undermine stakeholders' interests (Walker and Wan, 2012; Zheng et al., 2023), literature has analyzed various determinants of greenwashing, including top managers' characteristics (Zhang, Qin and Zhang, 2023; Yang et al., 2025). Within this context, board of directors' attributes can also play an important role in influencing greenwashing (Ma et al., 2025). Indeed, the upper echelons theory (Hambrick and Mason, 1984) highlights that the individual characteristics of managers (including board members) are able to influence their strategic decisions, thereby shaping corporate outcomes. In this regard, research has analyzed the effect of various board attributes on firm performance (Fernández-Temprano and Tejerina-Gaite, 2020), corporate social responsibility (Patro, Zhang and Zhao, 2018), and innovation (Sarto et al., 2019). Among the board attributes that can influence corporate outcomes, gender (Bernardi and Threadgill, 2010; Galbreath, 2018) and human capital (Saggese and Sarto, 2025) are particularly relevant.

Regarding the former, some studies show that the presence of women on board negatively influences corporate outcomes (Adams and Ferreira, 2009; Dale-Olsen, Schone and Verner, 2013), as gender diversity may increase conflict among directors, limit board cohesion, and hinder decision-making, thereby compromising firm performance (Adams and Ferreira, 2009). Conversely, other research documents that the presence of female directors promotes both financial (Campbell and Minguez Vera, 2009) and sustainability-related (Elmagrhi et al., 2019) outcomes. Indeed, women are more likely to follow a participatory leadership approach than men (Loukil and Yousfi, 2016), reduce information asymmetries (Gul, Hutchinson and Lai, 2013), and show greater sensitivity to stakeholder needs (Terjesen, Sealy and Singh, 2009). Moreover, being less inclined to manipulate corporate information, their presence has implications for corporate disclosure (Huang, Huang and Lee, 2014; Vermeir and Van Kenhove, 2008), including CSR-related reporting in terms of greenwashing. In this regard, although recent studies have begun to explore the impact of women presence on the board on greenwashing practices, the

existing literature remains limited and yields conflicting findings. Indeed, empirical evidence presents a mixed picture: while some studies suggest that female directors may mitigate greenwashing behaviors (Chen and Dagestani, 2023), others report a positive association, contending that improved gender balance does not inherently constitute an effective solution against the phenomenon (Ghitti, Gianfrate and Palma, 2024). Based on this, we hypothesize the existence of a relationship between female directors' presence and greenwashing, without formulating any expectation about the sign.

As for human capital, several studies show that top managers' human capital can influence how they perceive, interpret, and evaluate companies and their environments (Day and Lord, 1992; Hambrick and Mason, 1984). It can also affect how problems are defined and information is processed, thus influencing managerial decisions (Carpenter, Geletkanycz and Sanders, 2004; Sarto et al., 2024; Sarto et al., 2025). Specifically, regarding the boards of directors, studies show that board human capital impacts corporate outcomes, as directors' experience, knowledge and skills drive the execution of governing roles, with implications for corporate outcomes (Hillman and Dalziel, 2003; Berezinets, Garanina and Ilina, 2016). This may be also true for greenwashing, which might be influenced by a specific dimension of human capital, that is the sustainability-related knowledge. In this regard, some scholars claim that top managers competencies within sustainability area can influence sustainability-related outcomes (Peters, Romi and Sanchez, 2019; Al-Shammari et al., 2023), including CSR disclosure (Velte, 2023). Specifically, the presence of directors with sustainability-related education and/or experience affects CSR disclosure quality and transparency (Jamil, Mohd Ghazali and Puat Nelson, 2021; Lu et al., 2024), since these competencies can enhance managerial understanding of sustainability-related issues (Jamil, Mohd Ghazali and Puat Nelson, 2021). Building on these arguments—which underscore the relationship between the presence of directors with sustainability expertise and the quality of CSR disclosure—and considering that greenwashing entails the dissemination of misleading information regarding the company's social and environmental commitments, it is reasonable to expect that directors with sustainability knowledge may influence greenwashing practices.

3 Method

We test our predictions on a sample of 35 publicly listed non-financial Italian companies in 2023, after excluding firms lacking relevant governance and CSR data. Italy represents an ideal setting to explore our predictions considering the legislative measures (Law 120/2011) that have promoted the greater representation of women on corporate boards (Saggese, Sarto and Viganò, 2021). Furthermore, in Italy there is a rising concern about corporate accountability and environmental transparency (Sarto et al., 2025).

With this in mind, we gather information on publicly listed non-financial Italian companies from multiple sources (e.g. AIDA database, and hand-collected information from official company websites and LinkedIn profiles).

As for our dependent variable, we analyse greenwashing in terms of gap between firms' ESG disclosure information and sustainability real performance information (Zhang, 2022). In this regard, we compare the ESG Perception Index (which measures companies' sustainability perception) with the Standard Ethics Rating (which measures firms' actual sustainability by evaluating their level of compliance with international sustainability principles issued by the European Union (EU), the Organisation for Economic Co-operation and Development (OECD), and the United Nations (UN)). When the ESG Perception Index score is higher than the Standard Ethics Rating (positive discrepancy), we interpret this discrepancy as a potential signal of greenwashing. In this case, public perception is higher than the independent evaluation provided by Standard Ethics, suggesting a possible overestimation of the firm's sustainability commitment. If the ESG Perception Index and the Standard Ethics Rating are equal (correspondence), we conclude that there is no clear evidence of greenwashing. If the ESG Perception Index is lower than the Standard Ethics Rating (negative discrepancy), we posit that the observed gap may be attributable to factors unrelated to greenwashing, such as limited public awareness of the company's sustainability initiatives or inadequate corporate communication. Thereby, we measure greenwashing by employing a dummy variable equal to 1 in case of greenwashing (positive discrepancy), and 0 otherwise (correspondence and negative discrepancy) (Greenwashing).

Regarding the independent variables, we appreciate the presence of female directors and board members with sustainability knowledge (i.e. sustainability-related education and/or sustainability-related experience) (Jamil, Mohd Ghazali and Puat Nelson, 2021; Velte, 2023), using two different variables to strengthen our analysis. For the presence of female directors, we use the number of female directors (Num_womdir) (Katmon et al., 2019). Similarly, for the presence of directors with sustainability knowledge, we use the number of directors with sustainability knowledge (Num_sustknowdir) (Jamil, Mohd Ghazali and Puat Nelson, 2021).

Moreover, we use two additional proxies to catch our main independent variable. Specifically, we employ a dummy variable, Average_womdir (Average_sustknowdir) equal to 1 if the number of female directors (sustainability-knowledgeable directors) on the company's board is above the sample average, and 0 otherwise (Carbone, Mussolino, and Viganò, 2024). Finally, we include the following control variables: the firm size (Firm_size), measured by the number of firm's employees, the profitability, in terms of return on equity ratio (ROE), and the board size (Board_size) as the number of directors.

To test our predictions, we conduct the statistical analyses using logit regressions, as our dependent variable is binary.

4 Results

Table 1 presents the descriptive statistics for our variables.

Table 1: Descriptives

Variable	Mean	SD	Min.	Max.
Greenwashing	0.229	0.426	0	1
Num_womdir	4.971	1.580	0	8
Num_sustknowdir	5.257	2.758	0	11
Average_womdir	0.342	0.481	0	1
Average_sustknowdir	0.428	0.502	0	1
Firm_size	3413.4	7.440.841	16	34529
ROE	9.786	14.198	-50.19	54.69
Board_size	11.571	2.810	3	18

Table 2 shows the results of the logit regressions testing the relationship between the presence of female directors and directors with sustainability knowledge and greenwashing. Specifically, Model 2 shows that the coefficient of the number of female directors (Num_womdir) is positive and statistically significant (β=1.730; $p<0.05$). Therefore, a higher number of female directors is positively associated with the probability that the firm engages in greenwashing. Similarly, Model 3 highlights that the coefficient of the number of directors with sustainability knowledge (Num_sustknowdir) is positive and statistically significant (β=0.364; $p<0.05$). Consequently, there is a positive and statistically significant relationship between the presence of directors with sustainability knowledge and greenwashing.

Table 2: Logit regression models

	Logit regressions (Greenwashing)				
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Num_womdir		1.730**			
		(0.885)			
Num_sustknowdir			0.364**		
			(0.156)		
Average_womdir				2.961**	
				(1.412)	
Average_sustknowdir					1.970*
					(1.072)
Firm_size	-0.000	-0.000	-0.000*	-0.000	-0.000*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
ROE	-0.111**	-0.157**	-0.137**	-0.092*	-0.136**
	(0.048)	(0.063)	(0.059)	(0.049)	(0.055)
Board_size	0.144	-0.687	0.012	-0.212	0.084
	(0.156)	(0.494)	(0.168)	(0.237)	(0.165)
Constant	-1.798	-0.614	-1.958	0.668	-1.804
	(1.848)	(2.045)	(1.819)	(2.604)	(1.936)
Observations	35	35	35	35	35
R2	0.168	0.296	0.265	0.262	0.273
Prob (Chi2)	0.095	0.025	0.043	0.069	0.019
Mean VIF	1.36	2.63	1.37	2.26	1.33

As previously stated, to strengthen our analysis, we replicate it by measuring the presence of female directors and of directors with sustainability knowledge using the two binary independent variables, Average_womdir and Average_sustknowdir, respectively. Consistent with the results of Model 2, Model 4 shows a positive and significant relationship between a higher number of female directors (above the sample average) and greenwashing. Indeed, the coefficient is positive and statistically significant (β=2.961; $p<0.05$). Similar findings are reported for the presence of directors with sustainability knowledge. Indeed, Model 5 shows that the coefficient of Average_sustknowdir is positive and statistically significant (β=1.970; $p<0.10$). Therefore, firms with a higher number of directors with sustainability knowledge (above the sample average) have a higher probability of engaging in greenwashing.

5 Concluding discussions

The article examines the relationship between the presence of female directors and directors with sustainability knowledge and greenwashing. To achieve this aim, it tests our predictions on a sample of 35 publicly listed non-financial Italian companies in 2023 through logit regressions.

Results show that the presence of female directors is positively associated with greenwashing. This finding is counterintuitive compared to previous studies which suggest that female directors are less inclined to manipulate corporate information with positive implications for disclosure quality (Vermeir and Van Kenhove, 2008; Huang, Huang, and Lee, 2014). Moreover, it contrasts with studies that find the presence of female directors inhibits greenwashing (Chen and Dagestani, 2023). However, the result aligns with studies that report a positive relationship (Ghitti, Gianfrate and Palma, 2024) and show that a higher presence of female directors is associated with lower sustainability performance, as female directors are often excessively busy due to the numerous board positions they hold (Tonetto, 2022). Consequently, regarding greenwashing, the presence of female directors is not beneficial, as their busyness negatively influences the effective monitoring of greenwashing activities (Tonetto, 2022).

Similar results apply to the presence of directors with sustainability knowledge, also positively associated with greenwashing. This supports the idea that directors with sustainability-related education and/or experience have a greater understanding of sustainability-related issues (Jamil, Mohd Ghazali and Puat Nelson, 2021). Being more familiar with the process of disclosing sustainability information (Bilal, Songsheng and Bushra, 2017), they may also be more able to manipulate such information, thereby increasing the probability of greenwashing. These results remain valid across both measures used as independent variables.

Our study has theoretical and practical implications. From a theoretical perspective, it contributes to the literature on the role of gender and human capital for the board of directors by examining both the relationships between the presence of female directors and directors with sustainability knowledge and greenwashing. It also addresses a gap in the Italian setting, where the link between the specific dimension of human capital related to directors' sustainability knowledge and greenwashing remains unexplored (Jamil, Mohd Ghazali and Puat Nelson, 2021; Lu et al., 2024). At the same time, it enriches the literature on the determinants of greenwashing. From a practical perspective, by documenting the positive association between the presence of female directors and of directors with sustainability knowledge and greenwashing, the paper encourages nomination committees to consider the role of gender and human capital in the directors' appointment process, also taking into account the potential association with greenwashing.

Despite these contributions, our study has limitations. First, it is based on a sample of only 35 companies and focuses on the specific Italian context, which limits the generalizability of the results. Another limitation concerns how greenwashing is measured. In fact, we measure it by comparing the ESG Perception Index (a qualitative variable), which reflects companies' sustainability perception, with the Standard Ethics Rating (a quantitative variable), which measures firms' actual sustainability. This discrepancy can lead to interpretative challenges. Indeed, interpreting these differences and detecting greenwashing requires caution, since the two metrics reflect different corporate sustainability dimensions, and public perception is not always aligned with institutional assessments. Finally, the ESG perception index is obtained from the Reputation Science Observatory, which, although based on a reliable methodology using more than 100 parameters, is influenced by subjectivity.

6 Ethics declaration

We declare that ethical clearance for the research referred to in this paper was not required.

7 AI declaration

We used AI to help us paraphrase some sentences in order to shorten them and stay within the word/page limits of the paper, improve the fluency of the English, and find synonyms.

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Can Diversity Be an Opportunity to Enhance Ethics? Findings from a Multinational Survey in the Context of Trauma and Emergency Surgery

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Abstract

Ethics stands today as a primary pillar of modern medicine, and no medical specialty represents an exception. Acute care and trauma (AC&T) surgery is a complex clinical field, often characterized by high time pressure and little knowledge about the patient and circumstances. Our investigation wishes to deepen the role of diversity in AC&T teams as an opportunity to enhance ethics. The study, endorsed by the World Society of Emergency Surgery, analyses 402 questionnaires gathered from medical professionals from 72 countries, investigating three ethical issues (namely, patient's informed consent as a knowledge translation tool, the team leader as an ethical leader, and ethics as an educational subject). Findings underline the potential of diversity to enhance the attention towards ethical matters, offering food for thought to hospital managers and healthcare professionals.

Keywords: Trauma and emergency surgery; Diversity; Ethics; Team Dynamics; Knowledge Management

Paper type: Academic Research Paper

1 Introduction

Health systems and organizations are facing complex challenges largely driven by epidemiological and demographic trends such as aging (Calciolari and Luini, 2023), digital and technological development (Dal Mas *et al.*, 2023), reduction in healthcare spending to contain public budgets (OECD, 2024), and shortages of clinicians (Boniol *et al.*, 2022; WHO, 2016). In the depicted scenario, the provision of appropriate care (in terms of quality, patient satisfaction, effectiveness, and cost-effectiveness) is a matter of collaboration among health professionals (Silenzi *et al.*, 2018). As a result, multidisciplinary and interprofessional teamwork is increasingly required for different healthcare settings and pathologies, but good practices need to be identified to improve their effectiveness (Prenestini, 2023). The literature shows several beneficial outcomes of multidisciplinary and interprofessional work in teams (West *et al.*, 2002). Collaboration between specialists can change clinical practices and procedures, raise clinical standards, and finally improve the patient experience (Silenzi *et al.*, 2018).

Teamwork between disciplines and different clinicians, taking into account the patient experience, has always been a critical issue for trauma and emergency surgery, usually referred to in medical terms as acute care and trauma surgery (AC&T). AC&T is a multifaceted discipline due to its unique characteristics and context. Indeed, when managing AC&T cases, the multidisciplinary clinical team members must work under tremendous strain in a stressful and complex environment while attempting to communicate effectively (Cobianchi, Dal Mas, Massaro, *et al.*, 2021). Decisions must be made quickly, and common issues include time constraints to reach the outcome, limited knowledge of the emergency and trauma causes, the patients' pre-existing circumstances or conditions, or preferences regarding the feasible treatment options (Cobianchi, Dal Mas, *et al.*, 2023). Additionally, clinicians must deal with the possibility of unforeseen incidents and complications (Maurer *et al.*, 2021). In this context, conventional organizational practices are less effective. While new technological tools such as Artificial Intelligence (AI) can enhance surgical decision-making and support clinical professionals in their work (Loftus *et al.*, 2020, 2023), clinicians are often skeptical about their full potential, and several barriers in their acceptance arise (Cobianchi, Piccolo, *et al.*, 2023; Cobianchi, Verde, *et al.*, 2022). Therefore, integrative mechanisms, such as team assembly decisions, may be the sole opportunity to maximize performance and coordinate team member actions (Cobianchi, Dal Mas, Massaro, *et al.*, 2021; Massaro *et al.*, 2019).

Urgent decision-making in AC&T surgery may, therefore, raise various ethical concerns. When confronted with ethical issues, clinicians are compelled to promptly evaluate the advantages and disadvantages of their choices and the limited information they possess regarding their patients (Suah and Angelos, 2018). Ethics also

includes the consistent and compassionate translation of knowledge about the potential options and decisions with patients and their families or caregivers (Cobianchi, Dal Mas, *et al.*, 2023; Cobianchi, Dal Mas, Massaro, Bednarova, *et al.*, 2022; Sousa *et al.*, 2020; Woltz *et al.*, 2018). While traditional knowledge translation and sharing tools in elective surgery would include soliciting second opinions from colleagues and looking into the pertinent literature and guidelines (Bratianu *et al.*, 2024; Brescia *et al.*, 2024; Chang and Lin, 2015; Dal Mas, Garcia-Perez, *et al.*, 2020; Khedhaouria and Jamal, 2015), such strategies may not be feasible during emergencies. As a consequence, there is a significant likelihood of making errors or encountering ethical dilemmas when managing injured patients. This is especially true when lifesaving procedures are implemented during the initial assessment and resuscitation processes (Madani *et al.*, 2018). At the same time, the patient may have limited or no opportunity to be informed.

AC&T teams comprise a multidisciplinary group of individuals from various specialties, including anesthesia, emergency medicine, general and orthopedics surgery, nursing, and supporting staff, guided by a team leader responsible for coordinating the members' activities (Georgiou and Lockey, 2010). The team leader is key, as, guided by strong ethical principles, can experience conflicting obligations to stakeholders during the common emotional and complex debates and must lead the team through potentially challenging ethical situations with strength, compassion, fairness, and justice while eliminating potential implicit and explicit biases (Angelos *et al.*, 2021). In fact, making tough decisions requires the ability to seamlessly organize all team members to achieve the desired objective, even though decision-making is frequently viewed through the lens of an individual's internal cognitive process (Cobianchi, Dal Mas, Massaro, *et al.*, 2021; Madani *et al.*, 2018).

In such scenarios, knowledge translation, knowledge sharing, and knowledge transfer mechanisms are essential components of the team leader's and multidisciplinary team members' activities to communicate effectively and reconcile their differences, thereby enhancing their potential (Bratianu *et al.*, 2024; Cobianchi, Dal Mas and Angelos, 2021), especially when ethical dilemmas are in place (Scarlet, 2018a).

By definition, emergency surgery teams are diverse, as they consist of professionals with various backgrounds and specialties (Georgiou and Lockey, 2010). In order to provide adequate care to their patients, these professionals must possess interpersonal or soft skills (Cobianchi, Dal Mas, Massaro, *et al.*, 2021). The situation may be even more complex when teams include members who can be considered or perceived as diverse in terms of gender, race, ethnic background, age, political views, and sexual orientation.

The medical literature has been investigated the topic through the involvement of scientific societies. Studies conducted in general surgery have demonstrated that global performance is enhanced when the medical care environment is diverse, and patient satisfaction is also enhanced in such contexts (Gardner and Harris, 2020). However, recent investigations have also underscored the necessity of dedicated organizational and management policies to harness the full potential of diversity, which may eventually represent more a problem rather than an asset, enlarging organizational gaps (Cobianchi, Dal Mas and Angelos, 2021; West *et al.*, 2018).

To the best of our knowledge, there has been little investigation regarding the potential correlation between ethics and diversity in AC&T contexts. The study investigates the context of AC&T surgery as an ideal environment characterized by high complexity to understand the eventual impact of team diversity in fostering ethics. More in detail, our research deepens the factors that can improve certain ethical aspects, including the perceived importance of ethics as an educational subject, the perceptiveness of the moral role of the trauma team leader, and the importance of patient consent, comparing teams with their members perceiving them as "diverse" and those which were not.

2 Methodology

2.1 Data collection process

The study was conducted within a larger investigation about team dynamics in AC&T settings endorsed by the World Society of Emergency Surgery (WSES), one of the largest scientific societies in the field, with 900+ international members. An online survey was created using Google Forms.

In January 2021, the WSES secretariat distributed an email invitation to all 917 of its members, and also advertised through the society's website and X (former Twitter) account. The full protocol and statistical results, to which this article refers and comments, were published in the society's official peer-reviewed journal (Cobianchi, Dal Mas, Massaro, Biffl, *et al.*, 2022; Cobianchi, Dal Mas, Massaro, *et al.*, 2021).

2.2 Survey design and research protocol

The survey research protocol was built around prior research in the fields of AC&T surgery (Reichert *et al.*, 2020; Scarlet, 2018b; Woltz *et al.*, 2018), knowledge management, sharing, and translation in the context of healthcare and team dynamics (Dal Mas, Biancuzzi, *et al.*, 2020; Dal Mas, Garcia-Perez, *et al.*, 2020; Massaro *et al.*, 2014, 2019; Rese *et al.*, 2020), and clinical ethics in the physician-patient relationship and in emergency contexts (Angelos, 2020a; Angelos *et al.*, 2021; Cobianchi, Dal Mas and Angelos, 2021; Scarlet, 2018b; Suah and Angelos, 2018)

The initial questions were centered on the identification of the sample, including gender, years of experience in AC&T, type of institution (academic vs. non-academic), country where the employer was located, the role held, eventual participation within a formalized trauma team (institutionalized or not, and of what type), and the eventual involvement of diverse team members. Coming to this specific question, the investigators chose not to provide participants with a precise definition of "diversity" or "diverse team." Respondents were merely requested to indicate whether they perceived their team as diverse, in accordance with the widely recognized definition of "diversity." Ethics was investigated through the examination of 12 sentences to be rated on a 5-point Likert scale, with 1 representing firmly disagreement and 5 representing strong agreement. The objective of the items was to assess the topics of informed consent (Angelos, 2020a; Suah and Angelos, 2018), the formal attention to ethics in emergency surgery training (Angelos, 2020b; Angelos *et al.*, 2021), and the role of team leaders as ethical leaders (Angelos *et al.*, 2021; Cobianchi, Dal Mas and Angelos, 2021; Scarlet, 2018b, 2018a).

2.3 Data analysis

402 out of the 917 WSES members responded to the survey, with a response rate of 45.84%. A preliminary analysis was conducted to characterize the sample distribution in terms of gender, institution type (academic versus non-academic), respondents' membership in an officially set trauma team, and a diverse team. Furthermore, descriptive statistics were generated for the twelve ethical inquiries. Ultimately, the queries were categorized into three primary latent variables. In order to ascertain whether respondents differed by gender, type of institution, membership in an officially designated team, and a team that the surgeons characterized as "diverse," Kruskal-Wallis analysis was implemented.

3 Results

3.1 Distribution of samples

The 402 fully filled questionnaires obtained came from professionals from 72 countries, with the majority located in Europe. The sample was composed mainly of male surgeons (84%). Most participants belonged to university hospitals (72%), and officially established trauma teams (79.6%). 62% of the respondents indicated that they were employed in a diverse team.

3.2 Descriptive statistics and variations among respondents

The 12 items concerning ethics that were examined yielded an average result that ranged from a minimum of 2.83 to a maximum of 4.42, as reported in the article by Cobianchi et al. (2022).

The main findings can be summarized by examining the variations among respondents.

3.2.1 Significance of informed consent

Informed consent is considered a relevant knowledge translation tool in patient/doctor shared decision-making (Cobianchi, Dal Mas, *et al.*, 2023), and signing it stands a meaningful ethical moment worth discussing (Angelos, 2020a). The survey's results stressed the importance of consent, regardless of the participants' gender. Interestingly, respondents from academic institutions demonstrated a higher level of interest in the subject matter, with an average score of 3.238 compared to the average score of 2.827 among non-academics. In the same vein, respondents from formalized trauma teams paid more attention to this subject, with an average of 3.212 compared to the average of 2.921 (p-value 0.037). Lastly, surgeons who identified themselves as members of a diverse team underscore the importance of consent with an average of 3.328, as opposed to an average of 2.865 (p-value >0.001), as reported in Table 1 below, borrowed from the first article of the investigation by Cobianchi et al. (2022).

Table 1. Significance of consent. Source: Cobianchi et al. (2022)

Statistic	N	Average (SD)	Median (Q1-Q3)	Kruskal-Wallis rank-sum test	
				Chi Square	P-value
Gender				**0.262**	**0.877**
Female	61	2.770 (0.992)	3 [2-4]		
Prefer not to answer	3	3.000 (1.528)	3 [2.5-4]		
Male	338	2.834 (1.043)	3 [2.5-4]		
Kind of institution				**6.944**	**0.008**
Academic	292	3.238 (1.019)	3.5 [2.5-4]		
Non academic	110	2.927 (1.051)	3 [2-3.5]		
Part of a trauma team				4.308	0.037
No	82	2.921 (1.118)	3 [2-3.875]		
Yes	320	3.212 (1.007)	3 [2.5-4]		
Part of a diverse team				**18.746**	**>0.001**
No	152	2.865 (1.070)	3 [2-3.5]		
Yes	250	3.328 (0.976)	3.5 [2.5-4]		

3.2.2 Role of the team leader as an ethical leader

Concerning the role of the team leader as an ethical leader, results do not indicate any statistically significant differences in gender or type of institution. In contrast, findings underline that there are statistically significant differences between respondents belonging to formalized trauma teams, and those part of diverse groups, as reported in Table 2 below, borrowed from the first article of the investigation by Cobianchi et al. (2022).

Table 2. The role of the team leader as an ethical leader. Source: Cobianchi et al. (2022)

Statistic	N	Average (SD)	Median (Q1-Q3)	Kruskal-Wallis rank-sum test	
				Chi Square	P-value
Gender				**2.294**	**0.317**
Female	61	3.279 (0.595)	3.2 [3 - 3.8]		
Prefer not to answer	3	2.867 (0.416)	3 [2.7 - 3.1]		
Male	338	3.288 (0.565)	3.4 [3 - 3.8		
Kind of institution				**1.961**	**0.161**
Academic	292	3.306 (0.566)	3.4 [3 - 3.8]		
Non academic	110	3.224 (0.574)	3.2 [3 - 3.6]		
Part of a trauma team				4.562	0.032
No	82	3.171 (0.571)	3.2 [3 - 3.6]		

Statistic	N	Average (SD)	Median (Q1-Q3)	Kruskal-Wallis rank-sum test	
				Chi Square	P-value
Yes	320	3.312 (0.565)	3.4 [3 - 3.8]		
Part of a diverse team				**7.861**	**>0.001**
No	152	3.141 (0.576)	3.2 [2.8 - 3.6]		
Yes	250	3.370 (0.547)	3.4 [3 - 3.8]		

3.2.3 Training in ethics-related subjects

The majority of respondents were enthusiastic about the possibility of receiving training in ethics-related subjects, with no differences in responses among genders. Those affiliated with academic institutions prioritized ethical training more highly, with an average score of 3.742 compared to the average of 3.480 for all other respondents, similar to respondents from officially designated trauma teams (average of 3.734). Again, surgeons who were members of diverse teams exhibited a higher level of awareness, as evidenced by an average score of 3.830 and a p-value of less than 0.001. Findings are reported in the following Table 3, borrowed from the first article of the investigation by Cobianchi et al. (2022).

Table 3. Significance of Ethical Training. Source: Cobianchi et al. (2022)

Statistic	N	Average (SD)	Median (Q1-Q3)	Kruskal-Wallis rank-sum test	
				Chi Square	P-value
Gender				**2.455**	**0.293**
Female	61	3.695 (0.722)	3.8 [3.2-4.2]		
Prefer not to answer	3	3.133 (0.306)	3.2 [3-3.3]		
Male	338	3.671 (0.811)	3.8 [3.2 - 4.35]		
Kind of institution				**7.644**	**0.005**
Academic	292	3.742 (0.755)	3.8 [3.2 - 4.4]		
Non academic	110	3.480 (0.869)	3.6 [3 - 4.2]		
Part of a trauma team				**11.356**	**0.001**
No	82	3.424 (0.747)	3.5 [2.85 – 4]		
Yes	320	3.734 (0.796)	3.8 [3.2 - 4.4]		
Part of a diverse team				**22.296**	**>0.001**
No	152	3.408 (0.895)	3.6 [2.8 – 4]		
Yes	250	3.830 (0.682)	3.9 [3.4 - 4.4]		

4 Discussion and conclusion

Ethics stands as an imperative pillar in modern medicine, and the AC&T context is no exception, as emergency and trauma situations may require surgeons and other clinical professionals to respond quickly to ethical dilemmas. The investigation, endorsed by one of the major scientific societies in the field, aimed at deepening the topic through the lens of team diversity. Three primary ethical issues (namely, informed consent, the role of the leader as a moral leader, and ethics as a training subject for medical professionals) were examined

through the lens of gender, membership in an academic or non-academic institution, in an officially set team, and a diverse group.

Results underscore the increased focus that surgeons from academic institutions, official teams, and diverse groups are giving to the role of informed consent, seen as a relevant knowledge translation and shared decision-making tool from the physician in charge to the injured patient. The concept of surgical consent has evolved over time (Suah and Angelos, 2018). Before the operation, informed consent was primarily regarded as a legal and administrative obligation. However, recent research has emphasized the importance of informed consent as a critical tool for communicating with patients, and comprehending their wishes and concerns (Bratianu *et al.*, 2024; Ferguson Bryan *et al.*, 2020). This has led to acknowledging shared decision-making's importance (Dal Mas *et al.*, 2022; Woltz *et al.*, 2018). In this regard, the recent paradigm posits that surgeons must "speak less and listen more" (Angelos, 2020a) to facilitate improved knowledge translation, even in AC&T settings, where discussing with the injured patient may not always be practicable. Surgeons who work within academic environments and those members of officially established teams also acknowledge the importance of informed consent, probably due to the patient-centric organizational culture and the ongoing debate, which appears to be more assertive in academic institutions and within formalized teams. Results from diverse organizations are consistently superior to those from non-diverse ones. Although diversity in practice may present a challenge as a result of the distinctions among members, it has been demonstrated to result in exceptional outcomes. Professionals who are already engaged in bridging the gap with their diverse colleagues may be more willing to do so even when dealing with their patients (Cobianchi, Dal Mas and Angelos, 2021). Such knowledge translation actions may result in more time dedicated to such activities, or the involvement of support professionals like nurses as case managers (Bashkin *et al.*, 2023).

The second subject pertains to the team leader's function as an ethical leader, who is capable of integrating robust ethical principles into clinical decision-making. Individuals who are members of formalized teams and diverse organizations are more aware of the significance of ethics in the role of a team leader. Once more, surgeons from diverse teams provided the most favorable assessment. Consequently, it is possible to assert that individuals who are actively involved in interactions with various individuals believe that ethics is essential for improving patient outcomes and the seamless functioning of teams.

The third subject examined is ethical training, with comparable outcomes. Although most surgeons acknowledge the significance of appropriate ethical training, participants from academic institutions, formalized teams, and diverse groups demonstrate a greater interest. The surgical literature has once again emphasized the necessity of providing training in non-technical skills (Briggs *et al.*, 2015; Pradarelli *et al.*, 2020; Yule and Paterson-Brown, 2012), including ethics (Massaro *et al.*, 2014). Scientific societies have prioritized such subjects. Consequently, it is unsurprising that those more closely related to this debate (i.e., academicians and formalized team members) appear more focused on acknowledging this as a pertinent issue. Non-technical skills are indispensable for developing knowledge translation dynamics within teams, particularly when groups are classified as diverse (Bratianu *et al.*, 2024; Dal Mas, Garcia-Perez, *et al.*, 2020). Once more, diversity appears to exacerbate the necessity for ethical training as a critical component.

All in all, our findings suggest that teams with a lower degree of diversity may exhibit a lower level of sensitivity to patient preferences. Therefore, diversity in AC&T surgical teams may represent a powerful strategy to enhance sensitivity through ethics. Although previous research has demonstrated that contrasting cultures (e.g., more physician-centric vs. patient-centric) can coexist within organizations (Nembhard *et al.*, 2012), our findings emphasize that certain organizational factors (e.g., the team's university affiliation or diversity) may result in the development of a greater sensitivity to ethical issues. Organizations that are committed to fostering a more ethical and patient-centric perspective within AC&T teams should incorporate these components into the development of their organizational procedures. In fact, traditional coordination mechanisms seem less effective in AC&T contexts, where time pressure and expeditious action are the norm rather than the exception. As a result, teams must rely more on alternative strategies and tools to coordinate their actions. Integrative mechanisms, such as team composition including diverse members, may be effective in promoting ethical conduct and a more patient-centric culture, offering food for thought to hospital executives, scientific societies, clinical educators, and healthcare policymakers.

5 Ethics declaration

As specified in the main article text, the comprehensive study survey and full results were published in the article “Cobianchi, L., Dal Mas, F., et al. (2022), Diversity and ethics in trauma and acute care surgery teams: results from an international survey, World Journal of Emergency Surgery, Vol. 17 No. 1, p. 44.” under a Creative Commons Attribution 4.0 International License.

6 AI declaration

No AI tools were used in the drafting of the article.

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Assessing Carbon Emissions and Energy Use Behaviours among Medical Undergraduate Students in Taiwan

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Abstract

This cross-sectional study investigates the energy use behaviors, carbon emissions, and energy-related knowledge, attitudes, and practices (KAP) of undergraduate students from six private medical universities across northern, central, and southern Taiwan. Data were collected via structured questionnaires from May to June 2023, encompassing 184 students with diverse academic years, departments, and gender distributions (69% female). The study quantified daily activity durations involving energy consumption-such as air conditioning, heating, transportation, and use of electrical appliances-and estimated individual annual carbon emissions by integrating activity duration, energy consumption rates, and emission factors. Results indicate that air conditioning and heating account for the longest daily energy use (244 to 750 minutes), reflecting Taiwan's subtropical climate and high cooling demand. Transportation activities, including car, motorcycle, and public transit use, also contribute substantially, with Taipei Medical University students exhibiting the highest public transportation usage (mean 98 minutes). Departmental variations were noted, with pharmacy students using air conditioning most extensively and medical laboratory science students using public transit more frequently.

The KAP survey revealed moderate to high knowledge levels but comparatively lower positive attitudes and practices toward energy conservation, aligning with international findings. These results highlight the importance of targeted educational interventions to promote sustainable energy behaviors among medical students, who are future healthcare professionals with potential influence on institutional sustainability. This study fills a research gap by linking individual-level energy behaviors with carbon emission estimates in Taiwan's higher education context, providing a foundation for policy and behavioral strategies aimed at reducing the carbon footprint of medical education institutions.

Keywords: Carbon emission, Knowledge-Attitude-Practice (KAP), Taiwan, Subtropical climate, Energy

Paper type: Academic Research Paper

1 Background

Climate change driven by greenhouse gas (GHG) emissions from human energy consumption has become one of the most pressing global challenges. Since the Industrial Revolution, the average global temperature has increased by approximately 1.0°C as of 2017, primarily due to elevated CO_2 and other GHG emissions (UNDP, 2023). In response, the United Nations established the 2030 Sustainable Development Goals (SDGs) in 2015, with Goal 13 focusing on climate action. The United Nations Development Programme (UNDP) aims to reduce global net CO_2 emissions by 45% between 2010 and 2030 and achieve net-zero emissions by 2050.

Globally, energy consumption remains the largest contributor to GHG emissions. According to the International Energy Agency (IEA, 2021), the world emitted 33,622 million tons of CO_2 in 2019, with China and the United States as the top emitters, contributing 29.38% and 14.11% respectively. Taiwan ranked 22nd globally, emitting 256 million tons of CO_2 (0.76% of global emissions), with a per capita emission of 10.77 tons CO_2, ranking 19th worldwide (Taiwan EPA, 2023). Sectoral analysis reveals that Taiwan's industrial sector accounts for the highest emissions (48.74%), followed by transportation (14.17%), energy (14.05%), residential (11.54%), and service sectors (10.35%) (Taiwan EPA, 2021).

Within the service sector, educational institutions are significant energy consumers. Taiwan's higher education sector accounts for 65% of the electricity consumption within the education industry (Taiwan Power Company, 2021). Among universities, medical schools exhibit the highest energy intensity due to their reliance on precision laboratories and diagnostic equipment (Wang, 2016). This is consistent with findings from Liu et al. (2009), who observed that energy knowledge and attitudes improve with educational level, suggesting that university students represent a critical demographic for fostering sustainable energy behaviors.

Numerous studies have investigated energy use in educational buildings, providing valuable benchmarks. For instance, Li et al. (2017) analyzed university buildings in Guangzhou, China, reporting energy use intensity (EUI) values ranging from 61 to 82 kWh/m²/year. Ruusala et al. (2018) studied Finnish schools and daycare centers, finding an average EUI of 212 kWh/m²/year for schools, significantly higher than daycare centers. In Taiwan, Wang (2019) reported that universities' EUI ranged between 56.5 and 93.2 kWh/m²/year from 2015 to 2017,

with national universities showing higher energy consumption due to larger facilities and student populations. Daly et al. (2022) developed a comprehensive energy-use database for 3,701 Australian public primary schools, finding an average EUI of 38.0 kWh/m²/year and per-student energy consumption averaging 542 kWh/year.

This study specifically targets medical undergraduate students in Taiwan for several reasons. First, medical universities have been identified as among the highest energy-consuming academic units due to their specialized infrastructure and equipment needs (Wang, 2016). Second, Taiwan's healthcare sector contributes approximately 4.6% of the nation's total carbon emissions, surpassing the global healthcare average of 4.4%, with hospitals alone consuming 16% of domestic energy (Taiwan EPA, 2021). Third, medical students, as future healthcare professionals, play a pivotal role in shaping sustainable practices within the healthcare system. Enhancing their knowledge, attitudes, and behaviors regarding energy use can have a multiplier effect on institutional sustainability efforts. Finally, previous research (Liu et al., 2009) demonstrates that energy literacy and positive attitudes towards energy conservation increase with education, supporting the potential impact of interventions targeted at this demographic.

Research also shows that individual behavioral changes can significantly reduce energy consumption and associated carbon emissions. Streimikiene and Volochovic (2011) modeled carbon emissions from daily household activities in Lithuania under two scenarios: a baseline and an energy-saving behavior scenario. Their results indicated that annual GHG reduction potential could reach 5.65 Mt-CO_2e if households adopt energy-saving behaviors, surpassing the 2.4 Mt-CO_2e reduction potential of the industrial sector in 2010. This underscores the substantial impact that personal energy use behaviors can have on climate mitigation.

The Knowledge-Attitude-Practice (KAP) theory explains that behavioral change occurs through a sequential process: acquiring correct knowledge, forming positive attitudes, and adopting sustainable practices (Alsaleh et al., 2023). University students, as emerging energy producers and consumers, play a pivotal role in shaping future energy sustainability (Fang et al., 2022). Fang et al. (2022) found that Chinese university students' attitudes toward green energy vary by demand (renewable energy, nuclear power) and supply (energy-efficient appliances) aspects, with gender differences showing males more supportive of nuclear power due to differing risk perceptions. Similarly, a study in Malaysia revealed that while most university students had high knowledge levels about sustainable consumption (74.1%), their attitudes were moderate (65.6%), and actual sustainable behaviors were lower (49.2%), with 41% reporting low behavioral practice mainly due to lack of habit and limited awareness of overconsumption consequences (Ahamad & Ariffin, 2018).

By surveying students across northern, central, and southern private medical universities, this study aims to quantify annual carbon emissions based on daily energy-use activities and assess knowledge, attitudes, and practices (KAP) related to energy consumption, disaggregated by school, gender, and academic year. This approach fills a critical research gap, as prior studies have largely focused on institutional energy use without sufficiently addressing individual behaviors.

Hence, this study aims to estimate the annual carbon emissions of medical undergraduate students at private medical universities in northern, central, and southern Taiwan by analyzing the duration of their daily energy use activities. It also seeks to examine differences in energy consumption and carbon emissions across demographic variables such as school, gender, and academic year, as well as to assess students' knowledge, attitudes, and behaviors related to energy use through questionnaire surveys.

2 Materials and Methods

2.1 Study design

This cross-sectional study utilized a structured questionnaire to assess energy-related behaviors and carbon emissions among undergraduate medical students in Taiwan. The study population comprised students from six private medical universities: Taipei Medical University, Chang Gung University, China Medical University, Chung Shan Medical University, Tzu Chi University, and Kaohsiung Medical University. Data were collected between May 23 and June 12, 2023, via Google Forms to ensure standardized response formats and efficient data processing.

2.2 Participant recruitment

Undergraduate students enrolled during the 2022–2023 academic year were recruited through official university portals and student social media groups. To ensure adequate statistical power and comparability across institutions, a minimum of 30 valid responses was required from each university. The final sample

encompassed students from various academic years and majors, with a gender distribution representative of typical medical school enrollment in Taiwan.

2.3 Questionnaire development

The questionnaire comprised three sections to facilitate comparative analysis of carbon emissions and energy-related knowledge, attitudes, and practices (KAP) among universities:

- The demographic section collected key information, including response timestamp, institutional affiliation, gender, academic year, and major.
- The activity duration section quantified daily energy consumption patterns by recording time spent using various electrical appliances (e.g., lighting, computers, televisions, air conditioning, hair dryers, mobile phones) and details regarding commuting modes and durations. This section was adapted from the activity list developed by Streimikiene and Volochovic (2011), with additional items on commuting methods, frequency of dining out, and use of other electrical appliances.
- The KAP section, adapted from Tsai et al. (2013) and updated for cultural and technological relevance, assessed students' knowledge, attitudes, and practices related to energy consumption, including items on emerging technologies and contemporary consumption patterns.

2.4 Calculation methods for carbon emission

The average daily per capita carbon emissions (E_x) were calculated by summing the products of the duration of each activity, the associated energy consumption (Table 1), and the corresponding carbon emission factor (Table 2), and then dividing by the total number of students at each university. This is mathematically represented as:

$$E_x = \sum(D_{a,x} \times W_a) \times i_a / N_x \qquad \text{eq.(1)}$$

where $D_{a,x}$ is the duration of the activity a at university x. Data were collected via the questionnaire. W_a is the energy consumption for activity a (Table 1), i_a is the carbon emission factor specific to the energy type or transportation mode for activity a (Table 2), and N_x is the survey number of students at university x in the study.

Table 1: Total energy consumption and cumulative use data for various activities

Activity	Energy Consumption	Unit	Source
Cooking	0.2	m^3/hr	Streimikiene & Volochovic (2011)
Bathing	14	L/min	Taiwan Water User Equipment Standards https://law.moea.gov.tw/LawContent.aspx?id=FL025862
Transportation	60	km/hr	Assumed
Lighting	0.06	kW	Ministry of Economic Affairs Energy Handbook
Air conditioning	0.966	kW	
Computer	0.3	kW	
Television	0.14	kW	
Hair dryer	0.8	kW	
Mobile phone	0.034	kW	Counter point (2023)

Table 2: Carbon emission factors and their data sources used in individual activity calculations

Energy Type	Emission Factor	Unit	Source
Natural Gas	2.19	kg CO_2/m^3	Streimikiene & Volochovic (2011)
Water	0.174	kg CO_2/min	Taiwan Bureau of Energy (2022)
Electricity	0.495	kg CO_2/kWh	
Transportation Type	Emission Factor	Unit	Source
Public Transports [a]	0.047	kg CO_2/km	https://blog.zerozero.com.tw/30598/
Electric Scooter	0.025	kg CO_2/km	
Gasoline Scooter	0.046	kg CO_2/km	
Car	0.173	kg CO_2/km	

[a] Average of bus, MRT, train

2.5 KAP score and estimation

The Knowledge-Attitude-Practice (KAP) score for each subgroup was calculated by average knowledge, attitude, and practice scores for each student and dividing by the total number of students in the subgroup. Knowledge items were scored as 1 for correct, -1 for incorrect, and 0 for "don't know" answers. Attitude and

Practice were assessed on 5-point Likert scales, with Attitude ranging from strongly agree (5) to strongly disagree (1), and Practice from always (5) to never (1).

3 Results and discussion

3.1 Demographic description

The survey targeted undergraduate students from private medical universities in Taiwan, with the largest proportion of respondents from China Medical University (32.07%). Female participants constituted a majority (69.02%) compared to males (30.98%). The sample was predominantly composed of first- to third-year students. Regarding academic departments, while Public Health accounted for 19.02% of respondents, nearly half of the participants belonged to various other departments (48.91%), indicating a diverse disciplinary representation (Table 3). Other departments include Dentistry, Nutrition, Chinese Medicine, Physical Therapy, Occupational Safety and Health, Psychology, and others.

Table 3: Demographic variables of survey respondents

Demographic Variable		**Sample Size (%)**
University		
	Chung Shan Medical University	43 (23.37)
	China Medical University	59 (32.07)
	Chang Gung University	15 (8.15)
	Kaohsiung Medical University	24 (13.04)
	Tzu Chi University	29 (15.76)
	Taipei Medical University	14 (7.61)
Gender		
	Male	57 (30.98)
	Female	127 (69.02)
Academic Year		
	First Year	44 (23.91)
	Second Year	55 (29.89)
	Third Year	45 (24.46)
	Fourth Year	31 (16.85)
	Fifth Year	6 (3.26)
	Sixth Year	3 (1.63)
Department		
	Public Health	35 (19.02)
	Pharmacy	21 (11.41)
	Nursing	14 (7.61)
	Medicine	13 (7.07)
	Medical Laboratory Science and Biotechnology	11 (5.98)
	Others	90 (48.91)

3.2 Duration of activities

The analysis of activity duration (Table 4) reveals that air conditioning and heating are the most time-intensive activities among Taiwanese private medical university students, with average daily usage ranging widely across demographic groups (244–750 minutes). This extended use reflects Taiwan's subtropical climate and the corresponding high demand for indoor air conditioning. Transportation-related activities-specifically car use, gasoline motorcycle use, and public transportation-also constitute substantial daily time investments, though generally much less than air conditioning and heating (3–98 minutes on average).

Notably, public transportation usage is highest among students at Taipei Medical University (mean: 98 minutes), consistent with Taipei City's leading public transit market share. Gender differences are evident, with male students reporting longer average usage times for cars and gasoline motorcycles, while public transportation usage is similar between genders. Across academic years, fifth- and sixth-year students report the longest average durations for air conditioning and heating, while first- to third-year students have higher average public transportation usage. Departmental differences are also apparent; for example, pharmacy and medical laboratory science students report the highest average times for air conditioning/heating and public transportation, respectively. These patterns underscore the centrality of air conditioning and transportation in

student daily routines, highlighting their significance in campus carbon emission profiles and the importance of targeted sustainability interventions.

Table 4: Average usage time (mins) and standard deviations of air conditioning/heating, cars, gasoline motorcycles, and public transportation

Demographic Variable		**Air Conditioning / Heating (min)**	**Car (min)**	**Gasoline Motorcycle (min)**	**Public Transportation (min)**
University					
	Chung Shan Medical University	447±288	8±37	49±182	21±42
	China Medical University	468±316	9±34	18±21	29±92
	Chang Gung University	244±220	13±21	5±15	42±65
	Kaohsiung Medical University	503±235	3±11	13±21	10±18
	Tzu Chi University	445±319	8±17	35±49	6±18
	Taipei Medical University	345±234	5±11	4±4	98±92
Gender					
	Male	484±311	12±35	43±158	32±35
	Female	415±282	6±24	18±32	32±78
Academic Year					
	First Year	480±302	9±29	20±42	41±95
	Second Year	380±255	5±14	19±32	31±65
	Third Year	450±303	10±29	40±178	15±42
	Fourth Year	379±277	10±44	24±24	25±66
	Fifth Year	750±390	6±15	19±22	19±23
	Sixth Year	610±105	0±0	37±25	0±0
Department					
	Public Health	422±278	16±50	13±19	31±68
	Pharmacy	596±315	3±9	12±18	54±131
	Nursing	456±245	1±3	30±50	9±16
	Medicine	413±304	11±19	17±22	7±17
	Medical Laboratory Science and Biotechnology	447±175	8±18	14±20	59±123

3.3 Estimation of carbon emissions by university

A comparative analysis of average daily per capita carbon emissions across six private medical universities in Taiwan reveals substantial inter-university variation (Figure 1). Students at Chung Shan Medical University exhibited the highest mean daily emissions (9.87 kg-CO_{2e}), followed by Taipei Medical University (9.69 kg-CO_2e), China Medical University (9.16 kg-CO_{2e}), Tzu Chi University (8.49 kg-CO_2e), Chang Gung University (7.72 kg-CO_2e), and Kaohsiung Medical University (7.48 kg-CO_2e).

Disaggregated activity-level data indicate that air conditioning and heating consistently represent the largest source of emissions at most institutions, with values ranging from 1.94 to 4.00 kg-CO_2e per person per day. Notably, Kaohsiung Medical University reported the highest air conditioning/heating emissions (4.00 kg-CO_2e), which likely reflects the region's elevated ambient temperatures. Other significant contributors vary by university: gasoline motorcycles and cars are prominent at Chung Shan Medical University, while public transportation is the leading source at Taipei Medical University (4.59 kg-CO_2e). China Medical University and Chang Gung University both show considerable emissions from car use and public transportation, underscoring the influence of mobility patterns on institutional carbon profiles.

These findings highlight the dominant role of air conditioning/heating and transportation-related activities in shaping university-level carbon emissions. The observed differences underscore the need for targeted, context-specific mitigation strategies that address both energy use and mobility behaviors within university settings.

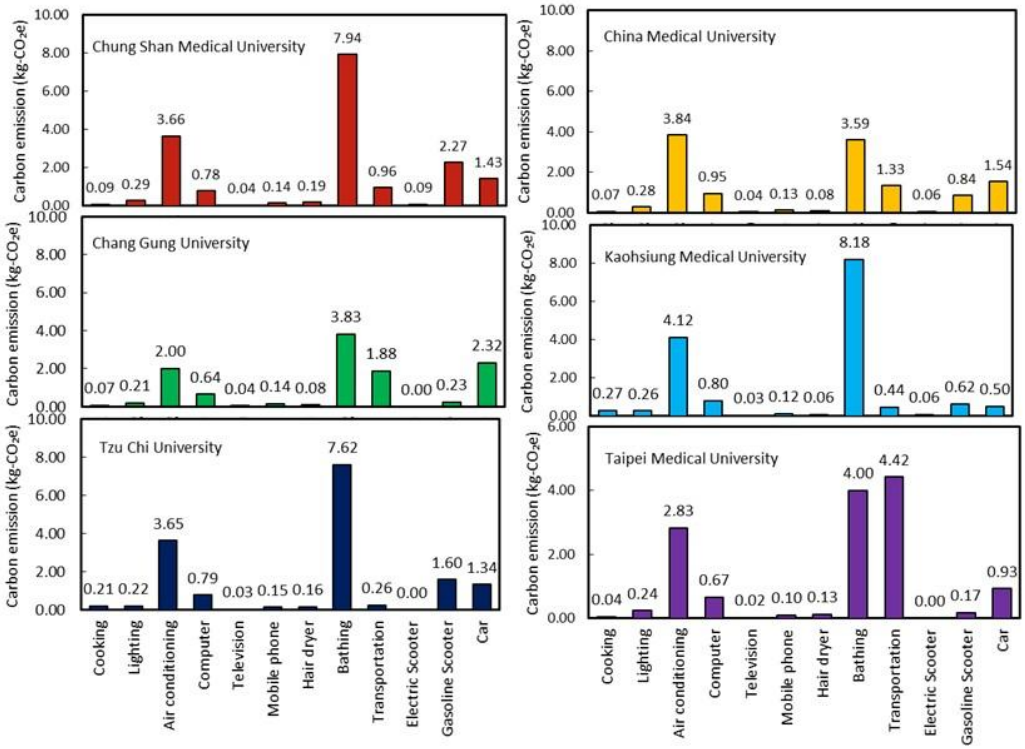


Figure 1. Average daily per capita carbon emissions (kg-CO_2e/person/day) by university and activities

3.4 Estimation of carbon emissions by university

Table 5 presents the comparison of average scores and standard deviations for Knowledge, Attitude, and Practice (KAP) among students from six medical universities. Knowledge was assessed with six items (score range: -6 to 6), Attitude with six items (range: 0 to 30), and Practice with five items (range: 0 to 25).

Across all universities, the mean Knowledge scores ranged from 3.79 (SD = 1.63) at Taipei Medical University to 4.80 (SD = 1.15) at Chang Gung University. The highest Attitude mean was observed at Chung Shan Medical University (19.95 ± 3.31), while the lowest was at Kaohsiung Medical University (18.42 ± 3.92). For Practice, Taipei Medical University reported the highest mean (18.79 ± 3.49), and Chung Shan Medical University the lowest (17.16 ± 3.09).

Overall, the Knowledge scores showed moderate consistency across institutions, with standard deviations ranging from 1.15 to 1.63, indicating relatively similar levels of knowledge among students. Attitude scores exhibited greater variability, particularly at Taipei Medical University (SD = 5.00), suggesting more diverse perspectives among students at that institution. Practice scores were generally comparable, with means spanning from 17.16 to 18.79 and standard deviations from 2.64 to 3.55.

Table 5: Comparison of average scores and standard deviations for Knowledge, Attitude, and Practice (KAP) among medical university students

Name of University (sample size)	**Knowledge (6 items) (Min-Max: -6 - 6)**	**Attitude (6 items) (Min-Max: 0 - 30)**	**Practice (5 items) (Min-Max: 0 - 25)**
Chung Shan Medical University (n=43)	4.70±1.34	19.95±3.31	17.16±3.09
China Medical University (n=59)	4.73±1.36	19.69±3.56	17.69±3.22
Chang Gung University (n=15)	4.80±1.15	18.47±3.66	18.53±2.64
Kaohsiung Medical University (n=24)	4.67±1.34	18.42±3.92	17.75±3.31
Tzu Chi University (n=29)	4.28±1.58	19.90±3.53	18.28±3.55
Taipei Medical University (n=14)	3.79±1.63	19.21±5.00	18.79±3.49

4 Conclusions

This study provides a comprehensive analysis of carbon emissions and energy-related knowledge, attitudes, and practices (KAP) among undergraduate students at six private medical universities in Taiwan. The results

reveal that air conditioning and heating are the primary sources of daily energy use, reflecting the influence of Taiwan's subtropical climate. Transportation activities-especially public transit-also constitute a significant portion of students' daily routines, with notable differences observed by gender, academic year, and department.

These findings underscore the need for targeted educational interventions to enhance sustainable energy behaviors among medical students. As future healthcare professionals, these students are uniquely positioned to influence institutional and societal sustainability. Universities can leverage these insights to design campus-wide energy-saving policies, integrate sustainability topics into medical curricula, and promote behavioral change through awareness campaigns and incentive programs.

5 Acknowledgements

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6 Ethics declaration

All participants in the questionnaire responded voluntarily and anonymously. If they experienced any discomfort during the process, they were free to withdraw from the study at any time.

7 AI declaration

I employed AI tools to refine the English grammar and translation to ensure accurate representation of the content.

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Assessing Firm-Level Drivers of High-Quality DE&I Disclosure in Corporate Sustainability Reports: A Stakeholder-Centric Perspective

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Abstract

In recent years, the growing emphasis on social sustainability and ethical corporate behavior has brought Diversity, Equity, and Inclusion (DE&I) to the forefront of both academic debate and corporate strategy. Movements such as Me Too and Black Lives Matter, alongside the impact of the COVID-19 pandemic, have accelerated awareness around social inequalities, urging firms to enhance transparency and commitment to inclusive practices. Despite this trend, empirical studies investigating the determinants of DE&I disclosure remain scarce.

This study aims to fill this gap by analyzing the quality of DE&I disclosure among S&P 500 firms. A manual content analysis is conducted using the Global Reporting Initiative (GRI) standards, leading to the construction of a DE&I Disclosure Quality Index (DE&ID). Each disclosure item is scored on a 0–3 scale, allowing a maximum index value of 51. The analysis incorporates "Requirements," "Recommendations," and "Guidelines" outlined in the GRI framework.

The second objective is to investigate the influence of firm-specific economic and financial characteristics—firm size, firm profitability, firm leverage, and firm age—on DE&I disclosure levels. Four hypotheses, grounded in stakeholder theory, are tested using OLS regression.

Results demonstrate that larger, more leveraged, and younger firms exhibit higher DE&I disclosure, driven by greater stakeholder pressure and the strategic benefits of enhanced transparency. This study contributes to the ESG literature by offering new insights into the drivers of DE&I communication, with implications for both academia and policy, and supports the integration of DE&I into corporate accountability frameworks.

Keywords: Diversity, Equity, and Inclusion (DE&I); Disclosure; Stakeholder theory; Sustainability reporting; Determinants

Paper type: Academic Research Paper

1 Introduction

Recently, a paradigm shift emphasizing economic and social sustainability, alongside increasing environmental responsibility, has been observed (Esposito et al., 2024). The aftermath of the pandemic and socio-political movements such as "Me Too" and "Black Lives Matter" have heightened awareness of social inequalities, compelling firms to address issues such as income disparity, work-life balance, and overall quality of life (Manoharan et al., 2021; García-Sánchez et al., 2023). This shift has also brought about a growing recognition that social sustainability is equally important to long-term corporate success as economic and environmental factors (Shohaieb et al., 2022). With nearly 49% of G250 companies now recognizing social factors as potential operational risks (KPMG, 2022), corporate strategies are increasingly focusing on addressing these challenges through actionable policies.

Among these societal factors, numerous studies underscore the growing significance of Diversity, Equity, and Inclusion (DE&I) as fundamental to advancing sustainability objectives, ensuring long-term corporate success, and fostering ethical and responsible business practices. This trend has led to a shift in corporate priorities, where DE&I is seen not just as a social issue but as a crucial element of corporate governance and strategy. These topics have attracted increasing attention from both academics and practitioners (Eccles et al., 2020; Parker, 2022).

A corporate culture that prioritizes DE&I fosters a more inclusive and collaborative work environment while enhancing competitiveness and innovation. Moreover, organizations that integrate DE&I into their core values are often better equipped to attract diverse talent, improve employee satisfaction, and adapt to the evolving expectations of stakeholders. Organizations actively investing in DE&I policies are better positioned to meet stakeholder expectations and institutional pressures, thereby improving their reputation, financial performance, and attractiveness to investors and talent (Harrison & Klein, 2007; Bear et al., 2010). As consumers and investors increasingly prioritize corporate sustainability and responsible business conduct, firms are urged to integrate

and disclose their DE&I initiatives as part of their broader corporate social responsibility (CSR) commitments, reinforcing transparency and accountability.

Despite this growing emphasis, empirical research on the determinants of DE&I disclosure remains limited (Shohaieb et al., 2022; Garcia-Sanchez et al., 2023), particularly regarding the financial and economic drivers behind such disclosures. This highlights the need for further investigation into the factors influencing firms' transparency in this area. By understanding these determinants, scholars and practitioners can gain insights into how to better assess and promote DE&I initiatives in organizations.

In addressing the aforementioned gap, this study aims to assess, through a manual content analysis, the quality of DE&I disclosure in the sustainability reports of firms within the S&P 500. This research will not only evaluate the content but also analyze the patterns and practices in how companies disclose DE&I efforts. The study will then investigate the economic and financial determinants of these disclosures, offering a more comprehensive understanding of the factors influencing corporate transparency on DE&I issues.

The following sections of this paper are organized as follows: Section 2 presents a background and introduces research hypotheses. Section 3 details the methodology, and Section 4 presents and discusses the obtained results. Section 5 draws conclusions.

2 Background and hypotheses development

To date, only three studies have examined DE&I disclosure and its determinants. Shohaieb et al. (2022) found that governance variables—such as board size, independence, and gender diversity—positively influence the disclosure of diversity management in the annual reports of non-financial organizations listed in the UK FTSE All-Share Index, based on data from 2013 to 2019. García-Sánchez et al. (2023) investigated how governance characteristics, including board gender diversity and expertise, affect the quality of diversity and inclusion disclosure in 189 European multinational companies over the period 2011–2020. Their findings indicate that board diversity and expertise enhance the effectiveness of communication, whereas board independence does not exert a significant impact. Moreover, their study highlights the role of European regulations and the COVID-19 pandemic in fostering greater transparency in diversity practices among these firms. Marrone et al. (2025) have examined the impact of governance determinants on the DE&I disclosure through a sample of 157 companies.

While these studies offer valuable insights into governance-related determinants, the influence of economic and financial factors remains largely underexplored.

Economic and financial information can often be embedded within other forms of disclosure. From this perspective, to examine how firm characteristics influence disclosure practices, the literature highlights several key drivers, particularly related to organizational size and financial performance.

From the perspective of stakeholder theory, larger firms are more likely to engage in extensive sustainability reporting. This is attributed to their greater societal and environmental impact, increased public exposure, and the higher level of scrutiny they face from stakeholders (Alduais et al., 2022; Fortanier et al., 2011; Gallo & Christensen, 2011; Hahn & Kühnen, 2013; Zimon et al., 2022). Managers of such firms often view sustainability disclosure not only as a tool for transparency but also as a strategic asset to enhance legitimacy, mitigate adverse selection, and differentiate from competitors. Moreover, large organizations typically possess more substantial resources, enabling them to invest in environmentally friendly technologies and structured reporting systems (Younis & Sundarakani, 2019).

On the financial side, scholars have argued that sustainability practices aligned with stakeholder expectations can enhance long-term firm value (Freeman & Reed, 1983; Eliwa et al., 2021). Firms with strong ESG performance often adopt a long-term strategic outlook and are more capable of absorbing the costs of sustainability initiatives (Kent & Monem, 2008; Kamaliah, 2020; Alshurafat et al., 2022). While several studies report a positive association between profitability and environmental or social initiatives (Rini & Adhariani, 2020), findings remain mixed. For instance, Fahad and Busru (2021) identify a negative relationship in the Indian context, underscoring the complexity of the profitability-disclosure nexus.

Another factor of interest is corporate leverage. Highly indebted firms may engage in sustainability initiatives as a signaling mechanism to maintain or regain stakeholder trust, particularly among creditors and investors (Haniffa & Cooke, 2005; Bai et al., 2024). In this context, sustainability reporting serves to legitimize corporate behavior and reduce perceived risk. Some studies suggest that higher debt levels incentivize environmental disclosure (Andrikopoulos & Kriklani, 2013; Al-Tuwaijri et al., 2004), while others observe positive links between CSR spending and debt financing (Oware & Mallikarjunappa, 2021). However, conflicting evidence exists—Alkhouri and Suwaidan (2023), for example, find no significant effect of CSR disclosure on the cost of capital in the Jordanian market. Moreover, high debt levels may constrain a firm’s capacity to invest in sustainability

reporting, especially when disclosure may reveal unfavorable information (Cormier & Magnan, 2003; Stanny & Ely, 2008). According to Ho et al. (2022), effective CSR reporting can reduce firm leverage by improving investor attention and liquidity.

In consideration of these premises, the study aims to test the following hypotheses:

- *H1: Firm size is positively associated with DE&I disclosure quality.*
- *H2: Profitability is positively associated with DE&I disclosure quality.*
- *H3: Financial leverage is positively associated with DE&I disclosure quality.*
- *H4: Firm age is negatively associated with DE&I disclosure quality.*

3 Methodology

3.1 Sample

As a starting sample, the S&P 500 index is chosen. This index is selected for its wide representation across various countries and industries, providing a reliable source for examining #rms sustainability disclosure practices. However, data on the independent and control variables were available for only 247 out of the 498 companies in the index. Among these, sustainability reports for the year 2023 were found for 170 companies. However, in this first phase of the study, only 57 companies were analysed.

3.2 Model specification

To test the relationship between firm characteristics and DE&I disclosure quality, this research has used a linear regression model. The following equation expresses the model of the present analysis:

$$DE\&I = \beta_0 + \beta_1 SIZE + \beta_2 ROE + \beta_3 LEV + \beta_4 AGE + \beta_5 BDS + \beta_6 BDD + \beta_7 BDI + \beta_8 BDA + \varepsilon$$

3.3 Variables

The DEI Disclosure Quality Index (DE&ID), developed by the authors following Marrone et al. (2025) through a content analysis approach (Krippendorff, 2018), serves as the dependent variable in this study.

The selection of disclosure items was informed by the Global Reporting Initiative (GRI) standards, widely regarded as a global reference framework for high-quality sustainability reporting (Ferraro & Cristiano, 2022). Each item was evaluated using a four-point scale from 0 to 3: a score of 0 reflects the absence of disclosure; 1 indicates a minimal or vague reference; 2 corresponds to a qualitative disclosure; and 3 signifies a disclosure supported by quantitative data. Consequently, the DE&ID index has a theoretical range from 0 to 51. The full set of evaluated items is included in the Appendix. For the content analysis, relevant terms and expressions were drawn from the GRI's "Requirements," "Recommendations," and "Guidance" sections.

The independent variables of the study are: firm size, firm profitability, financial leverage, and firm age, on DE&I disclosure.

The independent variables employed in this study include firm size (SIZE), firm profitability (ROE), financial leverage (LEV), and firm age (AGE). Specifically, SIZE is used as a proxy for firm scale and is calculated as the natural logarithm of total assets. ROE, serving as an indicator of profitability, is computed as the ratio of net income to shareholders' equity. LEV, capturing the degree of financial leverage, is measured as the ratio of total assets to shareholders' equity. AGE serves as a measure of the company's stability, and it is determined by the number of years since the company's establishment to 2025.

In order to enhance the robustness of the regression model, certain control variables were introduced, namely: board size (BDS), board diversity (BDD), board independence (BDI), and board age (BDA). BDS serves as a proxy for the size of the board of directors and is determined by the count of both executive and non-executive members within the board. BDD represents the percentage of female members within the board of directors. BDI is defined by the percentage of independent board members. BDA is calculated as the average age of its members.

4 Results and discussion

4.1. Descriptive statistics, correlation analysis, and VIF

Table 1 displays the descriptive statistics of the variables. The dependent variable, DE&ID, exhibits a mean value of 37.142, reflecting considerable variability in the extent of disclosure across the sampled firms. SIZE

shows an average value equal to 10.649, while ROE presents an average value equal to 23.146. LEV has an average value of 68.174, while AGE presents an average value equal to 0.450.

Table 1 shows the correlation matrix and allows us to exclude multicollinearity issues. In this regard, the most critical coefficient is between the BDA and BDI and assumes a value equal to 0.5973. According to Farrar and Glauber (1967), there are multicollinearity problems when the values exceed the threshold values of ± 0,8 or ± 0,9. Therefore, in light of this, it is possible to affirm the absence of multicollinearity problems in the interpretation of the results. Moreover, the Variance Inflation Factor (VIF) analysis yielded values ranging from 1.13 to 1.63, which is well below the commonly accepted threshold of 10 (Myers, 1990). These results suggest that multicollinearity does not pose a significant issue in this study.

4.1. Multivariate analysis

To test the hypotheses, the present research uses a multiple linear regression model. Table 2 shows the results of the analysis. The regression model explains about 21% of the variance of the dependent variable (R2 adjusted equal to 0.210). The hypotheses are partially supported by the findings.

Hypothesis 1 (H1) is supported by the results, which indicate that SIZE has a positive and significant effect on DE&I disclosure (p-value = 0.098). Larger companies are often under greater public scrutiny, which may drive them to disclose more information regarding diversity, equity, and inclusion (DE&I) practices. Larger firms generally have more resources and structured departments to manage social and environmental issues. These companies may also be more motivated to build and maintain their reputations in order to attract investors, customers, and talent. Moreover, large companies are typically subject to higher expectations from various stakeholders, including regulators, advocacy groups, and the general public, which may push them to be more transparent in their DE&I reporting. Their increased visibility and the potential reputational risks associated with neglecting diversity issues further contribute to the likelihood of them providing more comprehensive information.

On the other hand, Hypothesis 2 (H2) is not supported by the results, as the relationship between ROE (return on equity) and DE&I disclosure is found to be non-significant. The absence of a significant relationship suggests that financial performance, as measured by ROE, does not necessarily correlate with the extent of DE&I disclosures. This finding is interesting, as one might expect that companies with stronger financial performance would be more inclined to engage in CSR-related activities, including DE&I reporting, as a way to further enhance their reputation. However, the results suggest that DE&I disclosure could be driven by other factors, such as regulatory requirements or social pressures, rather than by financial metrics alone. It is possible that companies focus on DE&I practices as part of their broader sustainability or social responsibility initiatives, which may not always directly relate to immediate financial performance.

Hypothesis 3 (H3) is supported by the results, with LEV (leverage) having a positive and significant impact on DE&I disclosure (p-value = 0.087). Companies with higher leverage may face greater scrutiny from investors and creditors, who often view transparency in non-financial matters—such as DE&I practices—as an indicator of good corporate governance. In addition, companies with high levels of debt may be more inclined to signal their commitment to sustainability and social responsibility in order to mitigate risks associated with their financial position. The need to secure and maintain access to low-cost capital may also drive these companies to adopt more transparent reporting practices on DE&I. Leverage can serve as a signal to stakeholders that the company is managing its obligations effectively, and demonstrating responsibility in areas like diversity could enhance the company's attractiveness to potential investors.

Finally, Hypothesis 4 (H4) is supported by the results, with AGE having a negative and significant impact on DE&I disclosure (p-value = 0.098). Older companies may be less inclined to disclose DE&I information, possibly due to more established and entrenched organizational structures that may not prioritize diversity initiatives. Over time, these companies may have developed more rigid corporate cultures that are less adaptable to emerging societal expectations around issues like diversity and inclusion. Additionally, older firms may perceive less immediate pressure to address DE&I concerns, especially if they have been operating successfully for many years. These companies may already have well-established reputations and market positions, reducing the perceived need for transparency on social issues that may not directly impact their day-to-day operations. Furthermore, older companies may be less reactive to changes in societal norms, as they may already have a history of practices that do not emphasize diversity as much as newer organizations.

Overall, the findings suggest that while company size, leverage, and age have significant effects on DE&I disclosure, financial performance (as measured by ROE) does not seem to play a decisive role. The results highlight the complex interplay between various organizational characteristics and their approach to social responsibility and transparency. Larger companies and those with higher leverage are more likely to engage in

detailed DE&I disclosure, while older companies may be slower to adopt these practices. These insights contribute to the growing body of literature on corporate transparency and sustainability, shedding light on the factors that influence companies' decisions to disclose DE&I information.

Table 1 - Descriptive statistics, VIFs and correlation

Variable	Obs.	Mean	Std Dev.	VIF	DEI&D	SIZE	ROE	LEV	AGE	BDS	BDD	BDI	BDA
DEI&D	57	37.142	14.273		1								
SIZE	57	10.649	2.724	1.32	0.4529**	1							
ROE	57	23.146	16.843	1.16	0.221	-0.0674***	1						
LEV	57	68.174	9.145	1.23	0.2645**	0.3450	-0.0880	1					
AGE	57	0.450	38.935	1.34	0.4479**	0.4532*	-0.0564***	0.2113***	1				
BDS	57	13.709	2.435	1.51	-0.1516*	-0.1653	-0.0879	-0.0225	-0.3244**	1			
BDD	57	31.043	23.631	1.63	0.4590*	0.4972**	-0.2948*	0.2671*	0.5332*	-0.5429*	1		
BDI	57	87.645	17.456	1.23	0.3237*	0.2732*	0.0902	0.4348*	0.3562*	-0.5675	0.2315**	1	
BDA	57	60.509	5.670	1.33	0.3588**	0.2642***	-0.2012*	0.0458	0.6732	-0.3455*	0.4567	0.5973*	1

Table 2 - OLS regression results

Variable	Coefficient	Standard Error	p-value	Sign.
Cons	21.256	25.319	0.404	
SIZE	0.369	0.220	0.098	*
ROE	9.105	9.587	0.345	
LEV	0.278	0.160	0.087	*
AGE	-0.764	0.456	0.098	*
BDS	13.568	6.684	0.046	**
BDD	5.121	2.063	0.015	**
BDI	-0.035	0.186	0.849	
BDA				

Notes:
n = 57
R2 adj = 0.2107
***Significance at 1% level; ** Significance at 5% level; * Significance at 10% level

5 Conclusions

This study investigates the DE&I disclosures within the sustainability reports of companies listed on the S&P 500 index, focusing on how economic and financial characteristics influence disclosure practices. The findings reveal that firms that are larger, more indebted, and relatively younger tend to provide more extensive DE&I reporting, likely due to intensified stakeholder expectations and the strategic value of transparency.

The research contributes both theoretically and practically.

On a theoretical level, it advances the literature on ESG disclosure by shedding light on the relatively understudied area of DE&I reporting and its key drivers. While much of the existing research has focused on environmental and governance aspects of ESG, the social dimension—specifically DE&I—remains less explored. This study fills that gap by not only highlighting the importance of DE&I transparency but also by offering empirical evidence on the factors that influence its disclosure. In doing so, it extends current theories and frameworks related to corporate social responsibility and accountability. Moreover, it broadens the application of stakeholder theory to encompass DE&I transparency, offering new insights into how firms manage and communicate their responsibilities to various stakeholders. The study also contributes to a deeper understanding of how companies balance competing stakeholder interests, particularly in the realm of social issues like diversity and inclusion.

On a practical level, by evaluating the quality of DE&I disclosures and identifying firm-level determinants, the study supports more informed integration of DE&I principles into corporate strategies and governance frameworks. This research provides a robust framework for assessing the effectiveness of DE&I initiatives and reporting practices, enabling firms to adopt more comprehensive and transparent approaches. By offering

concrete insights into the factors that drive DE&I disclosure, the study helps organizations refine their CSR strategies and enhance their commitment to diversity, equity, and inclusion. Furthermore, it provides actionable recommendations for business leaders to improve their DE&I communication, ensuring that these issues are integrated not just into corporate rhetoric but into tangible actions that impact organizational culture and performance.

Additionally, it provides guidance for policymakers seeking to enhance disclosure standards, thereby reinforcing accountability and advancing the dialogue on corporate responsibility in the realm of DE&I. By highlighting best practices and identifying areas for improvement, this research contributes to the ongoing conversation about how to standardize and elevate DE&I reporting. Policymakers and regulatory bodies can use the study's findings to develop frameworks that encourage more detailed and accurate disclosures, pushing firms toward greater transparency. In this way, the study plays a crucial role in advancing the broader agenda of corporate responsibility, ensuring that DE&I becomes a central element of corporate governance and is given the attention it deserves in corporate disclosure practices.

Despite the relevance of the findings, this study is subject to certain limitations. First, the cross-sectional nature of the analysis does not allow for the assessment of the dynamic evolution of DE&I disclosure over time. Second, due to data constraints, the study focuses exclusively on the influence of firm size, leverage, profitability, and age, potentially overlooking other relevant factors. Lastly, the methodological approach adopted to assess disclosure quality—manual content analysis—although conducted following rigorous protocols, may entail a degree of subjectivity.

The identified limitations suggest interesting directions for future research. Longitudinal studies could examine the evolution of DE&I disclosure over time, allowing researchers to observe how disclosure practices have developed and adapted to new challenges and regulations. Such an analysis could also identify emerging trends and highlight how transparency on diversity, equity, and inclusion issues is influenced by external factors such as social, political, and economic changes.

Additionally, it would be useful to expand the analysis to other economic-financial dimensions or other business aspects, such as social performance or the impact of governance on the integration of DE&I into corporate strategies. Future studies could, for example, explore the relationship between DE&I disclosure and financial performance on a broader scale or investigate how diversity policies influence the long-term competitiveness of companies. Similarly, it may be interesting to analyze how different sectors or geographical areas approach DE&I disclosure, considering cultural and regulatory differences that could influence business behaviors.

Finally, future studies could explore further qualitative parameters of disclosure, such as relevance, comparability, verifiability, and neutrality of the information, to provide a more comprehensive view of corporate transparency in DE&I matters. Analyzing not only the quantity but also the quality of the reported data could contribute to improving reporting practices and enhancing stakeholder trust in the information provided. Furthermore, deepening the qualitative aspect could also help better understand how companies interpret and communicate their social responsibility, avoiding the risk of greenwashing or one-sided communication.

6 Ethics declaration

This research did not involve any human participants, personal data, or experimental procedures requiring ethical approval. Therefore, ethical clearance was not required for the study presented in this paper.

7 AI declaration

The authors further declare that no AI tools were used at any stage of the research process or during the preparation of this manuscript. This includes the formulation of the research questions, methodological design, data analysis, drafting, and language revision. All intellectual contributions are the result of the authors' independent work. This choice reflects both the academic nature of the study and the authors' commitment to ensuring full transparency and accountability for the content presented.

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Skill Mismatch: Exploring the Impact of Generative AI in Detecting Biases and Discrimination in Job Advertisements

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Abstract

The Human Resources field, on a national and global scale, faces increasing challenges related to Skill Mismatch, a phenomenon in which candidates' profiles do not align with labour market demand. The contributing factor analysed in this paper is the lack of inclusivity in job advertisements, as non-inclusive language and biases in the selection criteria may discourage applications from underrepresented communities. Ensuring compliance with Diversity & Inclusion (D&I) principles in job postings is essential to fostering fair hiring practices and promoting employment equity.

While AI-based technologies are finding increasing applications in the recruitment process, thus becoming part of the research topics in HR management, most existing tools primarily focus on gender discrimination, underestimating other critical aspects of D&I. This study explores how an integrated approach, based on a broader range of aspects of D&I European principles, may enrich AI-based tools to identify, but also solve, biases in job advertisements, enhancing inclusivity and employment equity for both candidates and recruiters. By expanding the scope of these tools, organizations can better align their hiring practices with the evolving expectations of a diverse and inclusive workforce.

The approach to the problem has been broken down into two main phases. First, guidelines were developed based on European non-discrimination regulations, providing a structured framework for evaluating job advertisements. Then, a Generative AI-based software was designed to screen job postings for inclusivity and compliance. The study underscores the potential advantages of AI-driven automation in screening job advertisements, reducing human biases, resource commitment, and processing time while ensuring adherence to D&I principles.

Keywords: Mismatch; Diversity and Inclusion (D&I); Generative AI; Job Advertisement (JobAds); Human Resources (HR)

Paper type: Academic Research Paper

1 Introduction

The Human Resources sector, at both national and international levels, encounters substantial challenges in addressing the skill shortage among candidates (Liboni et al., 2019; Mukhuty, Upadhyay and Rothwell, 2022; Picinin et al., 2023) and elevated employee turnover rates (Agrawal, Khatri and Srinivasan, 2012). This phenomenon is called Skill Mismatch (SM) (Stanković, Džunić and Marinković, 2021), and it is associated with persistent difficulties in identifying candidates possessing the required qualifications for specific roles.

The job posting constitutes the primary means of interaction between prospective candidates and organizations (Barber, 1998). Ensuring adherence to Diversity and Inclusion (D&I) principles within these advertisements represents a strategic approach that transcends marketing objectives. It enables the creation of equitable conditions for candidate-job matching, fostering inclusivity by eliminating biases that might otherwise discourage applications from underrepresented communities. Studies underscore the critical role of inclusive language in enhancing fairness and broadening the pool of qualified candidates (Saks, Leck and Saunders, 1995).

Although the AI-based tools in the HR field are primarily used during the candidates and Job Advertisements (JobAds) screening phases (Albert, 2019), most of the literature demonstrated how they are mainly focused on the detection of gender discrimination (Hu et al., 2022). This study aims to broaden this scope by exploring how an integrated approach, based on a wider range of aspects of D&I European principles, can enrich AI-based tools to identify and solve biases in JobAds, enhancing inclusivity and employment equity for both candidates and recruiters.

2 Background

The dimension of the SM is estimated through a labour market analysis, for which the Job Vacancy Rate (JVR) has been selected as the most significant indicator (Figure 1). The JVR is the percentage ratio of total job vacancies to the sum of occupied jobs and job vacancies (ISTAT, 2024). From the Labour Market Survey (ISTAT, 2023), ISTAT (Italian National Institute of Statistics) defines job vacancies as "the posts, either newly created or already existing, unoccupied or about to become vacant, which the employer actively seeks to fill with - and is prepared to make further efforts to find - a suitable candidate from outside the enterprise". Both data on JVR

and occupied positions are provided by ISTAT on an annual basis; in particular, the years from 2017 to 2023 are considered in this paper. Data on JVR refers to industrial and service companies, classified according to ATECO economic activity sections (ATECO, 2022); data on occupied job positions comes from the Asia Register, the statistical register of active enterprises, updated annually through a process of information integration from administrative sources, statistical sources and private companies (ISTAT, 2013).

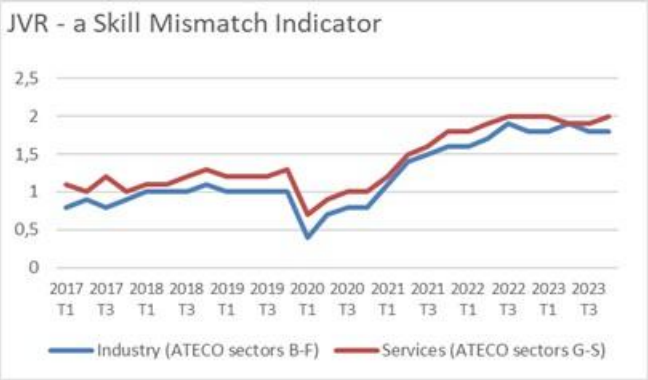


Figure 1 - Job vacancy rate (seasonally adjusted) in enterprises with at least 10 employees (ISTAT, 2024)

A higher JVR reflects unmet labour demand, whereas a lower rate can indicate a mismatch situation in which employers struggle to fill open jobs in specific periods or economic sectors (Lovaglio, 2022). This evidence underscores the need to analyse the underlying factors of mismatch to support effective policies and strategies.

This study focuses on internal company factors, particularly discrimination in employer branding and the recruiting process. The writing of a JobAd plays a key role in a candidate's decision-making process, shaping their initial evaluations about the company they will potentially engage with (Horvath and Sczesny, 2015). Therefore, discriminatory practices can potentially exclude some candidates even from the application for the jobs (Ningrum et al., 2020).

Various approaches, including field experiments, vignette studies and mixed methods, have been employed to uncover discriminatory practices in the recruitment process.

Regarding field experiments, Lee and Khalid (2015) explored racial discrimination in the hiring process for recent graduates in Malaysia. Specifically, they submitted 3,012 fictitious resumes from Malay and Chinese candidates to companies advertising job openings and analysed the interview callbacks based on racial identity. Their results showed that race played a more decisive role in securing a callback than the quality of the resume.

Beyond field experiments, vignette studies have also been conducted to examine discriminatory practices in the recruitment process. Kübler, Schmid, and Stüber (2018) applied this approach to investigate gender discrimination in apprenticeship hiring in Germany. Their study involved 636 HR managers who were asked to assess 3,164 short fictitious CVs. Each respondent evaluated five vignettes and then rated fictitious applicants on a scale from 1 to 10 to determine whether they would advance to the next stage of the hiring process. The findings revealed that, on average, women were rated lower than men, even when other variables were controlled.

Although these approaches are good measures to detect and investigate discrimination during recruitment, they rely on researchers to design and administer experiments or surveys. As a result, the structure of these studies may inadvertently create conditions that differ from real-world hiring practices. Additionally, researchers have limited control over sample sizes, as they are dependent on the number of responses received. For these reasons, it is more effective to address the issue at its root by acting on the JobAd writing phase, with the aim of identify in advance potential discriminatory elements towards the candidates. Firstly, JobAds are direct outputs of the hiring process, making them an authentic reflection of the labour market. Secondly, they serve as strong indicators of an organization's commitment to fair hiring practices (Leong, Tan and Loh, 2004), as they often reveal employers' preferences regarding their ideal candidates. Lastly, researchers can determine the sample size of their studies based on the number of existing JobAds (Ningrum et al., 2020).

Before the introduction of automated processes, JobAds analysis for identifying discrimination, was often conducted manually. However, this approach becomes ineffective and time-consuming when applied to a large number of job postings, while also being influenced by cognitive biases inherent in human judgment. Over time, AI has become part of the research topics in HR management, following a transition process from the early academic studies to its current global impact (Frissen, Adebayo and Nanda, 2023; Hu, et al., 2022). From 2024, AI systems used in employment, worker management, and access to self-employment are considered high-risk

under the EU AI Act (EPC, 2024). This applies specifically to "AI systems intended to be used for the recruitment or selection of natural persons, in particular to place targeted job advertisements, to analyse and filter job applications, and to evaluate candidates" (EPC, 2024). Exceptions include models that detect decision-making deviations from prior patterns and are not meant to replace or influence the previously completed human assessment without proper human review, as well as models that perform preparatory tasks for evaluations relevant to the specific context. There is growing concern that human biases may carry over to decisions made by these systems, which can amplify the effect through systematic application. AI-based software, in fact, are susceptible to various biases, including gender, racial, and cultural biases (Bender et al., 2021). These biases stem from the model's training data, which reflect human-generated content from the internet (Ray, 2023). Empirical studies have identified prevalent biases in candidate ranking software and chatbot interactions, catalysing a rising body of research dedicated to AI fairness over the last decade (Mujtaba and Mahapatra, 2024).

3 Method

The research has been structured into two main phases. The first one involves the development of guidelines to ensure accessibility and compliance in JobAds. These guidelines will serve as the foundation for the second phase, which focuses on the design of a software for screening job postings and identifying Non-Compliances. This latter phase has been further divided into two steps: prompt engineering and standardization of the output format to facilitate the rapid interpretation of results.

Since this paper presents a preliminary version of the tool, the software has been initially validated only for four categories, which are most discussed in the literature and hold significant international legal relevance: "Personal Protective Equipment (PPE)", "Gender", "Age", "Ethnicity and Origin".

3.1 Guidelines

The set of guidelines was based on non-discrimination principles embedded in European legislation, as well as regulations governing relationships between companies, candidates, and employees (EPC, 2006; CD, 2000/43/EC; EC, 2000; FRA, 2018; EUR-Lex, 1989).

The dimensions explored by the guidelines in this preliminary stage of tool validation include the following:

- "PPE": they must normally be provided, free of charge, by the employer, who ensures its proper functioning and hygienic conditions through maintenance, repairs, and necessary replacements (EPC, 1989).
- "Gender": directive 2006/54/EC concerns the implementation of the principle of equal opportunities and equal treatment of men and women in matters of employment and occupation and establishes a set of rights, duties, and prohibitions to achieve the goal of gender equality in the workplace (EPC, 2006).
- "Age": the prohibition of discrimination based on age is regulated by Directive 2000/78/EC, which establishes the principle of equal treatment and justifies age-related disparities based on certain objective and legitimate reasons, such as employment or training policies (CEU, 2000).
- "Ethnicity and Origin": discrimination based on race or ethnic origin is considered discrimination under Directive 2000/43/EC, which implements the principle of equal treatment regardless of race and ethnic origin (CEU, 2000).

The output obtained from this phase is not only a fundamental step in the software development process but can also serve as a standalone tool providing a framework for recruiters.

3.2 Prompt

Starting from the guidelines, a preliminary version of a software has been developed, using PySpark Notebooks in the Databricks environment. This tool queries ChatGPT (engine GPT-3.5 Turbo) to identify elements within JobAds that indicate a lack of inclusivity or Non-Compliance with legal standards. Since the project had already started when upgraded versions of ChatGPT were released, it was decided to continue with this engine to keep the progress made. Upgrading to a more recent version will be considered for future developments of the tool.

The tool's prompt has been structured into 3 sections:

- System prompt: role assignment to ChatGPT, definition of the context and boundaries within which the response should be developed.
- User prompt: the main prompt, which explores the lack of inclusivity or Non-Compliance with regulations for each dimension of analysis.
- A standardized output format to facilitate rapid interpretation of the results.

Since this tool is applied to the HR field, it must be flexible and capable of evolve alongside the regulatory and cultural context. Thanks to this architecture and the AI's ability to learn from examples and feedback, the system can be continuously optimized and updated. For example, it is possible to modify the prompt for a category affected by legislative changes without impacting the output of other categories.

In the System Prompt section, ChatGPT is assigned the role of a recruiter responsible for analysing the text of a JobAd and providing responses to a set of questions.

The reference investigation method for the User Prompt section is a knowledge-based approach to formulate a Discriminatory Keywords Dictionary (DKD). Books and regulations were reviewed to identify the keywords and terms related to discrimination. Synonyms and abbreviations were also included. In addition to the keywords, it was also important to consider Word Patterns Templates (WPT), defined as combinations of keywords and words with specific order, to extract more information from the text as DKD can only detect the occurrences of keywords (Ningrum, et al., 2020).

The reference method was applied limited to the definition of keywords and word patterns, but with some integrations in the approach, given the different purpose of this research. First, European D&I principles and legislation have been not only analysed but also included in a set of guidelines, as previously described. Second, starting from the guidelines, keywords and word patterns, which in our case are phrases and expressions that contain the keywords or indirectly refer to discrimination, have been identified and listed in Table 1.

Table 1 – Discriminatory Keywords and Word Patterns

Type of Discrimination	**Sample Quotes from sources**	**Keywords and Word Patterns indicating Discrimination**	**Keywords and Word Patterns indicating Non-Discrimination**
Personal Protective Equipment (PPE)	*Personal Protective Equipment should normally be provided free of charge by the employer, who ensures its proper functioning and hygienic conditions through maintenance, repairs, and necessary replacements (EPC, 1989).*	*Possession of Personal Protective Equipment (PPE), safety helmet, safety glasses, safety shoes*	*Use of Personal Protective Equipment (PPE)*
Gender	*Any direct or indirect discrimination based on gender is prohibited in both the public and private sectors, (...) concerning:* *a) the conditions for access to employment and work, both dependent and self-employed, including selection criteria and hiring conditions... (EPC, 2006)*	The JobAd is addressed exclusively to male/female candidates.	The text includes at least one explicit reference to both genders.
Age	*(...) Member States may provide that differences in treatment based on age do not constitute discrimination where they are objectively and reasonably justified (...) by a legitimate aim…* *Such differences in treatment may include, in particular:* *a) the definition of special conditions of access to employment (...) for young people, older workers...;* *b) the establishment of minimum age, professional experience, or seniority conditions for access to employment or certain advantages related to employment;* *c) the establishment of a maximum age for recruitment based on the training requirements for the job in question or the need for a reasonable period of employment before retirement (EC, 2000).*	*Minimum/Maximum age requirement, young candidate*	*Apprenticeship contract, internship contract, stage contract, years of experience, Junior/Senior role, night shifts*
Ethnicity and Origin	Direct Discrimination: *(…) occurs when a person is treated less favourably than another in a similar situation due to their race or ethnic origin.* Indirect Discrimination: *(…) occurs when an apparently neutral provision, criterion, or practice puts people of a particular race or ethnic origin at a particular disadvantage compared to others (CD/2000/43/EC).*	*- Origin* *- Nationality* *- Citizenship* *- Ethnicity* *- Domicile* *- Residence*	*- Residence permit*

The approach was structured this way because well-crafted prompts allow to translate complex requests into a form that the AI can process effectively and lead to more precise responses, reducing the probability of misunderstandings or irrelevant outputs.

After the DKD was produced, keywords and word patterns were developed into questions to query the AI and identify non-inclusive job postings.

As ChatGPT and current Large Language Models are trained on large-scale data collections from multiple languages, they automatically identify the input language without requiring a preliminary translation into English. Although the performance is generally better in English high-resource training languages still benefit from relatively good performance by ChatGPT. Given the flexibility in identifying languages, the proposed method can potentially deliver accurate results in other high-resource languages. Among these are Neo-Latin languages but also Russian, Chinese, Japanese, and Vietnamese (Lai et al., 2023). Considering these accurate results and that the available JobAds used to train the algorithm are written in Italian, it was decided to formulate the prompt in the same language, as this aligns with the objective of capturing more nuances of D&I principles, particularly concerning the "Gender" category.

Once chosen this approach, prompt engineering became essential to refining the AI's interpretative accuracy. As an emerging field, it requires an experimental mindset (Open AI). For this reason, an iterative process was followed to test various prompts, paying close attention to how small modifications could significantly alter the AI's responses. Further attention was given to the positive or negative framing of the question. Negative instructions often require the AI to interpret and reverse them, increasing cognitive load and the potential for misunderstanding. To avoid these issues, all questions contain positive instructions.

3.3 Output

The result is a binary output (True/False) that does not necessarily correspond to legally Compliant/Non-Compliant but may vary by category depending on the formulation and the positive framing of the question (Table 2). For example, in the "Ethnicity and Origin" category, the question asks to verify whether the JobAd text references the candidate's ethnicity, meaning that a True response indicates that the job posting is Non-Compliant. For the "Gender" category instead, the question asks whether the job posting is addressed to both men and women, meaning that a True response indicates that the job posting is Compliant. The type of error is used to determine the severity of the error in relation to the compliance of the response. A False Positive (FP) error indicates that the software's response is True instead of False, whereas a False Negative (FN) error indicates that the software's response is False instead of True (Hansen, von Krauss and Tickner, 2007). This error classification will be further explored in the Results section to assess the software's performance.

Table 2 – Output classification

Category	Compliant	Non-Compliant	Worst Type Error
Personal Protective Equipment	False	True	FN
Gender	True	False	FP
Age	False	True	FN
Ethnicity and Origin	False	True	FN

To support the learning process, the tool was provided with a set of 9 examples selected from real JobAds, chosen to cover all scenarios and categories, along with their expected outputs. The aim is to mitigate AI biases related to training datasets by providing examples on how to assess the compliance of a job posting. For each job posting in the dataset under analysis, a request is submitted to the ChatGPT, including the text of the advertisement, the question for each category, and the corresponding examples.

4 Results

Before analysing the results, it is appropriate to introduce the error classification used to evaluate the tool's performance. At first, the evaluation of the output focused solely on the accuracy of the tool, measured by the number of errors, without reference to the compliance of the advertisement. Then the focus shifted to the hypersensitivity of the tool, classifying the severity of the errors. As mentioned in the previous paragraph, the type of error is used to determine the severity of the error in relation to the compliance of the response (Al-Ashwal et al., 2023). Specifically, an FP error indicates that the software's response is True instead of False, whereas an FN error indicates that the software's response is False instead of True. In general, it is preferable to mistakenly detect a Compliant advertisement rather than fail to detect a Non-Compliant one. For example, an FN error for the category of "PPE" occurs when a JobAd requires the candidate to possess such equipment (so the correct response should be True, indicating Non-Compliance) and the JobAd should not. In this case, the tool fails to detect the error and incorrectly responds False, allowing the JobAd to pass without being detected.

To the best of our knowledge, there is currently no analysis of this kind in the literature regarding the evaluation of tools that apply Generative AI in the HR field.

To highlight the relevance of the proposed error classification, we report an incident that occurred in a corporate operating in the HR sector. A JobAd requiring candidates to possess their own safety shoes was not detected by the company's compliance monitoring systems and was consequently published on the firm's official channels. Such an error could damage the company's reputation, particularly because it reveals a critical issue in a process that should be aligned with international ethical certification standards.

The software was validated through controlled testing on datasets containing 40 JobAds, randomly extracted from job postings recently published by an international company operating in the HR sector, for which the expected outputs were predefined based on the guidelines. Currently, the best results achieved through prompt engineering, as described above, are summarized in Table 3. The highlighted cells indicate the most severe type of error, which is a Non-Compliant advertisement that was not detected.

Table 3 – Best output obtained on a test set of 40 job advertisements

Category	**Number of errors**	**% of error**	**Type error: False positive**	**Type error: False Negative**
Personal Protective Equipment	0	0,00%	0	0
Gender	0	0,00%	0	0
Age	1	2,50%	0	1
Ethnicity and Origin	2	5,00%	0	2

As described in Table 3, the software achieves excellent results for the "PPE" and "Gender" categories, with an error rate of 0%. This indicates a precise detection capability for these regulatory aspects. The "Age" category shows minimal errors (2.50%). This suggests that the system is generally reliable in detecting this kind of discrimination, although it may occasionally fail to identify a violation. The "Ethnicity and Origin" category (5% errors) also shows a contained error rate. The errors are FN, indicating that the software missed detecting non-compliant JobAds. This suggests that while the system performs reasonably well, there is room for improving the actual prompt to identify violations in these areas.

5 Conclusions

The findings of this study contribute to the growing body of research on the role of AI in mitigating biases in recruitment, particularly within JobAds screening. JobAds serve as the first evidence of an organization's fairness in hiring practices, highlighting the necessity of intervention from the writing stage to prevent discriminatory barriers.

The development of guidelines based on European D&I principles provides a standalone tool, offering a framework for recruiters when writing job postings. The implementation of the Generative AI-based software, trained to detect discriminatory JobAds following the principles outlined in the guidelines, allows to automatically detect any discriminatory content in the JobAds, so that recruiters can correct the error before publishing the job posting.

The test results indicate that the tool is generally reliable in detecting Non-Compliant JobAds concerning the four categories examined for software validation. However, some categories show a margin of error, highlighting the need for further reworks. Future improvements will focus on enhancing accuracy and expanding the tool's capabilities to ensure more complete and precise detection of discriminatory content. In addition to ensuring a fair selection process for candidates, the adoption of this tool also provides significant benefits for companies. Before the introduction of automated processes, JobAds screening was conducted manually, resulting in an expensive, human and time-consuming activity while also being influenced by cognitive biases inherent to human judgment. Implementing AI enables the automation of this process, making it sustainable in the long period, faster, scalable, and independent from human influence, thereby ensuring inclusivity and employment equity for both candidates and recruiters. The software can be implemented after the JobAd writing phase to assess the presence of any Non-Compliance, thereby directing the recruiter toward the job postings that require a further review before publication. Additionally, it remains possible to review JobAds that have already been published on official channels to identify any issues that may have been overlooked during the previous review process.

Beyond operational efficiency, adopting this tool also enhances the company's brand reputation. Ensuring that JobAds aligns with D&I principles demonstrates a commitment to fair and equitable hiring practices,

strengthening the organization's image as an inclusive and socially responsible employer (Saks, Leck and Saunders, 1995). This can increase its attractiveness to a wider pool of candidates, clients, and stakeholders.

Before considering a large-scale implementation of the tool, it is correct to highlight the challenges that need to be addressed. One of the main limitations is the relatively small dataset of JobAds on which the validation was conducted, which may not fully capture the complexity and variability of real-world postings. Future developments include the expansion of the job postings dataset, carried out gradually and under controlled conditions.

Additionally, now that the tool has been validated, there is significant room for expanding the scope of analysis by incorporating categories that, while not strictly requested by legal standards, are crucial to embracing the D&I perspective. For example, other categories of interest could be "Remuneration" or "Mobility and Driving Licences". The development will proceed according to the same methodology applied in this article, beginning with research on European legislation to enrich the guidelines, followed by the incorporation of the new categories into the software.

The future large-scale implementation of this tool may raise concerns about the potential replacement of human decisions in the recruitment process. However, its purpose is not to substitute human judgment but rather to support it. As suggested by Frost and Alidina (2019), such technologies are "a supplement to help hiring managers mitigate their biases, and are not a cure-all".

6 Ethics declaration

Ethical clearance was not required for this research, as it did not involve human participants, personal data, or procedures requiring ethical review.

7 AI declaration

AI tools, specifically ChatGPT (OpenAI), were used to support language refinement and rephrasing during the drafting process. All content, analysis, and conclusions remain the responsibility of the authors.

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The Role of University-Industry-Government Cooperation in Estonia for Sustainable Innovation

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Abstract

This study explores how university-industry-government (U-I-G) cooperation fosters sustainable innovation in the context of Estonia's post-industrial Ida-Viru region—a historically oil shale–dependent area undergoing a complex sustainability transition. Drawing on the multi-actor collaboration frameworks, which integrates both innovation and sustainability perspectives, this we study how collaborative efforts across institutional boundaries can enhance socio-technical change in peripheral European regions. Using a qualitative methodology 46 stakeholders from educational institutions, companies, municipalities, and umbrella organisations were interviewed to understand the dynamics of regional innovation system. The findings highlight the dual role universities and other educational institutions play—as knowledge producers and civic institutions—bridging technological advancement with societal values. The study reveals how knowledge spillovers, academic-industry exchanges, and boundary-spanning organizations enable sustainable innovation practices, even despite of significant structural challenges such as brain drain, low trust, weak entrepreneurship, and demographic decline. The analysis identifies enabling mechanisms, such as state support via the Just Transition measure, localized collaboration platforms like clusters, industrial parks, joint events and increased trust among actors—as pivotal to overcoming barriers. Companies in the region are adopting sustainable practices, ranging from incremental efficiency improvements to radical innovations such as resource valorization and bio-based production models. The findings also underscore the tensions between short-term economic goals and long-term sustainability. The research advances theoretical understanding of the multi-actor collaboration frameworks, including Triple Helix Twins model and its practical relevance in navigating the complex interdependencies between technological and social innovation. It concludes that reconfiguring regional innovation systems around sustainability goals requires not only institutional collaboration, but also the cultivation of shared values and systemic reflexivity.

Keywords: Sustainable innovation, sustainability, innovation, triple helix twin, university-industry-government cooperation

Paper type: Academic Research Paper

1 Introduction

The increasing global emphasis on sustainability and circular economy principles positions sustainable innovation as a cornerstone of not only business agenda, but also academic, community and policy makers. University-industry-government interaction is seen both as enhancing power and challenge in context of dynamic of sustainable innovation and dissemination and sustainable practices. Sustainable innovation balancing economic growth with environmental and social responsibility, faces complex, systemic challenges that require coordinated efforts among multiple stakeholders. Positioning the research within collaboration frameworks are essential for guiding these efforts because they provide structured models to understand, facilitate, and enhance interactions between key actors by exploring how sustainability and innovation reinforce or conflict with one another.

The research gap addresses challenges of sustainability transitions in post-industrial regions and defines sustainable innovation as inherently complex phenomenon, often requiring fundamental shifts in business models, stakeholder relationships, and regulatory frameworks. This calls for a systemic approach that integrates diverse actors—the kind of collaboration envisioned in collaboration frameworks.

The main research aims to explore how university-industry-government/public cooperation fosters sustainable innovation in Ida-Viru, Estonia. The research questions are as follows: (i) How are sustainable innovation challenges perceived by the actors in the region? (ii) How sustainable innovation actors view their interactions? (iii) How are sustainable innovation challenges enablers and outcomes perceived by the actors in the region?

Estonia is an interesting research context due to its emerging economy that is small and open, where local companies are often deeply involved in exporting and participating in global value chains. The Ida-Viru region in northeastern Estonia is a unique mono-industrial region in the Estonian context that has been historically reliant on oil-shale mining and energy production. However, the ongoing energy transition and exiting from the use of oil-shale poses significant challenges to its economic stability and resilience of companies.

This exploratory research is built on empirical findings from 46 interviews with educational institutions, businesses, municipalities, and umbrella organisations. The findings revealed the dual role of educational institutions as knowledge producers and civic institutions, bridging technological advancement with societal values. The study reports how knowledge spillovers, academic-industry collaboration, and boundary-spanning organizations enable sustainable innovation, even despite of significant challenges such as brain drain, low trust, weak entrepreneurship, and demographic decline.

The rest of the paper is structured into four main sections. It begins with a literature review that covers sustainable innovation, university-industry-government (U-I-G) collaboration theories, and related challenges. The methodology section explains the qualitative design and data collection, which leads into detailed findings grouped into thematic areas—challenges, actors, relations, enablers, and outcomes—culminating in a discussion and conclusions that connect empirical insights to theoretical frameworks and policy implications.

2 Literature review

2.1 Sustainable innovation and circular economy

Sustainable innovation integrates economic growth with environmental and social goals. It emerges as a response to the limitations of traditional innovation models that prioritize profit over long-term ecological and societal wellbeing (Boons & Lüdeke-Freund, 2013; Voegtlin & Scherer, 2017). Rather than treating sustainability as an external concern, sustainable innovation embeds it within the logic of value creation and technological development. The circular economy (CE) complements this perspective by emphasizing resource efficiency, closed-loop systems, and value retention across the product life cycle (Geissdoerfer et al., 2017). CE demands systemic change and multi-stakeholder collaboration, as firms alone cannot overcome institutional inertia or create enabling ecosystems (Bocken et al., 2014). Despite the growing traction of these approaches, many organizations struggle with operationalizing sustainability due to capability gaps, short-term pressures, and resistance to change. Universities, industries, and governments must jointly address these barriers by contributing complementary assets: scientific knowledge, implementation capacity, and strategic support. These University-Industry-Government (U-I-G) collaborations enhance innovation ecosystems by combining long-term vision with practical applications (Miedzinski et al., 2019; Kuhlmann & Rip, 2018). Joint efforts are especially visible in renewable energy, waste valorization, and green mobility (Baldassarre et al., 2020). U-I-G partnerships support both technological and social innovation—the latter involving new behaviors, collaborative models, and governance structures necessary for sustainable development (Markard et al., 2012; Hargreaves et al., 2013). As sustainability transitions involve uncertainty and institutional disruption, cooperation among diverse actors becomes critical for mutual learning and systems-level change (Carayannis & Campbell, 2021; Bozeman & Boardman, 2014).

2.2. Theoretical frameworks for U-I-G collaboration

U-I-G collaboration refers to the systematic interaction and partnership between universities, industries, and governments to pursue joint objectives in research, innovation, and societal development (Etzkowitz & Leydesdorff, 2000; Perkmann & Walsh, 2007). The multi-stakeholder collaboration for innovation is addressed by several theoretical frameworks. The Triple Helix model (Etzkowitz & Leydesdorff, 2000) remains one of the most influential frameworks for understanding university-industry-government collaborationThe Triple Helix emphasizes that innovation occurs not only within organizations, but across institutional interfaces—including joint ventures, science parks, and incubators. To address emerging sustainability imperatives, Etzkowitz and Zhou (2006; 2021) extended this model into the Triple Helix Twins framework. This version introduces a second helix—focused on sustainability and societal engagement—alongside the original innovation-oriented helix. The innovation helix retains its market logic, while the sustainability helix foregrounds public values, environmental concerns, and community needs. This dual-helix configuration allows for vertical interactions within each helix (e.g., university-firm R&D, government policy funding) and lateral linkages between them (e.g., sustainability spillovers from public co-creation into commercial innovation). In doing so, it enables the alignment of economic competitiveness with broader social and ecological missions—a core challenge in regions undergoing sustainability transitions. The Triple Helix Twins is especially relevant for peripheral and transitioning regions, where public engagement, place-based policy, and institutional experimentation are vital. By emphasizing the role of civic actors and societal legitimacy, the framework provides a more inclusive and reflexive model of innovation.

The innovation systems perspective offers additional insight into how collaboration unfolds in different contexts. The National Innovation System (NIS) focuses on institutional arrangements and policy at the country level, while the Regional Innovation System (RIS) emphasizes localized interactions and proximity advantages (Lundvall, 1992; Nelson, 1993; Cooke, 2001; Asheim & Gertler, 2006). In the context of sustainable innovation, RIS frameworks are particularly useful because they recognize place-specific challenges—such as demographic change, industrial lock-ins, or infrastructure disparities—and support bottom-up adaptation. RIS highlights the importance of institutional diversity, localized trust, and policy coherence in shaping innovation outcomes (Borras & Edquist, 2013). For peripheral regions, such as Ida-Viru, RIS thinking reinforces the value of local intermediaries—including development agencies, municipal actors, and university branches—in bridging structural gaps and translating national agendas into regional capabilities.

A growing body of literature points to the importance of intermediary actors—such as innovation brokers, consultants, and NGOs—in facilitating collaboration and innovation for sustainability (Howells, 2006; Klerkx & Leeuwis, 2009). These actors help align goals, manage conflicts, and foster experimentation in environments where institutional barriers exist. In sustainability contexts, intermediaries are essential for enabling transformative change, especially through living labs, pilot projects, or cross-sector alliances (Kivimaa et al., 2019; Stewart & Hyysalo, 2008). They play a key role in organizing knowledge flows, fostering mutual understanding, and embedding societal values in innovation pathways (Edler & Yeow, 2016).

2.3. Mechanisms and challenges of U-I-G cooperation for sustainability

Collaborative R&D initiatives are a central enabling mechanism through which U-I-G actors co-create knowledge for sustainable innovation. These programs often receive state funding and involve shared intellectual property, governance, and infrastructure (Bozeman & Boardman, 2014; Belderbos et al., 2004). Innovation hubs and science parks facilitate informal and formal linkages between universities and firms, acting as physical and organizational spaces for collaboration (Etzkowitz & Zhou, 2006; Clarysse et al., 2014). Public-private partnerships (PPPs), particularly in areas like clean energy and smart cities, serve as vehicles for pooling resources, sharing risks, and fostering scalable sustainable innovations (Kivimaa & Kern, 2016). These enablers are most effective when trust, mutual understanding, and clear governance frameworks are in place (Bruneel et al., 2010). Universities often institutionalize collaboration through Knowledge Transfer Offices (KTOs), which manage intellectual property, liaise with firms, and promote commercialization (Siegel et al., 2007). KTOs play a critical role in bridging academic knowledge with market applications, especially in the sustainability domain. Despite growing support for collaboration, several challenges are identified: mismatch of goals and timeframes; trust and communication gaps, especially between public agencies and firms in low-trust environments (Bruneel et al., 2010); capability asymmetries when smaller firms may lack resources to participate fully in collaboration; regulatory fragmentation in overlapping mandates and unclear policy signals can stall action. These issues highlight the need for adaptive governance models that align incentives, simplify coordination, and facilitate mutual learning (Ansell & Gash, 2008; Diercks et al., 2019).

3 Research design and methodology

The qualitative study employs an exploratory data-driven approach to examine how university-industry-government/public cooperation fosters sustainable innovation in the Ida-Viru region of Estonia. Framed within the Triple Helix Twins model, which highlights the dynamic interactions between academia, industry, government, public, the research explores the mechanisms enabling sustainability-oriented collaboration. Semi-structured interviews serve as the primary data collection method, allowing for in-depth engagement with stakeholders to understand how cooperative structures influence innovation and sustainability in the region (Galletta, 2013).

The Ida-Viru region in northeastern Estonia serves as an interesting case study area due to the level of complexity it faces. Historically reliant on oil-shale mining and energy production, the region is currently undergoing an energy transition away from fossil fuels, which poses economic stability concerns. This transition is influenced by Ida-Viru's rich industrial heritage, which has shaped its identity but also left it vulnerable to economic shifts. The region is predominantly Russian-speaking, which influences labour mobility, social integration, and educational attainment, creating additional layers of complexity in addressing unemployment. High unemployment rates are a persistent issue, exacerbated by a brain drain as younger, skilled individuals migrate to other parts of Estonia or abroad in search of better opportunities. These further strains the region's ability to diversify its economy and adapt to new sustainable practices.

The study includes 46 interviews conducted with representatives from industry, educational institutions, municipalities, and umbrella organizations (referenced in the results section as int_ind, int_edu, int_munic,

int_umb_org). Purposive sampling ensured that participants represent diverse institutional roles within the sustainability transition, including knowledge production, policy influence, and business execution as well as boundary spanning organisations. Selection criteria focused on engagement in sustainability initiatives, sectoral diversity, and institutional capacity to drive collaboration (Patton, 2014). Interviews took place between 2024 and 2025, conducted both face-to-face and online, with durations ranging from one to two hours. The interview design explored the Triple Helix collaboration in the context of sustainable innovation. Discussions with university representatives examined knowledge transfer mechanisms, research commercialization, and academic-industry cooperation models. Conversations with companies focused on innovation strategies, resource dependencies, partnership dynamics, and barriers to adopting sustainability practices. Policymaker and intermediary organization interviews addressed regulatory frameworks, policy incentives, regional governance, and the role of public-sector facilitation in sustainable innovation. Across all stakeholder groups, the interviews explored the entrepreneurial environment of Ida-Viru, key actors and their interactions, and the enabling or limiting factors shaping collaborative innovation efforts.

All interviews were recorded and transcribed for accuracy. Thematic analysis (Braun & Clarke, 2006) was employed to systematically identify emerging patterns and structural dynamics within university-industry-government-public interactions. The data was analysed by attributing 1-st level codes and then merging these into 2nd level themes: challenges, actors, relations, enables and outcomes for sustainable innovation.

4 Results

4.1 Challenges faced by actors in the region

The Ida-Viru region in northeastern Estonia is undergoing a complex and multi-layered transformation as it attempts to shift toward sustainable innovation. The transition away from oil shale—a historically dominant industry—coincides with several overlapping disruptions, including reform of education language, border region with limited across-border economic activities, broken value chains, and growing energy prices. The region's diversity, with a predominantly Russian-speaking population, creates collaboration barriers, while its dual image—strong in industry but weak in entrepreneurship—complicates development and re-training: "*Ida-Virumaa is an industrial region, specifically known for heavy industry with its factories and enterprises. People living in this area are used to working in factories—it's in their DNA, and it gives them a sense of security through stable employment. Those who work in spas or the tourism sector and are engaged in service jobs generally never transition to factory work. This means that people cannot be easily relocated or reassigned between sectors.*" (Int_ind_10). A lack of modern housing, limited cooperation, absence of a central coordinating actor, and a fragmented population further hinder the region's cohesion and progress.

Companies in the region struggle with financial and mindset-related barriers. Several still hope for the return of the oil-shale industry and focus on subcontracting, limiting long-term planning. Loan access is difficult due to low property values and a lack of guarantees, and interest in sustainability varies. Meanwhile, distrust in the state, sudden unexpected changes and a perceived lack of central government understanding of local realities remain obstacles: "*We recently spoke with investors, and they said they don't see a future here. They simply don't understand what is happening in the region. One factory is being closed, another is being restricted, and at any moment their operations could be halted due to some regulatory act or environmental requirement*." (Int_umb_org_1) Local governments lose potential revenue because income tax is allocated by place of residence, not work, and are also affected by the gradual loss of environmental tax income from oil-shale activity. Additionally, mismatches between educational institutions and businesses'—particularly in expectations for training and research—limit cooperation: "*Cooperation is taking place, but it does not meet the needs of the region's companies, as educational institutions are limited by the national curriculum framework as well as by a shortage of teaching staff with experience in the relevant field. The problem extends beyond Ida-Viru County and is relevant for all of Estonia*." (Int_ind_15) Additionally, companies want mostly immediate, practical solutions, while universities are more focused on long-term or academic goals, and only R&D-intensive firms are able to engage in research collaboration.

4.2 Relations between the actors in the region

In the Ida-Viru region of Estonia, a complex web of relations has emerged between various actors as they navigate multiple simultaneous transitions, such as the energy shift away from oil shale and broader socio-political and economic transformations. These relations manifest in several forms—regional, national, and international. Locally, collaboration occurs between large and small companies, often facilitated by

intermediaries like regional development agencies and industry associations. Educational institutions, such as vocational schools and university colleges, play a role in building ties with companies through internships, program co-development, and training initiatives: "*We have everything in place—there are cooperation projects and agreements with companies for carrying out internships. Entrepreneurs and representatives of professional associations are involved in the development of our curricula. We also offer workplace-based learning, meaning that we go directly to companies to provide on-site training*." (Int_edu_2)

At a broader level, the state and its regional offices are involved in fostering collaboration through policy support, funding schemes, and innovation platforms, though issues like over-regulation and at times insufficient local government engagement obstruct these efforts. Public authorities are viewed as shaping the enabling environment for other actors: "*The city must support the development of entrepreneurship. For example, we are planning to build a new production facility, but this requires additional land. We hope that negotiations with the local municipality will be constructive*." (Int_ind_5) Meanwhile, intermediaries help bridge gaps between diverse actors by organizing events, joint projects, and clustering initiatives: "*Organizing various events—such as seminars, information days, and hackathons—provides important opportunities for different stakeholders to meet, negotiate, and form cooperation agreements. Recently, a major hackathon in the creative industries sector brought together participants who developed ideas into products, services, or concepts, which were then presented to a jury.*" (Int_umb_org_6) Joint events such as site visits, fairs, seminars, conferences and hackathons create opportunities for knowledge exchange and partnership in diverse areas.

4.3 Collaboration and sustainable innovation enablers

The development of sustainable innovation in Ida-Viru is supported by a diverse set of enablers that foster collaboration and facilitate regional transformation. A key enabling factor is the regulatory framework, which provides both monetary and non-monetary support for cooperation. Specific instruments like Just Transition measure, entrepreneurship programs, training schemes, and the renewal of education and research services play a role in supporting collaborative efforts, although the efficiency and aim of these measures is viewed differently by various actors as is the future of the region: "*It was suggested (when discussing support measures) that, since this is a region historically dominated by heavy industry, the goal should be to transform it into a new major industry (replacing oil-shale industry). Supporting small businesses was considered unnecessary, as they are unlikely to generate significant new value or jobs. However, the Just Transition measure is based on different principles—its aim is to build a diversified, sustainable, and competitive economy in which no single large industry dominates*." (Int_umb_org_8).

In addition to institutional support, several relational and organizational enablers contribute to collaboration. Trust-building among actors has improved, especially through the growing role of umbrella organizations and cooperation platforms. Despite existing tensions—such as identity issues, language divisions, and scepticism toward newcomers—new cooperation platforms signal a growing willingness to engage in collaborative innovation: "*New types of platforms have emerged, such as hackathons, where young people come together, brainstorm, solve problems, and receive guidance from mentors. Recently, the KOOD/Jõhvi programming school held an event in Sillamäe. These events attract more young people and bring new energy to the region.*" (Int_munic_6) Multilingual capabilities—particularly in Estonian, Russian, and English—also enhance communication and collaboration across different actor groups.

4.4 Collaboration and sustainable innovation outcomes

The outcomes of sustainable innovation at the company level in the Ida-Viru region reflect both incremental and radical changes that are reshaping local industries. On the incremental side, many companies are improving their products and processes by adopting new technologies, digital tools, and sustainability standards. Common efforts include enhancing energy efficiency, implementing waste management systems, measuring environmental footprints, and providing employee training: "*We focus on valorizing production residues to turn waste from the manufacturing process into useful resources. We plan to start producing steam and electricity on our factory premises. In the longer term, we are also considering the use of biofuels, such as wood chips and pellets*." (Int_ind_16) These changes contribute to improvements in productivity and environmental performance to cope with changes in the external environment.

Radical innovations are also emerging, though less frequently, and they typically involve entering entirely new fields or transforming existing business models. This shift is particularly relevant in the context of the energy transition, where companies are seeking alternatives to oil shale and exploring more sustainable sectors or areas of activity: "*There are plans to begin producing calcium carbonate from oil shale ash. We already have patented technology in place to launch the production, and the next step is acquiring the necessary equipment."*

(Int_ind_17) The overall push for innovation has encouraged diversification and increased openness to collaboration, creating opportunities for knowledge spillovers and learning. While challenges remain, such as limited trust and uneven readiness among actors, the outcomes show that sustainable innovation is becoming an essential for regional resilience.

5 Discussion and Conclusions

Knowledge spillovers and academic-industry exchange play a crucial role in fostering sustainability-oriented innovation (Bozeman & Boardman, 2014; Perkmann et al., 2013). In the Ida-Viru region, universities, industries, and government entities collaborate to create a fertile environment for innovation. Universities act as knowledge producers, generating scientific and technical knowledge that can be transferred to industries through various channels such as joint research projects, internships, and collaborative platforms (Etzkowitz & Leydesdorff, 2000; Siegel et al., 2007). This exchange of knowledge helps industries adopt new technologies and sustainable practices, thereby driving innovation that aligns with environmental and social goals (Carayannis et al., 2021). The interaction between academic institutions and industries facilitates the diffusion of tacit and codified knowledge, enhancing the region's absorptive capacity and fostering a culture of continuous learning and adaptation (Muscio & Pozzali, 2013).

The interplay between social and technological innovation is essential for achieving sustainable development (Markard et al., 2012). Technological advances, such as digital platforms for recycling or bio-based materials, are necessary but not sufficient on their own. Social innovation, including new forms of collaboration, community engagement, and behavioural change, must accompany these technological efforts (Voegtlin & Scherer, 2017; Hargreaves et al., 2013). The Triple Helix Twins framework emphasizes the importance of integrating both social and technological dimensions to address complex sustainability challenges (Etzkowitz & Zhou, 2006; Zhou & Etzkowitz, 2021). This dual approach ensures that technological innovations are not only market-driven but also aligned with societal values and environmental priorities. In the Ida-Viru region, this interplay is evident in initiatives that promote public engagement and the co-creation of solutions that address both economic and sustainability objectives (Miedzinski et al., 2019).

Effective governance mechanisms are critical for balancing top-down policy directives with bottom-up entrepreneurial initiatives (Ansell & Gash, 2008). In the Ida-Viru region, local and state governments, along with regional offices of state institutions, play a pivotal role in shaping the policy environment that supports sustainable innovation (Edler & Fagerberg, 2017; Kivimaa & Kern, 2016). Top-down directives, such as regulatory frameworks and funding programs, provide the necessary resources and incentives for businesses to adopt sustainable practices. However, these directives must be complemented by bottom-up initiatives that leverage local knowledge and entrepreneurial spirit (Stewart & Hyysalo, 2008). The Triple Helix model facilitates this balance by encouraging collaboration between government entities, academic institutions, and industries (Etzkowitz & Leydesdorff, 2000). This collaborative approach ensures that policy measures are responsive to local needs and that entrepreneurial initiatives are supported by a conducive policy environment. Joint marketing activities, policy development involving companies, and cooperation platforms are examples of how governance mechanisms can effectively integrate top-down and bottom-up approaches to drive sustainable innovation (Bruneel et al., 2010).

Practical Implications

First, differentiated policy support is needed to reflect the varying sustainability orientations and capabilities of regional firms. While some companies pursue short-term efficiency improvements, others are actively diversifying through radical innovations. Policy instruments should thus be tiered—offering basic awareness and financial support for early-stage adopters, while providing more integrated co-creation spaces for advanced actors. Second, the role of universities and other educational institutions must evolve beyond that of knowledge producers to civic and institutional anchors capable of brokering sustainability visions. This includes embedding sustainability in curricula, encouraging community engagement, and co-developing context-relevant research agendas with local actors.Third, governance should emphasize integration. The policy ecosystem must align top-down measures (e.g., Green Deal, Just Transition Fund) with bottom-up entrepreneurial and social initiatives. This can be achieved through multi-level platforms that include not only U-I-G actors but also civil society—hinting at the potential utility of Quadruple and Quintuple Helix extensions in further research.

Theoretical Contributions

This research extends the Triple Helix Twins framework by providing empirical validation in a peripheral, post-industrial EU context. It highlights how interplay between innovation and sustainability logics can be both synergistic and conflictual, and how effective collaboration requires governance mechanisms capable of mediating this tension. It also adds to RIS theory by illustrating how peripheral regions can activate latent

innovation capacity through trust-based relationships, intermediary engagement, and place-sensitive policy design. By focusing on a transition region with socio-political complexities, the study enriches our understanding of how sustainability transitions can unfold unevenly and how governance structures can shape trajectories of inclusive regional innovation.

In conclusion, the Ida-Viru case demonstrates that sustainable innovation in peripheral regions requires more than institutional presence—it demands integrated collaboration frameworks, adaptive governance, and shared sustainability visions. The Triple Helix Twins framework is particularly useful in unpacking these dynamics, as it accounts for both the economic and societal dimensions of innovation. The future of sustainable regional development lies in fostering not only technological change but also relational infrastructures that align diverse actors toward common goals.

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7 Ethics declaration

Ethical approval for this study was obtained from the Research Ethics Committee of the University of Tartu (387/T-28, 19.02.2024).

8 AI declaration

The authors used OpenAI's ChatGPT to assist with language editing and improving the clarity of several paragraphs in the manuscript. All AI-generated suggestions were critically reviewed and manually edited by the authors to ensure accuracy, appropriateness, and alignment with the paper's arguments and findings. No AI tools were used for data analysis, interpretation of results, or generation of original research content.

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The Activation of Inclusive Behaviors Through Self-Awareness of Cognitive Biases: The Contribution of New Web3 Technologies

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Abstract
This paper seeks to advance understanding of the persistent gap between the growing societal and organizational attention to Diversity, Equity, and Inclusion (DE&I) and the limited reduction of non-inclusive behaviors and practices in real-world contexts. While inclusivity is inherently linked to the cultural and value systems of organizations, it is equally evident that socially undesirable or inappropriate behaviors fall within the realm of individual decision-making. These behaviors are frequently influenced by cognitive biases and prejudices, which tend to perpetuate or normalize inappropriate conduct rather than stigmatizing or sanctioning it. Despite increasing sensitivity to DE&I issues in both societal and organizational domains, training remains the most widely adopted intervention. However, such initiatives often yield only limited short-term awareness and rarely generate enduring structural change.
Accordingly, this paper first explores the intersection between DE&I and various forms of knowledge management, with particular attention to interdisciplinary frameworks that integrate diverse epistemological perspectives. Within this framework, the paper highlights the growing relevance of technology not only in terms of content accessibility and knowledge dissemination related to DE&I, but also as a transformative tool in shaping learning processes. Specifically, the focus is on emerging Web3 technologies—most notably immersive solutions such as virtual reality (VR) and Artificial Intelligence (AI)—which hold disruptive potential for reshaping traditional training paradigms. These technologies offer new opportunities for insight into individual decision-making mechanisms and behavioral patterns.
The development of advanced immersive applications presents the potential to transcend the limitations of passive cognitive learning by fostering active engagement in dynamic, simulated environments. This facilitates the unconscious acquisition of new skills and behavioral responses. The paper analyzes various implementation strategies and their outcomes, with particular emphasis on integrative approaches that combine VR, neuroscience, and artificial intelligence (AI). These multidimensional solutions appear especially effective in enhancing individual self-awareness and facilitating unconscious behavioral recalibration.
The study concludes by proposing an initial conceptual framework that categorizes the range of emerging approaches according to their respective objectives and impacts. It further identifies key strengths and limitations, offering guidance for the more effective design and deployment of DE&I training interventions.

Keywords: Diversity, Equity & Inclusion (DE&I*)*; Inclusive Behaviors; Cognitive Biases; Immersive learning; Virtual ad Mixed Reality+AI (VR&AI).

Paper type: Academic Research Paper

1 Introduction

This paper aims to contribute to the development of inclusive strategies and policies that promote socially desirable behaviors, both within society and corporate organizations, in order to counter inequalities and all forms of discrimination. Despite DE&I topics being fundamental principles for building fair and sustainable societies, and the considerable efforts objectively made by organizations and companies, the desired results are still not achieved. This shifting cultural landscape has spurred growing interest among companies to align with these evolving values, although not without challenges (Argyris & Schön, 1996; van den Brink & Benschop, 2012). Today, addressing DE&I requires more than effective marketing and communication strategies—it demands credibility, concrete initiatives, and verifiable outcomes (Kunda, 2006; Meister 2021a). Several consulting firms have even developed methodologies and synthetic KPIs for evaluating the D&I orientation of client companies (i.e. Noema HR, Etica SGR, or the DE&I Maturity Index by Deloitte).

Despite the progress, it is still not possible to assert that society or corporate environments are fully inclusive—i.e., capable of ensuring equitable treatment for every individual (Sue et al., 2007). This is because the issue of D&I does not lie in the intrinsic diversity of individuals—as every person possesses unique physical and psychological characteristics—but rather in the unequal treatment that some individuals receive based on incorrect assumptions. These assumptions stem from cognitive biases and deeply entrenched structural inequalities—such as those related to gender, economic status, and access to opportunities—which often persist due to a lack of knowledge, interest, or even active resistance within organizations (Saba et al., 2021; Wang et al., 2023). In this sense, D&I is less a structural or organizational matter and more a question of habitual,

instinctive behaviors that emerge in everyday social interactions and are shaped by underlying beliefs and biases—systematic distortions in how people process information and make decisions. These unconscious biases must be addressed and dismantled because of their profound influence on behavior across social, educational, and professional contexts, where they contribute to the reproduction of discrimination and inequality (Kahneman & Tversky, 1982; Kahneman, 2011; Ariely, 2010).

Within this framework, *Training* plays a potentially central role, as it targets individuals directly, ideally aligning them with the organization's value system. Although DE&I-focused training is widely adopted—particularly in large organizations—anonymous employee surveys often paint a contrasting picture, revealing ongoing issues such as lack of respect, attention, or outright discrimination. Consequently, DE&I programs may fall short of expected effectiveness (Dobbin & Kalev, 2016; Chang et al., 2019; Saba et al., 2021).

This raises a critical question: how can there be such limited progress toward an inclusive and equitable society, despite widespread consensus on its importance? A key reason lies in the mismatch between the rational content of most DE&I initiatives—*which primarily target the conscious mind—and the unconscious nature of many exclusionary behaviors, shaped by deep-seated cultural norms and cognitive biases*. The problem is not what is being done, but how such initiatives—particularly training—are conceived, designed, and delivered. In this context, immersive technologies (e.g., virtual reality, mixed reality, and metaverse platforms) offer a promising innovation by eliciting strong emotional engagement that can drive deeper behavioral change (Slater & Sanchez-Vives, 2016; Singha, 2023). They enable embodied experiences that foster empathy, increase bias awareness, and enhance learning retention (Bailenson, 2018; Meister, 2021b).

This paper explores how inclusive strategies, policies, and training programs can be designed for greater effectiveness. It is structured into three main sections: (1) a theoretical review of how DE&I has intersected with knowledge management literature, highlighting key contributions that have shaped new approaches to internalizing inclusive values, including the role of emerging technologies; (2) an analysis of current applications of immersive technologies in DE&I training, based on international and national case studies, corporate reports, and empirical observations, with a focus on assumptions, goals, content, technological choices, and outcomes; (3) the development of a preliminary conceptual framework outlining different approaches to immersive corporate training and their potential short-, medium-, and long-term impacts.

2 Inclusion, Knowledge Management, and Emerging Technologies: A Theoretical Perspective

The relationship between inclusivity and knowledge management (KM) has been extensively explored in academic literature, particularly in terms of how KM can contribute to building more equitable and inclusive environments. KM is inherently positioned as a key enabler of DE&I, as it centers on the creation, sharing, and application of knowledge within organizations or communities. By definition, KM should be inclusive, ensuring that the knowledge of all members—regardless of gender, ethnicity, ability, or cultural background—is valued and utilized (Nonaka & Takeuchi, 1995; Wenger, 1998). Integrative theories and models emphasize that KM practices must explicitly embed DE&I principles to be truly effective. This involves recognizing implicit biases within KM processes and addressing the specific needs of marginalized or underrepresented groups to ensure equitable access to and participation in knowledge-sharing systems (Cornelius-Hernandez & Clarke, 2024).

The connection between inclusivity and knowledge-sharing processes is particularly significant, as both reflect and shape an organization's culture. More inclusive organizations tend to manage knowledge more effectively because they foster multicultural environments in which individuals feel psychologically safe to share their ideas and expertise (Davenport & Prusak, 1998; Hislop et al., 2018). By promoting equitable access to information and participation, inclusive environments foster trust, collaboration, and cohesion, thereby enabling continuous learning and innovation at all organizational levels (Trees & Vlachos, 2022; Cheng et al., 2024). Empirical studies show that workplaces that embrace cognitive and cultural diversity are more likely to generate novel connections between ideas, driving creativity, knowledge generation, and innovation. Inclusive organizational cultures amplify knowledge sources, with positive implications for competitiveness (Ferdman, 2014). Furthermore, inclusive KM policies are associated with greater employee well-being, job satisfaction, organizational commitment, and loyalty (Meister, 2021a). Conversely, when cultural differences become obstacles to knowledge sharing between teams or individuals (Miminoshvili & Černe, 2021), the organization may suffer adverse outcomes. In this light, inclusivity becomes a strategic necessity rather than a normative ideal. This explains the growing academic and managerial interest in inclusive strategies aimed at optimizing KM systems (Creary, 2020; Durst, 2021; Dalkir, 2025).

Within such strategies, training plays a vital role, serving as the bridge between organizational values and their internalization by individuals, as part of their ongoing professional development (Wang et al., 2023).

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Emerging technologies play a growing role in fostering inclusivity within knowledge management (KM), functioning both as tools for accessibility and as mechanisms for promoting equitable organizational processes (Cascio & Montealegre, 2016; Bersin, 2020). Technologies such as voice recognition, machine translation, and ethical AI reduce barriers to knowledge access and mitigate algorithmic bias in recruitment (e.g., gender stereotypes or discriminatory patterns), performance evaluation, and information distribution (Pozza, 2024; Tursunbayeva, 2024; Borgese, 2025).

Two main applications stand out. First, in *DE&I-related decision-making*, inclusive technologies enable equitable knowledge flows through collaborative platforms, multilingual tools, and online communities of practice. Ethical AI helps identify discriminatory patterns in HR data and people analytics, enhancing the fairness of internal knowledge systems (Rhem, 2024). Second, in *inclusive training*, technologies offer personalized, accessible learning experiences that support diverse learners. This includes adaptive e-learning, culturally inclusive content, and immersive *VR training* (PwC, 2020).

Virtual Reality (VR) has proven highly effective in DE&I training across various educational and professional contexts (Richter & Sharabi et al., 2023; Purdue University, 2024). Its effectiveness stems from the experiential nature of learning in realistic, psychologically safe virtual environments that promote deep emotional and cognitive engagement. VR enables participants to adopt alternative identities (Peck et al., 2013; Springer & Günther, 2020), fostering perspective-taking and a deeper understanding of others' lived experiences (Mason & Chrobot-Mason, 2022; Google Research, 2024). This immersion significantly enhances empathy and increases individuals' willingness to modify discriminatory behaviors (Hasler, Spanlang, & Slater, 2017).

The emotional engagement produced by VR allows individuals to observe their own unconscious, altruistic, or self-centered behaviors, including phenomena such as the bystander effect (Darley & Latané, 1968; Batson, 2011); to explore their emotional responses (Damasio, 1999); and to increase implicit awareness of personal biases (Kolb, 1984; Kahneman, 2011; Devine, 2012). By enabling simulations of the experiences of marginalized groups, VR supports the transfer of perspective-taking and behavioral change to real-world settings, as shown by numerous empirical studies (Peck et al., 2013; Herrera et al., 2018; Banakou, Hanumanthu, & Slater, 2016). These technologies offer emotionally powerful, immersive experiences that the human brain perceives as real (Phelps et al., 2001; Immordino-Yang & Damasio, 2007), thereby integrating them more directly into individual cognitive and affective learning processes. Research in medical and psychological domains—including treatments for conditions such as dyslexia—has shown that emotionally charged micro-traumas experienced in VR can lead to more profound reprocessing of behaviors and long-lasting behavioral change (Wiederhold & Riva, 2019; Alcalde-Llergo et al., 2025). Recent experimental studies by Fernandez-Espinosa et al. (2025) further demonstrate that shared immersive experiences in multiplayer VR environments—such as those in the metaverse—can foster social inclusion and enhance team cohesion (Rossi, 2023).

When integrated with AI**,** VR's impact is amplified (Louthi-Hipche, 2024). AI enables behavioral data analysis, adaptive learning paths, and the generation of diverse, realistic training scenarios (Slater & Sanchez-Vives, 2016; Güven, 2025). However, responsible and inclusive design is crucial to avoid reinforcing existing biases, particularly with large language models (LLMs), which may introduce cultural distortions if not adequately designed (UNESCO, 2020).

While the potential is significant, recent critiques emphasize that many immersive solutions lack inclusivity in their design and may fail to ensure long-term behavioral change (Wired, 2021; Yong & Arya, 2023). Therefore, the effectiveness of such technologies depends not on their technical features but on their thoughtful, inclusive implementation.

3 The Conditions Underlying The Effectiveness of VR Applications in DE&I Training

The integration of virtual reality (VR) into DE&I training has received increasing academic attention due to its potential to enhance empathy, bias awareness, and experiential learning. However, *its actual impact on behavior and organizational culture remains under-investigated.*

This study is based on the hypothesis that the persistence of cognitive biases related to DE&I is rooted not only in knowledge gaps or organizational resistance, but in unconscious decision-making processes. Neuroscientific research highlights the need to target implicit memory to enable durable behavioral change (Immordino-Yang & Damasio, 2007; Genco, 2019).

Immersive VR environments can facilitate such change by eliciting emotional engagement and self-reflection. When combined with emerging Web3 technologies—such as artificial intelligence and neuromarketing—these experiences can reinforce self-awareness of bias through emotionally significant micro-traumas, thus supporting inclusive behaviors. The potential of these technologies lies in their ability to reconfigure individuals' processing

and integration of information within their lived experiences, both at the conscious and unconscious levels, through realism, active participation, and emotional engagement.

The aim of this study is in particular to explore the effectiveness of VR in DE&I training by: (1) assessing its capacity to increase awareness of unconscious bias; (2) evaluating the impact of scenario realism and narrative design; (3) examining the contribution of AI-enhanced personalization; and (4) identifying best practices for inclusive and scalable implementation.

Methodologically, the study adopts a mixed-methods approach, beginning with a reasoned selection and comparative analysis of major international VR-based DE&I training initiatives that have been effectively implemented over the past five years for employee development. This analysis draws on academic literature, grey literature, and media sources. The five-year timeframe is justified by the growing visibility and technological maturity of immersive solutions in organizational contexts, particularly following the COVID-19 pandemic.

In addition to international cases, the study examines two anonymized case studies from the Italian branches of multinational corporations—one operating in the consulting sector, the other in finance—both of which were subject to direct observation. These companies first decided to integrate VR into their training strategies, implementing DE&I-focused simulations enhanced with behavioral analytics. The behavioral data embedded in the VR platforms—such as interaction patterns and decision-making pathways—will also be analyzed.

The simulations primarily targeted professionals across various sectors (e.g., healthcare, education, finance, and technology). Most participating organizations also administered post-training surveys to assess changes in participants' bias awareness, empathy, and attitudes related to inclusivity. The case studies are analyzed based on their objectives, target audiences, content, experiential design, and evaluation metrics. Furthermore, in-depth interviews and focus groups with participants and facilitators are conducted to gain qualitative insights into user experience, perceived effectiveness, and areas for improvement. Observational data collected during training sessions serve to triangulate and enrich the analysis. The findings aim to inform the development of evidence-based guidelines for the effective design and implementation of immersive and inclusive training programs.

With reference to the 10 main international and national cases considered, as presented in Table 1, these can be viewed as both indicative and barometric of the diverse models for implementing DE&I projects through VR. All are immersive experiences developed around DE&I themes for the benefit of employees, yet they differ significantly—not so much in terms of the underlying technology or their shared objective of addressing unconscious bias, but rather in the type of experience offered, the degree of cognitive and emotional engagement elicited in participants, and the methods used to measure outcomes. Although all the experiences shared the same objective—namely, to raise awareness of individuals' cognitive biases—analyzing each case reveals the value of highlighting their distinctive features, particularly from a design perspective. As a result, even when the same technology is employed, markedly different approaches to the design and delivery of these training programs can be observed.

4 Immersive Technologies in DE&I Training: Insights for Design and Implementation

The development of immersive applications enables active engagement in dynamic, simulated environments that foster the implicit acquisition of new skills and behavioral patterns, moving beyond the constraints of passive cognitive learning. This paper examines implementation strategies and outcomes, with a focus on integrative approaches that combine virtual reality (VR), neuroscience, and artificial intelligence (AI). These multidimensional solutions have shown particular effectiveness in enhancing self-awareness and promoting unconscious behavioral recalibration. Key insights emerged from the analysis of VR-based DE&I training experiences, especially from a design perspective:

Table 1: Main Case studies of Immersive VR experiences in the context of DE&I

COMPANY	OBJECTIVES/DE &I TOPIC	TARGET	DESIGN/COMPE-TENCE/CONTENT	REALISM/ PERSONALISATION	EXPERIENCE	DELIVERY	AI & OUTCOME	FEEDBACK
GOOGLE (ICT) 2021-24	The program aimed to enhance awareness of unconscious bias and microaggressi ons in the workplace, promote empathy, and equip participants with practical tools to recognize and address discriminator y behavior	32 senior staff mem-bers of the internal security team.	13 DE&I emplo yees involved. The trai - ning was developed in 3 phases: 1) Initial Framing for Beha vior Change: identi-fication of behaviors to be addressed. 2) participant refle-ction on personal expe riences with bias or commit-ted a micro aggression to wards them or others. 3) charac - ters' scriptwriting and scenogra phy based on real incidents	The settings replicated real corporate spaces (e.g., meeting ro oms, video calls, Google Meet), and characters were designed to share identity traits with users, enhancing real-ism through voi ce acting and AI-driven dialogue. While partici-pants could look around, they we re unable to mo ve within the en	The experience used the Virtual Embo diment & People Caring Projective Tecniques and included four scenarios portraying everyday discrimination: assumptions based on appearance, diversity in conversations, feedback and performance, and group dynamics. Participants embodied two different protagonists per scenario to appreciate how perspective-taking influences the perception and emotional experience of bias. The trainee can observe the protagonists, control and respond to the situation in 3 ways: Call it out: to highlight the issue in a very overt way; Call it in: to dispel the misconception by pointing out that	The training lasted 90 minutes, including a facilitator-led briefing, a demo on how to use the Quest 2 headset (15'), a 45' immersive experience, and a 20–25' debriefing session, in small groups of 10. Most participants used the Quest headset; a few opted for the desk top version. The parti-cipant might have to click on the controller (or mouse) when they spot a bias as visible. Trainees could explore scenarios in any order	A reflection follows the first immersion with an optional metric report, such as the *number of biases reported as visible.* Due to the absence of standardized measurement protocols, behavioral data could not be collected or compared systematically. Despite these limitations, the initiative success fully increased realism and per sonal relevance in addressing bi as,	An optional post-training survey (with a 30% response rate) showed that 94% of respondents rated the experience as satisfa ctory (4.7/5), and 82% found it more effective than traditional DE&I formats (4.1/5). Open-ended feedback highligh ted increased awareness, emo tional engagement, and the ability to perceive issues from multiple perspectives.However, partici pants also noted key limi-tations. The graphical quality was often judged subpar, which compro mised immersion. Most critically, the passive nature of the expe rience—where users could not act or intervene—was seen as a

				vironment or in fluence the out come of the sce nes.	it is wrong, highlighting the quality/ expertise of the person the remark was directe towards; Ignore it: the character will stay silent.	and were not bound by a fixed progression.	offering valua ble insights for fu ture iterations of immersive DE&I design.	barrier to deeper enga gement. Participants expressed a desire for greater interactivity and agency in influencing scenarios.
NHS (HEALTH) 2022-2024	In response to widespre ad racism and discriminatio n within the NHS—parti cularly affec ting Black, Asian, and mi-nority ethnic (BAME)staff —the organi zation deve loped an im-mersive VR training pro gram aimed at improving empathy and managerial responses	The traini ng targe ted 270 staff mem bers, with a focus on manage ment and mid-level leaders, seen as key gate keepers	The initiative follow ed a mass exodus of ethnic minority doc-tors and was groun ded in 133 intervie-ws with NHSstaff, ga thered through the Tides study conduc ted by King's Colle-ge London. The VR content was constru cted from real-life testimonies and in cluded emotionally impactful reenact-ments of discrimina tory scenarios, such as PPE being locked away from Black staff during night shifts or unequal ac cess to pandemic-re lated childcareleave	High, in sense of helping to address some of the underlying issues and inequalities that are not often talked about by giving people a voice, and making sure others also listen to that voice. The training could also directly address the discomfort felt by bystanders when confronted by instances of racism.	The immersive training presents vi-deo-based scenarios that depict real experiences of ethnic minority NHS staff. Delivered through passive vir-tual embodiment, participants ob serve as spectators in a highly emo-tional and engaging context. Scenes include a Black nurse, Tunde, being told PPE was locked away at night—disproportio- nately affecting mino-rity staff working late shifts—and an Asian doctor, Jasmine, dismissed by HR after pointing out double stan - dards in shift change approvals du-ring the pandemic. The VR experien ce enables users to experience and witness these discriminatory situa tions firsthand, fostering empathy and awareness. The experience also highlights the bystander effect, as users are unable to intervene, reflecting real-world dynamics.	Video clips in VR The training, called "Walking in the shoes of …", involves participants wearing a virtual reality (VR) headset and watching videos depicting instances of racism and discrimi-nation by actors within an NHS setting. The virtual reality training as a digital repository: meant staff did not have to relive their experiences of discrimination when telling colleagues about the way they had been treated.	no quantitative outcome data were collected	Qualitative feedback highlighted the training's psychological impact: VR allowed staff to engage with difficult experiences without retraumatization and provided a powerful means to foster understanding without requiring victims to retell painful events.
DOMAIN GROUP (ICT) 2023	Integrated DE&I into its corporate cul-ture through an immersive training initia-tive, to evoke empathy,esta blish shared understandin g, and foster behavioral change and personal accountability	Targeting all 780 em ployees, including a train-the-trainer componen t	ND/Generic Contents	While the content was relatively generic, the emotional impact and realism were enhanced through avatars, scenario design, and interactive immersion.	The training leverages virtual embo diment techniques, allowing partici pants to assume alternative identi-ties—such as a different gender or racial appearance—visibly reflected within the virtual environment (e.g., through mirrors). This immersive setup enables users to firsthand experience acts of discrimination or abuse of power, thereby fostering deeper emotional engagement. The VR application is designed to simu late real-life scenarios, guiding parti cipants to identify bias, reflect on their emotional reactions, and rehe arse appropriate behavioral respon ses when witnessing exclusion or misconduct.	Delivered over 40 blended sessions, the training combined a one-hour VR experience with a two-hour facilitated workshop to discuss on how to behave correctly in these different scenario.	The response has been excellent, with partecipants able to enpathize and discuss the experience Emotion, increased empathy and personal accountability towards DE&I	The outcomes were highly positive: 95% satisfaction, 67 NPS, and significant increases in empathy and accountability—98% of participants reported understanding their personal role in DE&I, and 89% felt more receptive to the follow-up workshop. These results demonstrate the effectiveness of combining immersive VR with reflective group discussion to reinforce inclusive workplace behaviors.
VIACOMCBS PARAMOUNT (CINEMA) 2021	A VR training program on bias and inclu sion inspired by the Black Lives Matter movement, aiming to deepen partici pants' aware ness of others' lived experien ces and to pro mote allyship	Bias& in clusion VR training across multiple countries	The experience, co-designed with em-ployees to ensure authenticity, uses virtual embodiment and interactive fea tures to foster per-spective-taking, enabling users to recognize and re-spond to bias in psy-chologically safe scenarios.	Different scenario to create an empathetic learning experience.	"Unpacking bias" Virtual Embodi ment techniques and interactive feature. is an immersive journey focused on bias and inclusion, that enhances perspective-taking and the ability to look beyond your own point of view. It allows people to practice different behaviors in a psychologically safe environment; to face unconfortable yet everyday situations; to recognize bias (and learn where they may have missed it) and make decisions on how to act and react	Delivered remotely during the pandemic through web-based simulations and facilitator-led Zoom workshops	nd	Achieved high levels of engagement and empathy, particularly appreciated for its experiential depth compared to traditional e-learning.
VRAllexia 2025	The VR expe-rience develo ped to raise awareness and foster empathy & in clusion of indi viduals with dyslexia amo ng non dysle xic individuals	30 non-dyslexic participant s from the uni versity environ ment - primarily university professors and students			Non dyslexic individuals were im-mersed in the daily challenges faced by people with dyslexia. Built using the Unity game engine and deployed on Meta Quest devices, the simulation recreates a virtual campus (metaverse) where participants must navigate buildings, locate materials, and reach an exam room, while encountering realistic barriers such as distorted text, misleading directional signs, and limited assistance—mirroring the cognitive and navigational obstacles experienced by dyslexic students.	The project follows a user-centered and itera tive design approach, incorporating best pra ctices from Scrum me thodology. The experi-ence also integrates AI-driven recommen-dation systems and remote-administered psychometric assess-ments, showcasing VR's potential as an as-sistive and diagnostic educational technology	Effectiveness was eva luated via a structured post-experience questi onnaire covering demo graphics, VR experien ce quality, and dyslexia awareness. Results sho wed increased user un derstanding and empa thy toward dyslexia-re lated difficulties, sup-porting the value of im-mersive simulations in higher education and la ying the foundation for a modular virtual cam-pus inclusive of other vulnerable groups.	To evaluate the quality of the experience, ad hoc satisfaction surveys were administered
COMPANY	**OBJECTIVES/DE &I TOPIC**	**TARGET**	**DESIGN/COMPE-TENCE/CONTENT**	**REALISM/ PERSONALISATION**	**EXPERIENCE**	**DELIVERY**	**AI & OUTCOME**	**FEEDBACK**
JP MORGAN 2023	Client diver-sity inclusion: implemented a diversity and inclusion initiative ai-med at foste-ring aware ness and sti-mulating con-versation across interna tional teams.	Delivered across 7 events in 5countries including Australia, Singapore, and Hong Kong. The program engaged over 600 employees	How to create an engaging event to spark discussion around Inclusion that could be delivered in multiple countries with local staff	nd	A short, three-minute interactive VR scenario was used as a catalyst to spark discussion, supported by internal training materials and videos that enabled local teams to independently run the sessions.	The initiative followed a blended model (over 40 sessions): a one-hour VR experience followed by a two-hour facilitated workshop to deepen reflection on inclusive behaviors in workplace scenarios.	The initiative achieved high levels of engagement and impact:	Satisfaction 93% NPS of +68 ENGAGEMENT - 97% found VR more engaging than traditional training methods; EMPATHY – 95.5% of participants felt empathy toward their avatar" I could imagine myself in the character's shoes" ACTION 90,0% stated they would take action upon witnessing inappropriate behavior; FOLLOW UP - 95% expressed interest in further learning about unconscious bias; INTEREST – 87.8% showed interest in joining Business Resource Groups or other D&I initiatives
leading bank in Australia (2023?).	Immersive Training on LGBTQ+ Discri mination and Proactive Ally	161 employee	VR training simulation based on a real lived experience of an employee, allowing	"Step into the shoes of Jack": attempting to sign up to a gym with yourpartner	The simulation was grounded in the real-life experience of a bank emplo yee who faced overt bias while at-tempting to join a gym with his part ner, highlighting how customer ser-	Delivered across over 40 sessions in a blended format (1-hour VR simulation + 2-hour workshop to discuss on	Totally in someone else's shoes: "We are actually in It". "People completely lose every-thing about his skin	NPS +91, with 96% finding VR more engaging than traditional e-learning; 99.2% reported feeling strong empathy and understanding of what it means

	ship - A world leading bank set out on a mission to foster personal accountability and encourage employees to question and act against discriminatio n		you to make value-based decisions and practice taking action in the moment.	Pierre. How does it feel when you are dismissed and refused membership ba sed on your sexual orienta tion? Next, step into the shoes of Fred dy – a custo mer service represen tative at Fitness Front. Practice responding to a colleague discriminating against a customer.	vice interactions can be shaped by unconscious bias and sexual orienta tion discrimination. Participants en gage in a dual-perspective scenario: first, as Jack—a customer who is dismissed due to his sexual orienta tion; and then as Freddy—a custo-mer service representative witnessing a colleague discriminate against Jack. This immersive, narrative-based training allows users to explo re the emotional impact ofexclusion and to practice responding to inappropriate behavior in real time. Key themes addressed include interper sonal and institutional bias, bystan der effect, and poor service quality rooted in discrimination.	how to behave correctly in these different scenario). The program was met with overwhelmingly positive responses	color; your bias and youself". "In roleplay you don't feel you are in that situation, whereas in this situation you think, this is me. I feel like I am really them". "You really feel like you are part of it. It's a really fun way of learning. Instead of just clicking ahead on line or trying to memorize a lesson, you are actually under-standing it in the moment".	to be disrespected; 96% felt prepared to act if they witnessed similar behavior at work 86.4% reported complete immersion, losing awareness of the real world 99.2% indicated clear understanding of available reporting mechanisms The experience was praised for its emotional realism and effectiveness in building empathy and engagement—"bringing feeling back into banking."
SERVICE NOW (ICT) 2021	Building Inclu sive mindsets through Empathy-Based VR Training, by allowing employees to practice responding to bias and microaggressions in a psycho logically safe environment.	Company's employees	The design team specifically crafted a scenario to demonstrate best practices for bystanders looping back and checking in with victims of bias or microaggres sions.	The simulation presents an interview scenario in which employees rotate through three roles, empathy-building: a person of color being interviewed, a White panel member, and a White bystander.	The scenario depicts subtle but impactful incidents of bias, highlighting their effects on the candidate's performance and well-being. The application allows to practice inclusive mindsets and skill sets in a space where it is possible say the wrong thing or touch on what employees can do if they missed an opportunity to speak up. The experience includes reflection prompts that encourage partici-pants to assess their reactions and consider alternative actions, including how to loop ba ck and support individuals who experienced bias. This role-switch-ing mechanism enhances empathy and ac-ountability, particularly for employees who may have been unaware of their own biases or who previo-usly failed to intervene as bystanders differently.	The training is delivered remotely using headsets mailed to employees, with an accessible browser-based version for those affected by VR-induced nausea. Holding these at-home learning sessions has put employees more at ease by eliminating "the fear that folks hold around the judgment of saying the wrong thing" — or the harm created when employees witness their co-workers' bias in action.	There are prompts that ask employees to review their choices throughout the VR learning modules, and decide if they would have done anything else. The virtual format was also seen as reducing performance anxiety, as it offered a low-risk setting to explore sensitive topics and learn through mistakes. This case illustrates how VR can create meaningful engagement with DEI content by promoting perspective-taking, emotional awareness, and practical skill-building in complex social situations.	ServiceNow employees reported increased emotional insight—many expressed that embodying the affected individual made the experience of bias more tangible while others reflected on past inaction and welcomed the opportunity to "rehearse" better responses. The DIB team has received two sets of feedback: "'Wow, I didn't fully understand how that might feel. I've been the person who said this and now that I'm on the receiving end.. Taking on an identity in virtual reality doesn't mean you all of a sudden understand someone's lived experience but it can be a bridge into a deeper understanding. On the flip side, these VR trainings have spurred some employees to speak candidly about their regrets.
CONSULTING GLOBAL NETWORK & ITALIA 2021-22	Early adopter of VR DE&I training in 2019, first in the U.S. and later in Europe, to boost D&I Training on racial bias, with Italy (in 2021-22) focusing on core values including racism, disability & gender issues, using profiling algorithms.	Employees in International Context; Leadership in Italy (130)	A multidisciplinary team, coordinated by the HR dept., led the project over a six-month period. Through focus groups and interviews, the team engaged senior leadership and business unit directors. Internal research on employee sentiment and an in-depth analysis of the company's core business further informed the development process.	The platform features 3 realistic, work-related environments and immersive scenarios of increasing complexity. Realism is enhanced through interactive narratives, emotionally rich characters, and decision-making opportunities. The platform can accommodate multiple environments & situations.	Combining Virtual Embodiment and People-Caring Projective Techniques, the VR platform includes 3 professionally familiar scenarios—two indoor and one outdoor—such as client interaction, public engagement (e.g., a parking situation), and managing a team meeting. In each context, participants are driven to achieve a personal goal (the primary trigger), while simultaneously facing incidents that may affect outcomes depending on the salience of unconscious biases (e.g., related to gender, race, or disability). Realism is enhanced through emotionally nuanced characters that enable immersive dialogue, interaction, and decision-making.	Approximately 20 3h residential workshops were conducted in small groups, supported by internal facilitators, tutors, and technical staff. Each session included a 20' introduction, about one hour of VR experience, and nearly two hours of plenary discussion, focused on differences in decisions and behaviors among colleagues facing identical scenarios, proved highly valuable for self-awareness.	Each session allow a decision-making analysis, based on real-time data generated by the platform's algorithm. Participants remained anonymous to encourage open expression. At the end, each participant received a personalized feedback profile and an evaluation questionnaire via mail. The insights into individual behaviors and decision-making processes constitute new knowledge, enabling more targeted initiatives.	The post-experience evaluation of the workshops received an average score of 4.8 out of 5. Although participants faced some challenges with the technology, they found the analysis of the numerous decisions made within a short time frame across the three simulations to be highly effective. D&I topics were integrated and transversal across the scenarios, allowing for the measurement of participants' actual sensitivity to such issues, as well as the influence of unconscious mechanisms and the strength of individual biases.
FINANCE GROUP-IT (FINANCE) 2024-25	This financial group under took its first experience with VR, as part of an integrated assessement initiative aimed at evaluating individuals' soft skills portfolio, as DE&I. Value System Assessment & People Agility/DE&I	Young High potential talents/60	The project engaged, over a 4-month period, the HR manager responsible for designing the company's original assessment models, in order to ensure that both the narrative structure and the decision-making algorithm accurately reflected the organization's core values, culture, and attention for competencies related to "people caring".	The platform features a high level of realism in both indoor and outdoor environments. Avatars interact based on distinct personalities and emotional profiles, within a credible and structured narrative that simulates a full working day—from leaving home onward.	The simulation, based on the people caring technique, follows a typical workday starting from the moment the participant leaves home. It unfolds across 5 distinct scenes—set in both indoor and outdoor environments—with unexpected events that may or may not involve the main character, depending on their choices. Participants are free to interact, explore, and decide whether or not to influence the context, enabling the assessment of unconscious levels of sensitivity, active listening, and respect for others, while the decision-tracking algorithm generates an anonymous behavioral profile for each participant.	Ten 3h residential workshops were conducted in small groups, supported by internal facilitators, tutors, and technical staff. Each session included a 20' introduction, about one hour of VR experience (without controllers), and nearly two hours of plenary discussion, focused on differences in decisions and behaviors among colleagues facing identical scenarios proved highly valuable for self-awareness.	Each session allow a decision-making analysis in plenary, based on real-time data generated by the platform's algorithm. Participants remained anonymous to encourage open expression. At the end, each participant received a personalized feedback profile via mail. The insights into individual behaviors and decision-making processes constitute *new knowledge, enabling more targeted initiatives.*	Thanks to a post-experience questionnaire, evaluation of the workshops received an average score of 4.9 out of 5. One of the most compelling out comes of the workshops was participants' ability to recognize themselves in the quantitative results—particularly in terms of strengths and potential development gaps. Other feedbacks: "the time just flew by!", "Immersion removes the sense of time from the training. You are focused." By integrating immersive VR with traditional assessments, the project aims to capture more reliable behavioral insights.

Addressing Unconscious Bias: Despite diverse corporate challenges, DE&I interventions share a core objective: identifying and addressing unconscious biases that lead to non-inclusive behaviors. Training may target various audiences—from executives to frontline staff—and address themes such as cultural diversity, gender equity, disability inclusion, and organizational well-being.

Functional and Process-Specific Applications: The use of immersive technologies can be tailored to specific corporate functions. For example, they may assess leadership styles, support bias-free recruitment, or train sales teams in inclusive client interactions.

Instructional Design Over Technology: The impact of immersive training is driven more by pedagogical alignment than by technological sophistication. Effective design requires consistency between real-life managerial behaviors and virtual scenarios, demanding interdisciplinary collaboration.

*Narrative Credibility as a Core Driver: T*he effectiveness of the experience hinges on the realism and plausibility of the interactive narrative, rather than on the topic itself. Authentic storytelling anchored in relatable workplace dynamics is critical.

Pedagogical Strategies: Two dominant narrative approaches exist. A “direct” approach explicitly focuses on a specific DE&I issue, while an “indirect” one embeds DE&I themes in ambiguous situations, allowing spontaneous reactions to surface. The latter encourages deeper emotional engagement and critical reflection.

Role-Based Perspective: The user's role significantly shapes the experience. *Embodying a victim* of discrimination can evoke strong emotional responses but may lead to detachment if the character feels too distant from the participant's identity. Conversely, adopting a *proactive or caring role* fosters a stronger sense of agency and long-term engagement.

Delivery Formats: Training can be delivered through various modalities—fully immersive VR, web-based, mobile—and settings, including classroom or self-guided formats. Blended approaches, supported by skilled facilitators, are particularly effective in promoting reflection and integration of learning.

Emotional Engagement: The intensity and novelty of immersive VR experiences can trigger powerful emotional reactions. Gamified elements can enhance engagement and learning retention.

User Readiness and Attitudes: Receptivity to immersive training is not strictly age-dependent. Openness to innovation and emotional readiness should be considered during participant selection and training design.

Redefining Realism: Realism in immersive design should not be limited to visual fidelity. Emotional credibility arises from subtle sensory cues—ambient sounds, gesture-based interaction, contextual details—that trigger unconscious associations and emotional immersion.

Feedback and Awareness: Participant behavior can be evaluated through normative assessments (e.g., quizzes) or descriptive analytics offering individualized feedback. These mechanisms help surface implicit biases and areas for improvement.

Outcome Measurement and Data Analytics: A rigorous distinction must be made between subjective and objective measures. Behavioral tracking supported by embedded AI-algorithms enables the analysis of decision patterns, providing a data-driven foundation for experiential and evidence-based DE&I training.

Scalability: A key distinction exists between stand-alone VR experiences and scalable platforms that can evolve with new scenarios and protocols. Scalable systems enable long-term strategic integration into corporate learning ecosystems.

The Role of AI: Advances in AI are transforming immersive learning through natural language interaction, real-time data processing, and adaptive feedback. These innovations support the personalization of learning experiences based on cognitive and emotional readiness, paving the way for truly individualized training paths.

By translating these insights into design principles, organizations can move beyond compliance-based DE&I efforts toward sustained cultural transformation. When grounded in robust pedagogical design and supported by data-driven insights, immersive technologies can act as powerful enablers of inclusive knowledge sharing and organizational learning.

5 Discussion and Implications: Toward a Framework for Immersive DE&I Training Design

The preceding analysis underscores the wide-ranging diversity of VR-based DE&I applications at both international and national levels. In light of this, the paper proposes a preliminary reference framework aimed at distinguishing not only the varying objectives and design strategies of immersive DE&I training programs, but also their potential benefits across short-, medium-, and long-term horizons.

Given the expansive potential of immersive technologies in learning contexts, each project must be grounded in a clearly defined behavioral objective. Ultimately, the goal of VR-based DE&I programs is to promote *individual empowerment*—both by fostering self-awareness and behavioral change among those who may exhibit non-inclusive attitudes, and by equipping vulnerable groups with tools to assert and protect their rights.

From a content design perspective, distinct approaches to immersive DE&I training can be identified. The proposed framework (Figure 1) outlines four progressively impactful strategies, categorized by their potential to enhance awareness, drive behavioral transformation, and foster long-term empowerment. These range from informational modules—such as compliance training or knowledge testing—to deeper interventions aimed at developing critical self-reflection. The selection of technological solutions (e.g., VR headsets, mobile simulations, XR, or metaverse platforms) should follow, rather than dictate, instructional design needs. Key content elements—such as scripts, neurocognitive triggers, interactive dynamics, avatar personalities, and decision-making scenarios—must align with intended learning outcomes. In more advanced cases, decision-making algorithms may also be integrated to generate behavioral profiles and *new knowledge, enabling more targeted initiatives.*



Figure 1: The Different Design Approaches to Immersive Training in DE&I

Immersive DE&I training can be categorized into four distinct approaches, each with increasing levels of emotional engagement, behavioral impact, and long-term effectiveness:

1. Informational Approach This model focuses on raising awareness and transferring knowledge about DE&I-related issues—such as anti-discrimination policies or organizational guidelines—through structured, cognitively oriented simulations. While these experiences target the rational mind, they also leverage emotional cues to enhance memory retention and empathy. Two main formats exist:

- *Guided Simulations*, where users interact with avatars in predefined scenarios, testing their adherence to socially appropriate behaviors.
- *Perspective-Taking Simulations*, where users embody individuals from marginalized groups, temporarily "stepping into their shoes" (i.e. *virtual embodiment*)

Although impactful in the short term, these experiences often fail to generate sustained behavioral change. When the simulated identity is perceived as too distant or unfamiliar, users may psychologically distance themselves from the experience, limiting its long-term effectiveness.

2. Experiential Approach The experiential model deepens engagement through emotionally charged, cognitively complex scenarios. It often uses *people-caring projective techniques*, placing users in situations where they must respond to the discomfort or discrimination faced by others. These open-ended simulations encourage instinctive reactions, revealing unconscious biases and fostering critical self-reflection. For example, participants may witness an act of injustice and must choose whether and how to intervene. Because these scenarios evoke personal emotional resonance, they are more likely to produce medium- to long-term attitudinal shifts.

3. Transformational Approach Building on the experiential model, the transformational approach introduces *adaptive simulations*, real-time decision tracking, and personalized feedback mechanisms. Participants are given the ability to shape outcomes based on their choices, while algorithms monitor and assess their behavior. This feedback loop highlights discrepancies between perceived intentions and actual behavior, often generating *micro-emotional shocks* that encode the experience in implicit memory. For instance, a recruiter may discover through simulation that unconscious bias influenced candidate evaluation—revealed not through a test, but through tracked behaviors such as time spent, tone used, or number of questions asked. This reflective process facilitates deeper self-awareness and long-term behavioral recalibration.

4. Collaborative Approach in Metaverse Contexts The collaborative approach involves multi-user, avatar-based environments where participants interact in real time to complete shared tasks or engage in peer learning. These platforms support *collective problem-solving,* content exchange, and potentially anonymous interaction, which can foster openness and reduce bias in communication. Beyond training, these environments can also function as spaces for *peer support and community building*, offering a more social dimension to DE&I learning.

A final critical element is the *integration of immersive experiences with facilitated, classroom-based activities (Blended Learning).* Combining simulations with debriefings led by skilled trainers enhances internalization, reflection, and peer exchange. These moments serve as bridges between simulated insight and real-world behavioral application.

While increasingly complex simulations and advanced analytics demand higher investments, they also generate proportionally *greater organizational knowledge value through deeper behavioral insights* and the development of inclusive competencies at scale.

6. Conclusions

This study seeks to generate both theoretical and practical insights into the use of VR for DE&I training. Theoretically, it contributes to the growing literature on immersive learning by clarifying the mechanisms through which VR fosters perspective-taking, emotional engagement, and critical self-reflection. It also advances a multidisciplinary understanding of inclusive training by analyzing the interaction between technological affordances (e.g., realism, interactivity, AI-based personalization) and pedagogical design.

From a practical standpoint, the research offers actionable guidance for organizations seeking to implement or enhance VR-based DE&I programs. It argues that the effectiveness of diversity strategies depends not only on structural policies governing labor markets and career advancement but also on targeted interventions aimed at influencing individual behaviors. These include training initiatives as well as actions designed to challenge and delegitimize behaviors that violate human dignity. Allowing such behaviors to persist reinforces cognitive biases and exclusionary cultural models—affecting both perpetrators and those who internalize discriminatory norms as inevitable.

Organizationally, alignment among values, knowledge management practices, and actual behaviors is essential to avoid employee disengagement and cynicism. Effective diversity management models foster mutual understanding, improve the organizational climate, and enhance overall productivity—with positive spillovers at the societal level. Importantly, these changes are not purely cognitive; they rely on the development of empathy and individual responsibility, including recognition of passive non-inclusive behaviors—such as the failure to support a colleague in need, under the assumption that someone else will.

Within this framework, immersive technologies, when carefully designed and contextually integrated, offer high-impact and scalable training solutions, particularly for large organizations. However, VR applications vary widely in terms of goals, methods, and expected outcomes. This research therefore proposes a reference framework and set of guidelines to support responsible organizational decision-making.

In advanced immersive scenarios, emotional triggers embedded in the environment and avatar interactions significantly shape engagement. AI algorithms can track user behavior, assess contextual impact, and generate behavioral profiles over time. This enables the reconstruction of decision-making processes and promotes individual self-awareness by objectifying aspects often perceived subjectively.

A key insight of the study is that recognizing the gap between one's self-perception and actual behavior—particularly in emotionally charged or ambiguous virtual situations—can produce *emotional micro-traumas.* These experiences, though discomforting, are encoded in memory and integrated with prior knowledge. When perceived as meaningful, they can prompt immediate and lasting behavioral change. This is due to the brain's tendency to treat emotionally salient events—virtual or real—as equally relevant.

As such, the most advanced immersive learning designs—featuring neuro-trigger mechanisms and AI-driven behavioral analytics—not only facilitate knowledge transfer but can generate *entirely new knowledge*. Specifically, they enable: (1) The mapping of individual behaviors in unfamiliar or ambiguous social situations; (2) The reconstruction of the underlying decision-making processes; (3) The development of self-awareness concerning discrepancies between perceived intentions and actual behaviors, along with a clearer understanding of the consequences of one's actions or inactions.

While this study offers a comprehensive perspective on the potential of VR in DE&I training, it also acknowledges key limitations. These include restricted empirical access to organizational data and the difficulty of measuring long-term behavioral change—especially in isolating VR's unique contribution within complex training ecosystems. Continued research into the design, implementation, and integration of immersive DE&I training will be essential to ensure these technologies contribute meaningfully to the creation of more inclusive, equitable, and knowledge-centered workplaces.

7 AI Declaration

Generative AI (ChatGPT, OpenAI, April–May 2024 version) was used to support preliminary drafting in translation refinement, and the retrieval of non-academic sources (e.g., corporate case studies and reports). All content was subsequently verified, reviewed, and critically validated by the author.

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Artificial Intelligence and Gender Roles: A Structured Literature Review (SLR)

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Abstract

This study presents a Structured Literature Review (SLR) aimed to explore a relationship between Artificial Intelligence (AI) and Gender equality, with a particular focus on the historical developments of this topic and the identification of future research prospectives.

AI is widely regarded as a transformative force with the capacity to reshape numerous dimensions of global society. While its long-term effects on economic system remain subject to debate, the labor market is already emerging as a critical area of impact. Moreover, AI holds the potential to enhance efficiency and productivity, but it simultaneously raises concerns about job displacement, access to opportunities and, exacerbation of existing social inequality.

In this context, our objective is to examine how academic literature has responded to the emergence of AI, particularly analyzing the extent to which gender-related themes are integrated into discussions of AI development and application.

To achieve this, the review is supported by a bibliometric analysis, conducted using the Biblioshny package in R-Studio, were performed on a sample of 290 academic documents (Articles and Book Chapters) available on Scopus and published from 2015 to 2025. The dataset was selected through a rigorous and validated screening process to ensure relevance and academic quality. The analysis is structured around four main dimensions: the annual evolution of publications, the identification and frequency of emerging keywords and trending topics, and the geographical distribution of scholarly contributions.

The originality of this research lies in its methodological approach and use of bibliometric analysis, to explore a broad spectrum of academic publications over a significant period, serving as a potential base for further insights and future studies.

Keywords: Artificial Intelligence (AI), Gender equality, Business transformation, Structured Literature Review (SLR), Bibliometric analysis

Paper type: Academic Research Paper

1 Introduction

In recent years, Artificial Intelligence (AI) has emerged as a transformative force, reshaping the business landscape across various dimensions. Its impact extends beyond operational strategies and decision-making processes, significantly influencing corporate governance, organizational structures, and social dynamics within companies (Ustahaliloğlu, 2025). Indeed, AI holds the potential to profoundly transform the labor market by redefining professional roles, reshaping responsibilities, and increasing demands for digital and cognitive competencies. Nevertheless, its integration presents a series of managerial challenges and brings to light critical concerns related to gender equality (Dwivedi et al., 2021). While AI can improve social and economic outcomes for women, it also risks reinforcing existing gender inequalities (Wajcman et al., 2020).

A growing body of research highlights the risks associated with algorithmic systems, especially when they are designed without explicit principles of diversity and inclusion. In such cases, AI may inadvertently perpetuate and even amplify gender biases embedded in training datasets (Buolamwini & Gebru, 2018; Manresa-Yee et al., 2019; Fabris et al., 2020; Cornacchia et al., 2023; Doh et al., 2024; Benatti et al., 2024, Ferrara, 2024). Various mitigation strategies have been proposed — including data pre-processing, algorithmic adjustments, and post-processing interventions — but bias in AI remains a core challenge in building fair and inclusive systems (Ferrara, 2024).

In addition, statistical evidence continues to reveal a persistent gender gap in STEM (Science, Technology, Engineering, and Mathematics) disciplines, with men dominate both technical and leadership roles. The broader implementation of AI may deepen gender disparities, particularly if its development and governance remain dominated by male-centric perspectives. This increases the risk of women being further marginalized from positions of influence, reinforcing existing power asymmetries (European Commission, 2024).

The study aims to offer a comprehensive overview of the existing literature on the intersection of artificial intelligence and gender equality, offering insights for scholars, professionals, and researchers to identify key themes and guide future research directions.

Considering these issues, the analysis is guided by the following research questions:

- *RQ1.* Is AI perceived merely as a supportive tool or as a new member of the corporate team?

- *RQ2.* Given that AI is a "cognitive" system, does it inherently incorporate gender biases?
- *RQ3.* How does AI adoption affect the distribution of STEM skills?

To address these research questions (RQ), we utilized the Systematic Literature Review (SLR) method, chosen for its rigorous and transparent approach in systematically analyzing the vast body of literature on these themes. This methodology enabled a critical assessment of current knowledge on gender diversity and AI in the corporate world. The results, presented in a dedicated section, highlight the emerging trends and key topic concerning the impact of these technologies on business and gender prospectives.

2 Literature analysis

Artificial Intelligence (AI) is poised to significantly reshape the global economy, demanding major investments and changes in work practices for organizations and institutions (Dwivedi et al., 2021; Cazzaniga et al., 2024). Some experts compare AI's impact to that of the steam engine during the Industrial Revolution, which transformed manual tasks where humans had reached physical limits (Dwivedi et al., 2021; Cazzaniga et al., 2024). Today, AI is no longer futuristic realm but an integral component of the business model of many organisations and a key strategic element in the plans for many sectors of business (Dwivedi et al., 2021). In particular, AI enables machines to replicate human cognitive functions through technologies like machine learning, deep learning, neural networks, natural language processing, expert systems, and robotic automation (Davenport, 2018; Haenlein & Kaplan, 2019). These tools allow for dynamic data interpretation and adaptation, making AI central in sectors such as education, healthcare, manufacturing, public administration, and supply chains (Dwivedi et al., 2021).

In business contexts, AI can enhance or even replace human roles in decision-making, overcoming traditional cognitive limitations (Dwivedi et al., 2021; Daugherty & Wilson, 2018; Miller, 2018).

The infusion of AI into strategic decision-making marks a paradigm shift from conventional models based on human judgment and historical data analysis to data-driven, real-time analytics empowered by AI capabilities (Dwivedi et al., 2021).

Despite these promising advancements, many companies remain unprepared to capitalize on AI's full potential. According to Tambe et al. (2019), 41% of CEOs report that they are not at all prepared to use data analytics tools, and only 4% feel highly prepared. These challenges are not only technical but also organizational and cultural. AI's disruptive impact goes beyond technology, requiring businesses to rethink governance, organizational models, leadership styles, and workforce development (Bruttini et al., 2021). Managers are now expected to adopt skills different from the past, adapting to a context shaped by intelligent systems and collaborative technologies (Arduini & Beck, 2024). This shift in organizational culture coincides with a broader push for diversity and inclusion. Leadership models are evolving from authoritarian styles to more participatory and collaborative approaches, fostering environments where gender diversity is no longer a marginal issue but a strategic driver of innovation and adaptability (Paoloni & Demartini, 2016; Paoloni et al., 2023; Paoloni & Lombardi, 2023). Thus, the integration of AI into the workplace presents an opportunity to redefine roles and responsibilities, potentially supporting gender equality – but only if implemented thoughtfully. While AI can enhance efficiency and innovation, it also raises significant concerns about bias and discrimination, particularly in relation to gender.

In fact, this issue is one of the most pressing ethical challenges. AI systems are trained on data that may reflect historical, societal, or cultural biases. As Ferrara (2024) explains, these biases can result in systematic errors and unfair outcomes. A prominent example is Buolamwini's (2018) study, which revealed that facial recognition systems performed significantly worse on female and darker-skinned faces due to biased training datasets. Crawford (2016) further argues that AI systems reflect the inequalities of the societies that produce them, and without critical oversight, they can reinforce rather than dismantle these structures. Benjamin (2019) explores how emerging technologies like AI can exacerbate systemic oppression if not developed through ethical and inclusive frameworks.

The presence of gender bias in AI is closely tied to the underrepresentation of women in STEM fields (Ceci et al., 2009, Carrell et al, 2010; Wajcman et al., 2020) – another key topics. Some scholars have examined how AI development reflects broader gendered dynamics in both technological environments and workplace cultures. Schiebinger (2021) points to historical imbalances in scientific research teams, noting that male-dominated development groups are more likely to produce technologies that fail to reflect female experiences. Njoto et al. (2022) emphasize how workplace cultures – particularly in male-dominated STEM sectors – reward masculine norms, which can be inadvertently encoded into AI systems used in recruitment or performance evaluation. O'Connor & Llu (2023) focus on structural barriers that limit women's participation in AI development, including

lack of mentorship and support. All the authors cited argue that without gender-inclusive design, AI technologies will continue to mirror existing inequities.

Overall, the ongoing debate on the role of AI in human teams also reflects deeper questions about the nature of technology and work. Some scholars, like Brynjolfsson and McAfee (2014), frame AI as a tool to assist humans – highly efficient and powerful, but still dependent on human control. From this perspective, AI lacks the consciousness and social awareness necessary to operate as a true team member. Others, such as Vallor (2018), advocate for a more collaborative vision of ethically designed AI, that partners with humans in decision-making and creative tasks.

To explore the connection between artificial intelligence and gender diversity, we propose a structured review of the literature (SLR) on the topic, aimed at providing a comprehensive and up-to-date overview of the emerging trends in this research field. The application of a structured literature review (SRL), related to the topic in question, will allow for the contextualization of a highly significant and widely discussed issue in the current business world: the redesign of business, roles, and responsibilities from the perspective of artificial intelligence and female dimensions. Furthermore, a structured examination of the literature enables the assessment of the coherence and originality of the topics addressed.

3 Methodology

3.1 SLR

This study aims to examine the most recent literature on the intersection of artificial intelligence (AI) and gender equality. Given the steady growth of AI tools, a growing body of international research has focused on this topic, with several authors already applying literature review methods in this area (Mendonça de Lima et al., 2023; Cano-Marin, 2024; Ratten, 2024; Setiawan & Hendayana, 2024; Golgeci et al, 2025). To explore this complex relationship, we employed a *Systematic Literature Review* (SLR), a qualitative methodology designed for comprehensive analysis of academic sources (Tranfield et al., 2003).

Following a structured two-phases protocol (Marcos-Pablos & García-Peñalvo, 2018), the first involves formulating a query within a database, with the goal of identifying relevant academic sources based on the research topic (de Moya-Anegòn et al., 2007). For the purposes of this study, SCOPUS was selected as the database, recognized internationally as one of the most reliable and authoritative platforms. Following this query, in accordance with the SLR methodology, a systematic, rigorous, and timely screening process of the sources is undertaken.

Each step of source selection, which progressively narrows the initial pool through the application of exclusion criteria, must be thoroughly justified and documented (Marcos-Pablos & García-Peñalvo, 2018).

In comparison to traditional qualitative research methods, this approach offers several advantages:

- facilitates the systematic selection and review of a large volume of sources (Danese et al., 2018);
- allows for the mapping of sources according to various factors (e.g., topic, research area, geographic context, and research methodology) (Kauppi et al., 2018);
- minimizes the risk of errors in the study (Dada, 2018);
- ensures the replicability of the research through detailed documentation of the source selection process, thereby facilitating the review and ensuring that the research is reproducible by other scholars (Jesson & Lacey, 2006; Nofal, 2018).

As emphasized by Massaro et al. (2016), this specific protocol ensures the scientific rigor of the research and guarantees its replicability.

3.2 Extraction and Sorting Process

The SCOPUS selection string was set on 17/04/2025 by entering the combined search (AND) in the appropriate fields (Title, Abstract, and Keywords) for sources that simultaneously included “Artificial intelligence” or “AI” and “Gender”:

(TITLE-ABS-KEY (Artificial AND intelligence OR AI) AND TITLE-ABS-KEY (Gender))*

This first step of selection generated an initial sample of 6,484 documents. Subsequently, we initiated the screening process to refine the search and align it more closely with our research objectives.

Specifically, we:

- limited the publication years from “2015” to “2025” (new total: 5,646 sources);
- filtered the areas of interest of the sources to "Business, Management and Accounting" (new total: 379 sources);

- considered only the categories “Article”, “Book Chapter” (new total: 290 sources);
- included all open access sources, as well all that were written in English (total: 290 sources).

In conclusion, following the screening process outlined above, the search string was completed as follows:

AND PUBYEAR > 2015 AND PUBYEAR < 2025 AND (LIMIT-TO (SUBJAREA, “BUSI”) OR LIMIT-TO (SUBJAREA, “ECON”)) AND (LIMIT-TO (DOCTYPE, “ar”) OR LIMIT-TO (DOCTYPE, “ch”)) AND (LIMIT-TO (LANGUAGE, “English”))

The resulting sample was subsequently processed through bibliometric analysis.

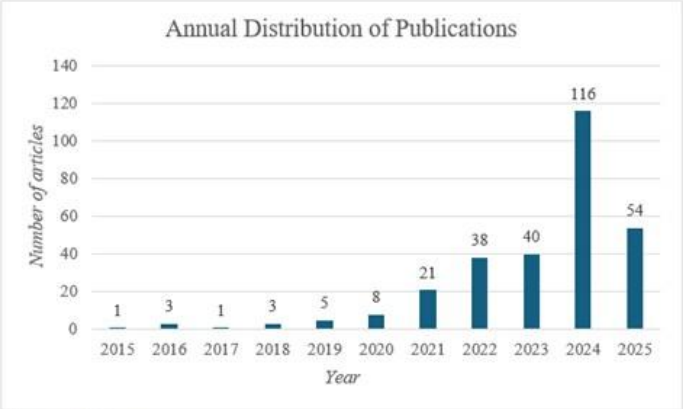
3.3 Bibliometric analysis

As a data processing tool, we employed the *Biblioshiny* package within the *R-Studio* program, known for its accurate and robust capabilities in analyzing academic sources (Derviş, 2019). Bibliometric analysis is widely recognized as one of the most efficient tools for assessing the state of the art regarding the academic dissemination of a specific topic (or the relationship between topics, as in our case) at the time of data extraction (Xie et al., 2020). Consequently, many scholars have leveraged bibliometric analysis enhanced by *Biblioshiny* in conjunction with SLR (Linnenluecke et al., 2020; Donthu et al., 2021). To implement this process, we followed the traditional coding procedure outlined by *Biblioshiny* (Derviş, 2019). Initially, we exported the 290 sources under analysis (filtered as detailed in the previous subsection) into a “BibTex” file. Subsequently, by directly inputting the coding string in *R-Studio*, we activated the *Biblioshiny* package to upload the file extracted from SCOPUS. Upon completion of the database upload, we were able to initiate the process of extracting the relevant information, which is summarized in the following section.

4 Findings

4.1 Results analysis

The analysis of the results follows a thorough investigation of the database, divided into four sections, which together weave a detailed narrative of the current research dynamics on the topic. Each section represents a key and relevant aspect of the bibliometric analysis, ranging from publication frequency to geographical distribution, from predominant keywords, providing a holistic view of the ongoing trends. Following the presentation of the results, the conclusions are drawn in section 5.

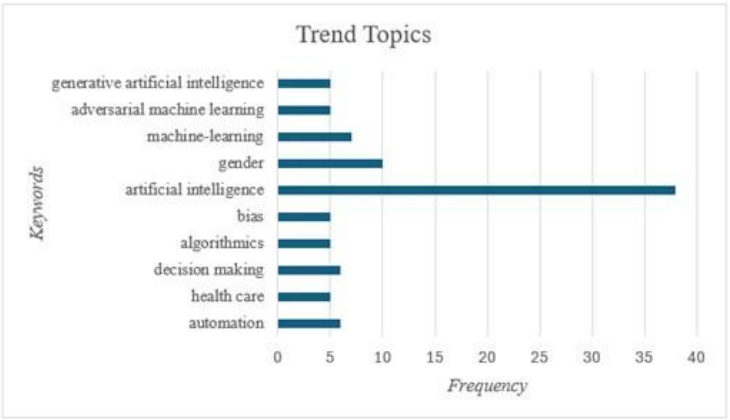


Source: Authors

Fig. 1 – Annual Distribution of Publications

Figure 1 is the result of the bibliometric analysis from the dataset described in subsection 3.1, illustrating the annual distribution of publications in the period 2015-2025. This reference period serves the purpose of gaining awareness of the recent literature published on the topic.

The graph presents the total number of publications (290), providing an immediate visualization of the volume of research developed over time. This representation is essential for identifying trends, peaks in productivity or potential gaps over time. Moreover, such analysis is crucial for understanding the trajectory of research over time, which may reflect changes in priorities concerning areas of interest.



Source: Authors

Fig. 2 – Trend Topics

Figure 2 illustrates an analysis of trendy topics based on frequent keywords in the publications included in the dataset. Prior to analysis, keywords were extracted and subjected to a normalization process involving the removal of punctuation and the conversion of all terms to lowercase, in order to ensure lexical uniformity (Bales et al., 2020). As emphasized by Bales et al. (2020), lowercasing is a standard procedure in the preprocessing of textual data for bibliometric studies, particularly when the objective is to conduct frequency counts or detect consistent patterns. This step is essential to prevent semantically identical terms from being treated as distinct due to typographic inconsistencies. Subsequently, word frequency counts were performed to identify the most recurrent terms. These terms were then visualized using a horizontal bar chart, designed to present the relative frequency of each keyword across the dataset. The extraction and visualization of the most frequent keywords also provide significant insights into the predominant themes and areas of interest within the field of study. This analysis is crucial for understanding the current focus of research and for identifying potential thematic gaps that could be explored in future studies. The lexical choices made in the scientific publications represent a crucial dimension of bibliometric inquiry. Authors typically select terms with strategic intent, aiming to enhance the visibility and thematic clarity of their work. Such terms are carefully chosen to encapsulate the core content of the research, with the dual aim of attracting the attention of peers within the same disciplinary domain and engaging a broader scholarly readership.

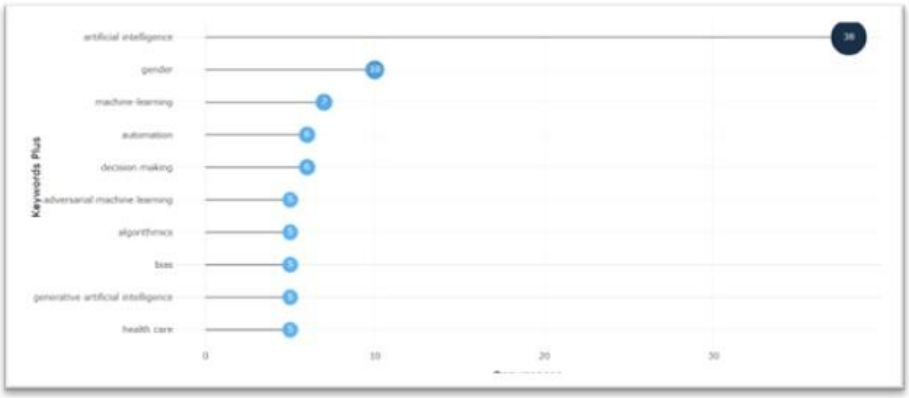
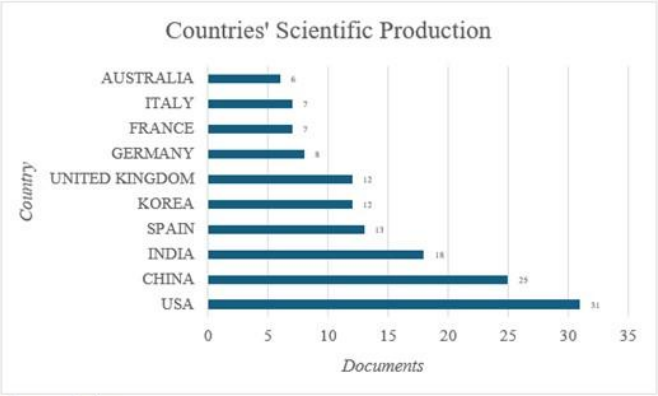


Fig. 3 – Keyword Frequency Analysis
Source: Authors

Following the analysis of trend topics, attention was directed to the study of keywords. This aspect is also central to bibliometric analysis, as it reveals the priorities and directions of current research, highlighting the themes that attract the greatest interest within the academic community. Keywords represent the terms deliberately chosen by authors to highlight the core elements and thematic focus of their research work. These descriptors are commonly employed to concisely summarize the content of scholarly articles and play a critical role in indexing and retrieval within academic databases. By facilitating the discovery of relevant literature, keywords support researchers in navigating the scientific landscape and enable the identification of thematic trends across various disciplines. In the context of a literature review, analyzing the most frequently occurring

keywords allows for the mapping of the current research landscape, shedding light on the topics that dominate scholarly discourse as well as those that may warrant further investigation. The extraction and visualization of keywords, as illustrated in Figure 3, serve not only to identify prevailing research trends, but also to reveal the interplay between different domains of inquiry and their degree of interconnection.



Source: Authors

Fig. 4 – Countries' Scientific Production

Figure 4, as the final object of analysis, represents the geographical distribution of the publications, based on the number of documents attributed to each country. To create this chart, data related to the scientific output of each country was extracted from the dataset. A horizontal bar chart was then constructed to show the number of publications associated with each nation. This type of extraction highlights which countries contribute the most to the body of literature under review. In summary, Figure 4 is useful for understanding how research spreads and is globally received.

5 Discussion and Conclusions

The bibliometric analysis offers a multidimensional view of the research landscape on the relationship between “Artificial Intelligence” and “Gender equality”, highlighting key themes, publication trends, and global contributions. From 2022 to 2024, there was a notable surge in publications (Figure 1), likely driven by growing interdisciplinary interest in the ethical and social implications of AI, influenced by cultural events, policy initiatives, and increasing awareness of algorithmic bias. The analysis reveals that “artificial intelligence” and “gender” are central themes – identified initially in Figure 2 and subsequently confirmed in Figure 3 – reflecting concerns about ethics, inclusivity, and the societal impact of emerging technologies. In particular, the increasing attention to AI indicates the urgency to develop ethical and accountable frameworks. Similarly, the recurring focus on gender suggests increased scholarly attention to how technology can reproduce social inequalities, calling for inclusive design practices. Geographically, the major contributions come from the United States and United Kingdom (Figure 4), reflecting their well-established research infrastructures and substantial investments in scientific innovation. However, countries like China are emerging as key players, signaling a pluralistic and inclusive nature of scientific inquiry in a global context characterized by constant evolution and interconnectedness.

The literature review highlights the recurring presence of themes related to artificial intelligence and gender equality, emphasizing their strategic relevance in the contemporary scientific debate. In particular, artificial intelligence is increasingly examined in relation to gender rebalancing dynamics. These findings allow for the development of well-founded responses to the research questions posed.

RQ1. Is AI perceived merely as a supportive tool or as a new member of the corporate team?

AI replicates human cognitive functions through technologies like machine learning, deep learning, neural networks and robotic automation, enabling adaptation and learning across sectors (Davenport, 2018; Haenlein & Kaplan, 2019; Dwivedi et al., 2021). While some authors view AI as a powerful tool under human control (Brynjolfsson & McAfee, 2014), others envision it as a collaborative partner in creative and decision-making processes (Vallor, 2018). This reflects broader debates on technology’s role in human work.

RQ2. Given that AI is a "cognitive" system, does it inherently incorporate gender biases?

The systematic review of the literature indicates that, in addition to the word “artificial intelligence”, the terms “gender” and “bias” appear with high frequency, suggesting a significant interconnection between these themes in the current scientific discourse. The deployment of AI in the workplace offers significant potential to

improve gender equity, yet it also carries the risk of reinforcing existing gender biases (Wajcman et al., 2020). Research highlights that without explicit diversity and inclusion principles, AI systems may perpetuate or even amplify gender biases present in training datasets (Buolamwini & Gebru, 2018; Manresa-Yee et al., 2019). Despite efforts to mitigate these biases through data pre-processing and algorithmic adjustments (Ferrara, 2024), addressing bias remains a critical challenge. AI systems reflect societal and historical inequalities, and, as such, they may inadvertently reproduce them unless carefully managed (Crawford, 2016; Benjamin, 2019).

RQ3. How does AI adoption affect the distribution of STEM skills?

Statistical evidence continues to show a persistent gender gap in STEM fields, with men dominating both technical and leadership roles. The wider adoption of AI may exacerbate these disparities, particularly if its development remains male-centric (European Commission, 2024). This underrepresentation of women in STEM is linked to gender bias in AI systems (Ceci et al., 2009; Wajcman et al., 2020), which may perpetuate existing power imbalances. Scholars like Schiebinger (2021) and Njoto et al. (2022) highlight how male-dominated environments influence AI design, potentially marginalizing women's perspectives. Without inclusive design, AI risks reinforcing gendered workplace cultures and structural barriers limiting women's participation (O'Connor & Llu, 2023).

In this regard, the findings of this review offer a conceptual framework that systematizes the most relevant themes emerging at the intersection of AI and gender, thus offering a structured basis for future scholarly inquiry. On a practical level, it provides policymakers, organizations, and developers with a valuable perspective to critically reflect on the societal relevance of these issues, fostering more inclusive and ethically grounded approaches to the design and implementation of AI technologies.

In conclusion, the limitation of this study is the use of a single database (SCOPUS) for the bibliometric analysis. Future research may overcome this constraint by incorporating additional bibliographic databases.

6 Ethics declaration

Ethical clearance was not required for the research.

7 AI declaration

AI tools were not used for the creation of the paper.

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Digital Technologies in the Knowledge Era: Opportunity or Challenge for Female Entrepreneurship?

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Abstract

Throughout history, women have played an active role in entrepreneurship, although their participation has often been invisibilized or restricted by social and legal norms. Today, digitalization and new technologies present significant opportunities to expand women's participation in entrepreneurial activities. However, they can also intensify existing challenges or generate new ones. In this context, it becomes necessary to analyze in depth how digitalization impacts on the specific opportunities and challenges faced by women entrepreneurs. The objective of this paper is to analyze the intersection in research between female entrepreneurship and digitalization. To do so, a comprehensive review of 171 scientific articles published in Web of Science (WoS) between 2010 and 2025 was conducted. The results report the main references in the literature on the nexus between female entrepreneurship and digitization: countries (China, USA, India and the UK), authors (McAdam, Maura from Dublin City University and Kelly, Grainne from Queens University Belfast), papers (Pergelova et al., 2019; McAdam et al., 2020; Ughetto et al., 2020), journals (International Journal of Gender and Entrepreneurship and Small Business Economics). The co-word analysis allowed us to identify seven main thematic fronts: (1) social networks, (2) financing, (3) Covid-19, (4) competitive advantage and internationalization, (5) entrepreneurship ecosystems, (6) education, and (7) miscellaneous topics. Each of these fronts was characterized in terms of the opportunities and challenges posed by digital transformation for female entrepreneurship[1]. The results are of interest to researchers concerned with women's entrepreneurship, policy makers charged with fostering gender-responsive entrepreneurship, and women entrepreneurs as they seek to seize the opportunities and circumvent the challenges posed by digital technologies.

Keywords: Women entrepreneurship, Female entrepreneurship, Digitalization, Artificial intelligence, Systematic literature review

Paper type: Academic Research Paper

1 Introduction

Entrepreneurship is a dynamic and rapidly expanding field of academic research with a long-standing intellectual tradition. It can be explored through various disciplines, functions, contexts, and perspectives. As the field has matured, research has diversified into distinct areas such as social entrepreneurship (De Bernardi et al., 2021; Gali et al., 2020), academic entrepreneurship (Lundqvist & Middleton, 2013; Sciarelli et al., 2021), international entrepreneurship (Martin & Javalgi, 2018; Schwens et al., 2018), entrepreneurial ecosystems (Rocha et al., 2021; Spigel, 2017), family firms entrepreneurship (Stanley et al., 2019; Bettinelli et al., 2017), and female entrepreneurship (Li et al., 2021; Wu & Li, 2020), among others. Likewise, entrepreneurship research has applied different methods of analysis such as multilevel analysis (Aguinis et al., 2011; Audretsch et al., 2019; Hörisch et al., 2017), PLS-SEM (Hernández-Perlines et al., 2016), fuzzy-set QCA (Douglas & Prentice, 2019; Douglas et al., 2020), or bibliometrics (Hota et al., 2020; García-Lillo, et al., 2023).

The growing interest in entrepreneurship, coupled with the increasing participation of women in business and management, has significantly heightened scholarly and policy attention toward women's entrepreneurship in recent years. For example, the European Commission supports women's economic empowerment and entrepreneurial initiatives through targeted programs and digital platforms such as the European online portal WEgate. Academic efforts to examine female entrepreneurship from diverse perspectives have resulted in the emergence of different terms to describe this phenomenon, including women entrepreneurs (Kelly & McAdam, 2023), female entrepreneurship (Skare et al., 2025; Kakeesh, 2024), shepreneurs (Mazhar et al., 2022), fempreneurship (Mishra et al., 2023), womenpreneurs (Dalimunthe et al., 2025; Setyaningrum & Muafi, 2022), entrepreneuring mothers (Vershinina et al., 2022), and mompreneurs (Boufares Tayaa & Bouzaabia, 2022), among others.

This study builds upon the work of García-Lillo et al. (2023), titled *"What is going on in entrepreneurship research? A bibliometric and SNA analysis."* The authors examine the field of entrepreneurship research and

[1] Given the limited length, this version includes a review of the opportunities and challenges of one of the thematic fronts (social media). The final version will include a review of each identified front.

identify sixteen distinct active research fronts, among which female entrepreneurship stands out as one of the most prominent. Their analysis also reveals that one of the most influential contributions in recent entrepreneurship literature is Nambisan's (2017) work on digital entrepreneurship. Although academic research is increasingly focusing on the role of digital technologies in entrepreneurial ecosystems, the gender perspective remains largely underexplored (Ughetto et al., 2020), thereby limiting progress in understanding the intersection between female entrepreneurship and digitalization. In this regard, recent studies such as Miah et al. (2025) have emphasized that digital businesses continue to represent a critical gap in the literature on female entrepreneurship.

Digital technologies have brought about a significant change in how the entrepreneurial process is understood, highlighting the role of digital platforms, artificial intelligence, and virtual ecosystems in the creation and scalability of new businesses. The digital context has not only redefined many traditional business models but has also posed new opportunities and challenges for various entrepreneurial profiles, including women. The convergence between female entrepreneurship and digitization has led to the emergence of new specific terms related to gender perspectives in digital businesses, such as digital women entrepreneurship (Paoloni et al., 2019), digital fempreneurship (Mishra et al., 2023), or female digital entrepreneurship (Alhajri & Aloud, 2024).

Academic literature has highlighted that women entrepreneurs may benefit from using digital technologies in their businesses (Modaffari et al., 2023) or in their entrepreneurial initiatives (Moeini Gharagozloo et al., 2023). In this regard, Wiig et al. (2024) identify four opportunities (virtual networks, online learning, opportunity creation, and scaling) that women use to overcome cultural barriers to entrepreneurship. Meanwhile, Yang et al. (2022) finds that digital financial inclusion significantly promotes women's entrepreneurial behavior. However, they may also face challenges if digitalization and technological change reinforce historically rooted inequalities. For example, Ibrahim and Ismail (2020) find that most training programs fall short in providing the digital and strategic skills necessary for the full participation of women entrepreneurs in the knowledge society.

The objective of this study is to examine the intersection of research on female entrepreneurship and digitalization. To this end, we conducted a comprehensive analysis of 171 articles indexed in the Web of Science (WoS), which enabled us to map the research landscape at this intersection, identify key thematic areas, and outline the opportunities and challenges that women entrepreneurs face within the digital context. Applying a gender lens to the study of entrepreneurship and digitalization enhances our understanding of the entrepreneurial phenomenon from a more inclusive and contemporary standpoint.

2 Methodology

We applied a two-tier analysis consisting of bibliometric and content analyses. The bibliometric techniques employed included productivity by active year of publication, countries, authors, journals, and co-word analysis. Previous studies have used similar methodologies in other fields (Bhatt et al., 2020). For the visualization of bibliometric analyses, we used Bibliometrix, an R-based software package (Aria & Cuccurullo, 2017).

In our case, the application of a two-tier analysis allowed us to:

- First, map the research field by identifying the main referents (countries, authors, documents, and journals) on female entrepreneurship and digitalization.
- Second, identify thematic fronts in research on female entrepreneurship and digitalization.
- Third, structure the main opportunities and challenges posed by digitalization to female entrepreneurship within each of the identified thematic fronts.

The WoS Core Collection database was used to retrieve scientific documents. The choice of this database further underscores the significance of the study's findings, as it is widely recognized by the scientific community as the primary source of high-impact and high-quality publications. The data were extracted on April 10, 2025. Therefore, the data for the final year of the analysis includes publications up to that date.

To avoid discarding relevant knowledge and to provide the broadest possible overview of the field, the search was conducted across three of its editions: Science Citation Index Expanded (SCI-EXPANDED), Social Sciences Citation Index (SSCI), and Emerging Sources Citation Index (ESCI). Moreover, given the multifaceted and interdisciplinary nature of female entrepreneurship and digitalization, publications from all WoS categories were considered.

2.1 Document selection criteria

According to Paul and Criado (2020), there are two popular methods for determining the inclusion/exclusion criteria of documents: one stricter (searching for keywords in the title, abstract, or keywords list of the

documents to review) and another more flexible (searching for keywords in the full text of the documents to review). We opted for the stricter option, as it would allow us to obtain a dataset more focused on the topic, which would then be used for content analysis of the documents.

The search equation applied to the fields “title, abstract, and keywords” for data collection was as follows: "wom* entreprene*" or "fema* entreprene*" AND "digital*" or "digiti*" or "AI" or "artificial intelligence". The initial search yielded a preliminary result of 188 documents. However, it was decided to include only “scientific articles” written in “English,” a common practice in literature reviews, which reduced the dataset to 173 articles.

In bibliometric analyses, it is common for the search equation defined by the researchers to retrieve some records from the databases that do not align with the topic under analysis. Therefore, an individual verification of the articles was carried out, which resulted in the removal of 2 records because they were not directly related to the subject analyzed. Thus, the final dataset for analysis consists of 171 articles published between 2010 and 2025.

Table1. Summary of inclusion/exclusion criteria.

Criteria	Removed documents	Selected documents
Web of Science Core Collection (SSCI, ESCI and SCI-EXPANDED)		188
Articles written in English	15	173
Manual verification	2	171
Final dataset		171

Source: prepared by the authors.

3 Results and discussion

3.1 Evolution of publications on female entrepreneurship and digitization

The descriptive results show that research on the female entrepreneurship-digitalization nexus is relatively recent, with the first paper in our dataset being from 2010. However, starting in 2020, coinciding with the COVID-19 health crisis, there was a growing interest in research in this field (see Figure 1). COVID caused society as a whole to face a major digital challenge, significantly transforming many areas of social and business life to adapt to the new situation. The use of ICTs (Kusumawardhani et al., 2022; Nur et al., 2023), digital transformation (Ibrahimi & Ibrahimi, 2024), resilience (Alhothali & Al-Dajani, 2022; Topcu et al., 2024) or the impact of the COVID-19 pandemic on women-led businesses (Mustafa et al., 2021; Ibrahimi & Ibrahimi, 2024) quickly emerged as topics of interest among researchers.

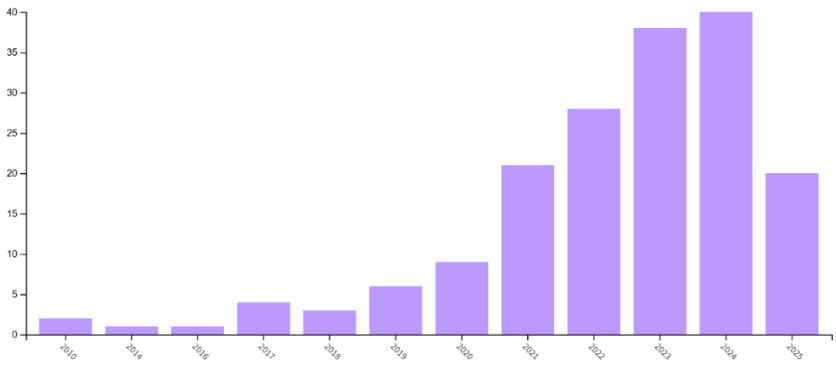


Figure 1. Evolution of publications on female entrepreneurship and digitalization.

3.2 Main referents in research on female entrepreneurship and digitalization

This section summarizes the main referents (countries, authors, papers and journals) in research on female entrepreneurship and digitization.

The bibliometric results reveal a significant concentration of scientific production on female entrepreneurship and digitization in countries such as China (12.5%), the USA (9.6%), India (8.6%) and the United Kingdom (7.6%) (see Figure 2). This leadership may be linked both to the research capacity of these countries and to their leading role in technological development and/or the promotion of inclusion policies. The differences in their regulatory frameworks, sociocultural contexts and public policies do not reflect a

homogeneous commitment to gender equality, which in many cases determines the focus of the studies conducted.

In the case of the United Kingdom and the United States, for example, there are consolidated policies to support female entrepreneurship, accompanied by specific initiatives in the technological field, such as funding programs, accelerators and mentoring networks with a gender focus, which could explain a more applied and multidisciplinary orientation in the research. On the other hand, although China leads in volume of publications, gender equality policies are more centralized and often less oriented to the intersection between gender and technology. In India, despite legislative advances, structural and cultural barriers continue to limit women's access to digital and financial resources.

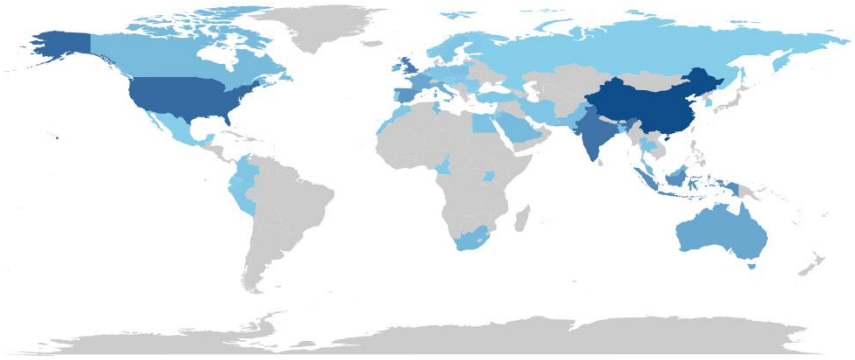


Figure 2. Scientific production by country.

The most prolific author in the research on female entrepreneurship and digitization is McAdam, Maura from Dublin City University (Ireland), who has published six articles and is also the most cited author for the set of documents analyzed. This author is followed in number of publications by Kelly, Grainne from Queens Univiversity Belfast (North Ireland), who has published three articles co-authored with McAdam. Huang, Yangjie from Hangzhou Normal University (China) and Setyaningrum, Retno Purwani from University Pelita Bangsa (Indonesia) have also authored three papers each on the topic analyzed.

The most influential documents are those by Pergelova et al. (2019) titled *"Democratizing entrepreneurship? Digital technologies and the internationalization of female-led SMEs"*, McAdam et al. (2020) titled *"Digital girl: Cyberfeminism and the emancipatory potential of digital entrepreneurship in emerging economies"*, and Ughetto et al. (2020) titled *"Female entrepreneurship in the digital era"*. All three articles were published in the journal *Small Business Economics*. Regarding publication frequency (see Table 2), International Journal of Gender and Entrepreneurship published the most (9 articles), followed by Small Business Economics (6), Sustainability (6), and Entrepreneurship and Regional Development (4).

Table 2. Publication frequency by journal

Journal title	Articles (No)	Articles (%)
International Journal of Gender and Entrepreneurship	9	5.2
Small Business Economics	6	3.5
Sustainability	6	3.5
Entrepreneurship and Regional Development	4	2.3
Journal of Entrepreneurship in Emerging Economies	3	1.7
Journal of Sustainable Tourism	3	1.7
Administrative Sciences	2	1.2
Asia & the Pacific Policy Studies	2	1.2
Cities	2	1.2
Cogent Business & Management	2	1.2

Source: prepared by the authors.

3.3 Thematic fronts identified at the intersection between female entrepreneurship and digitization

This section identifies and characterizes the main thematic fronts in research on female entrepreneurship and digitalization. The analysis identifies seven thematic fronts: (1) social media, (2) financing, (3) Covid-19, (4) competitive advantage and internationalization; (5) entrepreneurship ecosystems; (6) education and, (7) miscellaneous. The in-depth analysis of the analyzed papers has allowed us to characterize each front attending to the main opportunities and challenges faced by female entrepreneurship in the current digital context.

3.3.1 Thematic front 1: Social media

The largest thematic front is made up by 22 articles on female entrepreneurship and social networks. The papers focus on topics such as digital platforms (Mishra et al., 2023), Facebook (Camacho & Barrios, 2022; Ditta-Apichai et al., 2024), Instagram (Ramli & Razak, 2023; Heizmann & Liu, 2022; Baulch & Pramiyanti, 2018; Boufares Tayaa & Bouzaabia, 2022), culture (Al-Boinin et al., 2025), psychological empowerment (Chakraborty & Biswal, 2023), marketing strategies (Jiménez-Zarco et al., 2021), or social performance (Aracil-Jordá et al., 2023; Kuran & Khabbaz, 2025).

Low technological barriers to entry mean that social networks and digital platforms serve as a cradle for female entrepreneurship (Kang, 2022), offering women new routes to entrepreneurship (Mishra et al., 2023) and connections to digital mentors (Lall et al., 2023). In fact, 95% of women entrepreneurs surveyed in Egypt by Miniesy et al. (2022) stated that they would not have started their businesses without social networks. In some cases, entrepreneurship begins simply by transforming spaces they previously used for entertainment, such as Facebook, into business platforms (Camacho & Barrios, 2022).

Among the most prominent opportunities of social networks for female entrepreneurship are personal and relational empowerment (Miniesy et al., 2022), overcoming cultural barriers (Al-Boinin et al., 2025; Kong et al., 2024), keeping up with digitalization (Olsson & Bernhard, 2021), or expanding their economic and social space (Steel, 2017). According to Hammad and El Naggar (2023), online social capital helps women entrepreneurs develop skills and access resources needed to identify and exploit entrepreneurial opportunities. Regarding business management, social networks facilitate the promotion and expansion of their businesses (Olsson & Bernhard, 2021), improve brand visibility (Chakraborty & Biswal, 2023) and communication with customers (Mack et al., 2017). According to Chakraborty and Biswal (2023) platforms such as Instagram, Pinterest and TikTok are particularly effective to showcase products visually and engage directly with customers. Moreover, social media marketing actions have significant effects on both financial (Jimenez-Zarco et al., 2021) and social performance of women-led microenterprises (Kuran & Khabbaz, 2025).

One of the main challenges faced by women entrepreneurs in their entrepreneurship through social networks or digital platforms is the gap in knowledge and effective use of them, since it could limit their potential (Olsson & Bernhard, 2021). Effective implementation of these technologies requires technical skills that may not be available to all women entrepreneurs (Kuran & Khabbaz, 2025), especially in domains that require advanced technological skills (Kang, 2022). According to Kong et al. (2024) there are gender-differentiated effects in accessing and benefiting from these platforms, which could perpetuate existing inequalities. Also, cultural constraints and physical mobility in certain regions of the world may influence women's adoption, use and exploitation of social networks for business purposes (Al-Boinin et al., 2025; Mishra et al., 2023), as well as limit the expansion of their businesses beyond the domestic environment (Steel, 2017).

On the other hand, rapid technological evolution requires constant adaptation by women entrepreneurs (Mack et al., 2017), maintaining high quality standards in competitive digital environments (Roy Dutta, 2025), and building and maintaining effective online social capital (Hammad & El Naggar, 2023), which can be a constant challenge, especially for inexperienced entrepreneurs (Hammad & El Naggar, 2023). In addition, reliance on social networks may limit the visibility of certain content due to algorithms and platform policies (Grubnic, 2023).

3.3.2 Thematic front 2: Financing

This front is composed of 20 papers that direct research towards the role of finance in female entrepreneurship. The papers focus on topics such as loans (Yadav et al., 2024), capital funds (Coleman et al., 2019), digital financial inclusion (Yang et al., 2022; Hasan et al., 2023; Shao et al., 2023; Liu et al., 2022), digital financial literacy (Desai et al., 2025; Peter et al., 2025), financial behavior (Peter et al., 2024), financial innovation (Anggraini et al., 2024), BigTech (Sun & Xie, 2024), FinTech (Guo et al., 2021), financial bootstrapping (Alhammadi & Rahman, 2025; Rita & Nastiti, 2024), digital microfinance (Kromidha et al., 2023; Wulandari & Hj. Kassim, 2024), crowdfunding (Xie et al., 2024; Wang et al., 2023; Wang et at., 2022) and mobile money (Islam & Muzi, 2022).

3.3.3 Thematic front 3: Coronavirus

This front consists of 11 articles that focuses its attention on the COVID-19 pandemic and how digitalization has impacted female entrepreneurs in different countries such as Pakistan (Mustafa et al., 2021), Turkey (Topcu et al., 2024), Indonesia (Nur Asrofi et al., 2023; Kusumawardhani et al., 2022), Saudi Arabia (Alhothali & Al-Dajani, 2022), India (Chakraborty & Garg, 2024), Bangladesh (Khondker & Pettinotti, 2024), Kosovo (Ibrahimi & Ibrahimi, 2024), or across countries (Sörensson & Ghannad, 2024; Ben Romdhane & Elamine, 2024; Torres et al., 2023).

3.3.4 Thematic front 4: Competitive advantage and internationalization

This front is formed by 9 articles addressing organizational and strategic aspects of female entrepreneurship. Specifically, the papers by Dalimunthe et al. (2025), Setyaningrum and Muafi (2022), Dalimunthe et al. (2024) and, Abdelhalee and Farah (2023) focus their attention on the development of competitive advantages. While Tanti et al. (2021), Steel (2021), Anggadwita and Indarti (2025), Pergelova et al. (2019) and, Mondal and Sinha (2025) analyze the internationalization of women-led firms.

3.3.5 Thematic front 5: Entrepreneurship ecosystems

This front brings together the articles by Kakeesh (2024), Mamabolo and Lekoko (2021), Xie et al. (2021), Huang et al. (2025) and Mouazen and Hernandez-Lara (2023). All these papers integrate entrepreneurial ecosystems in the analysis of female entrepreneurship and digitization.

3.3.6 Thematic front 6: Education

This front brings together the articles by Feng and Sumettikoon (2022), Molina-López et al. (2021), Flores-Bañuelos et al. (2023), Orser et al. (2019) and, Feng and Sumettikoon (2023). All these papers address the phenomenon of female entrepreneurship education.

3.3.7 Thematic front 7: Miscellaneous

Finally, in addition to the main themes, other less prominent topics have also attracted the attention of researchers studying female entrepreneurship and digitization. These include the possibility of developing digital social capital (Urban & Moetse, 2024; Ratten, 2024; Hammad & El Naggar, 2023), women-owned start-ups (Schillo & Ebrahimi, 2022; Swartz et al., 2022; Torres Mancera et al., 2023; Mets & Vettik-Leemet, 2024), artificial intelligence (Kuran & Khabbaz, 2025; Rožman & Tominc, 2024), e-commerce (Setyaningrum & Muafi, 2023; Hasan et al., 2022; Harini et al., 2025; Yu & Cui, 2019), business performance (Hashim et al., 2024; Huang et al., 2025; Hadiyati et al., 2024) sustainability (Kimuli et al., 2022; Belas et al., 2025) or the role of institutions in female entrepreneurship (Sarpong et al., 2022; Althalathini & Tlaiss, 2023; Johnson & Mehta, 2024; McAdam et al., 2019; Jiao et al., 2022).

Although artificial intelligence (AI) plays an increasingly important role in business and management, it remains largely absent from the literature on female entrepreneurship. Only two articles in the dataset explore the potential impact of AI on female entrepreneurship (Rožman & Tominc, 2024; Kuran & Khabbaz, 2025).

4 Conclusions

The present study performs a bibliometric review and content analysis, identifying seven thematic fronts in the literature on female entrepreneurship and digitization: (1) social media, (2) financing, (3) COVID-19, (4) competitive advantage and internationalization, (5) entrepreneurship ecosystems, (6) education, and (7) miscellaneous. The content analysis has allowed us to structure the opportunities and challenges faced by female entrepreneurs across the different thematic areas.

5 Ethics declaration

The authors did not require ethical clearance for the development of the work.

6 AI declaration

The authors did not use artificial intelligence tools for the development of the work.

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Digital Transformation and Gender Equality in Public Administration: An Analysis of NRRP Policies and Implementation

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Abstract

Digital transformation is reshaping how public administrations operate, with artificial intelligence and emerging technologies playing a growing role in the management and delivery of public services. The National Recovery and Resilience Plan (NRRP) offers a strategic opportunity to modernize the Italian Public Administration (PA) and to foster more equitable and inclusive access to digital resources. However, administrative digitalization alone does not automatically ensure the overcoming of gender disparities. Without deliberate inclusion strategies, technological innovations risk reinforcing existing inequalities. This study analyzes the extent to which the NRRP, specifically through Mission 1, Component 1 (M1C1), has integrated gender equity objectives into PA digitalization initiatives. Adopting a qualitative content analysis (QCA) approach, this research examines a sample of ten Public Calls for Proposals issued by the Presidency of the Council of Ministers – Department for Digital Transformation (PCM-DTD) portal and manually coded based on two analytical dimensions: (1) compliance with NRRP horizontal principles, and (2) adherence to EU legal obligations on gender equality. Special attention was paid to the use of gender-aware language, objectives, and evaluation mechanisms.

The analysis reveals that all ten calls formally acknowledge gender equality in line with the NRRP's horizontal principles. However, such references are typically generic and are not translated into concrete requirements or measurable criteria. The reviewed calls lack any form of operationalization, such as gender-disaggregated indicators or structured evaluation mechanisms. Furthermore, binding EU legal provisions on gender equality are merely mentioned, without detailed elaboration or integration into project evaluation frameworks. This superficial treatment limits the enforceability of equity commitments and reflects a broader institutional gap between legal mandates and their practical implementation in the digitalization of the public sector. This study offers a novel contribution to the literature on public sector innovation by introducing a gender-sensitive perspective into the analysis of digital transformation policies. It critically reflects on the risks of procedural formalism and emphasizes the need to embed gender equality principles more deeply into digital public investments. The findings provide actionable insights for policymakers aiming to leverage technological innovation as a true vector for social inclusion and equity. The study is limited by its qualitative nature and the small sample size focused solely on Italian cases. Moreover, the analysis is restricted to document-based data without empirical validation through project outcomes or stakeholder feedback. Future research should integrate quantitative measures and fieldwork to assess the real-world impact of digital transformation initiatives on gender inclusion and explore comparative studies across different EU contexts.

Keywords: NRRP, Digital Transformation, Public Administration, Gender Equality, Public Funding, Inclusive Governance

Paper type: Academic Research Paper

1 Introduction

In the aftermath of the COVID-19 pandemic, Italy, in alignment with other European Union member states, embarked on an unprecedented effort of economic, social, and institutional revitalization through the formulation of the National Recovery and Resilience Plan (NRRP). The NRRP represents the Italian implementation of the broader Next Generation EU program, a temporary recovery instrument launched by the European Commission in 2020 to counteract the socio-economic consequences of the pandemic and to promote structural reforms toward a more sustainable and resilient European economy (Presidenza del Consiglio dei Ministri, 2025).

Valued at approximately €191.5 billion, the Italian NRRP is one of the most substantial plans among EU member states, structured around three overarching strategic axes: digitalization and innovation, ecological transition, and social inclusion (Presidenza del Consiglio dei Ministri, 2021). Its ambition is not limited to economic recovery but aims to reshape the developmental model of the country, addressing longstanding structural weaknesses such as low productivity, high youth and female unemployment, limited digitalization in both public and private sectors, and persistent regional inequalities (Consiglio dell'Unione Europea, 2021).

The NRRP articulates its objectives through six Missions, each representing a cluster of investment and reform interventions. Among these, Mission 1: Digitalization, Innovation, Competitiveness, Culture and Tourism occupies a central position, absorbing a significant share of the allocated resources (over €40 billion). Within this

Mission, Component 1 (M1C1) specifically targets the digital transformation of the Public Administration (PA). This includes investments in digital infrastructures, the promotion of interoperability and data sharing across public bodies, the strengthening of cybersecurity systems and digital identities, the adoption of emerging technologies such as artificial intelligence (AI), big data analytics, and blockchain solutions to improve public service delivery, and the implementation of open data initiatives to foster transparency and civic engagement (Presidenza del Consiglio dei Ministri, 2025).

The modernization of PA, thus, is conceived not merely as a technological upgrade but as a strategic transformation capable of generating broader socio-economic benefits, reducing administrative burdens, enhancing transparency and accountability, stimulating citizen participation, and supporting inclusive economic growth (Binder & Frankenhauser, 2024; Ray et al., 2025).

Nonetheless, it is now widely recognized that digital transformation processes are not inherently neutral. As recent research highlights, if technological innovation is pursued without explicit attention to inclusion dynamics, it risks amplifying existing social divides rather than bridging them (UNDP & University of Pittsburgh, 2021; OECD, 2023). Digitalization can create new forms of exclusion, particularly disadvantaging social groups historically underrepresented in the digital economy, including women, youth, and marginalized communities.

Gender disparities emerge as a persistent challenge: women remain underrepresented in leadership positions within public administrations, face gaps in digital literacy and access to technological resources and encounter systemic barriers to participating fully in innovation-driven sectors (Paoloni & Demartini, 2016; EIGE, 2020). Without proactive corrective measures, the digital revolution within the PA could therefore replicate or even exacerbate structural gender inequalities, rather than mitigating them. In this perspective, the NRRP should not be viewed solely as a catalyst for technological advancement, but also as a strategic lever to promote gender equality and foster more inclusive models of governance. Integrating a gender-sensitive perspective into digitalization policies is crucial to ensure that public innovation serves as a vector for equity, social cohesion, and empowerment (OECD, 2023; UNIDO, 2025).

However, despite this transformative potential, an initial review of the available literature suggests that the degree to which gender objectives have been concretely embedded within NRRP-funded digitalization initiatives remains limited and fragmented. Academic and policy-oriented analyses have predominantly focused on aspects such as process efficiency, technological advancement, and organizational innovation (Sørensen & Torfing, 2011; Bencivenga et al., 2021), whereas the equity dimension, particularly with regard to gender inclusion, has received scarce and marginal attention (Paoloni et al., 2023). To address this research gap, this study poses the following question:

- *RQ: To what extent has the NRRP integrated gender equity objectives within the digital transformation initiatives of the Italian Public Administration?*

This study employs a qualitative content analysis methodology, focusing on Component 1 of Mission 1 (M1C1) of the NRRP. Specifically, it examines a sample of ten Public Call for Proposals published by the Presidency of the Council of Ministers – Department for Digital Transformation (PCM-DTD). By systematically analyzing references to gender inclusion, the research investigates how digital innovation projects address or overlook the promotion of women's participation and leadership in the public sector.

Preliminary findings suggest that while gender equality is consistently referenced as a guiding principle within the analyzed funding calls, these references are not accompanied by concrete mechanisms such as evaluative criteria, measurable indicators, or enforceable obligations. This limited operationalization signals a superficial integration of gender equity goals and may constrain the potential of digital transformation to support truly inclusive and equitable public governance. The theoretical contribution of this research lies in enriching the debate on public sector innovation by introducing a gender-sensitive lens. Practically, the findings provide actionable insights for policymakers and public managers committed to ensuring that the digital revolution in government translates into a more inclusive, diverse, and equitable public administration.

The study acknowledges several limitations, primarily related to the qualitative nature of the analysis and the exclusive reliance on document-based data. Future research should complement these findings with quantitative assessments and stakeholder interviews to capture the real-world impact of digital inclusion policies.

The paper is structured as follows: Section 2 reviews the relevant literature on digital transformation, public governance, and gender equity. Section 3 outlines the research methodology. Section 4 presents the findings of the analysis. Section 5 discusses the implications and contributions of the study. Section 6 highlights the limitations and proposes directions for future research.

2 Literature Review

The digital transformation of public administration (PA) is widely regarded as a strategic lever for enhancing efficiency, transparency, and accessibility in public service delivery. However, this transformation is not inherently gender-neutral. If not carefully designed and implemented, digitalization processes may inadvertently reinforce existing structural inequalities, particularly those related to gender.

The Organization for Economic Co-operation and Development (OECD) stresses that while digital transformation presents new opportunities for women's empowerment and economic participation, systemic challenges such as socio-cultural barriers, stereotyping, and discrimination continue to hinder equitable access and inclusion (OECD, 2023). Similarly, the United Nations Development Programme (UNDP) underscores the necessity of inclusive digital strategies that are co-designed with women and marginalized groups, emphasizing the need for gender-responsive approaches to digital literacy, access, and governance (UNDP & University of Pittsburgh, 2021).

Digital Public Infrastructure (DPI) has emerged as a promising tool for promoting inclusive public services, enabling real-time access to administrative processes and reducing transactional costs for citizens. However, if DPI is not intentionally designed to address digital gender gaps, such as unequal access to connectivity, devices, or digital skills, it risks excluding women and exacerbating existing forms of marginalization (Binder & Frankenhauser, 2024).

The European Institute for Gender Equality (EIGE) reports that women continue to be underrepresented in digital employment and innovation fields, and that significant disparities persist in digital skills acquisition and participation in STEM education. Its 2020 Gender Equality Index notes that without direct action to mitigate such disparities, digitalization could further disadvantage women in the future labor market (EIGE, 2020).

UN Women further argues that structural gender inequalities in access to technology, finance, and decision-making power must be systematically addressed in all phases of digital governance. Without this integration, digital transformation could consolidate male-dominated power structures and perpetuate inequalities in access to innovation resources, leadership opportunities, and public visibility (UN Women, 2024). Recent academic literature has also examined the intersection between emerging technologies and gender equality, pointing out both the opportunities and the risks posed by artificial intelligence (AI), big data, and algorithmic decision-making in public administration. While AI can optimize workflows and enhance evidence-based decision-making, it can also replicate and scale gender biases embedded in training data or system design. For this reason, the implementation of AI in the public sector must be accompanied by critical audits, inclusive data governance, and gender-aware algorithmic transparency (Nwafor et al., 2025).

The World Bank highlights the importance of closing gender gaps in digital development by investing in digital inclusion strategies, targeted training for women and girls, and metrics to evaluate progress toward gender equity in digital policy. According to the 2023 report, without institutional accountability, well-intentioned digital reforms may fail to yield equitable outcomes (World Bank, 2023).

In parallel, the literature on public finance and gender equality stresses the relevance of integrating gender perspectives in budgetary processes. Gender-responsive budgeting has become a widely adopted tool among OECD countries, supported by methodological frameworks that link resource allocation with the promotion of gender equity goals (OECD, 2023). A 2025 European Parliament briefing confirms that several Member States have incorporated gender impact assessments into their national recovery plans, yet challenges remain in ensuring consistent application and evaluation (European Parliament, 2025). Despite these advances, implementation is often hindered by limited administrative capacity, particularly at the local level. Smaller public entities face difficulties in meeting complex reporting requirements and developing inclusive digital projects due to resource constraints (OECD, 2023).

This limits the effectiveness of equity-related measures and hampers broader participation.

Taken together, these contributions demonstrate that the digital transformation of PA must be grounded in equity-centered governance frameworks. It is not enough to adopt new technologies; policymakers must embed inclusive values into the design, implementation, and evaluation of digital public services to ensure that innovation becomes a tool for empowerment, not exclusion.

3 Methodology

This study adopts a qualitative content analysis (QCA) methodology to investigate the extent to which gender equity principles are integrated into digital transformation measures under the National Recovery and Resilience Plan (NRRP), with specific reference to Mission 1, Component 1 (M1C1). This component, managed by the Presidency of the Council of Ministers – Department for Digital Transformation (PCM-DTD), focuses on the modernization and digitalization of the Italian Public Administration (PA). The QCA approach is particularly well-

suited to examining regulatory and policy-oriented documents, as it enables the extraction, categorization, and interpretation of key references through a structured analytical framework (Elo & Kyngäs, 2008; Schreier, 2012).

The empirical analysis is based on a purposive sample of ten Public Call for Proposals retrieved from the official website of the PCM-DTD. These notices represent funding instruments through which M1C1 operationalizes its digitalization goals and allocates resources to implementing bodies. Each call is analyzed manually and coded according to two primary dimensions, which reflect the formal obligations and equity-related requirements imposed by the NRRP framework and EU law.

The first analytical dimension concerns the compliance of project implementation with the overarching principles of the NRRP. This includes alignment with horizontal criteria such as climate and digital tagging, youth empowerment, and gender equality. These elements are among the eligibility conditions required for funding applications and for public actors serving as implementing entities. Special attention is paid to whether gender equality is treated merely as a formal requirement or as a strategic objective embedded within project design and evaluation.

The second analytical dimension examines the duty of implementing bodies to respect gender equality in line with binding legal provisions. Specifically, this entails adherence to the principles enshrined in Articles 2 and 3(3) of the Treaty on European Union (TUE), Articles 8, 10, 19, and 157 of the Treaty on the Functioning of the European Union (TFEU), and Articles 21 and 23 of the Charter of Fundamental Rights of the European Union (European Union, 2016). These provisions collectively mandate the elimination of discrimination, the promotion of equal treatment in employment and decision-making, and the adoption of gender-sensitive governance practices across all public policies.

Special attention is given to the extent to which gender-aware language, objectives, and monitoring criteria are explicitly incorporated into funding calls and project evaluation mechanisms. Given the complexity and variability of these policies, a manual coding system was preferred over automated text-processing methods, as it allows for greater interpretative flexibility and ensures that semantic nuances related to gender policies are preserved (Mayring, 2014). By avoiding distortions often introduced by algorithmic text analysis, this approach enables a more accurate identification of critical gaps in gender reporting and compliance with equity principles (Schreier, 2012).

The coding process follows a deductive logic, grounded in preliminary document screening and informed by relevant EU and national regulations. The manual categorization allows for the identification of how gender equity is articulated within the funding criteria, evaluation frameworks, and implementation procedures of the selected announcements. This approach enables the detection of both explicit references to gender equality and implicit institutional mechanisms that may influence the inclusiveness of digital transformation projects (Schreier, 2012; Mayring, 2014).

Given the limited number of analyzed documents and the exploratory nature of the research, the study does not aim to provide generalizable conclusions. Instead, it offers a detailed and structured understanding of how gender equity is addressed in a sample of investment notices under M1C1. The results aim to contribute to ongoing policy discussions and scholarly debates on inclusive digital governance by highlighting gaps, good practices, and potential areas for regulatory and institutional improvement.

4 Findings

This section presents the results of the qualitative content analysis conducted on the ten public call for proposals published by the Presidency of the Council of Ministers – Department for Digital Transformation (PCM-DTD) under Mission 1, Component 1 (M1C1) of the NRRP.

Figure 1 illustrates the main features of the ten calls for proposals, highlighting the year of publication, financial allocation, and the extent to which gender equality references and operational indicators are present.

Public Call for Proposal	Year	Value (€)	References to Gender Equality	Operational Indicators
Reti Ultraveloci: Consultazione Piano 5G in mobilità - Copertura gallerie "Milano – Cortina 2026"	2025	12000000	Si	No
Migrazione al Polo Strategico Nazionale - Pubbliche Amministrazioni Centrali, Avviso PAC pilota ter	2025	300000000	Si	No
Mappatura delle reti fisse 2025: avviata la consultazione degli operatori	2025	Non specificato	Si	No
Reti Ultraveloci - Consultazione pubblica Piano "Rafforzamento reti di Backhaul"	2025	95000000	Si	No
Edge Cloud Computing - Avviso per Consorzi guidati da Università e Centri di Ricerca	2024	4000000	Si	No
Migrazione al Polo Strategico Nazionale - Pubbliche Amministrazioni Centrali, Avviso PAC pilota bis	2024	224700000	Si	No
Mobility as a Service for Italy - 7 territori	2023	16900000	Si	No
Migrazione al Polo Strategico Nazionale - Pubbliche Amministrazioni Centrali	2023	280000000	Si	No
Mobility as a Service for Italy - fondo complementare al PNRR	2022	16900000	Si	No
Mobility as a Service for Italy	2021	40000000	Si	No

Figure 1. Overview of NRRP M1C1 Public Calls for Proposals: Gender Equality References and Operationalization
Source: Author's elaboration based on data retrieved from the official website of the Department for Digital Transformation (PCM-DTD): https://innovazione.gov.it/dipartimento/avvisi-pubblici/

The findings are structured according to the two analytical dimensions introduced in the previous section: (1) compliance with NRRP horizontal principles, and (2) adherence to EU legal obligations on gender equality. This dual perspective enables a detailed assessment of both formal requirements and the substantive integration of gender equity considerations in digital transformation measures.

4.1 Compliance with NRRP Horizontal Principles

The first dimension of analysis examines the extent to which gender equality is embedded in the horizontal principles guiding NRRP-funded digitalization projects. All ten investment notices explicitly reference the need to align with the overarching values of the NRRP, including the digital and green transitions, youth empowerment, and gender equality. In most cases, compliance with these principles is treated as a formal eligibility criterion, whereby applicants are required to declare observance to national and EU priorities (Presidenza del Consiglio dei Ministri, 2025).

However, although all public calls formally refer to these principles, they are not translated into measurable indicators or specific project evaluation criteria. References to gender equality are included in standard templates or regulatory annexes, but they lack detailed guidance on implementation strategies or monitoring procedures (Neidig et al., 2024). For example, the announcements don't comprehend gender-disaggregated indicators, require specific gender equality actions, or assign evaluation points to projects with inclusive governance mechanisms. This limited articulation suggests a risk that gender equity may be addressed in form but not in substance.

Moreover, the generic phrasing implies that compliance is largely self-declared and not subject to independent verification. This approach raises concerns about the effectiveness of gender equality provisions in influencing project design and execution. The lack of standardized tools for assessing gender impact further limits the ability of implementing entities to incorporate meaningful equity measures.

4.2 Adherence to EU legal obligations on gender equality

The second analytical dimension examines the legal obligations stemming from the Treaty on European Union (TEU), the Treaty on the Functioning of the European Union (TFEU), and the Charter of Fundamental Rights of the European Union. Within the analyzed public calls for proposals, references to these normative frameworks are present but superficial and lack detailed articulation (European Union, 2016).

Specifically, among the formal obligations assigned to implementing entities is the requirement to "respect the principle of gender equality in relation to Articles 2 and 3(3) of the TEU, Articles 8, 10, 19, and 157 of the TFEU, and Articles 21 and 23 of the Charter of Fundamental Rights of the European Union."

Article 2 TUE establishes equality as one of the foundational values of the European Union. It calls for the respect of human rights and the principle of non-discrimination, laying the conceptual groundwork for gender equality in all EU actions. Article 3(3) TUE reinforces this by stating that the Union shall aim to promote equality between women and men in all its activities. These two articles frame gender equality not only as a legal requirement but also as a guiding political principle. The absence of direct references to these provisions in the investment notices indicates a disconnect between foundational EU commitments and their practical implementation in national funding mechanisms.

Article 8 TFEU provides the operationalization of this principle by requiring the Union to eliminate inequalities and promote equality between men and women in all its activities. This article is especially relevant in contexts of public investment, as it mandates the integration of gender equality objectives into the planning, implementation, and evaluation of EU-funded measures.

Article 10 TFEU complements this by calling for the combating of discrimination based on sex in all policies and activities. Neither of these articles is referenced in the analyzed announcements, nor are their implications concretely addressed in terms of funding criteria or expected project outputs.

Articles 19 and 157 TFEU introduce more specific obligations. Article 19 allows the Council to adopt measures to combat gender-based discrimination, which has led to the development of anti-discrimination directives at EU level. Article 157 is particularly significant as it establishes the principle of equal pay for equal work and authorizes the adoption of positive actions to ensure full equality in practice. The exclusion of these legal foundations in the text of investment notices suggests that the NRRP's implementation architecture may overlook essential regulatory tools that could strengthen gender accountability. Turning to the Charter of Fundamental Rights of the European Union, Article 21 prohibits any discrimination based on sex, while Article 23 explicitly mandates equality between women and men in all areas, including employment and work. Importantly, this article also allows for the adoption of measures that provide specific advantages in favor of the underrepresented sex. These rights-based imperatives offer legal justification for incorporating gender-sensitive

evaluation criteria and corrective mechanisms into public funding programs (European Union, 2016). Yet, none of the analyzed public call for proposals provide a more in-depth analysis this rights-based approach.

While the notices require implementing bodies to comply with national and EU legislation, this obligation is stated in general terms and not connected to specific gender equality mandates. The lack of explicit integration of these legal norms indicates a gap between policy design and regulatory frameworks. This detachment could weaken institutional accountability and reduce the normative pressure on implementers to prioritize equity objectives (Bencivenga et al., 2021; Ray et al.,2025).

None of the announcements provide procedures for verifying compliance with gender-related legal standards, nor do they specify consequences for non-compliance. As a result, gender equality appears as a soft obligation acknowledged in principle but weakly institutionalized in practice.

Overall, the findings highlight a disjunction between formal declarations of commitment to gender equality and the operationalization of these commitments in funding and implementation mechanisms. The limited translation of both NRRP principles and EU legal norms into actionable criteria signals the need for stronger institutional tools, clearer guidance, and enhanced monitoring to ensure that digital transformation serves as a vehicle for inclusive governance.

5 Discussion and conclusion

This section addresses the research question: To what extent has the NRRP integrated gender equity objectives within the digital transformation initiatives of the Italian Public Administration?

The analysis conducted on the ten investment notices under Mission 1, Component 1 (M1C1) reveals a fragmented and superficial integration of gender equality principles into the implementation framework of the NRRP's digitalization measures. While all the notices formally reference the need to comply with the NRRP's overarching principles, including gender equality, these references are predominantly declarative, lacking concrete operationalization through project criteria, evaluation frameworks, or monitoring mechanisms.

The findings show that compliance with gender equality objectives often remains at the level of self-declaration, without substantive mechanisms to verify or incentivize inclusive practices. In line with the literature (UNDP & University of Pittsburgh, 2021; OECD, 2023; World Bank, 2023), this reflects a broader challenge in digital governance reforms, where formal commitments to inclusion are not consistently translated into concrete implementation tools. Similarly, as highlighted by EIGE (2020) and UN Women (2024), structural gender gaps in digital skills, leadership, and participation persist and require proactive corrective measures that are largely absent in the analyzed notices.

From a legal perspective, the absence of explicit references to binding EU provisions, such as Articles 2 and 3(3) TUE, Articles 8, 10, 19, and 157 TFEU, and Articles 21 and 23 of the Charter, suggests a detachment between the normative foundations of EU gender equality governance and the practical design of NRRP-funded initiatives (European Union, 2016). As noted in the literature (European Parliament, 2025), effective mainstreaming of gender equality requires not only rhetorical commitment but also the integration of legal obligations into operational documents and funding instruments.

Moreover, the lack of gender-aware language, objectives, and monitoring criteria, as identified through manual content analysis, confirms the risks associated with procedural compliance devoid of substantive engagement with equity goals (Schreier, 2012). Projects are encouraged to "consider" gender equality but are rarely evaluated on their ability to promote it meaningfully, missing the opportunity to leverage digital transformation as a catalyst for inclusive governance (Neidig et al., 2024).

Overall, while the NRRP and M1C1 theoretically recognize the importance of gender equality within digital transformation, the practical implementation through public investment notices is characterized by a formalistic approach that limits the transformative potential envisioned in policy frameworks (Bencivenga et al., 2021). This gap between intent and action underscores the need for stronger institutional mechanisms, mandatory gender impact assessments, and more explicit conditionalities linked to funding allocations.

In conclusion, the integration of gender equity objectives within the digital transformation initiatives of the Italian Public Administration under the NRRP remains partial and insufficient.

Figure 2 summarizes the conceptual translation from policy frameworks to implementation and observed outcomes, highlighting the main gaps and areas for improvement identified in the analysis.

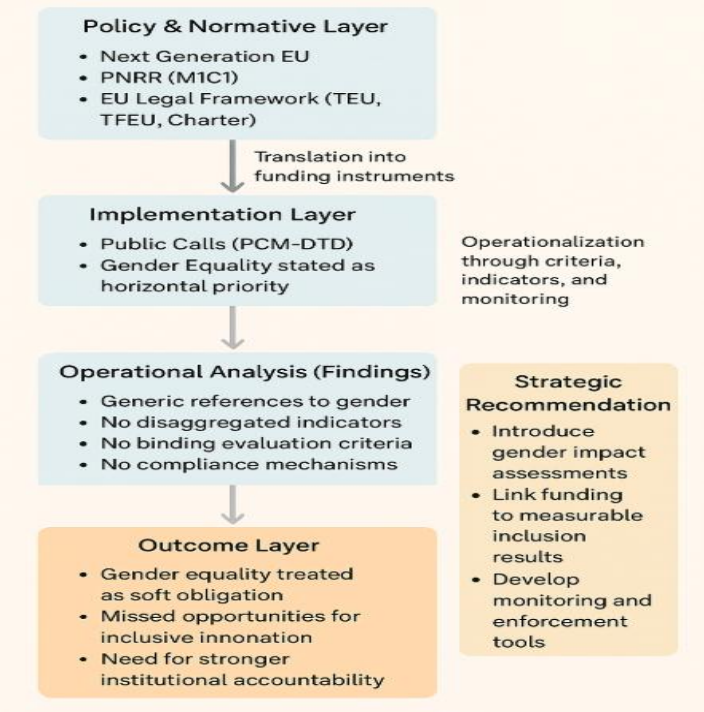


Figure 2. From Formal Commitments to Operational Gaps: a Gender-Sensitive Framework for PA digitalization
Source: author

A genuine commitment to inclusive digital governance requires moving beyond formal declarations towards embedding gender-sensitive criteria into every stage of project design, evaluation, and monitoring, thereby ensuring that innovation becomes a true driver of social equity rather than a reinforcement of existing disparities (Nelson & Piatak, 2021).

6 Limitations and future research lines

This study presents important findings regarding the integration of gender equity objectives within the digital transformation initiatives of the Italian Public Administration under the NRRP. However, several limitations must be acknowledged that affect the scope and generalizability of the results.

First, the analysis is based on a qualitative methodology and relies on a limited sample of ten public investment notices. Although purposively selected to reflect a relevant portion of Mission 1, Component 1 (M1C1), the sample may not capture the full diversity of measures implemented across different sectors and regions. Therefore, caution should be exercised in extending these findings to the entire NRRP framework. Second, the study focuses exclusively on document-based analysis without incorporating primary data from stakeholders, such as policymakers, project implementers, or beneficiaries. As a result, the analysis cannot assess the practical enforcement of gender equality obligations during project implementation or the real-world outcomes achieved through funded initiatives.

Third, the coding and interpretation processes, although systematically conducted, remain subject to inherent limitations of manual qualitative analysis, including the risk of subjective bias in categorizing and evaluating textual content. Efforts were made to ensure rigor and transparency; nonetheless, these methodological constraints should be recognized.

Future research could address these limitations by adopting a mixed-methods approach that combines content analysis with empirical investigations. For instance, future studies could integrate interviews, surveys, and case studies to gain deeper insights into the practical implementation of gender equality principles at the project level. Quantitative evaluations measuring actual gender-related outcomes in funded projects would also provide valuable evidence to complement the qualitative findings.

Moreover, comparative analyses across different EU member states could enhance understanding of how national contexts influence the integration of gender equality in NRRP-funded digital transformation initiatives. Such comparisons could identify best practices and inform the development of standardized guidelines for inclusive public investment strategies.

Finally, future research could explore the role of capacity-building programs, technical assistance, and monitoring mechanisms in strengthening gender mainstreaming in public administration reforms. Investigating how smaller municipalities and resource-constrained entities engage with gender equality obligations would be particularly relevant to ensure that digital transformation benefits are distributed equitably across all segments of society.

By addressing these future research lines, scholars and policymakers can contribute to advancing a more effective and inclusive approach to public sector innovation under major recovery and resilience frameworks.

7 Ethics declaration

This research did not involve any human participants, personal data, or experiments requiring ethical oversight. Therefore, ethical approval was not required.

8 AI declaration

No generative artificial intelligence tools were used in the writing, editing, or content creation of this manuscript.

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Industrial Districts and Women-Led SMEs: A Literature Analysis

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Abstract

The aim of this work is to investigate how the academic literature has addressed the relationship between industrial districts and female entrepreneurship. This relationship is particularly relevant since industrial districts are widely recognized as dynamic environments that foster innovation and business growth, especially for small and medium-sized enterprises (SMEs). The review seeks to identify the main areas of analysis that have emerged in recent years and to explore future research directions related to the role of territorial ecosystems in supporting women-led SMEs.

This study adopts a structured literature review (SLR) methodology to systematically analyze the scientific contributions published between 2008 and 2025. The review was conducted using the SCOPUS database. Each contribution was manually classified according to three dimensions: research focus, methodology used, and geographical area of the authors. This analytical framework allowed for the identification of recurring patterns and theoretical gaps.

The findings reveal that most studies focus on the structural and cultural barriers that female entrepreneurs face, even within cooperative environments such as industrial districts. These include limited access to credit, gender stereotypes, family responsibilities and weak support networks. A smaller body of literature highlights the strategic role of women's human capital, including leadership, training, and innovation capacity, in enhancing the competitiveness of district-based SMEs. Only a few studies explicitly explore how industrial districts can act as enabling ecosystems for female entrepreneurship. From a methodological standpoint, the literature is dominated by quantitative research, while qualitative studies remain limited but offer valuable insights into personal experiences and informal networks. In terms of geographical distribution, most contributions come from Asia and Southern Europe, reflecting both emerging interest in inclusive entrepreneurship and the historical importance of district models in countries such as Italy and Spain.

This study contributes to the literature by providing a comprehensive and up-to-date mapping of the intersection between industrial districts and female entrepreneurship. It highlights the need for more inclusive district governance and calls for future research using qualitative and mixed-method approaches to better understand the lived experiences of women entrepreneurs and the real impact of local production systems.

Keywords: Female entrepreneurship, Industrial districts, Gender and SMEs, Territorial ecosystems

Paper type: Academic Research Paper

1 Introduction

The structure of the Italian economy has long been characterized by the predominant presence of small and medium-sized enterprises (SMEs), which represent the driving force of the national economy (Paoloni, 2020). Despite their small size, Italian SMEs have distinguished themselves for their flexibility, adaptability and innovation capacity, largely enabled by their systemic behavior within clearly defined territorial aggregations known as "industrial districts" (Cortesi et al., 2004).

The Italian district system began to take shape in the 1950s and 1960s, in response to the needs of a rapidly changing economy. During the 1970s, with the spread of production technologies and the expansion of export markets, districts assumed a strategic role in reviving the Italian economy (Solinas and Baroni, 2001).

The geographical proximity of firms, their specialization in specific stages of the same production process, the mutual sharing of resources, skills and technologies, informal exchanges of information and knowledge transfer are all factors that enabled SMEs to overcome the limits of production scale, achieving economies of scale and competitive advantages comparable to those of larger firms (Markusen, 1996; Romero-Martinez and Montoro-Sanchez, 2008; Carpio, 2020; Kayanan et al., 2022).

The evolution of Italian industrial districts has provided the structural foundation for the emergence and consolidation of the Made in Italy phenomenon (Belfanti, 2019). Thanks to the aggregation of SMEs — capable of combining artisanal tradition with innovative production processes — a globally recognized brand of excellence has emerged, especially in key sectors such as fashion, furniture and design and agri-food. ISTAT data confirm that the district model accounts for over 25% of the national production system, making it a fundamental component of the Italian economy.

Over time, the district model has become one of the pillars of the Italian economic system, significantly contributing to regional development, employment growth and the strengthening of Made in Italy competitiveness (Minini, 2023). Its gradual evolution has demonstrated its effectiveness as a growth strategy

for SMEs, which benefit from a favorable ecosystem characterized by easy access to skilled labor, a network of specialized suppliers, and widespread technological innovation (Pyke et al., 1990).

Geographical proximity encourages constant interaction and the creation of economic relationships based on both cooperation and competition. These dynamics of cooperation and competition translate into a greater capacity for innovation: the industrial district serves as a highly innovative environment and a process accelerator that stimulates the adoption of new technologies, even among small businesses (Staber, 1998; Cortesi et al., 2004).

The systemic behavior of firms and their functional specialization lead to high productive efficiency: each firm focuses on a specific stage of the process, while the district as a whole operates as an integrated system, capable of quickly responding to changes in demand and the challenges of global markets (Becattini, 1987; Becattini, 1990).

In this context, relational capital plays a crucial role (Paoloni, 2011; Paoloni, 2020): district SMEs benefit from an environment where mutual trust and cooperation foster the exchange of knowledge, information and ideas, facilitate access to new business opportunities, and reduce transaction costs. This model allows small firms to survive and thrive even in highly competitive contexts, where isolated entities would struggle due to their limited size (Bucci et al., 2011).

Despite the dynamic and innovative nature of industrial districts, in recent years the firms within them have had to face the challenges posed by an increasingly globalized and fast-changing market. The growing complexity of the economic landscape has forced SMEs to rapidly adapt to new technologies and adopt more flexible and innovative business models. The use of advanced technologies has become a key factor in the growth and competitiveness of SMEs, which must compete with increasingly digitalized global actors (Hoffmann et al., 2023). Digital integration not only helps optimize internal processes but also improves business flexibility in responding to a dynamic and fragmented market (Pagano, 2020; Bettiol et al., 2021; Burlina & Montresor, 2022).

However, many Italian firms still exhibit a certain resistance to change, hindered by structural and financial constraints (Dei Ottati, 2018; Di Giacinto et al., 2023). Weak financial planning and low capitalization are significant limitations (Dessy, 1995; Paoloni, 2020; Modaffari, 2024). SMEs tend to finance their investments mainly through internal resources and short-term bank loans, limiting their ability to implement long-term growth strategies. Frequent reliance on credit leads to a vicious cycle: firms are forced to continuously renew credit lines in the short term, delaying or abandoning strategic investments and thus reducing growth opportunities (Giacosa, 2015; Balloni, 2000). These fragilities make them particularly vulnerable to economic shocks (Giacosa & Mazzoleni, 2016; Modaffari, 2024).

Recent crises have further exacerbated these difficulties, leading to a contraction in credit supply and reduced access to external funding.

Access to credit and innovation resources is even more limited for women-led SMEs. Female entrepreneurs face structural, cultural, and financial barriers that constrain their growth and innovation potential (Roy & Patro, 2022). Female entrepreneurship is often characterized by smaller relational networks and a stronger emphasis on work-life balance, factors that influence access to finance and development strategies (Paoloni, 2011).

One of the main issues is credit access: on average, women are less likely than men to obtain funding (Son et al., 2019; Ghosh & Vinod, 2017) and, when successful, often face less favorable terms (Roy & Patro, 2022). These disparities are linked to various factors, including lower availability of asset guarantees and limited familiarity with available financial instruments. Moreover, several studies highlight a greater risk aversion among women entrepreneurs, who tend to avoid bank loans and prefer to rely on personal resources or informal lending (Stefani & Vacca, 2013). While these tools may offer short-term solutions, they hinder the ability to make strategic investments in innovation and development, ultimately slowing down business growth (Paoloni, 2024).

It is worth noting that access to credit is not just an economic issue but also a cultural one: women entrepreneurs often struggle to balance family and professional responsibilities, which significantly affects their financial and strategic decisions (Poggesi et al., 2017). This need for balance leads to more cautious investment strategies and lower willingness to incur debt, driven by concerns that excessive financial exposure could compromise stability (Paoloni & De Martini, 2016). These dynamics significantly reduce women-led businesses' access to credit and limit their development potential.

While SMEs face numerous challenges in innovation and growth, the role of the district context in facilitating this transition should not be overlooked. Belonging to an industrial district may represent a strategic lever to mitigate some of the structural and financial weaknesses of the national production system.

This perspective becomes especially relevant when applied to women-led SMEs, which face additional barriers related to credit access, risk tolerance and work-life reconciliation.

Academic literature has begun to explore this possible correlation, highlighting both the opportunities offered by districts and the limitations of a model that, in some cases, struggles to innovate.

Based on these premises, it is essential to deepen the academic debate on the role of industrial districts in the development of SMEs — particularly women-led ones — in order to understand whether and to what extent the district model can offer a competitive advantage in today's transformative landscape.

To this end, the present study aims to analyze how the literature has evolved over recent decades, what research areas have been explored, what key themes have emerged, and what gaps remain. Using the methodology of a Structured Literature Review (SLR) (Guthrie et al., 2012; Dumay, 2014; Massaro et al., 2016; Paoloni & Demartini, 2016) and following the relevant protocol, this paper seeks to answer the following research questions:

- *RQ1. What are the main areas of analysis in the existing literature on female entrepreneurship in industrial districts?*
- *RQ2. What are the possible future research directions?*

The structure of the paper is as follows. Section 2 outlines the methodology adopted for the structured literature review. Section 3 presents the main findings of the analysis. Section 4 discusses and interprets the results in light of the existing academic debate. Section 5 provides concluding reflections and proposes possible future research developments. Finally, the last section highlights the study's limitations, its added value, and the originality of the research.

2 Research methodology

This analysis was conducted using the qualitative methodology of the Structured Literature Review (SLR), which is considered particularly suitable for systematically mapping the existing scientific landscape within a well-defined thematic area (Guthrie & Murthy, 2009; Guthrie et al., 2012; Dumay, 2014; Paoloni & Demartini, 2016; Massaro et al., 2016). This approach enables an in-depth examination of a large and complex set of academic contributions, with the aim of identifying recurring patterns, theoretical gaps and future research directions. In line with the objective of this study, the SLR proves to be an appropriate methodology for providing a structured and critical overview of the available evidence.

The SCOPUS database — widely recognized as one of the most comprehensive bibliographic sources at the international level (De Moya-Anegón et al., 2007) — was used for the retrieval of scientific contributions.

The search was carried out on April 29 2025.

The search strategy was built around a carefully selected set of keywords designed to capture publications relevant to the topic under investigation. The query used was as follows:

(("industrial district" OR "cluster" OR "regional economy") AND ("female entrepreneur" OR "women entrepreneur*" OR "gender and entrepreneurship"))*.

To increase the relevance of the results, the analysis was restricted to the fields "Article title," "Abstract," and "Keywords." This initial search returned a total of 98 documents.

Subsequently, only documents falling within the disciplinary areas of "Business, Management and Accounting" and "Economics, Econometrics and Finance" were retained, in accordance with the managerial and economic nature of the study (Massaro et al., 2016). This step reduced the sample to 73 documents.

Only fully published contributions, specifically "Articles", "Book" and "Book Chapters", were included in the final analysis. This step reduced the sample to 58 documents.

Additionally, to avoid issues related to linguistic comprehension (Mauro et al., 2017), only works published in English were considered.

At the end of this process, the final sample suitable for the SLR consisted of 49 documents.

The entire selection and filtering process is illustrated in Figure 1.

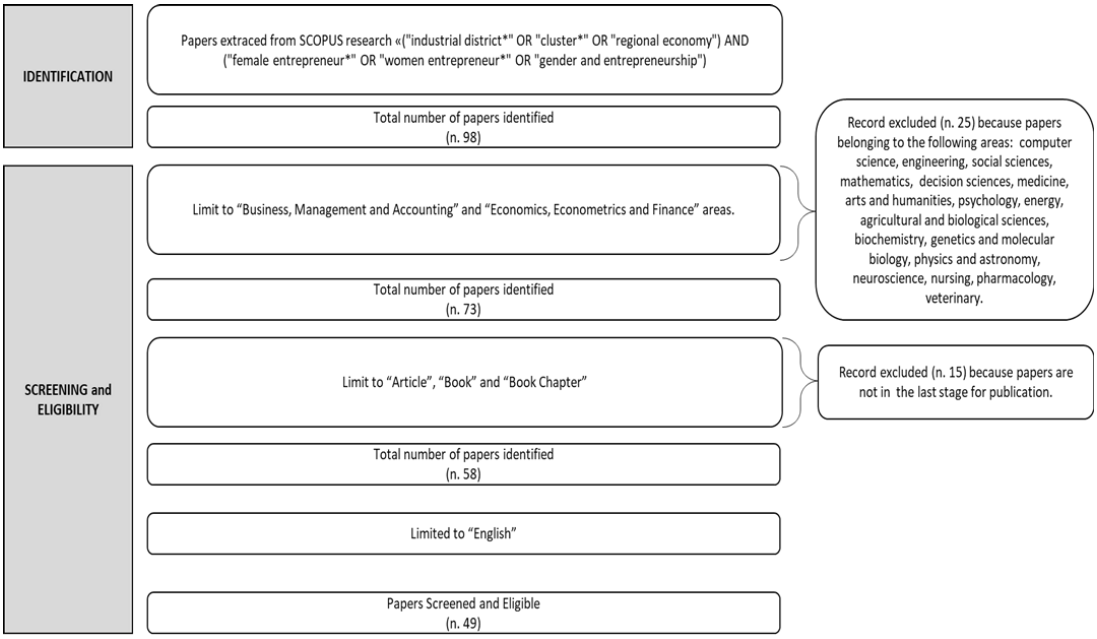


Figure 1: The procedure for selecting the eligible papers

2.1 Definition of the analytical framework

To conduct the Structured Literature Review (SLR), the authors carried out an in-depth examination of the title, abstract and keywords of each article included in the selected sample. This preliminary analysis enabled the development of an analytical framework designed to identify distinct units of analysis within each contribution, in line with the research objectives (Yin, 2014). The framework is structured around three main dimensions: the research focus, the methodology employed and the geographical area of reference, as illustrated in Table 1.

Regarding the Article Focus (A), the classification of the articles was performed manually to identify the main themes addressed by each study. The aim of this categorization was to assign each article to a specific macro-category, allowing for a clearer overview of the existing literature and the identification of insights to answer the research questions.

Three main recurring article foci were identified — along with one residual category — which represent the primary thematic directions in the literature:

- *A1. The role of industrial districts in the development of female entrepreneurship*: this category includes studies that examine the positive influence of industrial districts, clusters, and territorial networks on women-led businesses, highlighting benefits in terms of innovation, access to resources, collaboration, and integration into local markets;
- *A2. Gender barriers in industrial district contexts*: this group comprises contributions that show how, even within productive districts, female entrepreneurs face obstacles related to cultural stereotypes, limited access to credit, marginalization within local networks, or insufficient support for work-life balance;
- *A3. Entrepreneurial skills and female human capital in industrial districts*: this category gathers studies that highlight the value of women's hard and soft skills, training, resilience, and relational networks, considered key levers for the success and sustainability of their businesses;
- *A4. Other*: a residual category that includes studies dealing with female entrepreneurship from broader or alternative perspectives, which do not clearly fit into the three main categories mentioned above.

As for the Research Method (B), five types were identified:

- *B1. Literature analysis*: contributions consisting of systematic or narrative reviews of the existing literature on the topic;
- *B2. Qualitative research*: studies employing methods such as case studies, interviews, focus groups, observations, or content analysis;
- *B3. Quantitative research*: research based on statistical tools, using data collected through surveys, structured databases, or other numerical sources;
- *B4. Research mix*: studies combining both qualitative and quantitative approaches;

- *B5. Other*: a residual category including works that adopt methods not clearly attributable to the previous classifications.

Concerning the Geographical Area (C), the authors recorded the institutional affiliation country of each article's authors to understand the territorial distribution of the scientific production.

Once the methodological protocol was defined, the detailed analysis of the selected contributions was carried out in accordance with the criteria established for the SLR.

Table 1: Literature review of analytical framework

A. ARTICLE FOCUS	B. RESEARCH METHOD
A1. The Role of Industrial Districts in the Development of Female Entrepreneurship	B1. Literature analysis
A2. Gender Barriers in Industrial District Contexts	B2. Qualitative research
A3. Entrepreneurial Skills and Female Human Capital in Industrial Districts	B3. Quantitative research
A4. Other	B4. Research mix
	B5. Other

C. GEOGRAPHICAL AREA	
C1. East Europe	Hungary, Russia, Slovenia, Romania, Lithuania, Croatia, Serbia, Macedonia
C2. Middle East	Israel, Lebanon, United Arab Emirates, Jordan, Saudi Arabia, Iran, Iraq, Oman, Kuwait
C3. South and Central America	Argentine, Dominican Republic, Brazil, Jamaica, Mexico, Chile
C4. North America	USA and Canada
C5. Northern Europe	Austria, Belgium, Denmark, Ireland, France, Germany, Netherlands, Scandinavian countries, Switzerland, Poland, Czech Republic, Slovakia
C6. Southern Europe	Italy, Spain, Portugal, Greece, Turkey
C7. Asia	China, Japan, Korea, Singapore, Sri Lanka, Malaysia, Pakistan, India, Indonesia, Hong Kong, Thailand, Vietnam, Armenia, Nepal, Kazakhstan
C8. Africa	Tanzania, Uganda, Botswana, South Africa, Nigeria, Ethiopia, Zambia, Muritius
C9. UK	
C10. Oceania	Australia, New Zealand
C11. Mixed	

3 Results

3.1 Research focus

After analyzing the titles, abstracts, and keywords of each contribution included in the SLR, every document was assigned to one of the four identified thematic areas. Table 2 presents the results of the analysis for the period 2008–2025. The most recurring theme was A2 (Gender barriers in industrial district contexts), with 26 out of 49 studies (53%), indicating a strong interest in the structural, cultural, and institutional barriers that hinder the emergence and growth of women-led enterprises. This was followed by contributions categorized under A3 (Entrepreneurial skills and female human capital in industrial districts) with 15 articles (29%), and A1 (The role of industrial districts in the development of female entrepreneurship) with 7 studies (16%). Only one article was classified under A4 (Other). Figure 2 illustrates the evolution of these four research foci across the years from 2008 to 2025.

Table 2: Article focus of eligible papers divided by year of publication

A - Article Focus					
Year	A1	A2	A3	A4	Total by year
2008	1	0	0	0	1
2009	0	1	1	0	2
2011	0	1	0	0	1
2012	0	2	0	0	2
2013	1	2	0	0	3
2014	0	2	0	0	2
2016	0	4	0	0	4
2017	1	1	0	0	2
2018	0	0	1	0	1
2019	0	0	2	0	2

A - Article Focus					
Year	A1	A2	A3	A4	Total by year
2020	0	0	1	0	1
2021	1	1	1	0	3
2022	1	5	1	1	8
2023	1	4	4	0	9
2024	1	1	3	0	5
2025	0	2	1	0	3
Total by focus	**7**	**26**	**15**	**1**	**49**
%	**14%**	**53%**	**31%**	**2%**	

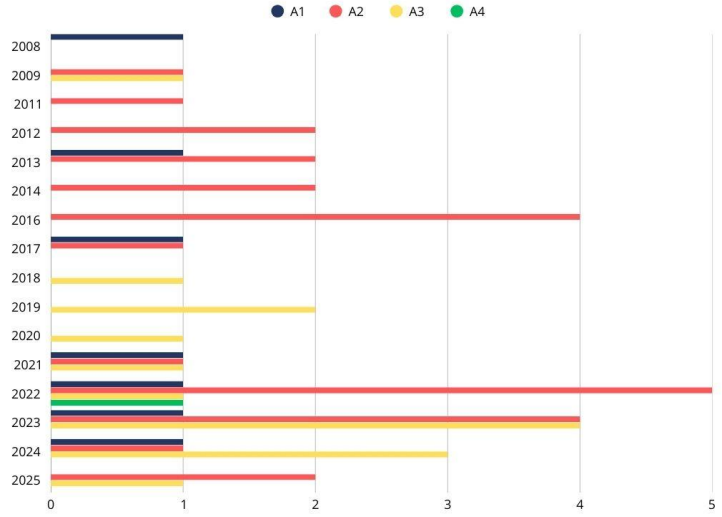


Figure 2: Time series articles focus evolution

3.2 Research method

Regarding the research methodology adopted, the majority of studies are based on a quantitative approach (B3), used in 25 contributions (51%). This is followed by qualitative research (B2), applied in 8 studies (16%), and literature analysis (B1), employed in 7 cases (14%). A smaller number of articles (4, equal to 8%) combine both qualitative and quantitative methods and were categorized under mixed-method research (B4). Finally, 5 articles (10%) were classified as Other (B5), as they rely on methodologies that are either not clearly identifiable or do not fit within the previous categories. Table 3 presents the results of the analysis for the period 2008–2025.

Table 3: Research method of eligible papers divided by year of publication

B - Research Method						
Year	B1	B2	B3	B4	B5	Total by year
2008	0	0	0	0	1	1
2009	0	1	1	0	0	2
2011	0	0	0	1	0	1
2012	0	0	1	0	1	2
2013	0	1	2	0	0	3
2014	0	0	2	0	0	2
2016	0	1	2	1	0	4
2017	0	1	1	0	0	2
2018	0	0	0	1	0	1
2019	0	0	2	0	0	2
2020	0	0	1	0	0	1
2021	1	0	2	0	0	3
2022	2	1	2	1	2	8
2023	3	0	5	0	1	9
2024	1	2	2	0	0	5
2025	0	1	2	0	0	3
Total by focus	**7**	**8**	**25**	**4**	**5**	**49**
%	**14%**	**16%**	**51%**	**8%**	**10%**	

3.3 Geographical area

With regard to the geographical affiliation of the authors, the most represented area is Asia (C7), accounting for 31% of the sample, followed by Southern Europe (C6) with 8 studies (16%). The Mixed category (C11), which includes contributions from authors affiliated with institutions in different countries, represents 18% of the total (9 articles). Other areas are less represented: Eastern Europe (C1) with 4 contributions (8%), the UK (C9) with 3 (6%), and individual studies from Africa (C8), the Middle East (C2), South and Central America (C3), and Northern Europe (C5). Finally, no contributions were found from North America or Oceania. Table 4 presents all the results.

Table 4: Representation of the geographical area of authors by year of publication

C - Geographical Area												
Year	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**Total by year**
2008	0	0	0	0	0	0	1	0	0	0	0	1
2009	0	0	0	1	0	0	1	0	0	0	0	2
2011	0	0	0	0	0	1	1	0	1	0	0	3
2012	0	0	0	0	0	0	0	0	0	0	0	0
2013	0	0	0	1	0	0	1	0	1	0	0	3
2014	0	0	0	0	0	0	1	0	1	0	0	2
2016	0	0	1	1	0	1	0	0	0	0	1	4
2017	0	0	0	1	0	1	0	0	0	0	0	2
2018	0	1	0	0	0	0	0	0	0	0	0	1
2019	0	0	0	0	0	0	0	1	0	0	1	2
2020	1	0	0	0	0	0	0	0	0	0	0	1
2021	0	0	0	0	0	1	1	0	0	0	1	3
2022	1	0	0	1	0	2	2	0	0	0	2	8
2023	1	0	0	0	0	1	5	0	0	0	2	9
2024	1	0	0	1	1	0	1	0	0	0	1	5
2025	0	0	0	0	0	1	1	0	0	0	1	3
Total by focus	**4**	**1**	**1**	**6**	**1**	**8**	**15**	**1**	**3**	**0**	**9**	**49**
%	**8%**	**2%**	**2%**	**12%**	**2%**	**16%**	**31%**	**2%**	**6%**	**0%**	**18%**	

4 Discussion

The analysis conducted provides a detailed picture of how the literature has addressed the topic of female entrepreneurship within industrial districts over the past two decades.

A first relevant element concerns the distribution of research foci. Most studies concentrate on the barriers faced by women entrepreneurs even within district contexts, which are generally seen as cooperative and inclusive environments (Gatewood et al., 2009; Haddad et al., 2016). This emphasis highlights how gender inequalities persist even in socio-economic settings considered favorable to entrepreneurial development (Machado et al., 2016). Difficulties in accessing credit, lack of institutional support, cultural stereotypes, and challenges related to work-life balance are recurrent issues (Mathew & Panchanatham, 2011; Mitchelmore & Rowley, 2013; Maseda et al., 2022). These challenges not only reflect broader structural dynamics but also suggest that industrial districts do not automatically foster inclusion.

Alongside this critical perspective, a smaller body of literature emphasizes the resources women bring to entrepreneurial ecosystems (Moreira et al., 2019; Vadnjal, 2020; Dalimunthe et al., 2023). These contributions highlight female human capital—such as managerial skills, leadership, and innovation capacity — as a strategic asset for SME competitiveness (Lee et al., 2024; Komp-Leukkunen, 2024). This approach shifts the focus from a problem-centered narrative to a more proactive vision, emphasizing the potential of women entrepreneurs when they operate in supportive environments and are backed by appropriate policies (Vadnjal, 2020; Sidik & Marikan, 2023).

From a methodological perspective, the majority of studies adopt a quantitative approach, using structured data and statistical tools. While this ensures analytical robustness, it may limit the ability to capture the complexity of gender dynamics in district contexts. Qualitative studies, though fewer, have provided valuable insights into lived experiences, informal networks, and cultural dimensions.

The geographical distribution of contributions also offers meaningful reflections. A significant portion of the analyzed literature comes from Asia, highlighting the growing interest of emerging economies in the role of women in business and territorial development processes (Mathew & Panchanatham, 2011). In many Asian countries, promoting female entrepreneurship has become a priority within broader strategies for social

inclusion and local economic empowerment (Hemalata et al., 2013; Banerjee & Desai, 2021). Southern Europe is also well represented, particularly through studies from Italy and Spain. This reflects the historical importance of industrial districts in these regions, where the territorial production model has significantly shaped the development of SMEs.

5 Conclusion and future perspectives

This literature review has made it possible to systematically reconstruct the current state of research on female entrepreneurship within industrial districts, offering valuable insights both in terms of synthesizing the main areas of analysis and identifying future research directions.

With reference to RQ1 (What are the main areas of analysis in the existing literature on female entrepreneurship in industrial districts?), three key thematic directions emerge from the analysis.

The most frequently addressed topic concerns the analysis of gender-related barriers that hinder women's access to and growth within industrial districts. This theme appears in over half of the reviewed contributions, confirming the growing academic attention to systemic inequalities that persist even in productive environments generally considered dynamic and cooperative (Mathew & Panchanatham, 2011; Mitchelmore & Rowley, 2013; Haddad et al., 2016). These barriers include cultural stereotypes, limited access to credit, unequal distribution of family responsibilities, and weak support networks. In many cases, districts fail to mitigate such obstacles and may even reproduce or amplify them, highlighting a structural lack of inclusivity (Gatewood et al., 2009; Maseda et al., 2022).

The second most explored area focuses on female human capital and entrepreneurial skills. In this perspective, women entrepreneurs are seen as bearers of strategic resources such as leadership, training, relational capabilities, and innovative vision (Vadnjal, 2020; Dalimunthe et al., 2023). The literature shows that these factors can represent a competitive advantage within district contexts, especially when supported by public policies and environments that foster female entrepreneurship (Sidik & Marikan, 2023; Lee et al., 2024). This strand of research helps to rebalance the debate by shifting the focus from challenges to opportunities.

Finally, a smaller set of studies analyzes the proactive role of industrial districts in supporting women-led entrepreneurship. In general, numerous contributions highlight how districts—thanks to their relational networks and shared resources — can provide favorable conditions for the creation and growth of businesses (Carpio, 2020; Kayanan et al., 2022). However, few of these studies explicitly refer to female entrepreneurship, suggesting the need for further investigation.

Regarding RQ2 (What are the possible areas for future research?), several potential directions can be hypothesized. First, future studies could further explore the relationship between industrial districts and female entrepreneurship, with a stronger focus on the actual impact of district membership on business performance. Additionally, it would be valuable to investigate the factors and enabling conditions that allow districts to become supportive ecosystems for women's empowerment—such as the presence of incubators, local public policies for credit access, or inclusive collaborative networks.

Lastly, there is a strong need to strengthen the methodological approach through case studies, interviews with female entrepreneurs, and surveys conducted within districts. These methods could provide deeper empirical evidence on women's lived experiences in local production systems—an aspect still underrepresented in current literature.

6 Limitations

This study presents some methodological limitations. The analysis was conducted manually, a choice that allowed for greater flexibility and cost-effectiveness, but also introduced a degree of subjectivity in the classification of contributions. To mitigate the risk of bias, the authors worked jointly in defining the categories. Moreover, the research was carried out using a single database (SCOPUS); the inclusion of other sources such as Web of Science or Google Scholar could enhance the coverage. Finally, since the classification was based on titles, keywords, and abstracts, some methodological or contextual information may have been overlooked, limiting the completeness of the categorization.

7 Ethics declaration

This research did not involve human participants, animals or sensitive data, and therefore did not require ethical approval.

8 AI declaration

No AI tools were used in the writing, analysis or creation of this paper.

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Investigating Digital Transformation and Business Model Innovation in Made in Italy Sectors

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Abstract

This study examines the intersection of digital transformation (DT) and business model innovation (BMI) within traditional "Made in Italy" sectors, such as Food & Wine, Fashion & Clothing, Home & Furnishings, and Automation. While these industries are renowned for their cultural heritage, they face the challenge of integrating digital technologies to remain competitive without losing their identity. The research explores how Italian firms in these sectors are navigating the balance between embracing digital innovation, particularly within the framework of Industry 5.0, and preserving traditional values. Industry 5.0, with its emphasis on human-centered innovation and sustainable practices, provides a lens through which to understand the evolving relationship between digital technologies and traditional craftsmanship. Through a qualitative multiple case study approach, this study aims to uncover how digital technologies, aligned with Industry 5.0 principles, are reshaping business models.

Keywords: Digital transformation, Business Model Innovation, Made in Italy, Industry 5.0

Paper type: Academic Research Paper

1 Introduction

In recent years, digitalization has become a key driver of societal and economic change (Grybauskas, Stefanini & Ghobakhloo, 2022). Accelerated by globalization and market volatility, firms increasingly view digital technologies as essential for resilience and competitiveness (Datta & Nwankpa, 2021). However, digital transformation (DT) is not merely technological; it represents a structural shift in how organizations create value and engage with their ecosystems (Stolterman & Fors, 2004; Shini et al., 2024). It fosters new forms of interaction between people, processes, and products, enabling innovation unconstrained by traditional resource limitations (McDonald & Rowsell-Jones, 2015).

Digital technologies are at the core of Industry 4.0, that encompasses a convergence of digital and physical systems, including artificial intelligence (AI), cloud computing, the Internet of Things (IoT), augmented reality (AR), and additive manufacturing (Tiraboschi & Seghezzi, 2016; Ustundag & Cevikcan, 2017). More recently, Industry 5.0 has emerged, emphasizing human-centric innovation and collaboration with intelligent systems (Skobelev & Borovik, 2017; Horvat, Jäger & Lerch, 2025).

In this context, DT is a powerful enabler of business model innovation (BMI), allowing firms to rethink the mechanisms through which they create, deliver, and capture value (Osterwalder & Pigneur, 2010; Demil & Lecocq, 2010).

Despite growing academic interest, empirical evidence on how DT unfolds in traditional, non-digital sectors remains limited. Much of the existing research has focused on digitally native or technology-intensive industries, leaving a gap in understanding how firms—particularly those embedded in established, physical industries—navigate digitalization and business model reconfiguration.

This study explores the intersection of DT and BMI in the "Made in Italy" sectors—specifically Food & Wine, Fashion, Home & Furnishings, and Automation (the 4A industries; Aiello et al., 2015). These sectors, rooted in artisanal values and cultural heritage (Fortis, 2005), now face the dual challenge of maintaining their identity while embracing innovation. It is within this tension—between innovation and tradition, between digital acceleration and heritage preservation—that this research finds its core motivation.

Through a qualitative multiple case study (Stake, 1995; Tellis, 1997; Yin, 2009), this research investigates how Italian firms in the 4A sectors adopt digital technologies to innovate their business models while preserving tradition. The central question guiding the study is: *How do traditional firms implement DT to enable BMI while maintaining their distinctive identity?*

By addressing this question, the study contributes to a broader understanding of how heritage-based industries can navigate DT within the Industry 5.0 paradigm, without compromising their cultural and competitive essence.

2 Theoretical background

2.1 Redefining industrial paradigms: the transition from Industry 4.0 to Industry 5.0

In manufacturing and industrial contexts, DT has materialized through Industry 4.0, characterized by the integration of cyber-physical systems, big data analytics, and intelligent automation to enhance efficiency and responsiveness (Tiraboschi & Seghezzi, 2016; Joensuu-Salo et al., 2018; Kamble, Gunasekaran & Gawankar, 2018). However, as sustainability concerns and societal expectations intensify, Industry 5.0 is emerging as a more human-centric paradigm. Rather than focusing solely on automation and productivity, Industry 5.0 emphasizes ethical, social, and environmental dimensions, promoting a more sustainable and inclusive model of innovation (Horvat, Jäger & Lerch, 2025; Rehman & Umar, 2025).

Three core perspectives illustrate the transformative nature of Industry 5.0. The first, rooted in EU frameworks, stresses social and environmental responsibility, advocating for sustainable practices and worker empowerment alongside economic performance (Miraz et al., 2022). The second emphasizes human-machine collaboration, particularly through collaborative robots (cobots), which enhances human creativity and enable more personalized production processes (Li et al., 2021; Nourmohammadi, Fathi, & Ng, 2022). The third perspective highlights the integration of ethical and user-centered intelligent technologies, advocating for transparency, inclusiveness, and responsible innovation (Aslam et al., 2020; Golovianko et al., 2023).

In sum, Industry 5.0 represents a paradigm shift toward innovation that balances technological advancement with human empowerment, social value, and environmental sustainability.

2.2 Understanding Business Model Innovation (BMI)

Business Model Innovation (BMI) refers to the intentional process by which organizations rethink, redesign, and reconfigure the underlying logic through which they create, deliver, and capture value (Osterwalder & Pigneur, 2010). This may involve a variety of changes, such as the introduction of novel revenue streams, the adaptation of value propositions to evolving customer needs, or the restructuring of internal operations and external partnerships. BMI can entail both incremental and radical transformations, but it is particularly impactful when it challenges established industry logics of value creation.

Unlike product or process innovation, which typically focus on improving specific offerings or operational efficiency, BMI represents a more fundamental transformation of the organization's architecture. It involves changes not only in the "what" and "how" of value delivery, but also in the "why"—that is, the strategic intent behind a firm's activities. Accordingly, BMI has been described as *"the discovery of a fundamentally different business model in an existing business"* (Markides, 2006, p. 20), and as *"the search for new business logics of the firm and new ways to create and capture value for its stakeholders"* (Casadesus-Masanell & Zhu, 2013, p. 464).

The strategic relevance of BMI lies in its potential to redefine industry boundaries and reshape competitive dynamics. Through innovative configurations, firms can unlock new avenues for differentiation and performance. Moreover, BMI enhances organizational resilience by fostering adaptability and responsiveness in the face of environmental change—particularly crucial in today's context of rapid digitalization, shifting consumer preferences, and growing demand for sustainability and personalization.

2.3 DT, Industry 5.0, and BMI: shaping new value creation mechanisms

Recent scholarship has highlighted how DT enables BMI (Matt, Hess & Benlian, 2015; Li, 2020; Verhoef et al., 2021). Specifically, technologies such as AI, IoT, cloud computing, and data analytics support the reconfiguration of business model components.

Digital tools enhance value propositions through personalization, driven by real-time customer data (Wikström & Ellonen, 2012; DaSilva et al., 2013), and improve customer relationships by optimizing user experiences (Ammirato et al., 2021). Operationally, digital technologies increase efficiency in production and supply chain management, though they also require new technical skills (Müller, Buliga & Voigt, 2018; Müller, 2019). Partnerships evolve through technological collaboration, promoting innovation and transparency (Schneider, Leyer, & Tate, 2020), while distribution benefits from cost reductions, faster logistics, and omnichannel strategies (Gao, Keoy & Lim, 2025).

In terms of financials, digitalization enables new revenue models and cost efficiencies but also demands significant investment in IT infrastructure (Dasí et al., 2017; Kiel, Arnold & Voigt, 2017). Within this context, Industry 5.0 introduces a more human-centered, sustainable, and ethical approach to innovation. It prompts firms not only to adopt advanced technologies but also to align business models with values such as social

responsibility and human empowerment, expanding the strategic scope of BMI and opening new pathways to long-term competitive advantage (Botti & Baldi, 2025).

3 Methodology

This study adopts a qualitative multiple case study methodology (Tellis, 1997), which is particularly appropriate for exploring complex and context-dependent phenomena within real-life settings (Stake, 1995; Yin, 2009). Rather than seeking statistical generalization, the objective is to generate in-depth analytical insights that illuminate the mechanisms and dynamics underlying BMI in traditional sectors undergoing DT (Hennink, Hutter & Bailey, 2020). Four firms were purposively selected based on their relevance to the 4A sectors (Food & Wine, Fashion & Clothing, Home & Furnishings, and Automation), the presence of documented DT initiatives, and the public availability of rich secondary data. Each case represents a different sector, allowing for cross-case comparison while ensuring sectoral diversity. Firms were also selected for their recognized commitment to innovation and their alignment with the values of the “Made in Italy” identity. The study relies exclusively on secondary data sources. These include publicly available company interviews and documents such as strategic plans, sustainability and innovation reports, press releases, websites, social media content, and industry publications. In addition, relevant academic and practitioner literature, as well as media articles and databases (e.g., Orbis, AIDA), were used to triangulate and enrich the dataset. This approach ensures a comprehensive and multifaceted understanding of each firm's DT journey and related business model innovations. Data were analyzed through thematic coding. Preliminary themes were informed by existing literature on DT and BMI, then iteratively refined through close reading and comparison of the cases.

4 Results

The experiences of leading Made in Italy firms such as Barilla, Gucci, Fiat Chrysler Automobiles (FCA), and Fedrigoni demonstrate how the integration of DT and the human-centric, sustainable principles of Industry 5.0 can serve as enablers of BMI. Each company has adopted digital technologies not merely for operational efficiency, but as strategic tools to reconfigure value creation mechanisms. By embedding digital capabilities within broader socio-environmental, consumer-centric and stakeholder engagement frameworks, these firms have transformed their business models to better align with contemporary expectations of personalization and sustainability. Table 1 provides a detailed comparison of how each case exemplifies this transformation, outlining the specific ways in which DT and Industry 5.0 have been mobilized to drive new forms of value creation.

Table 1 - DT, Industry 5.0, and BMI in Made in Italy: case studies across key sectors

Company	Sector	Key DT	Industry 5.0 Integration	BMI
Barilla	Agrifood	Utilization of blockchain to ensure traceability and digital platforms for consumer engagement (crowdsourcing for product co-creation, e.g., new pasta shapes).	Integration of sustainability through the ¡Tierra! project, combining digital tools and eco-friendly agriculture.	Development of new customer engagement methods through co-creation and sustainability-focused initiatives.
Gucci	Luxury Apparel	AR for personalized shopping experiences and immersive consumer interaction.	Partnership with external designers and artists to ensure sustainability and ethical production.	Introduction of digital tools for customization, creating a sustainable luxury experience with a focus on innovation.
Fiat Chrysler Automobiles (FCA)	Automotive	Adoption of smart factory technologies to enhance production efficiency, especially in electric and autonomous vehicles.	Human-machine collaboration for electric and autonomous vehicle production; focus on sustainable manufacturing.	Shift towards human-centric production that balances craftsmanship and cutting-edge technologies in automotive design.
Fedrigoni	Paper & Printing	Creation of digital platform for customers to co-create products, offering advanced material options.	Integration of digital tools into traditional paper production, preserving artisanal quality while embracing innovation.	Co-creation platform for personalized paper products, blending traditional craftsmanship with digital technologies.

4.1 Emergent themes

Based on the analysis of secondary data sources, four recurring themes appear to characterize how DT and the principles of Industry 5.0 are reportedly employed to support BMI in the selected Made in Italy companies. First, strategic intent and leadership emerge as fundamental enablers of transformation (Singh et al., 2023). In all analyzed cases, top executives appear to have played an active role in shaping digital initiatives aligned with long-term corporate values and identity. Rather than adopting technology for its own sake, firms communicated a vision in which innovation reinforced their heritage, quality, and competitiveness. In the context of Industry 5.0, this integration extends beyond the adoption of new technologies, encompassing the fusion of human creativity and machine efficiency, thus enhancing competitive advantage (Modgil, Singh & Agrawal, 2023). Second, several sources indicate the presence of cultural tensions (Yan, 2008) related to fears of eroding traditional craftsmanship or diluting brand authenticity—concerns particularly salient within the symbolic context of Made in Italy, where there is resistance to replacing traditional craftsmanship with automated processes. These tensions were reportedly addressed through change management initiatives involving employee engagement, training, and communication strategies aimed at framing digitalization as a continuation, rather than a rupture, of tradition.

Third, the cases suggest that DT often entailed resource reconfiguration (Muneeb et al., 2023), especially the development of new capabilities in data analytics, digital marketing, and user experience design. In many instances, this process combined internal upskilling with external collaborations, highlighting a hybrid model of resource orchestration in digitally evolving firms. This resource shift is integral to Industry 5.0, where businesses must focus on both technological capabilities and the enhancement of human-technology collaboration.

Finally, all four companies show evidence—through their public strategies and projects—of a shift toward customer-centric innovation (Nugroho, 2025), enabled by technologies such as AI, IoT, and digital platforms. These tools allowed firms to offer personalized experiences, foster value co-creation, and engage customers more directly (Ramaswamy & Ozcan, 2018). Particularly transformative has been the role of digital platforms, which facilitated ecosystem creation, data-driven decision-making, and more agile business models (Chesbrough, 2003; Gawer & Cusumano, 2014; West & Bogers, 2017; Teece, 2018). The core advantage of digital platforms for physical businesses lies in their ability to aggregate and connect diverse stakeholders—such as suppliers, consumers, and service providers—into a single ecosystem. This interconnectedness allows firms to scale more effectively through network effects, where the value of the platform increases as more participants join. Furthermore, these platforms generate vast amounts of user data, providing valuable insights that can inform business model adjustments, marketing strategies, and product offerings. Generalizing, a cross-cutting theme is the adoption of a human-centric approach to digitalization. In all cases, technology was deployed not merely to streamline operations but to enrich the human experience—whether through enhanced personalization, as mentioned earlier, or the augmentation of employee capabilities. In line with Industry 5.0 principles, digital tools were often framed as complements to human skills, supporting rather than displacing traditional craftsmanship and knowledge. This orientation reflects a broader cultural shift in innovation practices, where human values are placed at the center of technological development.

Thus, these emergent themes highlight the interconnected nature of leadership, cultural adaptation, resource reconfiguration, and customer engagement in the successful implementation of BMI and the advancement of Industry 5.0.

4.2 Comparative Insights

Alongside the recurrent themes, we observed differences related to sectoral contexts, technological maturity, and organizational structures. The cross-case analysis reveals how DT and BMI are interwoven within the contemporary trajectories of Made in Italy firms, also highlighting sector-specific variations. A central insight concerns the alignment between DT initiatives and brand values. Rather than adopting technologies indiscriminately, each firm carefully selected digital tools that resonated with its core identity and heritage. For example, the Food & Wine company employed blockchain to ensure traceability and reinforce its commitment to transparency and quality, while the Fashion & Clothing firm integrated augmented reality in ways that enriched customer interaction without compromising its artisanal legacy. This strategic coherence between digital innovation and brand ethos emerged as a key differentiator, enabling firms to innovate while remaining authentic in the eyes of consumers. The cases also illustrate the importance of sector-specific digital strategies (Arnold, Kiel &Voigt, 2016; Rachinger et al., 2019).

Although all companies shared the goal of enhancing efficiency, innovation, and customer engagement, their approaches varied significantly depending on industry dynamics. The Automotive company leveraged advanced Industry 4.0 technologies—such as real-time monitoring and intelligent automation—to pioneer outcome-based

service models, enabling predictive maintenance and performance-driven value delivery. Meanwhile, the Home & Furnishings firm focused on platform-based ecosystems to enhance the user experience. This tailoring of digital strategies to sectoral needs underscores the contextual nature of transformation and the necessity of embedding innovation within specific operational and market frameworks.

5 Discussion and implications

Building on the findings, this study offers a framework, illustrated in Figure 1, that integrates key antecedents, dimensions of DT and Industry 5.0, and mediating factors crucial for facilitating the transition from traditional business models to innovative business models, where the synergy between technology and human capabilities plays a central role.

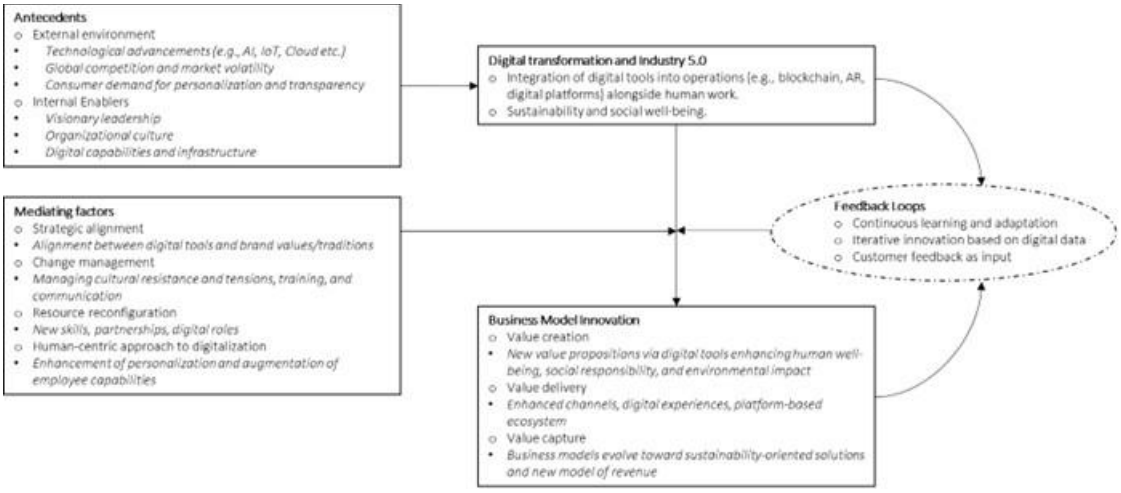


Figure 1: A framework for DT and Industry 5.0 impact on BMI: mediating factors and strategic implications for traditional firms

The framework begins by identifying the external and internal factors driving this transformation. Externally, technological advancements form the backbone of Industry 5.0. These technologies do more than enhance operational efficiency; they complement human capabilities, fostering creativity, intuition, and decision-making. This collaboration between humans and machines is particularly relevant for Made in Italy enterprises, where the artisanal approach and high-quality production methods can be augmented by advanced technologies, enabling the creation of more personalized, creative, and sustainable products. Global competition, market volatility, and the growing demand for personalization and transparency are also significant drivers of change. The rising expectation for social responsibility and personalized experiences presents a strategic opportunity for Italian manufacturers to reinforce their commitment to sustainability—a core characteristic of many Italian brands—while meeting the evolving needs of consumers. Internally, visionary leadership and organizational culture (Kurniadi, Lian & Wahidy, 2020) are crucial enablers of this transformation. Effective leadership must foster a vision that embraces digitalization while prioritizing human well-being, ensuring digital tools enhance both efficiency and creativity. For Italian businesses, often rooted in craftsmanship traditions, fostering a culture of collaboration between human expertise and technology is essential for maintaining competitive advantage. Organizations must also ensure their workforce and infrastructure are ready to support this transition, facilitating not just automation but effective collaboration—an essential element of Industry 5.0's success. In terms of DT, the adoption of new technologies in Industry 5.0 goes beyond traditional automation. Technology is seen not just as a tool for improving efficiency, but as a means to enhance human creativity and capabilities, aligning seamlessly with the core values of the Made in Italy sector, which blends innovation with tradition. The digitization of processes enables the personalization of work, empowering both employees and customers to co-create value. For Italian manufacturers, this means integrating advanced digital tools into artisanal production processes, allowing for customization while preserving the handcrafted quality that defines their offerings. Furthermore, digital platforms enable real-time feedback and personalized experiences, fostering deeper, more meaningful customer relationships. Consumers not only receive bespoke products but actively participate in their creation, adding value that extends beyond the product itself and enhances the overall customer experience (Ramaswamy & Ozcan, 2018; Abbate, Codini & Aquilani, 2019; Abbate et al., 2022).

The mediating factors outlined in the framework are essential for the successful implementation of Industry 5.0 in BMI. A critical element is strategic alignment between digital tools and brand values (Yeow, Soh & Hansen, 2018). For Made in Italy enterprises, aligning technological adoption with core values such as craftsmanship, innovation, and sustainability is key. This ensures that DT efforts resonate with employees and customers alike, preventing the dilution of the brand's traditional identity while embracing technological advancements.

Another key factor is change management (Ghiringhelli & Virili, 2021). Overcoming resistance to technology requires cultivating a mindset that views digital tools as enablers, not substitutes. For Italian companies with a strong reliance on traditional methods, this cultural shift may be met with resistance from both employees and leadership. Continuous training and transparent communication are crucial to ensure a smooth transition, helping employees view new technologies as supportive tools that enhance their work (Ramus, 2001)

Moreover, the reconfiguration of resources is pivotal in integrating human and digital capabilities, a process that requires not only the adoption of advanced technologies but also the development of new skills, the creation of digital roles, and the establishment of strategic partnerships (Chaturvedi & Prescott, 2022). In this context, the role of employees is evolving, with a greater focus on digital literacy, critical thinking, and collaboration with technological tools (Reddy, Sharma & Chaudhary, 2020). This balance between human and technological input helps enhance productivity, optimize quality, and enable more personalized offerings. Furthermore, building strong partnerships with technology providers, research institutions, and other stakeholders is essential to foster innovation, support continuous learning, and ensure the sustainable integration of digital capabilities. As such, the reconfiguration of resources involves a dynamic approach where digital roles, skill development, and strategic collaborations are key to driving both technological and human-driven growth in the business model transformation.

Lastly, the framework also highlighted the human-centric approach to digitalization as a mediating factor (Wan et al., 2023). This approach manifests in the enhancement of personalization and the augmentation of employee capabilities. Specifically, the adoption of digital technologies that center on the human experience enables more precise customization of products and services, addressing the individual needs of customers with greater accuracy. Simultaneously, the integration of digital tools into the workforce not only enhances operational efficiency but also amplifies employee capabilities, thereby contributing to a more dynamic and innovative work environment.

The outcomes of this DT center on new mechanisms of value creation, delivery, and capture (Sjödin et al., 2020). In terms of value creation, Industry 5.0 facilitates the development of new value propositions through the application of digital tools that promote human well-being, social responsibility, and environmental sustainability. Made in Italy companies are well-positioned to lead in this space, as sustainability and craftsmanship are core to their brand identity. By embedding this transformation into their business models, they create value for society as a whole. Value delivery in Industry 5.0 involves more personalized and dynamic interactions between businesses and customers, facilitated by advanced channels, digital experiences, and platform-based ecosystems. These technologies enable real-time feedback and enhanced personalization, fostering deeper, more meaningful relationships. For Made in Italy companies, this shift offers an opportunity to create bespoke offerings that align with consumer desires, leveraging digital platforms to connect with customers and deliver tailored experiences. By integrating these digital tools into their value delivery processes, companies can maintain their artisanal identity while responding more effectively to evolving market demands. The concept of value capture evolves as well, with businesses moving toward more sustainable, outcome-based models. Service-based offerings and pricing models that factor in both efficiency and environmental impact are becoming more prevalent. For Made in Italy enterprises, this could mean shifting toward service-oriented models that focus on long-term customer relationships and experiences rather than just products.

In the framework, feedback loops (Sjödin et al., 2021) —driven by DT and BMI—play a crucial role in the impact of Industry 5.0 on the new logic through which value is created, delivered, and captured. These feedback loops encompass continuous learning and adaptation, iterative innovation based on digital data, and customer feedback as input. Together, these elements facilitate the dynamic and adaptive nature of the transformation, supporting the evolution of business models within the context of Industry 5.0. For Made in Italy businesses, this highlights the importance of iterative innovation and the constant refinement of both products and processes, facilitated by customer feedback and digital data. The customer feedback loop is especially critical, fostering deeper collaboration and responsiveness. By incorporating customer insights, Made in Italy enterprises can better anticipate consumer needs and continuously improve their offerings, ensuring long-term sustainability and competitiveness.

This work also highlights the profound theoretical implications emerging from the transition from Industry 4.0 to Industry 5.0 within the context of BMI. By emphasizing the collaborative nature of human-machine interaction and the integration of traditional craftsmanship with digital innovation, this study challenges existing

frameworks and provides new insights into innovation models that blend technological advancements with traditional practices.

6 Conclusion, limitations and future research directions

In conclusion, this study provides valuable insights into the intersection of DT and BMI within traditional sectors, specifically the Made in Italy industries. These firms have successfully integrated digital technologies into their existing frameworks, redefining their business models while preserving their artisanal roots and cultural identity. The study also illuminates the evolving paradigm of Industry 5.0, where the focus shifts from automation to collaboration, highlighting the synergy between human creativity and technological advancements. Building on the insights presented throughout, these theoretical contributions call for a fundamental rethinking of traditional business models, where a blend of innovation and heritage is essential. This work further offers valuable perspectives by emphasizing the critical role of mediating factors which shape the transition toward more adaptive and resilient business models.

However, several limitations should be acknowledged. The small sample size of cases limits the generalizability of the findings, and future research would benefit from a larger, more diverse sample encompassing firms from different regions and industries. Moreover, as industries continue to evolve in response to technological advances, the findings underscore the importance of strategic alignment between digital adoption and organizational identity, providing a framework for further exploration of the factors that drive successful adaptation. Future research could delve deeper into how the mediating factors influence the long-term sustainability of DT efforts, especially within traditional sectors where the preservation of cultural heritage is just as crucial as embracing new technological advancements.

To further explore this topic, primary data collection could be utilized, including interviews with industry leaders and practitioners, as well as quantitative methods such as surveys. Qualitative interviews can provide deeper insights into how companies balance innovation with preserving cultural heritage in the context of DT. On the other hand, quantitative approaches can offer broader patterns and trends across different sectors, helping to identify key factors that influence successful adaptation to Industry 5.0. Combining these methods would allow for a more comprehensive understanding of the dynamics driving sustainable DT in traditional industries.

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8 Ethics declaration

Ethics approval was not required for this study.

9 AI declaration

No AI tools were used in the development of this paper.

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Artificial Intelligence in Social Media Advertising: To Say or Not To Say?

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Abstract

The increasing integration of Artificial Intelligence (AI) in the advertising industry is opening up both promising opportunities and new challenges for brands leveraging social media to promote their offerings. The rise of Generative AI (gen-AI) is reshaping how advertising content is developed. Yet, while the benefits of creative automation are evident, little is known about how disclosing AI involvement influences consumer perceptions and attitudes toward advertisements. This research investigates the effects of openly stating the use of AI in social media advertising on how consumers perceive and respond to content. Results of two experimental studies show that transparency regarding AI use significantly boosts perceived advertising credibility and enhances comprehension of the advertising message. These findings indicate that consumers value transparency in AI-generated content. The study offers practical implications for marketing professionals and underlines the importance of further research into the ethical and regulatory dimensions of AI use in advertising.

Keywords: Artificial Intelligence, Social Media Advertising, Advertising Credibility, Advertising Language Comprehension.

Paper type: Academic Research Paper

1 Introduction

Thanks to the diffusion of firms' digitalization processes (Isaksson, Harjunkoski, and Sand, 2018), social media have become ubiquitous, making communication an integral part of human life (Başev, 2024). As reported by the Global Web Index (2024), a typical user spends 143 minutes per day using social media platforms. Accordingly, the advertising sector has started to produce digital advertisements within social media, which constantly see a boost in the number of users (Başev, 2024) and the amount of expenditure (Statista, 2024). This scenario underlines the opportunities that social media offers to businesses in terms of promoting their products and services.

Among digital technologies, Artificial Intelligence (AI) sees wide applications (e.g., Vakratsas and Wang, 2020; Başev, 2024; Lim et al., 2024), and its integration represents a paradigmatic change in contemporary marketing strategies and advertising practices. Several brands (e.g., Burger King, Netflix, and National Geographic) utilize AI in roles such as copywriting, editing, and other functions (Başev, 2024). Among AI technologies, Generative AI (gen-AI) has become prominent in the advertising industry (Euchner, 2023) because it is expected to automate even more creative tasks typically reserved for humans and generate economic value in future years (Huang and Grady, 2022).

While the adoption of gen-AI tools could represent a positive strategy able to support content creation and campaign optimization, it raises questions about the transparency and authenticity of digital content. The threat of deepfake images and videos used in contexts such as advertising campaigns has prompted politicians and regulators to come up with proposals to prevent their use. Similarly, tech companies have adopted self-regulations (such as the Coalition for Content Provenance and Authenticity – C2PA) to allow consumers to access data (e.g., content owner and AI tool used) about AI-created content. Specifically, the ground-breaking "transparency icon" developed by the C2PA will feature the symbol containing the letters "CR," which represents "Content CRedentials." Functionally, the Content CRedentials symbol can be embedded within the metadata of images, videos, and PDF files through photo and video editing applications. From the user's perspective, upon encountering online content bearing the "CR" acronym, a click on the symbol will enable them to determine the rightful owner, access details regarding the AI tools utilized in the content's creation, and gain insights into the production workflow.

The proposed regulations (like as the C2PA protocol) - aimed at ensuring transparency regarding the origin of online content - underscore a critical need to safeguard users, especially in the context of advertising produced using AI. The increasing sophistication and pervasiveness of AI-generated advertisements necessitate clear and accessible information about their creation process. Without such transparency, users may struggle to distinguish between authentic content and AI-generated promotions, potentially leading to misinformed decisions and an erosion of trust in online information. Therefore, it is paramount to investigate the users'

perceptions and attitudes towards advertising created with AI. Understanding how individuals interpret and react to these novel forms of promotion is crucial for developing effective regulatory frameworks and ethical guidelines. Accordingly, since the effects of AI-generated advertising on user perceptions and attitudes remain largely unexplored, this research aims to bridge this gap in the literature. Specifically, this research aims to investigate whether declaring the use of AI (*vs.* not declaring it) in social media advertising creation can affect consumers' perceptions (e.g., the credibility of the advertising) and attitudes (e.g., language comprehension of the advertising).

Through two experimental studies, this research shows that declaring (*vs.* not declaring) the use of Artificial Intelligence for the creation of an advertisement significantly enhances advertising credibility and language comprehension of advertising. These findings suggest that transparency in AI-generated content can improve consumer perceptions and attitudes toward advertising, offering valuable insights for marketers, while highlighting the need for further research exploration of ethical and regulatory concerns.

2 Conceptual framework and hypotheses development

Previous research has identified several key factors within online advertising that significantly influence consumer responses (e.g., Odoom, Narteh, and Odoom, 2022; Kamaruddin, Mohamed, and Aris, 2020). One such factor is advertising credibility, which has been consistently recognized as a critical determinant of consumer perception (MacKenzie and Lutz, 1989; Eisend, 2006). Additionally, language comprehension plays an essential role in how consumers process and interpret advertising messages, particularly in digital and multilingual contexts (Puntoni, De Langhe, and Van Osselaer, 2009).

Building on these insights, the present study investigates whether explicitly disclosing the use of Artificial Intelligence in creating advertisements affects consumer perceptions (such as perceived advertising credibility) and attitudes (such as perceived advertising's language comprehension). This investigation is grounded in the Persuasion Knowledge Model (PKM), which posits that consumers develop an understanding of persuasive tactics over time and utilize this knowledge to assess and respond to advertising content (Friestad and Wright, 1994). When consumers recognize persuasive intent or perceive manipulative strategies, they often activate resistance mechanisms to counter the influence (Fransen, Smit, and Verlegh, 2015; Ringold, 2002). In this context, transparency regarding how and by whom the content is created – including whether AI tools are involved – can shape consumers' evaluative and affective reactions toward the advertisement.

Empirical evidence supports this view, indicating that disclosing relevant information can enhance trust in advertising (Schweitzer et al., 2019; van der Heide and Lim, 2016). A similar reaction can be expected by disclosing the involvement of AI in message generation.

Empirical evidence supports this view, indicating that disclosing relevant information, such as the involvement of AI in message generation, can enhance trust in advertising (Schweitzer et al., 2019; van der Heide and Lim, 2016). Drawing from Source Credibility Theory, which highlights the influence of a communicator's trustworthiness and expertise on message persuasiveness (Fogg et al., 2001), AI can be perceived as a credible and competent source. This perception may lead consumers to view AI-generated advertising as more reliable, thereby positively impacting their evaluations (Khan and Mishra, 2024). Consequently, we propose that transparency about AI involvement can bolster the perceived credibility of the ad and signal corporate honesty and openness. On the attitudinal side, recent literature (e.g., Gao et al., 2023; Al Tawalbeh et al., 2024) shows that AI contributes to enhanced personalization and linguistic adaptation in advertising. These capabilities make ad content more understandable, relevant, and engaging for target audiences. Therefore, we argue that when consumers are made aware of AI's role in content creation, their comprehension of the advertising language may improve due to perceived gains in message quality and adaptability.

Overall, building upon the Persuasion Knowledge Model, we assert that if the use of AI is not reported, consumers may perceive it as an attempt to deceive. On the contrary, declaring it can reduce resistance, and increase credibility, and comprehension.

Formally, we proposed the following hypotheses:

- H_1: The declared use of AI (*vs.* not declared) positively affects the consumers' perceived advertising credibility.
- H_2: The declared use of AI (*vs.* not declared) positively affects advertising language comprehension.

3 Methodology

We conducted 2 experimental studies. Study 1 aimed to test whether the AI's use declaration affects the credibility and the language comprehension of the advertising. The use of AI (not declared *vs.* declared) was

manipulated in a between-subjects design, holding constant all other elements in social media advertising. Specifically, the stimulus was an advertisement on the Instagram platform that used wine as a product category. It was entirely created by an AI-generative tool. In particular, ChatGPT is used for the creation of the text part, while DeepAI is used for the creation of the visual part. The manipulation of the Artificial Intelligence use (not declared *vs.* declared) was made by inserting a logo with the words "created with AI" placed at the bottom right of the visual part of the advertising, and a logo with the words "Content created with Artificial Intelligence" placed at the end of the textual part of the advertising.

Study 2 aimed to obtain additional support for the previous results by providing evidence of the generalizability of the proposed effect against a different product category (i.e., body wash). The use of AI (not declared *vs.* declared) was manipulated as in Study 1. The stimulus was an advertisement on the Instagram platform (entirely created by an AI-generative tool as in Study 1) that used body wash as a product category. As in study 1, the manipulation of the Artificial Intelligence use (not declared *vs.* declared) was made by inserting a logo with the words "created with AI" placed at the bottom right of the visual part of the advertising, and a logo with the words "Content created with Artificial Intelligence" placed at the end of the textual part of the advertising.

Figure 2 shows the experimental stimuli used in the studies, which allowed for testing the research hypotheses concerning different product categories (i.e., wine and body wash).

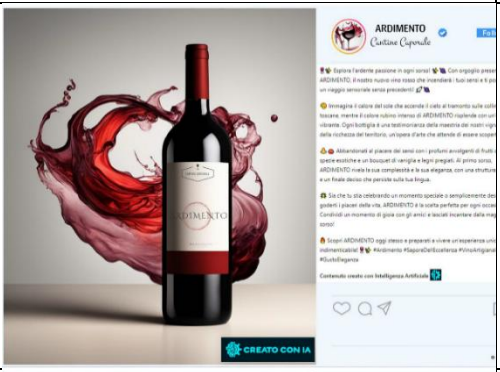
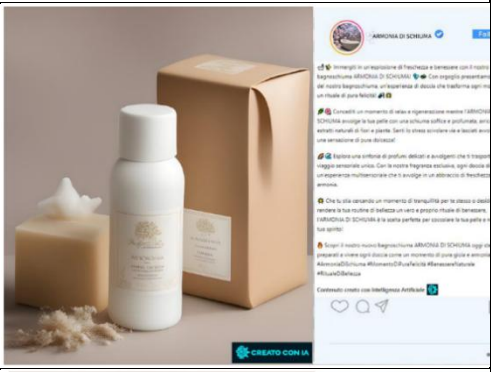
		Product category	
		Wine (Studies 1 and 2)	Body wash (Study 2)
Artificial Intelligence use	Declared		
	Not declared		

Figure 1: Stimuli used in the experimental studies

3.1 Study 1

Two hundred and thirty Italian users (50.4% females; M_{age} = 26.50; SD_{age} = 6.80) took part in the study and were randomly assigned to one of the two conditions. Advertising credibility was captured by three 7-points items (Kim, Ratneshwar, and Thorson, 2017; α = .88); while advertising language comprehension was captured by three 7-points items (Lin and Wang, 2016; α = .80). Results of a first one-way ANOVA - considering the use of AI as independent variable and the advertising credibility as dependent variable - showed that the advertising credibility was significantly higher in the case of AI'use declared compared to not declared ($M_{AIdeclared}$ = 4.225, SD = 1.49; $M_{AInotdeclared}$ = 3.554, SD = 1.323; F(1, 228) = 12.94, p < .000). Results of a second one-way ANOVA - considering the use of AI as independent variable and the advertising language comprehension as dependent variable - showed that the advertising language comprehension was significantly higher in the case of AI'use declared compared to not declared ($M_{AIdeclared}$ = 4.296, SD = 1.208; $M_{AInotdeclared}$ = 3.747, SD = 1.186; F(1, 228) = 12.05, p < .000). Overall, these findings provide support for the effect of AI'use declared (vs. not declared) on

consumers' perception of advertising credibility and consumers' attitude toward the advertising language comprehension.

3.2 Study 2

Three hundred and twenty-four Italian users (58.3% females; M_{age} = 25.94; SD_{age} = 7.12) took part in the study and were randomly assigned to one of the four conditions in a 2 (AI's use: not declared vs. declared) by 2 (product category: wine *vs.* body wash) between-subjects design. Advertising credibility and advertising language comprehension were measured as in Study 1 (respectively, α = .86; α = .80).

Results of a first two-way ANOVA on advertising credibility with the use of AI (not declared *vs.* declared) and product category (wine *vs.* body wash) as between-subject factors confirmed a significant main effect of AI's use ($M_{AIdeclared}$ = 4.227, SD = .106; $M_{AInotdeclared}$ = 3.699, SD = .107; F(1, 320) = 12.36, p <,000). The results also showed a significant main effect of the product category (M_{Wine} = 4.14, SD = .107; $M_{BodyWash}$ = 3.787, SD = .106; F(1, 320) = 5.51, p =.019). Finally, no significant interaction effect between AI's use and product category was found (F(1, 320) = .028, p = .866).

Results of a second two-way ANOVA on advertising language comprehension with the use of AI (not declared *vs.* declared) and product category (wine *vs.* body wash) as between-subject factors confirmed a significant main effect of AI's use ($M_{AIdeclared}$ = 4.379, SD = .090; $M_{AInotdeclared}$ = 3.869, SD = .091; F(1, 320) = 15.867, p < .000). They also showed a significant effect of the product category (M_{Wine} = 4.298, SD = .091; $M_{BodyWash}$ = 3.95, SD = .090; F(1, 320) = 7.391, p =.007). No significant interaction effect between AI's use and product category was found (F(1, 320) = .884, p = .348). Overall, these findings suggest that the effect of AI's use declared (*vs.* not declared) on consumer perception of advertising credibility and consumer attitude toward the advertising language comprehension holds regardless of the product category, then provide preliminary evidence of the generalizability of the proposed effects.

4 Discussion and conclusion

The results of this research provide empirical evidence that declaring the use of Artificial Intelligence in the creation of advertisements, as opposed to not disclosing it, positively influences consumers' perception of advertising credibility as well as their attitude toward the comprehension of the advertising language. In particular, openly stating the involvement of Artificial Intelligence enhances both how trustworthy the advertisement is perceived and how easily the message is understood by the audience.

Furthermore, these effects were replicated in a different product category – body wash – suggesting that the impact of AI disclosure on consumer perception and attitude is not limited to a specific type of product. These findings offer preliminary support for the generalizability of the proposed effects, indicating that transparency regarding AI usage in advertising may consistently improve consumer responses across various market segments.

This paper presents a fresh perspective on advertising research by examining how disclosing the use of AI in the creation of social media ads affects consumer responses. Although the integration of AI in digital marketing has been widely explored, few studies have specifically investigated the impact of transparency about AI involvement on consumer perceptions and attitudes. Findings from this study suggest that openly communicating the role of AI in ad creation can be viewed as an extension of the Source Credibility Theory (Khan and Mishra, 2024). In this context, even highly sophisticated technologies such as gen-AI can serve as credible sources, provided their involvement is made explicit – ultimately fostering greater user engagement with social media advertising.

Enhancing perceived advertising credibility could stimulate consumer engagement and may also influence brand perception, opening new avenues to explore how responses to the advertisement can indirectly shape opinions about the sponsoring brand. Furthermore, by analyzing the effects of AI disclosure on both consumer perceptions (e.g., advertising credibility) and attitudes (e.g., comprehension of advertising language), this paper offers a comprehensive framework for understanding the complex consequences of AI transparency in advertising. This integrated approach contributes to a more nuanced and holistic understanding of how audiences interact with AI-generated promotional content.

4.1 Implications and research limitations

The findings underscore the strategic value of openly disclosing the use of Artificial Intelligence in digital advertising efforts. For marketers, embracing transparency by clearly communicating the involvement of AI technologies in advertising creation can significantly enhance the perceived credibility of the message – an

essential factor in fostering consumer trust. Transparency signals honesty and authenticity, which may lead consumers to develop more favorable attitudes toward the brand itself. This insight carries practical significance for companies aiming to integrate AI into their communication strategies: rather than concealing AI usage, highlighting it can strengthen consumer confidence and engagement.

Importantly, the study reveals that even sophisticated tools like gen-AI can be viewed as trustworthy sources when their role is clearly communicated. This, in turn, positively shapes user perceptions and attitudes within the context of social media advertising. Moreover, improvements in perceived advertising credibility and message comprehension may extend beyond the ad itself, potentially influencing how consumers perceive the brand behind the content – suggesting a broader, indirect branding benefit.

From a managerial perspective, companies should view AI not just as a tool for efficiency but as an asset for enhancing message quality and trustworthiness. They are encouraged to leverage AI for creative functions – such as generating ad copy or optimizing content delivery – provided that its role is transparently stated. Additionally, brands might consider developing communication guidelines or labels indicating AI involvement, as a way to standardize transparency practices. Finally, companies should explore how transparency in AI use can be incorporated into broader brand positioning strategies, especially in markets where ethical tech use and consumer trust are competitive differentiators.

Although this study demonstrates a significant effect of AI disclosure (as opposed to non-disclosure) on consumer perceptions, and attitudes, it does not delve into potential moderating factors that could shape these outcomes – such as consumers' familiarity with AI technologies, the reputation of the brand, or the degree of consumer involvement with the product. Future research could examine how these variables influence the relationship between AI transparency and key outcomes like perceived ad credibility and comprehension of advertising language.

Additionally, the current work emphasizes outcome measures – credibility and language comprehension – without fully exploring the underlying psychological processes that might drive these effects. Subsequent studies could investigate whether the act of disclosing AI use affects perceptions of authenticity, levels of skepticism, confidence in the brand, honesty, or trust – core psychological constructs that are particularly relevant in AI-driven marketing contexts.

While the study includes two product categories (wine and body wash), it does not assess how different types of products or industries might influence the effectiveness of AI disclosure. It is plausible that consumer responses to AI transparency vary across sectors – for example, between high-tech products and everyday consumer goods, or between tangible items and experiential services. Further research should explore whether these contextual factors moderate the effects observed.

Moreover, this study is limited to digital advertising and social media formats. Future investigations could expand the scope to include a wider range of platforms, such as streaming services, search engine marketing, or in-app advertising, to assess the consistency of the observed effects across diverse digital environments.

Lastly, the sample is composed of Italian consumers, which may limit the generalizability of the findings. Cultural attitudes toward AI and transparency can differ significantly depending on the country, industry norms, or regulatory frameworks. Cross-cultural research could offer valuable insights into how AI disclosure is perceived in different international contexts and whether the observed effects hold globally.

5 Ethics declaration

All research is conducted in accordance with ethical principles.

6 AI declaration

Artificial intelligence tools were employed in the creation of the advertising stimuli used in the experimental studies. Specifically, ChatGPT was used to generate the textual content of the advertisements, while DeepAI was utilized to produce the visual components of the advertising materials.

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Exploring AI Integration in Sicilian SMEs: An Investigation on Awareness and Perspectives

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Abstract

In an increasingly digitalised society, Artificial Intelligence (AI) is gaining prominence as a key driver of business innovation and competitiveness. While much research has focused on AI adoption in large enterprises, fewer studies have explored its integration within small and medium-sized enterprises (SMEs), especially in regions with specific socio-economic contexts. This study investigates the awareness, perceptions, and adoption of AI technologies among SMEs in Sicily, a region in southern Italy, characterised by unique economic and organisational dynamics. Adopting a mixed-methods approach, the research combines qualitative insights from in-depth interviews with entrepreneurs from both digital and non-digital sectors, and a large-scale quantitative survey targeting over 2.000 Sicilian SMEs. The methodological framework is structured in sequential phases, where the qualitative component plays a foundational role in informing and shaping the subsequent quantitative investigation. The qualitative findings reveal significant disparities in AI awareness and implementation between sectors, highlighting both enablers and barriers such as digital maturity, organizational culture, training needs, and resistance to change. These insights informed the development of a structured questionnaire to capture broader trends in AI readiness, perceived benefits, and challenges. The study contributes to the literature on digital transformation in SMEs by applying the Technology–Organization–Environment (TOE) framework to a specific regional context, offering both theoretical insights and practical recommendations for policymakers, training institutions, and business leaders seeking to foster inclusive AI adoption.

Keywords: Artificial Intelligence, SME, Sicily

Paper type: Academic Research Paper

1 Introduction

Interest in Artificial Intelligence (AI) is growing in a rapidly transforming and increasingly digitalised society. As stated by Ho et al. (2022), Artificial Intelligence has received increasing attention from various areas of society, industry, and business, considered the Fourth Industrial Revolution (Zhang et al., 2021). Recent studies (e.g., Khalid, 2020; Dwivedi et al., 2021) described Artificial Intelligence as a field that combines computer science with large datasets to enhance the quality of business decision-making. Specifically, Dwivedi et al. (2021) claimed that Artificial Intelligence is broadly characterised as the simulation of human cognitive processes by machines (software systems) employing advanced technologies such as machine learning, deep learning, data mining, natural language processing, and image recognition, among others. Recent literature (e.g., Awan et al., 2021; Sestino and De Mauro, 2022; Chen, Esperança and Wang, 2022) provided support for the convergence of Artificial Intelligence and Big Data analytics by enabling the systematic organization of previously fragmented information into coherent frameworks, thereby facilitating the transformation of raw data into actionable insights and accelerating strategic decision-making at the organizational level. An extensive body of literature has examined the adoption of AI and its implications for business performance, demonstrating its potential to reduce operational costs and enhance predictive accuracy (Agarwal et al., 2021), increase productivity through the automation of routine human activities (Acemoglu and Restrepo, 2018), foster product innovation (Babina et al., 2024), optimize business processes (Adesina, Iyelolu and Paul, 2024), and drive business growth (Bag et al., 2021). Consequently, there is an increasing emphasis among enterprises on the deployment of Artificial Intelligence technologies, recognizing their considerable potential to enhance organizational performance (Mikalef and Gupta, 2021), although substantial challenges to widespread adoption remain (Yu et al., 2020).

The technological and strategic implications of Artificial Intelligence are increasingly recognized by the academic community as a pivotal domain of inquiry (Sun and Medaglia, 2019), particularly as the assimilation of Artificial Intelligence practices influences both financial and non-financial outcomes within small and medium-sized enterprises – SMEs - (Baabdullah et al., 2021; Badghish and Soomro, 2024). As remarked by Sjödin et al. (2021), small and medium-sized enterprises should be prepared to adopt digital processes and business model innovation as business processes evolve into more digital ones. Therefore, as suggested by Chen and Lin (2021),

understanding the underlying mechanisms and critical drivers through which Artificial Intelligence shapes firm performance offers considerable contributions to both theoretical development and managerial practice. Consequently, there is a pressing demand to examine the complex, and predominantly qualitative, dimensions that influence Artificial Intelligence adoption in SMEs. As central contributors to economic growth (Gherghina et al., 2020), SMEs constitute a vital component of global economies, especially within emerging and developing markets (Ndiaye et al., 2018; Badghish and Soomro, 2024). In contrast to larger firms, SMEs are characterized by heightened agility in responding to technological disruptions and exhibit superior adaptability to market dynamics, underpinned by their streamlined decision-making structures (Baeshen, Soomro and Bhutto, 2021). As stated by Rawashdeh, Bakhit and Abaalkhail (2023), these firms increasingly deploy disruptive technologies to scale their operations and enhance organizational efficiency. In response to the current wave of industrial transformation, SMEs have further catalyzed the integration of digital technologies (Ghobakhloo and Iranmanesh, 2021). Additionally, heightened stakeholder pressures have recently intensified SMEs' engagement with innovation-driven strategies (Gherghina et al., 2020). Iyelolu et al. (2024) suggested that Artificial Intelligence technologies can significantly improve product development, operational efficiency, competitive advantage, and customer engagement for SMEs. Concerning the latter, Kedi et al. (2024) stated that AI technologies (e.g., natural language processing, machine learning, and predictive analytics) represent relevant tools able to improve customer engagement and retention through personalized content and recommendations. As a result, thanks to AI-driven marketing strategies, SMEs reported notable improvements in sales performance and return on investment (Kedi et al., 2024).

Despite the previous literature showing different positive impacts due to the implementation of Artificial Intelligence in SMEs, it is important to stress that AI adoption by SMEs encountering barriers and challenges ranging from internal resistance to organizational complexity and legal considerations (Venkateswarlu et al., 2022), and financial constraints (Bakhtiari et al., 2020). Moreover, as suggested by Schwaeke et al. (2024), local factors (e.g., economic conditions, cultural aspects, and government incentives) significantly influence Artificial Intelligence implementation in SMEs. With this in mind, we have decided to focus our research on SMEs in Sicily (southern Italy). Specifically, the present research aims to examine Sicilian SMEs' adoption of Artificial Intelligence technologies, focusing on the awareness, perspectives, and needs of entrepreneurs operating in an area with specific socio-economic characteristics. Given the relatively limited adoption of Artificial Intelligence among SMEs and the contextual challenges that may arise in regions with distinct economic conditions, our study seeks to provide a comprehensive understanding of the factors (technological, organizational, and environmental) that facilitate or hinder Artificial Intelligence integration in this landscape. Accordingly, to add to the literature, the present study utilizes the Technology–Organization–Environment (TOE) framework to propose a conceptual model that explains the readiness of firms towards the adoption of Artificial Intelligence and the firm performance within SMEs with specific socio-economic characteristics like Sicily.

2 Methodology

This study adopts a mixed-methods research design, integrating qualitative and quantitative approaches to provide a comprehensive understanding of the enablers and barriers to artificial intelligence (AI) adoption among small and medium-sized enterprises (SMEs) in Sicily. The methodological framework is structured in sequential phases, where the qualitative component plays a foundational role in informing and shaping the subsequent quantitative investigation.

The initial phase involved a qualitative exploration aimed at capturing in-depth perspectives and contextual nuances that are often not accessible through standardized survey instruments. Specifically, we conducted three semi-structured interviews with entrepreneurs from selected Sicilian SMEs. The interviews served a dual purpose: (1) to generate exploratory insights on the current state of Artificial Intelligence awareness, usage, and resistance within different industrial contexts, and (2) to identify emergent themes and variables essential for designing a valid and context-sensitive questionnaire.

The interview guide was developed around four thematic domains: company profile (including size, sector, and turnover), level of digital maturity and existing IT infrastructure, current uses and perceptions of Artificial Intelligence technologies, and perceived barriers to adoption (e.g., financial, cultural, or regulatory). These themes were deliberately broad to allow for the emergence of unanticipated insights. The flexibility of the semi-structured format enabled us to adapt the questions in real-time based on the interviewee's background, fostering a more natural and reflective conversation.

The selection of interviewees was purposive selected to include entrepreneurs operating both within and outside the digital technology sector. This comparative design allowed us to contrast attitudes and experiences related to Artificial Intelligence adoption between digitally mature firms and those with limited exposure to

digital innovation. Notably, this distinction yielded valuable insights into how sectoral characteristics, organizational culture, and employee demographics mediate openness to technological change.

Importantly, the qualitative phase was not intended to produce generalizable results, but rather to provide an empirically grounded basis for the development of the survey instrument used in the quantitative phase. Through thematic analysis of the interview transcripts, we identified key constructs—such as the perceived utility of AI, organizational readiness, resistance factors, and training needs—which were operationalized into survey items. In this sense, the interview phase functioned as an essential diagnostic tool, enabling us to design a questionnaire that reflects the lived realities and language of the target population, thus increasing the content validity of the instrument.

Moreover, the qualitative findings helped refine the scope and structure of the questionnaire by highlighting sector-specific concerns and contextual constraints that may not be captured by standard theoretical models. This iterative process—moving from open-ended qualitative exploration to structured quantitative measurement—ensured both conceptual depth and empirical breadth in our research design.

The second stage of the research involved designing a survey instrument informed by the most salient insights derived from the interviews. After conducting the in-depth interviews, we realized a mapping of small and medium-sized enterprises (SMEs) to identify key actors to participate in the survey. In order to carry out a quantitative analysis, we needed to create a database of companies to be contacted via email, through which we would present the research and invite participation in an online questionnaire.

To build this database, we relied on the AIDA database (Analisi Informatizzata delle Aziende), a comprehensive commercial information platform that provides detailed financial and corporate data on Italian companies. Specifically, AIDA is a commercial database providing detailed information on over one million Italian companies, with a focus on limited liability companies. AIDA includes company profiles, financial statements, economic and financial indicators, ownership structures, corporate linkages, and other relevant business data. The platform is widely used in academic, financial, and professional contexts for research and analysis of Italian enterprises (https://dfka.it/area-crediti/aida/).

Our search strategy within AIDA focused on identifying limited liability companies that met the European Union's criteria for SMEs, specifically as applied in the Italian context. According to these criteria, SMEs are defined as companies with fewer than 250 employees and either an annual turnover not exceeding €50 million or an annual balance sheet total not exceeding €43 million. Additionally, we restricted our search to companies with either their registered or operational headquarters located in the region of Sicily.

This search yielded a total of 2.457 companies. Since AIDA does not include a specific email field but does provide company website URLs, we developed a Python script to extract email addresses by scraping these websites. Out of 1.299 websites available through AIDA, we successfully retrieved 761 email addresses. For the remaining companies, we manually searched online sources to identify contact information. Through this combined approach, we obtained a total of 2.081 valid email addresses. This set of 2.081 email addresses constitutes our target population for the distribution of the questionnaire and serves as the empirical basis for our quantitative investigation currently in progress.

2.1 Results

The qualitative phase of the research consisted of three in-depth interviews with managers from Sicilian SMEs operating in the software development and construction equipment sectors. These interviews revealed contrasting levels of awareness and use of Artificial Intelligence (AI) tools. Two companies demonstrated advanced familiarity with generative AI tools such as ChatGPT, Gemini, and GitHub Copilot, integrating them into areas such as software development, document analysis, customer support, and marketing. As one respondent explained: "We use it in various contexts—for code analysis, client quote evaluations, document summarization" (Interview 2). Another noted: "We are trying to foster a culture of AI usage... The tools are mature; we are the ones who need to mature" (Interview 1). A third interviewee, however, reported a very limited understanding of AI and highlighted resistance within the company due to a lack of digital competencies: "I am aware of my lack of knowledge… I wouldn't even know how to apply it in my daily work" (Interview 3).

Then, as emerged from the qualitative exploration, respondents from the digital sector demonstrated a high level of familiarity with Artificial Intelligence technologies, which were already integrated into various business functions, including software development, marketing, design, and administration. The most frequently cited benefits were increased efficiency, information synthesis, and process optimization. However, challenges such as the quality of AI-generated outputs, inappropriate technical applications, and concerns over displacement in creative roles were also noted.

Despite a generally high level of awareness, both interviewees emphasized the need for structured training and internal guidelines to ensure effective AI utilization. While Artificial Intelligence implementation was already well advanced in these companies, respondents stressed the importance of responsible use and attention to human capital. They expressed optimism about AI's potential—particularly in automating repetitive tasks and enhancing design processes—but also predicted a turbulent transition phase, potentially marked by a "natural selection" among firms with varying levels of preparedness. Their strategic outlook was both positive and pragmatic, highlighting the competitive advantage of adaptability and workforce training.

In contrast, interviews with entrepreneurs from non-digital sectors revealed a markedly different outlook. Significant resistance to technological change emerged, often attributed to generational dynamics within the workforce, deeply ingrained routines, and a lack of familiarity with AI tools and their potential benefits. This knowledge gap was compounded by a general disinterest in pursuing training initiatives in the field of artificial intelligence.

These findings informed the design of a structured questionnaire aimed at exploring the broader landscape of AI awareness, adoption, and perceived benefits or obstacles among Sicilian SMEs. The questionnaire is divided into four thematic sections: (1) company and respondent profile, (2) familiarity and attitudes toward AI, (3) current or potential applications of AI in business processes, and (4) perceived challenges and future outlooks related to AI implementation.

3 Discussion and conclusion

The initial findings from the qualitative interviews suggest a heterogeneous landscape of Artificial Intelligence awareness and adoption among Sicilian SMEs. On one hand, some companies—especially in the software and digital services sectors—are already experimenting with or integrating AI tools into various phases of their business operations. These firms display a proactive attitude and a strategic vision oriented toward innovation, albeit tempered by concerns about the quality of AI-generated outputs and the risk of over-reliance. On the other hand, companies from more traditional sectors appear to be at an earlier stage, often limited by a lack of knowledge, digital skills, and internal resources.

This divergence highlights the need for differentiated strategies in promoting the diffusion of Artificial Intelligence across the regional business fabric. The insights gained through the interviews were crucial in designing a questionnaire capable of capturing a broader and more nuanced understanding of the factors enabling or hindering AI adoption across sectors. The forthcoming quantitative phase of the research, based on a population of over 2.000 SMEs, will allow us to validate and expand these preliminary observations, offering empirical evidence on the current state of AI readiness in Sicilian enterprises.

This study can contribute to the growing body of literature on digital transformation in SMEs, while also providing practical implications for policymakers, innovation hubs, and training institutions seeking to support a more inclusive and sustainable approach to AI adoption in less digitally mature regions.

3.1 Implications and research limitations

The insights emerging from this exploratory phase offer several implications for both research and practice. First, the evident disparity in AI awareness and adoption among SMEs suggests that a one-size-fits-all approach to digital innovation may be ineffective. Tailored support policies, training programs, and sector-specific case studies are needed to address the specific barriers faced by different types of firms. Policymakers and regional development agencies could leverage these findings to design targeted interventions aimed at increasing digital competencies, especially in low-tech sectors or smaller enterprises.

From a research perspective, the study provides a grounded framework for further investigation, combining qualitative depth with the potential for broad quantitative validation. The structured questionnaire developed on the basis of interview data allows for the measurement of key variables such as perceived benefits, challenges, and future intentions related to AI.

However, this study also has some limitations. The qualitative phase was based on a small number of interviews, which, while rich in detail, may not fully capture the diversity of the regional SME ecosystem. Furthermore, the contact database was constructed using web scraping and manual search techniques, which—despite resulting in a large number of email addresses—may still present a selection bias, favoring firms with an online presence. Finally, as the quantitative phase is still ongoing, the conclusions drawn at this stage remain provisional.

Future research could expand the qualitative component to include a wider variety of sectors and firm sizes, and follow up the quantitative survey with case studies or longitudinal analyses to track the evolution of AI adoption over time.

4 Ethics declaration

All research is conducted in accordance with ethical principles.

5 AI declaration

AI-based tools such as ChatGPT were used to support the development of the Python script for web scraping email addresses from company websites, as well as to assist with translation tasks throughout the research process.

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Digital Finance for SMEs and Startups: Literature Review and Research Proposals

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Abstract

Financial digitalisation represents a systemic transformation that affects the entire business lifecycle, emphasising trust, transparency, sustainability, and innovation. Digital tools and platforms, such as crowdfunding and online peer-to-peer lending, increase access to credit and mitigate entry barriers, particularly for startups and small and medium sized enterprises. New technologies, including blockchain and big data, reduce information asymmetries, improve risk assessment, and strengthen stakeholder trust. The transparency of these platforms, associated with the use of reputational signals (for instance credit ratings and reviews), plays a pivotal role in attracting investors and optimizing capital allocation. The democratisation of access to finance supports innovative business models that are not just profit-driven but also oriented towards social and environmental value.

In this context, our research aims to systematically conceptualise digital finance tools, their specific benefits and challenges. The integration of advanced digital technologies into financial services allows greater access to lending resources and innovative funding models. Moreover, several issues and trends emerge, such as, the regulatory uncertainty, the data quality for privacy and cybersecurity, increasing use of AI to customise financial services and risk assessment. Specifically, our study presents a detailed analysis of the state of the art on the connections between digital finance and entrepreneurship, focusing on credit rating in the digital context. In addition, it also provides propositions through which firms can gain competitive advantage and highlights the democratization of credit and financial inclusion, made possible by reducing geographical and socio-economic barriers. Several implications emerge from a managerial point of view and from a theoretical perspective.

Keywords: Fintech, Crowdlending, Digital Marketplace, Digital Platform, Entrepreneurship

Paper type: Academic Research Paper

1 Introduction

The literature on crowdfunding and FinTech solutions highlights how these forms of financing integrate or replace traditional sources (i.e., venture capital, business angels, bank loans), demonstrating their crucial importance for small and medium sized enterprises (SMEs) and startups seeking capital (Martínez-Climent et al., 2018). A central aspect is the reduction of information asymmetry through platform reputation, investor feedback, lead investors' role, and the use of social networks and personal relationships (Shneor and Vik, 2020; Cai et al., 2021).

Crowdfunding platforms operate as digital intermediaries, offering screening, regulatory compliance, and fraud risk mitigation (Cai et al., 2021). The integration of emerging technologies enhances transparency and risk analysis while maintaining the central role of trust, which has now shifted towards algorithms and digital interfaces (Hawlitschek et al., 2018). Global regulations, such as the JOBS Act in the USA and European and Chinese regulations, significantly influence the diffusion of crowdfunding, with more permissive approaches (UK) or restrictive ones (China) determining the pace of its growth (Basha et al., 2021).

Beyond the entrepreneurial domain, crowdfunding also facilitates financing of social and sustainable projects, attracting investors motivated by positive impact (Wehnert and Beckmann, 2021). The success of crowdfunding campaigns depends on the quality of their content (pitch, images, videos), establishing a strong network, and active engagement with backers. These elements trigger the "herding effect" and enhance the project's reputation.

Our study aims to provide valuable assessments and insights for entrepreneurs, policymakers, and researchers interested in the potential of digital finance as a lever to support economic development, particularly for startups and SMEs.

The research questions to be addressed are the following: what is the current state of the literature on the relationship between digital finance and entrepreneurial activities? What is the state of the art regarding the risks of digital finance and credit rating for firms?

To answer these research questions, with a specific focus on startups and SMEs, we adopt a systematic approach in the search for works related to the topic of interest. We have followed the Preferred Reporting

Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009; Page et al., 2021). Overall, 172 articles have been included in the final analysis and the collected data has been analysed using the bibliometric methodology (Kraus et al., 2022).

This paper is structured as follows: the next section illustrates the theoretical background of the study; section 3 details the methodology used; section 4 shows the main finding and section 5 presents the discussion. Finally, the last section concludes and provides some implications, emphasising further research.

2 Theoretical background

Digital finance, such as crowdfunding and P2P lending, provides greater access to funding compared to traditional channels, reducing the entry barriers for SMEs and startups. Crowdfunding and P2P represent some digital lending tools that can outperform the conventional lending in the retail sector. Crowdfunding is not just a financial mechanism, but a relational process that relies on the ability to inspire and maintain funders' trust (Allison et al., 2015). Online P2P lending platforms denote an innovative model in which co-development and the creation of both economic and social value are central. P2P can complement traditional finance, offering small businesses credit options, serving customers who are less served by traditional channels (Liu et al., 2020).

These digital lending tools not only facilitate exchanges between firms and lenders but also foster collaborative dynamics that generate both economic and social benefits, through co-development models, value creation, and social engagement (Martínez-Climent et al., 2018).

A stream of research, under Signalling Theory, examines how digital lending platforms reduce information asymmetry in P2P markets, improving access to and conditions of credit (Lin et al., 2013 and 2016). Several works evaluate the phenomenon through quality signals and how initial investments, or emotional narratives could enhance the success of campaigns (Allison et al., 2015; Moss et al., 2015), while local funders respond more to personal relationships than to economic data (Agrawal et al., 2014). The role of investor trust is emphasised, also driven by the transparency of personal data (Burtch et al., 2014). Determinants of success of crowdfunding campaigns can be the credibility and reputation of the fundraiser, the size of the social network, the campaign quality (content, duration, videos, and images), transparency, and trust (Shneor and Vik, 2020).

Social Capital Theory has received increasing attention in crowdfunding research (Cai et al., 2021), emphasising the importance of trust and social capital in attracting funding through crowdfunding platforms. Trust acts as a bridge to overcome information asymmetries between entrepreneurs and potential funders. Also relevant are trust and the perception of reliability of loan applicants on P2P lending platforms.

A few studies highlight advantages and challenges compared to traditional methods (Bruton et al., 2015). Some authors suggest enhancing platform transparency and security through regulation while supporting the development of emerging technologies (blockchain, AI) in improving transparency and mitigating risks (Wehnert and Beckmann, 2021; Bargoni et al., 2024; Sharma et al., 2024).

There is a need to better understand the interaction between investors, entrepreneurs, and platforms, with a particular focus on the role of regulation and social dynamics in the context of startups and SMEs to support the growth of early-stage businesses.

These aspects will be further explored in the following sections, where the literature on the topic will be analysed.

3 Methodology

Our research design is based on the PRISMA framework (Moher et al., 2009; Page et al. 2021). To conduct an in-depth analysis of crowdlending and P2P lending, we identified a set of keywords by analysing the terminology related to the topic and we created a search query to be used in the Web of Science (WoS) database. This approach allows the inclusion of a broad and relevant set of articles, reducing the risk of omitting significant information from the analysis. The search query formulated is shown in Table 1.

Table 1 – Query, symbols and operators

Query	Symbols	Meaning and intended purpose
crowdlend* OR loan* OR lending OR "loan-based" OR "lending-based" OR ("peer-to-peer" OR "p2p") NEAR/1 lending) AND (platform* OR marketplace* OR "digital marketplace" OR "online marketplace" OR "online platform" OR "digital platform")	*	Truncation character to include words with the same root or slight terminological variations.
	Topic	Thematic data field, for example, title, abstract, and keywords.
	AND	Boolean operator to find database records containing all terms separated by this operator.
	OR	Boolean operator to find database records containing any of the terms separated by this operator.
	NEAR/x	To find records where the terms joined by this operator are within a specified number of words from each other.

The research covers the period from 1992 to January 2025, to include the whole development of the topic starting from the publication of the first article on the subject.

In the initial 'Identification' step, we found 2,434 contributions on the Web of Science database. In the second step, a screening was carried out and our search was refined by applying the following inclusion criteria: categories (Business, Management, Business Finance); language (English); source type (articles and Early Access, literature reviews were excluded); journal quality filter (e.g., ABS "4*", "4", and "3"); and contextual filter (documents not relevant to the topic). No specific time interval was defined.

We had a total of 172 articles in the final analysis.

We used the bibliometric methodology (Kraus et al., 2022) and the R-studio Bibliometrix package (http://www.bibliometrix.org/) (Aria and Cuccurullo, 2017), which provides a set of tools for quantitative research in bibliometrics and scientometrics, including the web software Biblioshiny. This analysis allows for the identification of the most popular topics addressed in a particular field. This approach, on one hand, helps to better understand how the research field is structured and how it is evolving. On the other hand, it allows for a deeper understanding of the impact of this research in the field of management.

4 Findings

Table 2 presents the metrics and impact of the leading journals or sources contributing to the analysed research field, using bibliometric indicators to assess their impact (h-index, g-index, and number of publications).

Although crowdfunding and lending platforms are related to finance, there is a limited presence of finance journals among the leading publications. The most significant journals come from fields such as management (Management Science) and decision-making (European Journal of Operational Research), with a high impact in terms of citations and published articles. Thus, the topic studied seems an interdisciplinary phenomenon related to technology, sociology, and management, rather than being treated as a strictly financial issue.

The most cited works locally and globally are shown in Table 3. Local citations refer to the number of times an article is cited by other articles within the selected dataset, while global citations refer to all citations received by the article from publications worldwide.

Table 2 – Main Journals and Impact

Source	H index	G index	M index	Tot Cit	Publ Num	Start Year
European Journal of Operational Research	9	9	0,265	903	9	1992
Journal of Business Research	7	10	0,241	131	10	1997
Management Science	7	9	0,538	1388	9	2013
Information Systems Research	6	12	1	145	13	2020
Journal of Corporate Finance	6	8	1	110	8	2020
Mis Quarterly	6	7	0,5	364	7	2014
Internet Research	5	8	0,714	91	8	2019
Review of Financial Studies	5	6	0,625	440	6	2018
European Journal of Finance	4	5	0,667	44	5	2020
Journal of Business Ethics	4	5	0,667	120	5	2020
Journal of Empirical Finance	4	4	0,5	73	4	2018
Journal of Financial Economics	4	4	0,444	176	4	2017

Source	H index	G index	M index	Tot Cit	Publ Num	Start Year
Journal of Management Information Systems	4	5	0,333	454	5	2014
International Review of Financial Analysis	3	4	0,5	18	6	2020
Journal of Financial and Quantitative Analysis	3	3	0,75	58	3	2022
Journal of International Financial Markets Institutions & Money	3	3	0,75	13	3	2022
Technological Forecasting and Social Change	3	5	0,5	138	5	2020
Entrepreneurship Theory and Practice	2	3	0,182	629	3	2015
Financial Management	2	2	0,286	152	2	2019
International Journal of Consumer Studies	2	2	0,286	42	2	2019
International Journal of Electronic Commerce	2	2	0,125	139	2	2010
International Journal of Entrepreneurial Behavior & Research	2	2	0,4	22	2	2021
International Journal of Entrepreneurship and Innovation	2	2	0,2	52	2	2016
Journal of Business Venturing	2	2	0,074	152	2	1999
Journal of Financial Stability	2	3	0,4	128	3	2021

The research highlights how P2P lending platforms are transforming the financial environment, influencing investment decisions, risk assessments, and relationships between participants.

On the one hand, the importance of 'social' and network information emerges in the analysis of information asymmetry, where the quality of social connections (Lin et al., 2013) and data from social media (Ge et al., 2017) can reduce the risk of default.

On the other hand, investment decisions are driven by market mechanisms (Wei and Lin, 2017), geographical distortions (Lin and Viswanathan, 2016), and cultural differences (Burtch et al., 2014), while instance-based assessment models provide new perspectives for credit risk assessment (Guo et al., 2016).

There is a debate on whether P2P lending platforms act as substitutes or complements to traditional banks (Tang, 2019; Vallee and Zeng, 2019), while in the social domain, the role of intrinsic and extrinsic factors (Allison et al., 2015) and signals of virtuousness and entrepreneurial orientation (Moss et al., 2015) in determining the success of campaigns and the strength of repayments is highlighted.

Table 3 - Most cited documents

Documents	Local citations	Global citations
Lin, M., Prabhala, N. R., and Viswanathan, S. (2013). Judging borrowers by the company they keep: Friendship networks and information asymmetry in online peer-to-peer lending. Management science, 59(1), 17-35.	73	700
Wei, Z., and Lin, M. (2017). Market mechanisms in online peer-to-peer lending. Management Science, 63(12), 4236-4257.	31	149
Lin, M., and Viswanathan, S. (2016). Home bias in online investments: An empirical study of an online crowdfunding market. Management science, 62(5), 1393-1414.	29	346
Tang, H. (2019). Peer-to-peer lenders versus banks: substitutes or complements? The Review of Financial Studies, 32(5), 1900-1938.	22	276
Burtch, G., Ghose, A., and Wattal, S. (2014). Cultural differences and geography as determinants of online prosocial lending. MIS quarterly, 38(3), 773-794.	20	262
Guo, Y., Zhou, W., Luo, C., Liu, C., and Xiong, H. (2016). Instance-based credit risk assessment for investment decisions in P2P lending. European Journal of Operational Research, 249(2), 417-426.	19	212
Allison, T. H., Davis, B. C., Short, J. C., and Webb, J. W. (2015). Crowdfunding in a prosocial microlending environment: Examining the role of intrinsic versus extrinsic cues. Entrepreneurship theory and practice, 39(1), 53-73.	15	401
Vallee, B., and Zeng, Y. (2019). Marketplace lending: A new banking paradigm? The Review of Financial Studies, 32(5), 1939-1982.	15	92
Ge, R., Feng, J., Gu, B., and Zhang, P. (2017). Predicting and deterring default with social media information in peer-to-peer lending. Journal of Management Information Systems, 34(2), 401-424.	12	134
Moss, T. W., Neubaum, D. O., and Meyskens, M. (2015). The effect of virtuous and entrepreneurial orientations on microfinance lending and repayment: A signaling theory perspective. Entrepreneurship theory and practice, 39(1), 27-52.	10	228

The main results of our analysis suggest the existence of four key research areas, which are described in detail below.

New perspectives on crowdfunding and P2P lending emerge in a first area, revealing that crowdfunding platforms do not simply function as financial intermediaries but operate as genuine "institutional entrepreneurs", influencing rules and behaviours in the market (Mollick and Nanda, 2016). Numerous factors shape funding decisions, including the importance of reputation and social signals (Lin et al., 2013; Iyer et al., 2016), informational constraints and behavioural dynamics (Ge et al., 2017)

A second area includes studies on crowdfunding and alternative finance which highlight how project communication, and social networks influence the success of campaigns (Mollick, 2014). The adoption of strategic linguistic styles (Sonenshein, 2011), the use of advanced credit scoring models and the application of economic theories of information (Agrawal et al., 2014) underline the role of transparency and trust in the decision-making process of investors.

In another area, the focus is on P2P lending and some perspectives on informational asymmetries, emphasising the importance of "soft" information in the decision-making process (Iyer et al., 2016) and the risks of discrimination against borrowers (Pope and Sydnor, 2011). Well-structured market mechanisms in online P2P lending can mitigate adverse selection (Wei and Lin, 2017) and act as a complement or alternative to traditional bank credit offerings (Tang, 2019).

A last area, focused on digital innovation, emphasises the role of technological innovations in reducing intermediation costs, expanding access to financial services, and developing new business models. The literature on lending markets and imperfect information (Akerlof, 1970; Diamond, 1984) demonstrates how information asymmetries can lead to adverse selection and credit rationing phenomena (Stiglitz and Weiss, 1981). At the same time, it highlights the importance of signals (Spence, 1973) and long-term relationships (Petersen and Rajan, 1994) as mechanisms to mitigate these issues.

5 Discussion

Crowdfunding and P2P lending emerge as forms of financing capable of redefining traditional intermediation logic and promoting financial innovation and inclusion, with an interplay of technological, social, and regulatory factors. It is important to highlight the credit democratization, made possible by the reduction of geographical and socio-economic barriers (Tang, 2019; Agrawal et al., 2014; Eckhardt et al., 2019; Butticè, 2017).

The dominant theoretical models are Signalling Theory and Social Capital Theory, with a focus on reducing information asymmetry, and discrimination in lending. Transparent information management, strong relational networks, and risk assessment are essential for building trust in these digital platforms. Their design should strike a balance between transparency, and innovation (Basha et al., 2021). Emerges the role of technological innovations in reducing intermediation costs and expanding access to financial services.

Some studies examine how lenders assess the credibility of aspirants based on visible signals and available information on their online profiles. Several elements influence this perception of reliability: visual signals (i.e. photos and profile appearance), descriptions of the applicant's story or the reason for the loan, ratings and reviews from other lenders. The narratives denote a key element in fostering strategic change (Sonenshein, 2011). In the digital finance contests, credit ratings rely on dynamic behavioural data, such as: online sales performance, customer reviews, social media activity. Some related risks concern the opacity of AI models, big data use, privacy and ethical questions. These factors seem critical because, specifically in the context of P2P microfinancing, there are no direct and personal relationships between the lender and the applicant. Therefore, lenders rely on indirect indicators to decide whether to financially support a project. A high perception of reliability increases the likelihood of success for the applicant in receiving the loan (Gen Li et al., 2019; Shafi and Mohammadi, 2020).

Startups and SMEs, especially in their early stages, find in crowdfunding an opportunity to test innovative projects and strengthen their capital base (Cumming et al., 2013, 2022, 2023; Bruton et al., 2015). An inclusive orientation of crowdlending emerge, promoting socially driven finance and supporting small scale entrepreneurial initiatives, often aimed at individuals with limited collateral. Unconventional strategies emerge for credit delivery, enabling simplified access to capital, particularly for firms excluded from traditional banking channels. Central dimensions of P2P platforms regard the challenges of information asymmetry: analysing data on borrowers is crucial to establish appropriate interest rates and minimize defaults. Personal networks and online reputation can serve as informal guarantees, reducing perceived risk and encouraging participation from new investors. Credit rating plays a pivotal role, especially for startups and SMEs, to facilitate interactions between investors and funding applicants by enhancing trust while mitigating associated risks (Wang et al., 2021). The primary tools for measuring credit ratings are linked to qualitative indicators, like the experience and

expertise of the entrepreneurial team, the reputation and reviews gained on other platforms, the quality of project communication (videos, images, and storytelling), the public engagement and social media interactions, and sentiment analysis to evaluate the perceived reliability of potential investors.

6 Conclusions, implications and further research

This study develops a systematic literature review and identifies key challenges for the digital lending ecosystem and new frontiers in alternative finance, highlighting the relevance of information disclosed in unregulated markets, and its influence on investment decisions (Bourveau et al., 2022). In online lending investments, a marked "home bias" persists, where geographical and cultural proximity between the lender and borrower influences lending decisions (Burtch et al., 2014). Financial knowledge and risk propensity drive to use P2P lending platforms more frequently (Han et al., 2019). The digitalisation and the creation of a credit ecosystem represent the context in which P2P lending can operate both as a complement and an alternative to traditional banking credit, particularly for borrowers with intermediate risk profiles or those located in underserved areas by conventional banks (Tang, 2019).

Crowdfunding and P2P digital lending, as financial tools, overcome difficulties of startups and SMEs in providing guarantees (required for bank financing), allow a reduction costs linked to the dynamics of the transactions. P2P lending platforms, often aimed at supporting small businesses or ethical projects, facilitate access to credit for startups and businesses, particularly in contexts with limited funding options.

Several implications emerge. From a theoretical point of view, special attention should be given to fundraising for startups and SMEs, understanding the synergies among traditional and innovative financing tools assuming a relevant role in the growth of these kinds of companies. There is a need to understand the interaction among investors, small entrepreneurs, and digital lending platforms, with a focus on the social dynamics within the context of SMEs and startups.

Regarding managerial implications, the main challenge is to signal the business project quality. A clear strategy in information systems and the contribution of independent directors with broad relational networks are essential. Moreover, the risk of fraud on the lending platforms is another controversial aspect that involves investors and their company's choices.

Regulatory implications remain central to ensuring a favorable environment for the development of digital lending tools and for supporting business growth. In a context with information asymmetries and fraudulent behaviors, it needs the implementation of effective enforcement strategies. At the same time, the growth of digital lending platforms raises valuable regulatory questions.

Future research should investigate the importance of alternative lending solutions to support the growth of early-stage businesses, highlighting advantages and challenges compared to traditional methods. Qualitative and quantitative analysis could be performed to examine the behavior of digital financing operators, providing insight into the complementarity or substitute roles among new and traditional financial forms. Other potential research areas to explore include the big data role in achieving superior credit ratings in a digital environment, and the blockchain financing mechanisms in enhancing trust and transparency in startup companies.

7 Acknowledgment

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8 Ethics declaration

Ethical approval was not required for the research presented in this paper.

9 AI declaration

No AI tools were used in the development of this paper.

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Enterprise Architecture Model for Knowledge Assets

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Abstract

Enterprise architecture (EA) is a fundamental framework for aligning technology, processes, and information systems with organizational strategy. In the context of knowledge assets and artificial intelligence (AI), EA provides the necessary structure for effective knowledge management and AI integration. However, traditional EA models face limitations in handling dynamic knowledge flows and AI-driven insights. This summary explores EA's role in managing knowledge, the impact of AI on knowledge assets, and necessary modifications to improve AI integration.

EA plays a crucial role in structuring and governing knowledge within organizations. Frameworks like TOGAF and Zachman facilitate the creation of repositories, workflows, and governance structures to optimize knowledge storage, retrieval, and dissemination. In AI-driven organizations, EA ensures that AI initiatives align with knowledge management strategies, preventing disruptions while enhancing decision-making capabilities.

Knowledge serves as both an input and output in AI systems. High-quality, structured data is essential for training AI models, while AI-generated insights contribute to organizational knowledge. However, poorly curated or siloed knowledge assets can lead to biased models and unreliable results. Enterprise architects must ensure the integrity, accessibility, and interoperability of knowledge assets.

Conventional EA models struggle with:

- A lack of flexible standards for data pipelines, making it difficult to integrate AI-driven DataOps and MLOps.
- Siloed architectures that limit knowledge-sharing and AI effectiveness.
- Static frameworks that do not support real-time knowledge processing.

To enhance AI integration, organizations should:

- Adopt modular, dynamic EA metamodels supporting microservices and AI scalability.
- Implement knowledge-centric frameworks incorporating semantic models and ontologies.
- Integrate DataOps and MLOps pipelines to facilitate continuous AI model refinement.
- Foster a knowledge-sharing culture through training and transparent governance.

By evolving EA frameworks and fostering a collaborative organizational culture, businesses can optimize knowledge management and AI utilization for sustained performance.

Keywords: Architecture, assets, knowledge management.

Paper type: Practical Paper

1 Introduction

Artificial Intelligence (AI) is increasingly promoted as a transformative force capable of reshaping business efficiency and driving sustainability efforts. From intelligent automation to decision support, AI promises both performance enhancements and more responsible, sustainable practices. However, both AI integration and sustainability require one fundamental capability: the organization must be able to explain, model, and measure itself. Without internal coherence and visibility, AI cannot align with real business needs, and sustainability metrics risk remaining superficial.

In many organizations, this requirement is directly linked to enterprise-level business analysis. The quality of business models, data ecosystems, and process understanding determines how well an organization can articulate its goals and adapt to emerging technologies. Failures in digital transformation and sustainability initiatives often stem from a lack of integration between business vision, data strategy, and technology execution (Brynjolfsson & McAfee, 2017).

To avoid such pitfalls, we must explore the models that structure how organizations think about themselves. Enterprise Architecture (EA)—as a means of digital twin construction for the enterprise—emerges as a crucial solution. By linking strategy, business functions, IT, and data, EA provides a foundation for integrating AI and achieving sustainability goals. This paper investigates the enterprise architecture approach, evaluates its strengths and limitations, and proposes necessary modifications to align with future-oriented, knowledge-centric, AI-enabled organizations.

2 Enterprise Architecture (EA) as a framework for knowledge management and AI integration

Enterprise Architecture offers a formal structure to describe and manage an organization's processes, systems, data, and strategy. Originally developed to bridge business-IT alignment (Zachman, 1987; TOGAF, 2018), EA has evolved into a comprehensive framework that supports organizational agility and transformation. EA provides organizations with a high-level blueprint to plan and manage change in a structured and coherent way.

For AI integration, EA plays an enabling role. It creates an architectural layer that governs the lifecycle of data, systems, and applications needed for AI deployment (Lankhorst, 2017). At its core, EA aligns technology with strategic goals through a set of interrelated models—business, application, data, and technology architectures. These models ensure that AI solutions are not implemented in isolation but are linked to operational and strategic objectives.

Knowledge management is another domain tightly connected to EA. As organizations generate and process increasingly complex data, EA frameworks help manage knowledge about the enterprise and its value chains. AI solutions, such as natural language processing or recommender systems, rely heavily on well-structured, context-rich data ecosystems. EA ensures these ecosystems are interoperable and coherent with enterprise-wide standards.

By enabling traceability from high-level strategy down to infrastructure and data flows, EA facilitates responsible AI integration. It allows for governance mechanisms, accountability models, and ethical safeguards to be embedded directly into enterprise systems. This integrated perspective is critical to support scalable and transparent AI usage (Weill & Ross, 2004).

3 Enterprise Architecture and knowledge management

Enterprise Architecture frameworks play a crucial role in structuring and governing knowledge flows across organizations. This role extends far beyond information systems, touching how teams collaborate, how decisions are made, and how insights are disseminated. Through its layered design, EA models map the organization's structure in a way that identifies where knowledge is created, stored, and used (Dietz, 2006).

Prominent EA frameworks, including TOGAF (The Open Group Architecture Framework) and the Zachman Framework, explicitly prioritize coherence and adaptability. These characteristics are essential for knowledge management, particularly in environments experiencing rapid technological change. EA frameworks help define and connect repositories (e.g., enterprise data lakes, document stores), workflows (e.g., case handling, escalation paths), and governance systems (e.g., compliance reporting, knowledge custodianship) (TOGAF, 2018).

This governance perspective is critical. EA does not only structure how knowledge is organized, but also enforces standards that determine who has access to what knowledge, under what conditions, and through which systems. In data-intensive organizations, these questions are tightly linked to compliance and trust—factors increasingly vital in an AI-driven world.

AI initiatives must be synchronized with EA strategies to succeed. An AI deployment not anchored in enterprise knowledge architecture risks becoming a point solution—disconnected, ungoverned, and potentially harmful. For example, AI models trained in isolation may reproduce outdated business logic or amplify organizational biases. Aligning AI projects with EA ensures that AI systems reinforce, rather than fragment, the enterprise knowledge ecosystem (Gregor & Hevner, 2013).

Moreover, EA supports digital traceability—the ability to track the lifecycle of information from input to decision. This capacity is particularly important for AI explainability and auditability, two attributes required under emerging regulatory frameworks (e.g., EU AI Act, 2023). Thus, EA's structural approach serves as both a technical and ethical scaffold for the responsible use of AI within knowledge-centric organizations.

4 The role of knowledge in AI usage

Knowledge is both the lifeblood of AI and its most valuable product. Within enterprise settings, AI systems are deeply reliant on access to high-quality, structured, and contextualized knowledge. Conversely, their outputs—recommendations, predictions, insights—are themselves forms of knowledge that must be governed, interpreted, and integrated into ongoing operations. This dual role places knowledge management at the core of any sustainable and effective AI strategy.

4.1 Knowledge as inputs

AI systems, particularly those leveraging machine learning (ML), rely heavily on curated, accurate, and context-rich data. This data represents the distilled knowledge of organizational processes, customer behavior, market dynamics, and operational performance. For AI models to learn meaningful patterns, this data must be available in structured formats and governed by sound metadata and ontological standards (Russell & Norvig, 2021).

The processes that prepare knowledge for AI—data curation, knowledge engineering, and semantic modeling—are not trivial. They involve mapping business concepts to data, cleaning and aligning datasets, and creating taxonomies and ontologies that reflect organizational semantics. Without these steps, AI systems risk being built on incoherent or biased foundations. Indeed, failures in AI projects frequently trace back to weaknesses in the knowledge pipeline rather than flaws in algorithmic design (Gebru et al., 2021).

Enterprise Architecture contributes here by providing a formal structure to organize these preparatory processes. The EA framework defines how data is collected, classified, stored, and transformed—thus ensuring consistency and interoperability across the enterprise. In particular, it provides clarity on the provenance, trustworthiness, and purpose of data, which are essential for AI model training and validation.

4.2 Knowledge as output

Just as AI systems require knowledge to function, they also generate new knowledge that must be absorbed back into the enterprise. Predictive models, diagnostic tools, recommendation engines, and natural language interfaces all produce insights. These insights must be actionable, traceable, and integrated into business processes to deliver value.

Here, again, EA provides critical scaffolding. It ensures that the outputs of AI systems feed into decision-making structures, operational workflows, and organizational memory. For instance, enterprise knowledge graphs—often modeled and maintained as part of the EA initiative—can serve as both input and output interfaces for AI, bridging structured knowledge representation with dynamic insight generation (Paulheim, 2017).

More importantly, EA defines governance for how AI outputs are consumed. Decisions influenced by AI must be auditable, explainable, and aligned with business ethics and compliance requirements. By framing knowledge flows within organizational governance models, EA enables responsible and transparent AI use (Floridi et al., 2018).

4.3 Risks of poor knowledge management

When knowledge management is fragmented or weak, AI performance suffers significantly. Poorly curated knowledge leads to biased models, unreliable insights, and ultimately poor decisions. Data silos prevent holistic training sets, lack of versioning creates reproducibility problems, and ungoverned feedback loops can result in concept drift and degradation of model quality over time (Sculley et al., 2015).

Enterprise architects have a mandate to prevent these outcomes by designing knowledge systems that ensure data integrity, accessibility, and interoperability. This role includes selecting appropriate tools, defining reference architectures, implementing shared vocabularies, and aligning stakeholders across business and IT domains.

As AI becomes embedded in more strategic decisions, the stakes grow higher. Misuse of AI due to poor knowledge quality can result in reputational damage, regulatory sanctions, or significant financial losses. Thus, knowledge quality and its management via EA become risk mitigation imperatives as well as value creation strategies.

5 Limitations of traditional EA metamodels in handling knowledge and AI

While Enterprise Architecture offers a promising framework for managing AI and knowledge flows, traditional EA metamodels exhibit structural and conceptual limitations. These limitations hinder their ability to fully support the dynamic, real-time, and iterative nature of AI-centric knowledge management practices.

5.1 EA is a framework for knowledge management—not a knowledge management framework

First and foremost, it is important to recognize that EA frameworks—such as TOGAF and Zachman—are designed to model and manage enterprise components and their interactions. They provide structure for aligning strategy, processes, systems, and data. However, they are not inherently designed as knowledge

management frameworks. EA creates space for knowledge within and about the enterprise, but does not treat knowledge as a dynamic, evolving asset in itself (Lankhorst, 2017) (Figure 1).

This means that EA metamodels tend to focus on static contexts (applications, roles, capabilities) and relationships, but they lack dynamic constructs for AI to operate on them. As AI systems become more central to enterprise functioning, this lack of a dedicated "knowledge and learning" layer becomes a bottleneck.

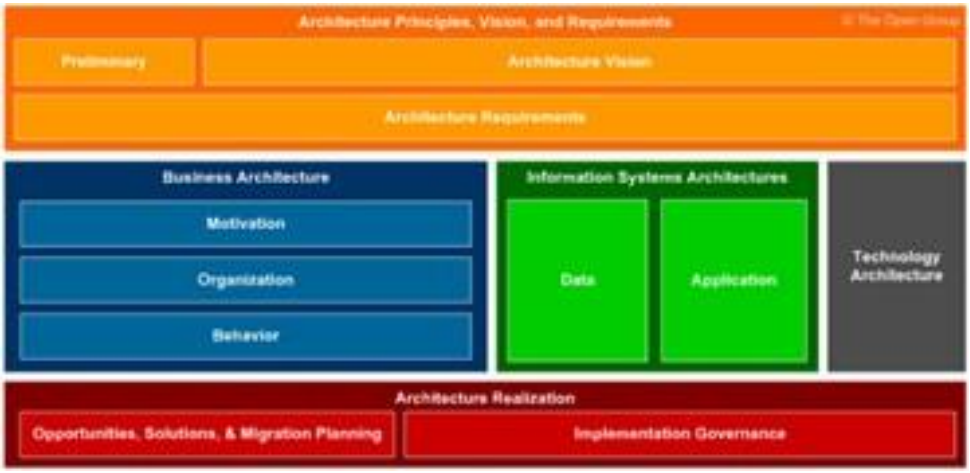


Figure 1: TOGAF considers data and context, but not its own status as data, or a translation of data into business knowledge. As such it lacks an appropriate space for Intelligence models, both natural and artificial.
Source: TOGAF Standard 10

5.2 Lack of flexible standards for data and knowledge pipelines

AI systems require agile, iterative data pipelines—often implemented through DataOps and MLOps practices (Kreuzberger, Kluge, & Bruns, 2020). Traditional EA frameworks were not built with such practices in mind. Their governance-heavy, waterfall-oriented methodologies struggle to accommodate rapid model iteration, continuous data integration, and experimentation loops that characterize modern AI development.

This misalignment creates friction between EA teams and data science teams. EA calls for long-term stability and formal approvals; AI requires short-term agility and empirical tuning. Without architectural accommodations for continuous integration and deployment (CI/CD) of AI models, EA can inadvertently stifle innovation and delay time-to-value.

5.3 Siloed Architectures and Data Fragmentation

Another critical limitation is the persistence of siloed systems within many EA implementations. Even when EA frameworks are adopted, organizational inertia often leads to fragmented data ownership, tool mismatches, and incompatible knowledge representations. These silos prevent AI systems from:

- accessing comprehensive, standardised datasets and limit the ability to generate cross-functional insights (Zhao et al., 2017).
- addressing structural optimisations.

Traditional EA approaches tend to reinforce vertical domains (e.g., HR, Finance, Operations) rather than promote horizontal data integration. This verticality is insufficient for AI use cases, which often depend on blended data sources and complex, multi-domain reasoning.

5.4 Limited Support for Real-Time Knowledge Processing

Modern AI systems increasingly rely on real-time or near-real-time data processing. Whether it's fraud detection, predictive maintenance, or customer engagement, the ability to access and reason over knowledge dynamically is key to competitive advantage.

However, most EA models are built around static representations—capability models, application portfolios, data catalogues— that can be used for dynamic impact analysis, though it remains structural and theoretical. They do not easily accommodate event-driven architectures, streaming analytics, or real-time reasoning engines (Marjanovic & Freeze, 2012). As a result, EA implementations lag behind the operational tempo required for AI-enabled responsiveness.

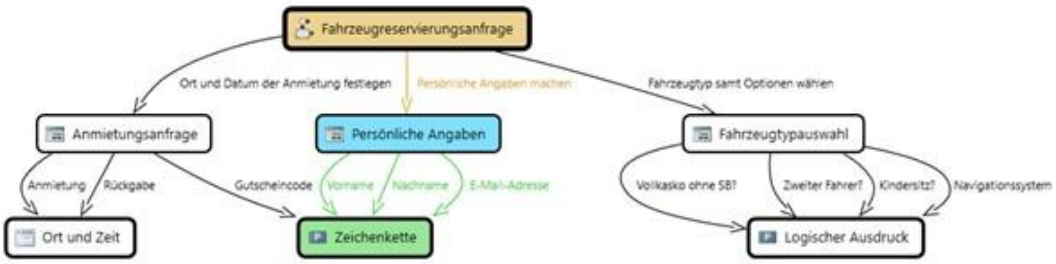


Figure 2: Static impact analysis extracted from an enterprise architecture representation.
Source: MID Innovator

5.5 A missing cognitive layer

Finally, traditional EA frameworks can but often do not model cognitive assets—the beliefs, assumptions, and mental models that drive organizational behavior (Figure 1). This is a normal result of a data-centric fashion in the industry. Yet, these are crucial for understanding how knowledge is interpreted, how decisions are made, and how AI should align with or challenge current thinking.

AI can produce insights, but unless those insights are embedded into workflows, beliefs, and decisions, they generate little value. Without an architectural view of cognition, learning, and knowledge feedback, EA misses a key component of the AI knowledge cycle (Nonaka & Takeuchi, 1995).

6 Modifications to improve knowledge management and AI integration

Enterprise Architecture (EA) must evolve from its traditional role into a dynamic, knowledge-centric framework capable of enabling AI initiatives, not unlike the principle of the Digital Twin. As organizations increasingly depend on AI to achieve strategic goals and adapt to complexity, modifying EA to support fluid knowledge flows, continuous learning, and real-time responsiveness becomes imperative. This section explores key modifications and enhancements required for EA frameworks to support modern knowledge management and AI integration effectively.

6.1 Dynamic and modular metamodels

Traditional EA metamodels, such as TOGAF's Content Metamodel, provide a static, materialistic representation of business, data, application, and technology domains (The Open Group, 2018). While useful for long-term planning, these static models lack the agility needed to support AI-driven systems, which require contextualised knowledge, frequent iterations, feedback loops, and adaptability.

Dynamic and modular metamodels, by breaking down functionality into independently deployable components, align with the iterative nature of AI development (Newman, 2015). Incorporating such architectural paradigms into EA allows for modular knowledge and data components that can be updated, replaced, or recombined without affecting the broader system.

This would also allow for dynamic impact analysis over structures, and thus, architectural optimisation.By providing machine-readable, self-describing architecture elements, EA increases interoperability and improves automated reasoning and AI-assisted architecture management.

6.2 From data-centric to knowledge- and capability-centric models

A significant paradigm shift is required: moving from data-centric EA (functional elements) to frameworks that prioritize knowledge, skills, and capabilities (nonfunctional elements) as first-class architectural entities. While data remains foundational, it must be contextualized within broader knowledge systems that encompass semantics, use cases, business meaning, and strategic intent (Dietz, 2006).

Ontologies and knowledge graphs—used extensively in semantic web and AI applications—can be integrated into EA metamodels to represent domain knowledge more precisely (Paulheim, 2017). These structures enable richer inference, support explainability, and improve the relevance of AI-generated insights.

TOGAF's standard metamodel can be extended to include knowledge assets, skill definitions, and learning dependencies. For example, Figure 34 from the TOGAF 9.2 documentation proposes a layered content model, but could be augmented to add layers for organizational learning and AI feedback mechanisms (The Open Group,

2018). This would recognize knowledge not just as a byproduct of operations, but as a central architectural concern.

6.3 Integration of continuous improvement at the level of architecture and value chain

AI initiatives thrive on continuous experimentation, feedback, and improvement. EA must therefore embed continuous integration and continuous delivery (CI/CD) principles, not only in software pipelines but at the architecture level. This includes:

- DataOps: Applying DevOps principles to data analytics workflows, focusing on automation, quality, and collaboration (Erl et al., 2021).
- MLOps: Managing the lifecycle of machine learning models, including versioning, retraining, testing, and monitoring (Kreuzberger et al., 2020).
- KnowledgeOps: Managing the lifecycle of information, knowledge, and the soft skills that underline processes is a key element to supporting conscious continuous improvement.

EA should define reference architectures that include reusable pipeline components for data ingestion, model training, and deployment, and position these within business processes. These components must also interact with governance layers to ensure compliance, traceability, and ethical standards in AI deployment.

Furthermore, continuous improvement loops should span the entire value chain. EA should model not only operational capabilities but also how those capabilities evolve through learning, AI feedback, and cross-functional knowledge sharing.

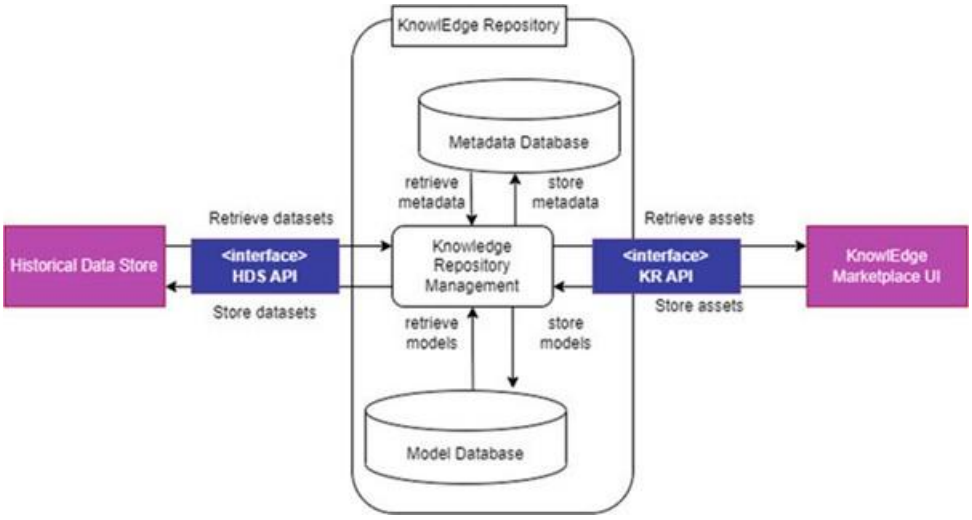


Figure 3: A model for AI model integration within an enterprise.
Source: Nizamis et al 2023

6.4 Culture and organizational change management

Technology alone does not drive transformation. For knowledge and AI integration to succeed, organizations must cultivate a knowledge-sharing culture supported by governance, incentives, and structural enablers. EA has a crucial role to play in modeling and enabling these changes. A modern EA function must include:

- (Transversal) Communities of practice modeled as organizational entities.
- (Contextual) Training programs and knowledge transfer mechanisms mapped to capability development.
- (Structural) Governance models that promote cross-functional collaboration, transparency, and accountability.

Change management frameworks—such as Kotter's 8-Step Model or ADKAR—can be embedded into EA roadmaps to ensure that the transition toward AI-enabled knowledge management is adopted sustainably (Hiatt, 2006). EA should make explicit the dependencies between cultural norms, digital skills, and architecture goals.

6.5 Real-time knowledge systems

AI systems often operate in environments that require real-time or near-real-time decision-making. Traditional EA frameworks, which are primarily descriptive and retrospective, must be extended to handle real-time knowledge flows. This can be achieved through:

- Event-driven architectures (EDA): Enabling systems to respond to triggers from internal or external sources in real-time. EA should map event types, sources, and consumers at the architectural level (Chen et al., 2014).
- Streaming analytics: Incorporating tools into EA blueprints to support live data processing.
- AI observability layers: Capturing telemetry on how AI models behave, what decisions they influence, and how outputs are interpreted. These insights feed into continuous knowledge refinement loops.

Real-time knowledge systems should be architected with scalability, low-atency, and explainability in mind—ensuring that they can evolve alongside business needs and regulatory demands.

7 Conclusion

Enterprise Architecture stands at a critical inflection point. Traditionally tasked with aligning IT systems to business goals, it now faces the dual imperative of integrating AI and fostering sustainable, knowledge-driven organizations. This duality requires EA to evolve from a static documentation function into a living, learning structure that continuously adapts to organizational feedback, new insights, and dynamic knowledge flows.

7.1 EA as a Catalyst for Knowledge-Driven AI

Throughout this paper, we have argued that AI is inseparable from knowledge management. AI's performance, fairness, and strategic value depend on access to structured, high-quality, and well-governed knowledge. Similarly, AI systems generate new forms of knowledge-insights, classifications, recommendations - that must be interpreted, contextualized, and institutionalized.

Enterprise Architecture plays a central role in this cycle. It provides the structure, models, and governance mechanisms necessary to align AI initiatives with organizational goals and constraints. However, to fulfil this role, EA must undergo significant transformation.

7.2 The case for a knowledge-centric EA

Traditional EA frameworks are not inherently designed to manage knowledge as a dynamic and strategic asset. They must be augmented with:

- Modular, dynamic metamodels to accommodate rapid innovation.
- Semantic models, ontologies, and knowledge graphs to support AI reasoning and integration.
- CI/CD, DataOps, and MLOps pipelines to enable AI lifecycle management.
- Real-time processing and event-driven systems to support responsive decision-making.

In doing so, EA becomes not just a framework for managing systems and processes, but a platform for organizational learning. It enables enterprises to become more adaptive, transparent, and capable of leveraging AI for competitive and sustainable advantage.

7.3 Toward a culture of sustainable AI

Ultimately, the integration of AI into enterprise knowledge systems is not only a technical challenge—it is a cultural and ethical one. Organizations must embrace continuous learning, transparency, and collaboration. EA can model and support these cultural shifts by including:

- Shared knowledge repositories and common vocabularies.
- Mechanisms for trust, accountability, and auditability in AI decisions.
- Pathways for human oversight and ethical reflection on AI outcomes.

By embedding these principles in the very architecture of the enterprise, organizations can ensure that AI serves not only efficiency goals but also broader social and environmental responsibilities.

7.4 Final reflection

The convergence of AI, knowledge management, and enterprise architecture defines a new frontier for digital transformation. As businesses seek to navigate volatility, complexity, and sustainability, a flexible, knowledge-centric EA can serve as both compass and engine.

Rather than treating AI as an external technology to be bolted onto existing structures, forward-thinking organizations will recognize it as part of the evolving fabric of enterprise knowledge. EA, properly reimagined, is the loom on which that fabric can be woven.

8 Ethics declaration

No ethical clearance was necessary for the current work.

9 AI declaration

An artificial tool was used in the development of this paper as follows:

- To detect missing elements or weaknesses of the original argumentation, leading to further research.
- To provide a template paper structure based on the argumentation. Structure which was manually reviewed, edited, and corrected by the author.
- To write the first draft text based on the argumentation, structure, and references provided by the author. This draft was reviewed, edited, and corrected by the author.

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Looking for Co-Founders: Exploring the Co-Founders Selection Process in Venture Studios

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Abstract

Startups' success is strongly influenced by the capabilities, traits, and dynamics of their founding teams. While the role of co-founders in shaping venture outcomes is well established in entrepreneurship literature, little is known about how they are selected in contexts where founding teams are externally assembled, such as within venture studios. Venture studios represent a distinct form of new venture creation (NVC), where organizations (rather than individuals) initiate and structure the entrepreneurial process. Central to this model is the strategic recruitment of external co-founders who are expected to lead ventures they did not originate. The goal of this paper is to investigate how co-founder selection processes are designed and implemented within venture studios, with a focus on the underlying decision criteria and timing strategies adopted in practice.

This research adopts a qualitative, exploratory design based on multi-case illustrative studies of three European venture studios: Rocket Internet, Hexa, and Mamazen. Findings reveal that the co-founder search in venture studios is a deliberate strategic activity. Rather than being recruited solely for executional tasks, co-founders are selected for their entrepreneurial mindset, risk appetite, and capacity to take full ownership of the venture. Venture Studios do not hire CEOs but rather recruit founder-like individuals to lead ventures alongside them, offering shared equity and full operational responsibility from day one. This inversion of traditional entrepreneurial logic positions venture builders as orchestrators of resources and talent, aligning with Gartner's (1985) view of entrepreneurship as an organizing activity and the Resource-Based View's emphasis on leveraging human capital.

Keywords: Venture Studio, Venture Building, New Venture Creation, Co-Founders, Entrepreneurship

Paper type: Academic Research Paper

1 Introduction

The success of startups is intricately tied to the characteristics and dynamics of their founders, who drive a venture's vision, strategy, and execution. Founders' personality traits (Salmony & Kanbach, 2020), professional experiences, social capital and key capabilities (Eisenhardt & Martin, 2000; Zahra et al., 2006) play crucial roles in shaping individual behaviour and the broader trajectory of their organisations. Founder-related factors, such as knowledge, experience, competence, and team dynamics, strongly influence startup performance (Oe & Mitsuhashi, 2012; Lazar et al., 2020), affecting a venture's ability to innovate, attract funding, and scale. Founders are not only strategic decision-makers but also symbolic and cultural anchors of a venture, shaping its vision, identity, and direction from inception. Also, founders who have built strong relationships within their professional networks are better positioned to recruit key talent and attract investment, which is essential for the progress of new venture creation (NVC) (De Carolis et al., 2009).

Despite the central role of co-founders in shaping venture outcomes, little is known about the organizational processes through which co-founders are identified and selected, particularly in contexts where the founding team is not organically formed but externally assembled. This phenomenon is increasingly visible in emerging innovation players such as venture studios that follow a systematic and structured process of NVC: the venture builder model (Beaver, 1998; Baumann et al., 2018; Gutmann, 2019; Szigeti, 2019). The venture builder model represents a structured and systematic approach to NVC, characterized by its logic of parallel entrepreneurship.

Unlike traditional models, where founders build one venture at a time, venture builders create multiple startups in parallel using shared resources and standardized processes. This centralized approach accelerates venture creation and reduces early-stage risks. By institutionalizing entrepreneurship, venture builders enhance efficiency and adopt a portfolio strategy that spreads risk across ventures.

What makes this model especially intriguing is the possibility of reversing a traditional entrepreneurial logic: rather than entrepreneurs initiating a venture, it is the venture builder who develops an idea and then seeks out co-founders to lead and grow it (Mohammadi et al., 2023).

This inversion raises a new field of exploration for the entrepreneurial identity (Mmbaga et al., 2020; Radu-Lefebvre et al., 2021) streams of research and enriches the literature on the NVC process (Davidsson & Gordon, 2011; Davidsson & Gruenhagen, 2021), a core topic in entrepreneurship research (Carlsson et al., 2013),

considered not as a single event but as a dynamic process (McMullen & Dimov, 2013). It also involves how individuals or teams identify, develop, and exploit new business opportunities, moving from the generation of a venture idea to the exploitation of a venture opportunity and is shaped by the continuous interactions between the entrepreneurs, the venture opportunity, and the surrounding environment (Davidsson & Gordon, 2011; Vogel, 2017).

There remains a notable gap in the academic literature concerning the role of co-founders within venture builders' processes. Little is known about how these co-founders are identified, evaluated, and ultimately selected by the venture studio. The co-founders selected must fit into the culture and processes of the venture studio while also possessing the requisite entrepreneurial traits to lead their respective startups toward success. Selecting co-founders is a strategic activity in the venture-building journey because Venture Studio manages several new ventures in parallel and often in different industries or markets (Rathgeber et al., 2017).

Research on co-founder selection in the context of the venture builder model is scarce and composed of grey literature (Mohammadi et al., 2023), and understanding this process can offer valuable insights into the best practices for creating strong founding teams. Unlike traditional startups, which are often initiated by a single entrepreneur or a small founding team, venture studios systematically create multiple ventures, requiring a more structured and strategic approach to co-founder selection.

To date, no systematic academic inquiry has addressed the decision-making processes, selection criteria, or organizational logic that guide the formation of founding teams within venture studio contexts. There is limited empirical evidence on how co-founders' identities are shaped in these externally guided contexts, what selection mechanisms are employed, and how venture studios orchestrate the selection process to align with their broader venture-building strategy. Addressing this gap is critical not only for refining our understanding of venture building as a distinct model of NVC but also for expanding the theoretical boundaries of entrepreneurship research to encompass emerging, practice-led models of entrepreneurial behaviour (Gruber & MacMillan,2017).

Moreover, we aim to answer the following research question: How do venture studios operationalize and manage the selection of co-founders, and what drives the timing and criteria? The goal of this paper is to investigate how co-founder selection processes are designed and implemented within venture studios, with a focus on the underlying decision criteria and timing strategies adopted in practice. To address this question, the research will adopt an exploratory, qualitative design through a multi-case illustrative study (D'Ippolito et al., 2019). It will focus on three European venture studios that exemplify the practice of systematically searching for external co-founders.

The desired outcome is to provide a clearer and empirically grounded understanding of this phenomenon, which remains largely absent from academic discourse. By doing so, the study seeks to contribute to a more nuanced comprehension of the venture builder model and to identify co-founder recruitment as a distinctive and defining feature of venture builders, particularly in the form of venture studios. Understanding this can help improve the efficiency and sustainability of NVC, benefitting not only the ventures themselves but the entrepreneurial ecosystem as a whole (Spigel, 2015).

2 Theoretical Context

This study is framed within the broader domain of entrepreneurship research, specifically focusing on the Venture Builder (VB) model as a structured and replicable approach to new venture creation (NVC) (Davidsson & Gordon, 2011; Davidsson & Gruenhagen, 2021). The creation of a new entrepreneurial activity is therefore increasingly understood as a structured and dynamic process that may originate not only from individuals but also from existing organizations, such as corporates (Gutmann, 2019), startup studios, or digital agencies (Szigeti, 2019) that act as enabling actors in the entrepreneurial ecosystem (Spigel, 2015). These innovation players engage new venture creation activities by systematically building new companies in parallel and adopting the lean startup approach (Ries, 2011), following intentional processes that combine ideation, validation, and execution phases. In such contexts, the NVC process requires both intentionality and concrete action in relation to a specific venture idea (Davidsson & Gruenhagen, 2021). This perspective aligns with Gartner's (1985) conceptualization of entrepreneurship as an organizing activity, where the entrepreneur is not merely an idea generator but someone who brings together resources, people, and opportunities to form a new venture. Furthermore, building on Weick's (1979) notion of organizing as a process, creating a venture can be viewed as enacting a structure through continuous interaction between actors and their environment. It is also essential to consider the journey that moves from a venture idea to a venture opportunity (Vogel, 2017). Within those conceptual frameworks, venture builders operate as orchestrators of such processes, intentionally assembling teams, aligning resources, and shaping the structure and trajectory of new ventures. Thus, NVC is not only about

opportunity recognition but also about the capacity to organize and execute strategically in a replicable manner, and this is a core feature of the venture builder model. The venture builder model offers a distinct perspective on NVC, positioning organizations rather than individuals as the initiators of entrepreneurial activity.

The Resource-Based View (RBV) of the firm (Barney, 1991), and particularly its extension through the Resource Orchestration framework (Sirmon et al., 2007), offers the most appropriate theoretical lens for analysing co-founder selection within venture building processes because it conceptualizes strategic advantage as rooted in the firm's ability to structure, bundle, and leverage key internal resources (Symeonidou & Nicolaou 2018). In the context of venture studios, co-founders are critical entrepreneurial resources whose skills, networks and capabilities (Zahra et al., 2006) can shape the trajectory of a startup. The orchestration of these resources (selecting the right individuals, forming complementary founding teams, and aligning them with validated opportunities) reflects a deliberate and strategic process that enables the scalable and repeatable nature of the venture builder model. Unlike traditional startups, which often rely on organically formed founding teams, venture studios must systematically match entrepreneurial talent to emerging ventures in parallel, making resource orchestration relevant and essential to understanding how value is created and sustained in this context.

While grounded in entrepreneurship theory, this research also intersects with the field of human resource management (HRM), particularly in its attention to talent acquisition and selection strategies. Understanding how venture studios design and execute their co-founder selection processes also contributes to HRM by illuminating practices for recruiting high-impact individuals in high-uncertainty environments (Uggerslev et al., 2012; Rocha & Pozzoli, 2025). This interdisciplinary positioning enables the study to offer both theoretical contributions to entrepreneurship and practical insights relevant to HRM, particularly in emerging organizational forms characterized by parallel entrepreneurship and structured innovation.

3 Methods

This study adopts a qualitative methodology based on illustrative multi-case studies (D'Ippolito et al. 2019) to investigate how venture builder models operate, particularly with respect to the co-founder selection process. Cases were selected through an extensive review of qualitative secondary data (Miles & Huberman, 1994), allowing for a nuanced understanding of the phenomenon.

3.1 Case selection

Case selection followed a theoretical sampling approach (Miles & Huberman, 1994), based on qualitative secondary data collected between January and April 2025. Data sources included company websites, LinkedIn profiles, practitioner reports, industry articles, job postings for co-founders, and valuable materials that illustrate how venture studios define the co-founder's role and communicate expectations.

To ensure contextual consistency, only European venture studios were selected. This approach, suited to exploratory research in emerging fields (Ployhart & Bartunek, 2019), allows for a grounded understanding of co-founder selection in structured NVC processes.

We selected three cases, Rocket Internet, Hexa, and Mamazen, because they exemplify contrasting models and co-founder selection strategies, ranging from global scaling and replication to mission-driven, sector-specific venture building. These cases allow us to compare how different venture studios actively recruit and integrate co-founders into entrepreneurial opportunities that have already been structured internally.

Together, these cases illustrate the breadth of co-founder selection strategies across different venture studio models, ranging from global scalability and a copycat approach in B2C business (Rocket Internet and Mamazen) and rapid execution to mission-driven problem-solving B2B business (Hexa). Their inclusion in the study enables a comprehensive understanding of how venture studios interpret, operationalize, and execute the critical task of forming co-founding teams, thereby contributing to developing a broader theoretical framework for co-founder selection within structured venture-building processes.

3.2 Case analysis

3.2.1 Rocket Internet

Rocket Internet represents a particularly distinctive example of a venture studio model, often described in the early literature (Baumann et al., 2018) as a "startup factory" due to its industrialized and highly structured approach to new venture creation. Founded in 2007 by the Samwer brothers, Rocket Internet's mission has been to build and scale internet-based companies rapidly by replicating proven business models from other contexts

following a copycat approach. Central to its model is the separation between the ideation and execution of business models. Instead of originating novel startup ideas, Rocket Internet focuses on operational excellence, selecting and empowering co-founders to implement business models that have already demonstrated success in other markets (Baumann et al., 2018).

The firm favours profiles with strong analytical skills and operational discipline. These attributes correspond closely to those identified in entrepreneurship literature as predictive of entrepreneurial effectiveness, such as conscientiousness, openness to experience, and emotional stability (Zhao & Seibert, 2006; Brandstätter, 2011; Obschonka et al., 2013).

Co-founders are recruited to lead ventures from inception through scale-up. Typically, two to four co-founders are assigned to each startup and are responsible for setting up operations, hiring the team, overseeing business development, and achieving market leadership. While they retain a personal equity stake in the company, Rocket Internet maintains controlling ownership, enabling centralized governance and resource orchestration (Sirmon et al., 2007; Baert et al., 2016).

What is particularly notable in Rocket Internet's model is the internal pipeline used for identifying co-founders. Rather than relying solely on external recruitment or open calls for applications, the studio frequently selects promising internal employees who have demonstrated entrepreneurial readiness. This internal mobility allows for greater control over the selection process and enhances team cohesion, as candidates are already familiar with Rocket Internet's fast-paced and metric-driven culture (Rocket Internet, 2025).

This case is particularly relevant to the study of co-founder selection because it highlights a context in which founders are actively sought after and appointed to ventures that they did not originate. It underscores the importance of role identity, selection mechanisms, and organizational fit in venture building. Furthermore, it serves as a useful model for understanding how some venture studios mitigate startup risk through controlled processes and strategic resource orchestration (Symeonidou & Nicolaou, 2018).

3.2.2 Hexa

Hexa, formerly known as eFounders, is a Franco-Belgian startup studio founded in 2011. Initially focused on B2B SaaS startups, the studio capitalized on the growing adoption of cloud-based technologies in corporate environments. In 2022, eFounders rebranded as Hexa, evolving into a multi-vertical platform of startup studios with dedicated tracks in Web3, fintech, AI, and health sectors.

Hexa adopts a systematic new venture creation (NVC) process structured into four core phases: inception, build, scale, and growth (Szigeti, 2019).

What distinguishes Hexa's model is its emphasis on structured co-founder recruitment during the exploitation phase of a venture idea. After an idea has been validated, the studio recruits two co-founders for each new venture: typically a CEO with a business-oriented profile and a CTO responsible for technological execution (Szigeti, 2019). This reflects a deliberate strategy to construct complementary founding teams, consistent with existing literature that emphasizes the importance of diverse yet synergistic skill sets in successful founding teams (Ruef et al., 2003; Beckman & Burton, 2008).

The recruited co-founders are not the idea's originators but are selected for their execution capacity and alignment with the venture's vision, making Hexa a prototypical example of the "late co-founder" model in structured venture creation.

Hexa's selection process is rigorous, receiving over 1,000 co-founder applications annually while selecting only 12 individuals to lead its six annual ventures (Hexa, 2025). The selection criteria include ambition, entrepreneurial mindset, and readiness to work collaboratively within the venture studio framework.

In return, Hexa provides extensive support to its co-founders, including pre-seed funding, office space, team recruitment, mentorship, and hands-on involvement from a team of experts. During the first year, all operational and salary costs are covered, offering founders a lower-risk pathway into entrepreneurship while allowing Hexa to retain strategic control. Once the NewCo is launched, equity is shared between Hexa and the co-founders based on pre-negotiated terms, aligning incentives and preserving founder motivation (Hexa, 2025).

Hexa's model thus provides a compelling lens through which to examine how venture studios orchestrate co-founder selection and team formation, balancing structured processes with entrepreneurial flexibility in the context of high-growth venture creation.

3.2.3 Mamazen

Mamazen, founded in Italy in 2017, represents a pioneering force in the Italian startup ecosystem as the first entity to implement a venture builder model. Mamazen's approach is characterized by its structured, risk-mitigated process of venture creation, aiming to increase startup survival rates by rigorously validating ideas and carefully selecting the founding teams best suited to lead them (Mohammadi et al., 2021).

Mamazen's co-founder selection reflects a deliberate strategy that aligns with findings in co-founder literature emphasizing the importance of complementary skills, cultural fit, and founder identity (Mathias & Williams, 2017; Aven & Hillmann, 2018). Through its structured approach, Mamazen recruits external co-founders who are not the originators of the venture idea but are carefully matched to already-validated concepts (Mohammadi et al., 2023).

The selection process at Mamazen begins only after the venture idea has passed a rigorous validation phase (Mohammadi et al., 2024). Once this foundation is established, Mamazen opens its co-founder recruitment. In this phase, they are looking for complementary roles (Beckman & Burton, 2008).

Mamazen employs a multi-step evaluation process that includes resume screenings, structured interviews, practical simulations, and immersive bootcamps. These assessments are designed to evaluate not only candidates' managerial and entrepreneurial experience (Hsu, 2007; Toft-Kehler et al., 2014) and ability but also their alignment with Mamazen. In line with findings from the literature on founding team formation (Clarysse & Moray, 2004; Lazar et al., 2020), Mamazen emphasizes that cultural and interpersonal fit is critical for long-term collaboration.

Moreover, Mamazen introduces a 1–3 month trial period during which selected candidates work part-time on the venture while maintaining other employment. Thereby incentivizing a short period of hybrid entrepreneurship (Folta et al., 2010; Raffiee & Feng, 2014).

This phased integration allows both the studio and the co-founders to assess mutual commitment before fully formalizing the relationship. The startup studio provides significant support during this transition (Mamazen,2025). Such support structures reduce early-stage risks and co-founder's fast turnover (Allen & Shanock 2013), aligning with studies that link entrepreneurial ecosystems with resource orchestration mechanisms (Sirmon et al., 2007).

Co-founders at Mamazen receive 70% equity in the new venture, subject to a five-year lock-up clause with good leaver/bad leaver provisions. This generous equity structure enhances founder motivation and aligns incentives over the long term, reinforcing findings from entrepreneurial finance that stress the importance of equity ownership in fostering accountability and commitment (Bolino & Turnley, 2007).

Its structured, research-driven, and founder-centric approach provides a robust framework for understanding how co-founder selection contributes to startup success. Mamazen's practice of external co-founder recruitment, based not on ideation but on alignment with a pre-validated venture opportunity, offers a powerful lens through which to re-examine the nature of entrepreneurial identity and team formation in venture building processes.

4 Results and Conclusions

Our findings reveal that the search for co-founders is not incidental but constitutes a core strategic activity within the venture-building process. Unlike traditional startups, where the founder is often the initial developer, venture studios initiate the business idea and then actively seek individuals to co-lead and scale the venture. This structural inversion of entrepreneurial agency shifts the role of the co-founder from originator to orchestrator, requiring not only alignment with the studio's mission but also the presence of distinct entrepreneurial capabilities.

Venture studios pursue co-founders primarily to infuse ventures with an entrepreneurial mindset, risk appetite, and long-term commitment, traits typically associated with startup founders rather than hired managers. These individuals are not recruited as CEOs of existing firms but as full co-founders with shared equity and responsibilities from day one. This distinction is critical: co-founders are expected to assume ownership and actively shape the trajectory of the venture rather than merely execute a pre-defined strategy. The selection of co-founders thus functions as a mechanism for embedding entrepreneurial identity within an externally generated venture, bridging the gap between structured venture creation and founder-led dynamics.

From a theoretical perspective, this study contributes to the literature on NVC (Davidsson & Gruenhagen, 2021) by identifying co-founder recruitment as a defining characteristic of the venture builder model. In doing so, it highlights a significant departure from traditional founder-led models of entrepreneurship, reframing co-founder selection not as a spontaneous process but as a deliberate and repeatable activity embedded in structured venture creation. This insight advances our understanding of how venture builders operationalise NVC through institutionalised talent alignment and team formation processes. Simultaneously, the study extends the resource orchestration perspective (Sirmon et al., 2007) by offering empirical evidence of how human capital is actively structured, bundled, and leveraged within the venture studio context. Rather than treating co-founders as static inputs, the venture builder model conceptualises them as dynamic and strategically orchestrated resources. This dynamic coordination of people and capabilities across multiple

ventures demonstrates how resource orchestration unfolds also in environments characterised by parallel venture creation.

For practitioners, especially venture studios, this research underscores the need to recruit individuals who embody founder-like capabilities rather than defaulting to managerial profiles. Studios must develop talent acquisition strategies that go beyond formal qualifications to assess entrepreneurial drive, strategic agility, and value alignment. Furthermore, the use of structured, iterative selection processes, such as those employed by Mamazen and Hexa, provides a replicable model for identifying high-potential co-founders in uncertain, high-growth environments.

This exploratory study opens several avenues for future research. First, who are these co-founders who join ventures they did not originate? A deeper investigation into the typologies and backgrounds of co-founders in venture studios could illuminate emerging patterns in entrepreneurial careers. Second, the co-founder selection process itself warrants closer examination, particularly the role of bias, the effectiveness of evaluation tools, and the dynamics of team formation. Finally, further comparative studies across different venture builder models (e.g., corporate venture builders vs. venture studios) could yield valuable insights into how structural differences shape co-founder roles and outcomes.

By offering a structured view into the co-founder selection process within venture builders, this study contributes to both entrepreneurship and human resource management literature, providing a theoretical and practical framework to better understand how entrepreneurial talent is identified, integrated, and empowered in new organizational forms of NVC.

5 Ethics declaration

This research did not require ethical clearance, as it did not involve the collection of sensitive or personally identifiable data from human participants.

6 AI declaration

AI tools were used in organizing and presenting the content of this paper in a clear and coherent manner. The AI-assisted outputs were critically reviewed, edited, and integrated by the author to ensure academic rigor and alignment with the research objectives.

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Bridging Innovation and Market: An Exploratory Analysis of AI Startup Value Propositions

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Abstract

This paper explores how AI startups articulate their value propositions—a critical element in defining and communicating value to customers. AI startups, in fact, struggle to align their technological capabilities with real market needs. Drawing on an exploratory multiple-case study of ten Italian AI startups, this research tries to investigate emerging patterns and main challenges AI startups face in articulating the value proposition. Preliminary findings reveal a fragmented landscape: while some startups adopt detailed use cases and visuals to support their claims, others rely on minimal communication and invite direct contact. Value propositions often emphasize efficiency and cost savings but lack quantification and substantiation. The study highlights the tension between technological sophistication and market clarity, especially in cross-industry applications. By focusing on how AI startups construct their value propositions, this research contributes to both AI entrepreneurship literature and broader discussions on value proposition strategy in emerging, high-tech markets.

Keywords: AI startup; Value Proposition; Entrepreneurship

Paper type: Academic Research Paper

1 Introduction

Artificial intelligence represents an opportunity for entrepreneurs in several ways: it is a technology that enhances existing business activities (e.g., market analysis, customization, automation of processes) while also enabling new businesses that introduce innovative products and services (Obschonka and Audretsch, 2020; Troise et al., 2022; Giuggioli and Pellegrini, 2023). Some scholars in entrepreneurial literature consider AI an external enabler of entrepreneurial opportunities, as it provides access to new markets by revealing previously unidentified or unmet needs (Davidsson and Sufyan, 2023). In other words, AI allows entrepreneurs to develop an entrepreneurial process in which opportunities are transformed into new economic activities that create value.

As an enabler of entrepreneurship, AI can be leveraged by new entrepreneurs, particularly emerging startups that consider AI as their primary activity for value creation and sell AI as a final product or service (Steininger, 2019). According to the definition provided by Truong (2024), AI startups are new ventures that develop—rather than merely use—their own machine learning algorithms and systems, integrating them into their products and services. Alternatively, they may rely on existing AI modules from the open-source ecosystem to build their offerings.

AI startups have garnered significant attention in recent years, as they are considered—alongside Big Tech—the driving force of future economies. According to the CB Insights Report (2024), the total financing of the world's top 100 AI startups amounted to $10.4 billion, reflecting a 48% market growth compared to 2022. However, despite this rapid expansion, a recent report by DemandSage (2025) indicates that 90% of AI startups fail, primarily due to a poor understanding of market demand or weak product-market fit—factors that outweigh financial or team-related issues. These contradictions highlight a significant gap in both practice and academia, creating ample space for further research.

Academic literature on AI startups is still emerging (Weber et al., 2022), and there is limited knowledge on how these startups operate and are structured. Most research stems from business model literature, where scholars such as Weber et al. (2022) and Garbuio and Lin (2019) have attempted to classify AI startups based on their business models. Other insights come from a fragmented body of research on AI startups and AI companies, detailing their characteristics and challenges (Lee, Kim, and Ivan, 2024). Among the various obstacles identified in the literature—including AI startups' difficulties in acquiring and training large datasets, high infrastructure requirements, and competition with Big Tech—this paper focuses on a fundamental issue: the complex relationship between technological expertise and market understanding. AI startups frequently struggle to translate their advanced technological capabilities into solutions that are both functional and aligned with real market needs (Kelly et al., 2022).

More specifically, this paper aims to explore how AI startups design and present their offerings to the market. To analyze this, we adopt the value proposition as the key analytical construct. The value proposition is not merely a means of communication, it is a strategic tool through which a company defines and delivers a coherent package of value to customers (Lanning, 2019; Payne et al., 2017). A strong value proposition reflects a firm's ability to identify external opportunities (Teece, 2007), respond to environmental uncertainties, and address consumer needs in ways that enhance their willingness to pay (Guo, Yang, and Han, 2019; Baden-Fuller and Haefliger, 2013).

Thus, the research question guiding this study is: "How do AI startups articulate their value propositions?"

Although aspects of this topic have been discussed in the broader literature on high-tech startups, this paper incorporates AI-specific challenges to provide a more nuanced understanding. Like other technology-driven startups, AI startups face uncertainty when formulating their customer value propositions because they typically lack previous product generations or past experiences to draw from (Wouters, Anderson, and Kirchberger, 2018; Kirchberger, Wouters, and Anderson, 2020). However, unlike other technology-driven startups, AI startups encounter additional challenges that further complicate the process of translating technological advancements into marketable solutions. One of these challenges is their tendency to develop applications for multiple industries simultaneously, which can lead to generic or unfocused value propositions that fail to resonate with specific customer segments. Additionally, AI startups introduce novel terminology that differs from previous technological paradigms, making it more difficult for non-technical customers to grasp the usability and potential impact of AI solutions. Furthermore, the adoption of AI raises ethical and socio-economic concerns that may negatively affect how customers perceive its usefulness and desirability (Chalmers, MacKenzie, and Carter, 2021; Merhi, 2023). Given these challenges, it is crucial to analyze how successful AI startups construct their value propositions to effectively position themselves in the market.

This study employs an exploratory multiple-case study approach, focusing on the value propositions of ten Italian AI startups. The analysis aims to identify both common patterns and differences in how these startups articulate their value proposition.

By addressing this research question, the paper contributes to two key areas of literature. First, it advances research on AI startups by exploring how they develop their value propositions, offering insights into how they compete and sustain themselves in a market dominated by Big Tech and other startups. Second, it contributes to the broader literature on value propositions, which has traditionally focused on well-established companies rather than startups. Investigating AI startups' value propositions provides new perspectives on how emerging technology firms craft and communicate their value in uncertain and rapidly evolving environments.

2 Theoretical background

2.1 AI startups

AI startups can be defined as young and innovative companies that use artificial intelligence technology as a core element of their products and services. Since the concept is relatively new, emerging definitions aim to establish clearer boundaries around what qualifies as an AI startup. As noted by Truong (2024), some startups claim to be AI-based merely by referencing the use of AI technologies. However, Truong advocates for a stricter definition, identifying AI startups as ventures that develop their own machine learning algorithms and systems and integrate these into their products and services. This definition excludes startups that merely use data analytics to make predictions or automate specific processes without demonstrating any form of machine intelligence.

AI startups are typically characterized by deep technical competencies, which enable the continuous advancement of their AI technologies (Lee, Kim, and Ivan, 2024). As Chalmers, MacKenzie, and Carter (2021) point out, AI is a highly technical and science-driven field, making AI startups comparable to other technology-oriented startups. While several scholars analyze AI startups through this lens (see Lee, Kim, and Ivan, 2024), they also highlight important distinctions to better understand the unique nature of these ventures. For instance, Lee, Kim, and Ivan (2024) emphasize that AI startups often focus on the quality and maturity of their technologies. Maturity brings them closer to market readiness, but the fast-evolving nature of AI demands constant technological development. Moreover, these startups frequently pay special attention to ethical concerns in the development and application of AI (Merhi, 2023; Lee, Kim, and Ivan, 2024). In addition, as discussed by Fossen, McLemore, and Sorgner (2024), AI startups face significant disadvantages related to limited access to training data and the high infrastructure requirements associated with AI development.

Another, more structured stream of literature explores AI startups through the lens of business models. Garbuio and Lin (2019), in their analysis of healthcare AI startups, distinguish between two business model

archetypes: startups that provide information and those that aim to connect multiple parties. Building on this perspective, Weber et al. (2022) develop a taxonomy of AI startups, distinguishing AI-based business models from traditional ones. They identify four archetypes of AI startups: (1) Service/Product Providers, (2) Facilitators of AI Development, (3) Data Analytics Providers, and (4) Deep Tech Researchers.

2.2 Value proposition and tech-startup

The value proposition is not merely a means of communication, it is a strategic tool through which a company defines and delivers a coherent package of value to customers (Lanning, 2019; Payne et al., 2017). A strong value proposition reflects a firm's ability to identify external opportunities (Teece, 2007), respond to environmental uncertainties, and address consumer needs in ways that enhance their willingness to pay (Guo, Yang, and Han, 2019; Baden-Fuller and Haefliger, 2013).

As Payne et al. (2020) suggest, the literature on value propositions is characterized by two main streams: one derived from practitioners (Osterwalder et al., 2014; Dennis, 2018) and the other from academic researchers (Anderson et al., 2006; Payne et al., 2017). While practitioner-oriented contributions focus primarily on the strategic design of value propositions, academic studies offer a more critical view, exploring drivers, dimensions, and consequences. Most academic research has concentrated on established companies, aiming to highlight best practices in designing and implementing value propositions (Lindgreen et al., 2012; Payne, Frow, and Eggert, 2017). Paradoxically, although the role of the value proposition is well recognized in the startup context (Osterwalder et al., 2014), few academic studies have directly examined startup value propositions (Kirchberger, Wouters, and Anderson, 2020). As Wouters, Anderson, and Kirchberger (2018) note, the studies that do exist often focus on how startups can craft attractive value propositions to appeal to investors. However, startups deserve much more attention in this area. They operate under conditions of extreme uncertainty—lacking both historical reference points and a customer base from which to gather market feedback (Kirchberger, Wouters, and Anderson, 2020). Moreover, they frequently target multiple industries simultaneously, which can result in vague or overly generic value propositions (Wouters, Anderson, and Kirchberger, 2018; Nussipova, 2022). These challenges are particularly relevant for tech startups, including AI startups. For these companies, having a value proposition means being able to turn a technological innovation into a marketable offering. Yet they often lack the market and strategic capabilities needed to do so (Gofman and Jin, 2024; Jacobides et al., 2021).

Another difficulty in developing value propositions for startups is the need for flexibility—they must be able to adapt their value proposition as they learn more about the market. According to Kirchberger, Wouters, and Anderson (2020), this requires close collaboration with customers to build in an iterative way their value proposition. Wouters, Anderson, and Kirchberger (2018) suggest that startups develop two sequential value propositions: the value proposition of the offering, which focuses on the problem solved and the startup's unique contribution, and the value proposition of the assistance, which highlights the partners, providers, and resources used to realize and deliver the offering. In other terms Wouters, Anderson, and Kirchberger (2018) stress the clarity in expressing the startup's value. In their work, Kirchberger, Wouters, and Anderson (2020) emphasize two key elements in evaluating startup value propositions: specificity and substantiation. Specificity, also linked to the quantification, refers to the ability to quantify the value offered—for example, by translating benefits into measurable performance outcomes. Substantiation means offering convincing evidence to support the value proposition's claims through use cases, demonstrations, or proof that the value has been realized in practical and useful ways.

Due to the wide variety of offerings, existing studies do not point to a dominant type of value proposition (e.g., quality, speed, efficiency). However, Van Le and Suh (2019) found that tech startups increasingly emphasize aspects such as privacy protection, security, and trust in their value propositions.

3 Methodology

To explore how AI startups define their value propositions, we adopt a qualitative methodology based on a multiple case study approach (Eisenhardt, 1989). Our case selection follows predetermined criteria to ensure sufficient variation within the sample and to enable a meaningful cross-case comparative analysis (Eisenhardt and Graebner, 2007).

Starting from a list of 1,291 Italian AI startups identified through Crunchbase, we selected those that had secured at least €1 million in external funding, using this as an indicator of market traction and potential. This filtering resulted in a sample of 94 startups. We then further refined the sample by including only companies founded after 2014 and with at least 10 years of operational experience, considering this time span appropriate given the maturity required in the tech industry. Applying this criterion yielded a final list of 75 startups. From this list, we intentionally selected 10 cases that meet the definition of AI startups proposed by Truong (2024) -

startups that develop their own machine learning algorithms and systems and integrate these into products and services - and for which sufficient public information was available. Priority was given to maximizing diversity in terms of their value propositions. In line with Yin (2017), we used multiple data sources for data analysis and triangulation, including (1) official websites, (2) Crunchbase, (3) news articles.

To analyze how AI startups build their value propositions and merge technology with target markets, we first provide a description of each startup following the framework proposed by Weber et al. (2022), which includes details such as primary AI technology, data type, data source, and hardware provision. Secondly, we break down the value proposition using dimensions derived from the literature on technological value propositions. Specifically, we analyze value proposition formulation across six key dimensions: the type of expressed advantage (Van Le and Suh, 2019) - economy, efficiency, speed, customization, community, emotion, trust; the orientation of the value proposition (Wouters, Anderson, and Kirchberger, 2018) - technology-oriented vs customer-oriented; the specificity in terms of value quantification (Kirchberger, Wouters, and Anderson, 2020); the substantiation, referring to the presence of use cases or supporting documentation (Kirchberger, Wouters, and Anderson, 2020); the completeness of the value proposition, considering both the offering and the assistance dimensions (Wouters, Anderson, and Kirchberger, 2018). Additionally, we examine the language used to communicate the value proposition using the multiaztertest (Granados, Lorenzo-Espejo and Lorenzo, 2023) acknowledging that AI often introduces new technical vocabulary that differs significantly from previous technological paradigms. This shift can make it more difficult for non-technical users to understand and evaluate the usability and relevance of AI solutions.

The analysis covers all available information related to the presentation of the client's problem, the description of the proposed solution, and the explanation of how the offering is implemented.

After outlining both AI and value proposition characteristics for each case, we conduct a cross-case comparative analysis to identify patterns and distinct approaches in how AI startups construct and communicate their value propositions.

4 Preliminary Results

A preliminary exploration of the selected sample of AI startups reveals several emerging characteristics in how these firms articulate their value propositions. There is no single prevailing benefit consistently expressed, although efficiency is a commonly mentioned advantage. However, these benefits are rarely quantified, and only a few startups provide concrete metrics or substantiated claims. While some startups offer detailed explanations supported by use cases, videos, or product visuals, others provide minimal information and instead invite direct contact, suggesting a preference for personal interaction in explaining the value of their proposal.

The orientation of the value proposition tends to be more technology-driven when the solution targets a specific industry, while customer-oriented propositions are often framed in terms of applicability across multiple sectors. Generally, the more specific the target industry, the more technical the language used—reflecting the complexity of both the problem addressed and the proposed AI-based solution.

Additionally, when data-related solutions are involved, references to privacy and trust become more prominent, indicating awareness of the ethical and practical concerns associated with AI data processing.

Overall, while many startups attempt to clearly communicate the benefits of their offerings, the level of specificity and substantiation remains limited. This may help explain the gap often observed between technological potential and market adoption.

5 Conclusion

This study will have practical implications, offering a framework for transforming AI technology into real market utility while also providing insights into how AI startups can better design their competitive advantage to differentiate themselves from major AI corporations. Regarding theoretical implications, the paper enriches the literature on AI startups by shedding light on their specific characteristics. In particular, it will contribute to understanding the entrepreneurial dynamics related to AI startup by analyzing value proposition formulation strategies. The main limitations of this study concern sample selection, as the analysis focuses on a small group of AI startups, all of which are based in Italy.

Future stages of the research will focus on a more detailed case analysis and the identification of recurring patterns in AI startup value proposition strategies. In addition, the study will highlight the advantages and disadvantages of different strategic models.

Future research could extend the sample and the analysis to other countries or conduct cross-country comparisons to gain a more comprehensive understanding of successful value propositions adopted by AI startups.

6 Ethics Declaration

The ethical clearance was not required for the research.

7 AI Declaration

No AI tools were used for the creation of the paper.

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Exploring Configurations of Growth Hacking Success Factors in SMEs: An FSQCA Approach

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Abstract

The pursuit of sustainable and accelerated growth in small- and medium-sized enterprises (SMEs) can be effectively promoted through the application of Growth Hacking (GH) strategies. Improving the performance of GH practices within SMEs has therefore emerged as a critical objective for both practitioners and researchers. Drawing on the theoretical foundations of the Technology-Organization-Environment (TOE) framework, this article proposes an integrated analytical model to explore the determinants of GH performance in SMEs. Based on a sample of SMEs actively engaged in GH initiatives, the research will employ fuzzy-set qualitative comparative analysis (fsQCA) to examine the configurational relationships between technological, organizational, and environmental factors that influence GH outcomes. It is expected that: (1) no single condition will be sufficient on its own to achieve high GH performance; (2) multiple and equally effective combinations of internal and external factors will lead to successful outcomes, supporting the principle of equifinality; and (3) key technological capabilities, such as digital transformation and data analytics, along with organizational adaptability and responsiveness to environmental dynamism, will emerge as critical elements in successful configurations. Furthermore, relying solely on technology adoption or external market conditions may prove insufficient to maximize GH performance without appropriate organizational adaptation. These findings enrich the current understanding of the complex mechanisms influencing GH performance and offer practical insights for SMEs wishing to design more effective and resource-efficient growth strategies.

Overall, this research is expected to make a threefold contribution. First, it enriches the theoretical foundations of GH research by applying and extending the TOE framework in a configurational context. Second, it advances methodological practice by employing fsQCA to uncover complex causal relationships often missed by traditional methods. Third, it provides actionable insights for practitioners and policymakers by identifying strategic pathways to optimize GH practices according to different organizational contexts and resource profiles.

Keywords: Growth hacking, Technology organization environment-TOE, digital transformation, managerial experimental approach

Paper type: Academic Research Paper

1 Introduction

In an increasingly competitive and dynamic business environment, organizations continuously seek innovative and cost-effective strategies to maintain a competitive advantage in the market and attract and retain an ever-greater number of consumers in order to achieve rapid and sustainable growth over time (Bresciani et al., 2021; Troise et al., 2022).

Recent research has shown that GH, a managerial approach based on experimentation (Macca, Santoro, & Christofi, 2025), serves as an indispensable conduit for advancing company growth, promoting greater production efficiency, increased competitiveness, and sustainable development (Macca, Santoro, Jabeen, et al., 2025). As the digital era progresses, GH has increasingly established itself as a key approach to sustainable growth, particularly among SMEs, which, often having limited financial and human resources, are constantly seeking sources of competitive advantage to stimulate business growth (Giordino et al., 2025; Macca, Santoro, Jabeen, et al., 2025). Furthermore, SMEs are notably active in innovative experimentation and in the integration of automation tools and data analysis (Cristofaro et al., 2025). As a result, today's SMEs need tools and frameworks that can help them quickly redesign their value chains, promoting innovative, agile, and lean models (Feiz et al., 2021; Ghezzi & Cavallo, 2020). Many companies in recent years have used GH in their production processes or to innovate and scale their business models, and recent qualitative research has confirmed its effectiveness and its growing use in both small and large enterprises (Bargoni, Santoro, et al., 2024; Scuotto et al., 2025).

Despite its growing prominence, the exploration of GH antecedents on organizational performance remains an underdeveloped research area. Recent studies have attempted to create performance measurements to understand how to evaluate the effectiveness and impact of these on implemented GH practices (Bresciani et al., 2024; Giordino et al., 2025; Joshi et al., 2025). However, these studies have analyzed such measurement

variables in isolation on GH performance, neglecting possible biases or gaps regarding the best or necessary configurations needed to achieve such performance. In particular, the aforementioned studies have not delved into the underlying reasons for differences in GH performance among SMEs. They have also overlooked the analysis of key driving factors and their configurations. At the same time, these studies have failed to systematically uncover the coordination and synergistic effects among multiple drivers, such as technology, organization, and environment, that contribute to GH performance in SMEs. Therefore, managers and entrepreneurs are forced to identify the complex relationship between multiple factors and synergistic effects influencing the performance of GH practices. Armed with this understanding, they can judiciously select appropriate GH strategies tailored to the unique factor endowments of their respective SMEs. Consider, for example, SMEs that, being resource-scarce and aiming to focus on a specific objective, could achieve their GH goal more quickly and efficiently if they knew the best combinations of conditions like internal factors, technologies, and resources. In light of these challenges, the issue of effectively allocating resources within SMEs to enhance the effectiveness of GH practices remains a pressing concern. Therefore, this study aims to identify the influential factors that impact the performance of GH in SMEs. It will analyze the configurations that drive GH performance in SMEs, effectively distinguishing between core and peripheral conditions that influence such performance. Through this analysis, the complex operational mechanisms of various combinations of conditions on the performance of GH in SMEs will be explained.

Accordingly, this research employs the TOE framework (Tornatzky et al., 1990), recognized for its suitability in examining the adoption and diffusion of emerging technologies, to conduct an empirical analysis of the determinants influencing GH performance among SMEs. The TOE framework provides a structured approach to examining how internal and external conditions shape an organization's ability to implement GH successfully. Adopting a configurational approach and focusing on promotional pathways, the study seeks to uncover the key factors that drive performance levels in GH initiatives within SMEs, as well as to identify the conditions exerting the most substantial influence. Grounded in the TOE framework, a conceptual model is developed to systematically elucidate the factors shaping GH performance in the context of SMEs.

This study sets out to use a fsQCA approach to assess the variations in condition configurations and influence mechanisms contributing to diverse GH results.

2 Literature Review and Theoretical Framework

2.1 Research progress of GH performance in enterprises

GH has rapidly emerged as a pivotal concept within the domains of business strategy, innovation management, and entrepreneurship. Originating at the intersection of software engineering, creative marketing, and data-driven experimentation, GH was first articulated by Sean Ellis in 2010 as "a process of rapid experimentation across the funnel to learn the most effective way to scale sustainable customer adoption" (Ellis & Brown, 2017; Troisi et al., 2020). Characterized by its agility, cross-functional collaboration, and reliance on data analytics, GH fundamentally departs from traditional marketing approaches by prioritizing low-cost, high-impact strategies. Initially, its techniques proved particularly advantageous for startups and SMEs, where limited resources demanded innovative, scalable solutions for customer acquisition and retention (Ellis & Brown, 2017; Holiday, 2012).

Over time, however, the strategic advantages associated with GH—particularly its scalability, cost-efficiency, and iterative experimentation—have attracted interest from larger, more established organizations (Bargoni, Santoro, et al., 2024). As firms face increasingly dynamic, volatile, and digitized competitive landscapes, GH has transitioned from a tactical practice to a broader strategic framework aimed at fostering innovation, responsiveness, and sustained growth (Bohnsack & Liesner, 2019; Sanasi, 2025). Large enterprises are progressively restructuring internal processes to emulate startup-like experimentation models while leveraging their extensive resources to institutionalize GH practices at scale. Sanasi (2025) identifies diverse implementation models within growing ventures, ranging from decentralized experimental teams to centralized innovation hubs, highlighting a shift in GH's organizational relevance from a niche startup tool to an enterprise-wide strategic lever.

In parallel with its diffusion across varied organizational settings, researchers have sought to develop systematic frameworks for evaluating GH performance (Bresciani et al., 2024; Giordino et al., 2025; Joshi et al., 2025). Key performance indicators commonly employed include customer acquisition cost, customer lifetime value, retention rates, and growth efficiency. Broader financial and organizational metrics, such as revenue growth, return on marketing investment, and market penetration, also serve as important measures of GH efficacy (Giordino et al., 2025). Complementing these quantitative metrics, conceptual frameworks have been

developed to structure GH processes around iterative cycles of ideation, prioritization, experimentation, and evaluation. Cristofaro et al. (2025), for instance, conceptualize GH as a "scientific method," emphasizing the role of digital tools—such as A/B testing, funnel analytics, predictive modeling, and customer segmentation—in accelerating learning and fostering data-informed decision-making across organizational functions.

Recent empirical studies have further illuminated the relationship between GH practices and firm performance. Bargoni et al. (2024) demonstrate that GH enables organizations to lower customer acquisition costs, enhance user retention, and achieve more sustainable growth trajectories. Giordino et al. (2025) focus specifically on SMEs, identifying a positive correlation between GH capabilities and both financial and organizational outcomes. In larger enterprises, the integration of GH practices entails more complex dynamics. Gerlich et al. (2025) explore how dynamic capabilities, particularly the management of exploration-exploitation tensions, influence the successful scaling of GH initiatives. Their findings underscore the necessity of fostering organizational learning and cross-functional collaboration while navigating the inherent frictions between agility and bureaucratic structures. Bresciani et al. (2024) highlight how human, relational, and structural capital collectively strengthen GH initiatives, underscoring the importance of internal capability development for maximizing strategic outcomes, particularly in larger, more complex organizations. Moreover, technological advancements, particularly in AI, have become key enablers of GH strategies. Santoro et al. (2024) detail how AI technologies automate experimentation, personalize customer engagement, and enhance decision-making processes while also raising new challenges concerning data ethics and regulatory compliance. Finally, intellectual capital plays a critical role in GH effectiveness.

Despite the increasing scholarly attention devoted to GH, the empirical examination of its performance outcomes remains relatively limited. Recent studies primarily highlight the positive influence of individual antecedents, such as marketing capabilities, disruptive innovation, big data analytics capability, and innovation capability, on GH effectiveness (Bargoni et al., 2024; Joshi et al., 2025). Furthermore, findings consistently demonstrate a favorable association between GH capability and both organizational and financial performance in SMEs (Giordino et al., 2025). However, these studies typically adopt a variable-oriented approach, analyzing the isolated effects of specific factors without considering how they may interact in complex and complementary ways. Particularly, there is still a need to understand which configurations of capabilities, resources, and strategic conditions are most conducive to high GH performance. To date, no study has systematically identified the necessary and sufficient conditions (or optimal configurations) that collectively drive successful GH implementation, particularly within the SMEs context. This absence limits both theoretical development and practical guidance for firms seeking to design effective GH strategies.

2.2 Research framework

To analyze the antecedents that determine the major impact of GH strategies on the organization’s performance, this study adopts the TOE framework developed by Tornatzky and Fleischer (1990). The TOE framework provides a structured lens to examine how technological innovations are adopted within firms, and posits that the adoption process is influenced by internal factors (technological and organizational), as well as external environmental factors. In this framework, the technological context refers to the existing and emerging technologies that firms leverage to enhance innovation capabilities and operational efficiency. The organizational context captures firm-specific characteristics, including managerial commitment, human capital resources, and the prevailing internal culture that collectively shape innovation behavior. Finally, the environmental context encompasses the external conditions, such as market dynamics, competitive pressures, and regulatory frameworks, that exert influence over strategic decision-making.

Several theoretical and methodological considerations underpin the adoption of the TOE framework in the present study. First, the TOE framework offers a robust structure for analyzing the interaction between internal and external determinants of innovation. Given that this research aims to identify GH's critical enablers across technological, organizational, and environmental domains, the TOE framework serves as an appropriate and validated foundation for systematic categorization and analysis. This alignment ensures a comprehensive understanding of the multiple influences at play, ranging from internal capabilities, such as data-driven decision-making cultures, to external forces, like market turbulence, all of which are critical to successfully implementing GH strategies. Second, GH represents a digitally driven, innovation-centric approach that synergistically integrates technological advancement, agile organizational practices, and heightened market responsiveness. As the TOE framework has been extensively employed in prior studies on digital innovation, information technology adoption, and organizational transformation (Clemente-Almendros et al., 2024; Hossain et al., 2024; Marrucci et al., 2023), its application in the context of GH ensures theoretical continuity and extends its relevance to an emerging and interdisciplinary domain. In addition to leveraging the TOE framework, this study

adopts a configurational approach by employing fsQCA to explore how different combinations of technological, organizational, and environmental factors lead to successful GH outcomes. This methodological choice acknowledges that in complex, dynamic environments, such as those characterizing digital markets, outcomes may arise through multiple equally viable pathways.

Through this configurational lens, the study investigates the specific patterns of technology, organization, and environment that jointly contribute to high GH performance. The fsQCA method allows for the identification of distinct causal recipes, thereby offering nuanced insights into how various firms, contingent upon their internal strengths and external challenges, can achieve success through alternative but effective pathways. In doing so, this research aims to advance understanding of GH implementation by illuminating the complex, interdependent nature of technological, organizational, and environmental enablers.

2.3 Technological Factors

In the technological domain, this study identifies big data analytics capability and firm digital transformation as critical enablers of GH. Prior research underscores that technological conditions are key determinants in enhancing organizational GH performance, as digital tools, platforms, AI, and machine learning facilitate the rapid experimentation, optimization, and scaling processes central to GH practices (Gerlich et al., 2025). Given GH's reliance on iterative experimentation that generates extensive data, efficient processing becomes essential to support SMEs in developing their GH capabilities (Cristofaro et al., 2025; Jabeen et al., 2023; Macca, Santoro, Jabeen, et al., 2025; Wamba et al., 2017). Strengthening big data analytics capabilities through the adoption of digital tools and technologies is thus imperative. The ability to extract actionable insights from data enables firms to ground strategic decisions in empirical evidence rather than intuition or market perceptions (Cadden et al., 2023; Tseng, 2023).

Firm digital transformation plays a particularly pivotal role in this process, reshaping how organizations engage with customers, interpret market signals, and execute strategic initiatives (Bohnsack & Liesner, 2019; Ribeiro-Navarrete et al., 2021). By integrating infrastructures such as the Internet of Things, AI, data analytics, and cloud computing, digital transformation enhances organizational agility and supports informed decision-making. Empirical evidence highlights the strategic value of digital tools, which not only deepen customer engagement but also build capabilities for swift adaptation to environmental changes based on empirical insights (Hassan et al., 2023; Ramadani et al., 2023). Consequently, digital transformation fosters a more adaptive and responsive GH approach, enabling SMEs to maintain competitiveness in dynamic markets through continuous learning and innovation (Bargoni, Smrčka, et al., 2024; Troisi et al., 2020).

2.4 Organizational Factors

The organizational dimension encompasses a firm's internal capacity to support GH strategies. This includes five key components: Innovation capability, Cross-functional collaboration, Iterative experimentation, Experimentation resource allocation, and Proactive customer and market orientation. Existing research often explores GH through perspectives such as agile methodologies, entrepreneurial orientation, and technology adoption (Bargoni, Smrčka, et al., 2024; Cristofaro et al., 2025; Macca, Santoro, & Christofi, 2025; Troise et al., 2022). Nevertheless, given the distinct characteristics of GH — namely, its reliance on rapid experimentation, interdisciplinary integration, and customer-centric innovation — a deeper understanding of specific organizational factors becomes essential. Innovation capability enables enterprises to generate novel ideas, swiftly adapt to changes, and creatively solve problems, forming the foundation for successful GH initiatives (Gerlich et al., 2025; Jabeen et al., 2023). Cross-functional collaboration, by bringing together marketing, product development, data analytics, and engineering teams, fosters knowledge sharing and accelerates the identification of growth opportunities (Macca, Santoro, Jabeen, et al., 2025). Iterative experimentation refers to the continuous testing, learning, and refinement cycle that is crucial for validating hypotheses and optimizing growth tactics (Ries, 2011; Sanasi, 2023, 2025). Meanwhile, experimentation resource allocation ensures that sufficient human, financial, and technological resources are dedicated to conducting and scaling experiments, directly influencing the speed and success rate of growth initiatives (Bresciani et al., 2024; Cavallo et al., 2023; Choi et al., 2022). Finally, a proactive customer and market orientation (Narver et al., 2004) enables organizations to anticipate emerging trends and evolving customer needs, ensuring that GH efforts are relevant and impactful. Therefore, differences in the presence and combination of these organizational factors can profoundly affect the performance of enterprises pursuing GH strategies.

2.5 Environmental Factors

In the environmental dimension, Environmental dynamism and Industry-specific forces are examined as external enablers of GH strategies. Environmental dynamism reflects the speed and unpredictability of technological advancements and market changes (Sharfman, 1991; Autio et al., 2018), requiring enterprises to adapt their GH strategies to sustain performance continually. Technological dynamism refers to frequent innovation within industries, while market dynamism involves shifts in customer needs and preferences. Alongside this, industry-specific forces—such as regulatory intensity, competitive pressure, and technological maturity (Porter, 1980; Schendel, 1994)—define the strategic environment in which GH occurs. High competition or rapid innovation cycles demand more aggressive and agile tactics, while stable industries may favor incremental improvements. Investigating the combination and differences between environmental dynamism and industry-specific forces is essential, as each uniquely influences how enterprises structure and execute GH initiatives.

The developed research model is illustrated in Figure 1.

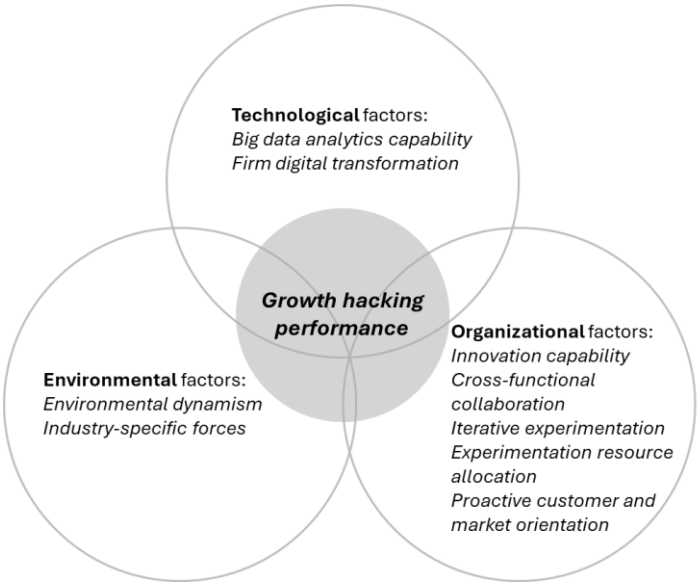


Figure 1: Research model

3 Research design and methods

This research intends to employ fsQCA to investigate the configurations of technological, organizational, and environmental conditions that contribute to GH performance in enterprises. The choice of fsQCA was motivated by its ability to analyze causal complexity, allowing for the identification of equifinal pathways where multiple configurations of conditions lead to the same outcome (Ragin, 2008). This method aligns with the study's aim to uncover the necessary and sufficient conditions for achieving high GH performance in SMEs.

This paper presents a collection of pertinent data through a questionnaire survey. To ensure the consistency of measurement variables and research inquiries, a five-point Likert scale is employed, and an initial questionnaire is devised based on the TOE framework and the research findings concerning GH performance. Under the guidance of a professional consultant with experience in a network of entrepreneurs and companies of various sizes, together with input from scholars specializing in the GH approach, the questionnaire was refined and revised to produce the final version.

The research sample included SMEs operating in a wide range of sectors in order to capture a variety of different organizational contexts and backgrounds (Eisenhardt, 1989). Empirical data were collected through the distribution of a structured questionnaire to more than 50 SMEs based in Italy. Data collection was facilitated by LinkedIn and targeted e-mails, exploiting an established network of Italian entrepreneurs and SME representatives. Italy was chosen as the research setting due to its particular economic structure, in which SMEs are the cornerstone of economic development and employment generation (Giordino et al., 2025; Jabeen et al., 2023; Jafari-Sadeghi et al., 2020). Selection criteria required that each organization actively integrate GH strategies into their operations to innovate, scale, or experiment with their business processes. This ensured the relevance and applicability of the insights derived from the sample.

Data collection was conducted from January to March 2025. To maximize the response rate, participants were thoroughly informed about the study's objectives and the specific nature of the requested information. Following several follow-up reminders, a total of 31 fully completed questionnaires were collected. The questionnaire utilized in this study included nine independent variables and one dependent construct. Responses were collected using a five-point Likert scale, ranging from "Strongly Disagree" to "Strongly Agree".

Two variables were selected to investigate the technological factors: Big data analytics capability and firm digital transformation. The first variable evaluated the organization's ability to process and analyze large amounts of data and to implement technological tools and platforms in its growth processes. The second variable assessed the organization's disposition to integrate AI and machine learning technologies in its growth processes.

From the perspective of organizational context, four variables were selected. Innovation capability was measured to explore the degree to which the company has a culture that is open to innovation and data-driven. Cross-functional collaboration was measured to investigate the presence of teams with diverse skills and expertise (e.g., marketers, data analysts, coders) within an organization. Iterative experimentation was measured to assess the degree to which an organization engages in constant testing and refinement of its strategies. Experimentation resource allocation was measured to assess the organization's availability of resources and budget for testing and experimentation. Proactive customer and market orientation were measured to investigate the organization's ability to quickly adapt to changes in the market and make fast decisions.

The environmental factors were represented by the variables of Environmental dynamism (Giordino et al., 2025; Marrucci et al., 2023) and Industry-specific forces (Takata, 2016). Environmental dynamism was measured to assess the level of changes that may occur in the organization's market environment. Industry-specific forces were assessed to examine how price, competition, customer, and supplier power factors may shape the firm's performance. These dynamics shape the opportunities, constraints, and pressures organizations face and can significantly impact how GH strategies are designed and executed.

Following Giordino et al. (2025), the dependent variable (outcome), GH performance, is divided into two aspects: organizational performance and financial performance. Specifically, the first is defined as the collection of observations that indicate a company's market and operational aspects so that measures related to the organization's reputation, market positioning, and sales volume can be outlined (El-Kassar & Singh, 2019). In contrast, the second is detailed as metrics indicating a firm's ability to generate value for its shareholders, and it includes metrics such as EBIT, ROI, and ROS (Lin et al., 2013).

Follow-up semi-structured interviews were conducted with 19 entrepreneurs (founders) who had voluntarily participated in the survey and provided their contact information. Each interview, lasting between 45 and 60 minutes, aimed to complement and deepen the survey findings through qualitative data, including personal experiences, examples, and case studies from recent and past projects. The interviews also explored participants' perceptions of the conditions necessary to achieve high GH performance.

fsQCA was employed to analyze the data, leveraging its suitability for examining complex causal relationships where multiple pathways can lead to the same outcome (equifinality) (Ragin, 2008). Grounded in configuration theory, fsQCA interprets conditions (e.g., big data analytics capability) and outcomes (e.g., organizational and financial performance) as sets, enabling a nuanced analysis of their interdependencies (Fiss, 2011; Ragin, 2008).

4 Expected results, implications and contributions

This study is expected to generate new insights into the complex and configurational mechanisms underpinning GH performance in SMEs. By applying a fsQCA approach, the research anticipates identifying multiple, equally effective combinations of technological, organizational, and environmental factors that lead to high GH performance. It is likely that no single condition will emerge as universally sufficient; instead, different configurations of conditions are expected to explain successful GH outcomes, thereby confirming the principle of equifinality in dynamic organizational environments.

Specifically, it is expected that core technological capabilities, such as digital transformation initiatives and big data analytics capability, will consistently appear across high-performing configurations. Organizational factors such as cross-functional collaboration, innovation capability, and the ability to allocate resources to iterative experimentation are also anticipated to play a central role. Environmental factors, particularly environmental dynamism and industry-specific competitive pressures, are likely to act as significant contingencies that shape the effectiveness of internal capabilities. The analysis is also expected to distinguish between core and peripheral conditions, offering a more nuanced understanding of which elements are critical across multiple pathways and which are contextually dependent.

The expected findings carry important theoretical implications. First, this study advances the understanding of GH by systematically applying the TOE framework to a new domain (GH) where such a structured approach has been largely underexplored. By moving beyond traditional, linear models and embracing configurational analysis, the study contributes to the theoretical development of both the TOE framework and GH literature, demonstrating how multiple interacting factors jointly determine strategic outcomes in SMEs. Furthermore, the adoption of fsQCA enables the uncovering of causal asymmetry and complexity, offering a richer explanation of how GH practices succeed under varying organizational and environmental conditions.

In practical terms, the study provides valuable guidance for SME managers, entrepreneurs, and consultants seeking to enhance GH effectiveness. By identifying specific configurations of technological readiness, organizational capabilities, and environmental alignment that drive superior performance, the study will enable practitioners to prioritize interventions based on their unique internal and external contexts. For instance, SMEs with limited financial resources may achieve high GH performance by focusing on agile organizational practices and proactive market orientation, whereas firms with greater digital capabilities might leverage advanced data analytics and cross-functional teams to scale their initiatives more effectively. The configurational approach thus offers a strategic tool for more targeted and efficient resource allocation.

Additionally, the results have relevant policy implications. Policymakers and business support organizations can use these insights to design programs that foster the critical capabilities and environmental conditions necessary for GH success among SMEs. In the Italian context, where SMEs are central to economic growth and innovation, the study's findings can inform national strategies aimed at improving the competitiveness and digital maturity of smaller enterprises.

5 Ethics declaration

No ethical clearance was required for the research conducted in this paper.

6 AI declaration

No AI tools were used in the development or writing of this paper.

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Entrepreneurs' Perceptions of AI: Level of Adoption, Competences, and Learning Ecosystem

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Abstract

The advent of the Fourth Industrial Revolution has marked a profound shift in the global economy, driven by the integration of artificial intelligence (AI), the Internet of Things, and quantum computing. AI stands out as a transformative force, profoundly reshaping industries, labour markets, and economic interactions. Also, AI's widespread implementation generates both opportunities and disruptions, with forecasts of the displacement of millions of jobs and the creation of new roles. However, these transformations vary significantly across regions and demographics, with countries like Italy facing unique challenges, including a substantial digital skills gap among the working population. Despite the growing interest in AI's technological and economic implications, limited research has investigated how specifically entrepreneurs adopt and utilise AI technologies in their daily business practices. While existing literature has focused predominantly on sector-specific applications—most notably in healthcare—entrepreneurship as a dynamic and multifaceted phenomenon remains underexplored in this context. Indeed, our study investigates how entrepreneurs adopt AI into their professional routines, the digital competencies they display during this process, and the learning ecosystems that support their acquisition of AI-related knowledge. To reach our research aim, we adopt a qualitative approach, conducting semi-structured interviews with a sample of entrepreneurs operating in Southern Italy. Through thematic analysis, we aim to highlight the existing patterns of AI adoption and the support mechanisms within the entrepreneurial ecosystems. The findings contribute to a deeper understanding of the AI adoption for entrepreneurs and their main digital competencies gap, offering theoretical insights and practical implications for policymakers, educators, and innovation stakeholders.

Keywords: artificial intelligence, AI adoption; knowledge gaps

Paper type: Academic Explorative Research Paper

1 Introduction

According to numerous analysts and futurists, the global economy has entered the Fourth Industrial Revolution, characterised by integrating artificial intelligence (AI), the Internet of Things, and quantum computing. Following the widespread adoption of information and computer technologies, whose advancements continue to accelerate, AI has emerged as a transformative force with the potential to impact various sectors, including business and the economy, significantly transforming interactions and experiences between stakeholders and citizens (Loureiro, Guerreiro & Tussyadiah, 2021). Integrating AI into various industries is reshaping the labour market, leading to both the reorganisation of existing roles and the creation of new opportunities. According to the jobs report (2023), AI is expected to displace approximately 83 million jobs and generate around 69 million new positions, resulting in a net reduction of 14 million jobs globally. The Tony Blair Institute projects that AI could displace between 1 million and 3 million private sector jobs, with annual job displacement peaking at 60,000 to 275,000 over the next few decades (Tony Blair Institute for Global Change, 2024). Despite these changes, long-term unemployment increases are anticipated to be relatively modest, as new job creation driven by AI growth is expected to offset many losses. Globally, the impact of AI on employment varies by region. A survey indicates that only 29% of people in Poland and Germany believe AI will create many new jobs, while just 24% in Hungary share this optimism.

According to a report by Implement Consulting Group (2024), approximately 24 million jobs exist in Italy, with a notable portion susceptible to automation through generative AI. Specifically, 58% of these positions are expected to collaborate with AI technologies, while 35% may remain unaffected. The report suggests that new roles emerging in the AI-driven economy are anticipated to offset jobs lost due to automation, potentially leading to a neutral long-term effect on overall employment figures (Implement Consulting Group Study, 2024). According to the Fondo per la Repubblica Digitale (FRD), set up in 2021 by the Italian government to boost the digital skills of citizens, 54% of those aged 16-74 lack basic digital skills, compared with an average of 46% in the European Union.

Despite these insights, research remains scarce on how digital tools effectively support entrepreneurial activity and how entrepreneurs utilise emerging technologies in the digital era. According to Corvello et al.

(2022), adopting digital technologies in economic activities influences entrepreneurs by offering resources that support their activities. However, the relationship between the complex phenomenon of entrepreneurship and digital tools still requires further exploration. To the best of our knowledge, existing studies primarily examine AI's impact on businesses in various industrial sectors, particularly healthcare (Cannavale et al., 2022).

Further research is needed to understand the dynamics and applications of new technologies in entrepreneurship. Indeed, we formulate these research questions:

- *RQ1: How do entrepreneurs adopt and integrate AI technologies into their daily professional practices?*
- *RQ2: What digital competencies do entrepreneurs demonstrate when adopting AI technologies?*
- *RQ3: What elements characterise the learning ecosystem supporting entrepreneurs' acquisition of AI-related knowledge and competencies?*

To reach our research aim, we will adopt a qualitative approach, based on semi-structured interviews with Italian entrepreneurs: our sample will be focused on entrepreneurs from Southern Italy. The paper proceeds as follows: the next section aims to discuss the managerial literature focused on AI adoption for entrepreneurs. Further, we explain the qualitative methodology applied, which comprises a thematic analysis of the interview transcriptions. Lastly, results are presented, and practical and theoretical implications are discussed.

2 Literature review

AI is profoundly impacting the work environment for intellectual jobs and entrepreneurial activities (Corvello et al., 2022). Entrepreneurs, in particular, must cope with the constantly changing environment in which they operate while also leveraging technology to remain agile and competitive (Rosenblat & Stark, 2016). According to Shepherd and Majchrzak (2022), the field of research regarding AI and the stream of literature on entrepreneurship have been kept separate until recently. However, "combining these tools is potent in generating impactful outcomes" (Shepherd & Majchrzak, 2022). Scholars have identified internal and external factors affecting the association between work and AI. Among the internal factors, researchers have recognised individual characteristics (Nambisan, 2017), while the external factors are the contexts in which entrepreneurs operate, such as the size or the business sector. The literature review performed by Giuggioli & Pellegrini (2022) highlighted an existing stream of research focused on investigating the relationship between entrepreneurial performance and AI adoption. It emerges that among the reasons for exploiting AI are the positive effects of automation in marketing, sales, and finance. The growing interest in exploring entrepreneurs' perceptions of AI stems from these technologies' substantial potential for business innovation and performance (Gupta & Yang, 2024). Digital tools powered by AI enable entrepreneurs to process and analyse large volumes of data, thereby significantly enhancing operational efficiency. According to Upadhyay, Upadhyay, and Dwivedi (2021), performance expectancy, defined as "the perceived benefits that an individual receives through technology", along with effort expectancy, are critical determinants of entrepreneurs' intentions to adopt digital technologies. Furthermore, the adoption of AI in entrepreneurial contexts has been shown to positively influence business outcomes, increasing the likelihood of success and improving overall entrepreneurial performance (Liu & Wang, 2024). Another strength of AI for entrepreneurs is the possibility of easily acquiring information about foreign markets or programming tasks (Gupta, 2024).

Given the immense potential of AI for business, it is essential to explore entrepreneurs' perceptions of these technologies (Gupta & Yang, 2024). Research suggests that performance expectancy—defined as the perceived benefits derived from using technology—alongside effort expectancy, are key determinants of an entrepreneur's intention to adopt digital technologies (Gupta, 2024). Furthermore, entrepreneurs' perceptions of AI technologies are closely linked to their existing competencies. Kruger and Steyn (2020) presented a conceptual model of entrepreneurial competencies needed to utilise Industry 4.0 technologies, including AI. Their model emphasises the need for both technical and soft skills, such as adaptability and innovation, further reinforcing the importance of competence integration. Kumar and Ratten (2024) noted that successful AI adoption in family businesses requires not only technical knowledge of AI technologies, but also skills in operations management, decision-making, and customer engagement.

Various conceptual frameworks have been developed to define the skills and competencies required in the context of rapidly evolving technologies. One of the most widely recognised is the 21st Century Skills Framework, which emphasises the competencies essential for thriving in a technologically advanced society (Partnership for 21st Century Skills, 2009). This framework goes beyond technical know-how to include personal attributes such as critical thinking, creativity, communication skills, and the ability to collaborate effectively—all of which are crucial for navigating modern professional environments. Another relevant model is the Entrepreneurial Competence Framework, which focuses explicitly on the skill set needed to successfully launch and manage a business (Bacigalupo, 2019). It includes different areas such as opportunity recognition, value creation, and risk

management. Additionally, the Future Skills Framework seeks to anticipate the skills that will be essential in the coming decades. It combines hard and soft skills, emphasising adaptability, digital literacy, leadership, and continuous learning. This model is particularly valuable for entrepreneurs who must remain agile and innovative in order to stay competitive in dynamic markets.

To further support the development of entrepreneurial competences in a digital age, the Digital Competence Framework (DigComp), developed by the European Commission, outlines the key digital skills necessary for functioning in a digital world, including the use of artificial intelligence (Carretero, 2017). DigComp identifies several core areas such as information and data literacy, problem solving with digital tools, digital content creation, and the ethical use of digital technologies—all of which are increasingly relevant for entrepreneurs navigating the complexities of modern business. For this research, we will focus on five of the competences highlighted in the DigComp framework.

3 Methodology

This study adopted a qualitative approach, which was well-suited to the exploratory nature of our research objectives (Yin, 2009). The goal was to understand the experiences of craft entrepreneurs in Southern Italy who are either using or considering using artificial intelligence (AI) in their businesses. To achieve this, we conducted semi-structured interviews, providing the flexibility to explore individual perspectives while ensuring consistency in addressing key themes related to the Digital Competence Framework.

The interview questions were designed based on the existing literature on the Digital Competence Framework (Carretero, 2017) and were organised into four key sections:

1. Introduction and Socio-Demographic Characteristics – to gather background information about the participants.
2. AI Usage – to explore AI practices.
3. Competences – to assess the Competences AI usage.
4. Learning Pathways and Learning Development Ecosystem – to examine the available resources and the Learning Pathways entrepreneurs choose.

The research is in progress, and this first work focused on a sample of 10 craft entrepreneurs from Southern Italy. A total of two in-person interviews were conducted in April 2025, each lasting approximately 20 minutes. The sample has been summarised in Table 1

Table 1 – Interview Participants

Name	**Age**	**Gender**	**Business activity**
Entrepreneur 1	35	Woman	Ceramics
Entrepreneur 2	31	Woman	Textile business

Prior to the interviews, participants provided consent for the use of their data, which was documented and reflected in the interview transcripts. The audio recordings obtained were transcribed using the AI service Sonix AI and subsequently translated from Italian to English with the assistance of ChatGPT. The data were then analysed using thematic analysis. The instrument employed for this process was ChatGPT, following the approach outlined by Koroleva and Jogezai (2025).

4 Results

The qualitative data analysis reveals that entrepreneurs in the study are in the early stages of adopting artificial intelligence (AI) within their businesses. Most participants reported that their experience with AI is recent, indicating that the integration of AI tools is still in its nascent phase.

"*My experience with AI started this year—it's very recent". (Entrepreneur 2)*

They mainly use AI for creative tasks (creating a text or image), research, and occasional problem solving, but not yet daily. They appreciate AI as an enhancer, not a creator.

"*It's useful when I need to create texts, because I don't express myself well with words" (Entrepreneur 1)*

"I use it like a search engine sometimes… it pulls info from across the web". (Entrepreneur 2)

Entrepreneurs recognise AI's potential but see limits for their area of business. The perceived usefulness is task-specific (text creation), but industry-specific scepticism, *"no utility for ceramics", "it's a bit complicated because maybe in Italy it's a niche"*. Entrepreneurs' view aligns with findings that perceived usefulness predicts adoption only when users see relevance to their context.

Some respondents perceive AI as cognitively demanding, preferring manual and intuitive processes. This indicates a low perceived ease of use, a strong predictor of non-adoption.

"I don't feel… I don't know, I… Anyway, I always tend to modify what it gives me. I don't know. Actually, I only use it out of necessity. If I can't write a text, I ask artificial intelligence to help me with that, but otherwise, no". (Entrepreneur 1)

Analysis based on the five competences outlined in the Digital Competence Framework (Carretero, 2017) revealed fragmented digital competences among respondents. Entrepreneurs demonstrated familiarity with AI for Digital Content Creation, but their use was limited mainly to generating marketing materials or promotional content rather than, for example, coding. Safety competence was also evident: participants consistently expressed a cautious attitude towards sharing data with AI tools, ensuring that only non-sensitive, non-personal information was processed. In the area of problem-solving, entrepreneurs acknowledged using AI for support. However, humans always make final decisions, reflecting a lack of trust in AI as an autonomous decision-making tool. In contrast, the interviews did not substantially reflect competencies related to information and data literacy, communication, and collaboration.

Regarding learning pathways, the study found that entrepreneurs primarily engage in peer learning, self-training, and low-cost online courses to develop their digital competencies. Learning processes are predominantly informal and socially situated.

"Word of mouth and social media…" (Entrepreneur 1)

"I took it online on Learn… there was a course specifically about how to talk to AI". (Entrepreneur 2)

Importantly, participants expressed a strong preference for peer-based, short, and easily accessible learning experiences, emphasising the need for practical, concise, and community-driven approaches to digital competences development.

"I prefer short and free courses". (Entrepreneur 1)

5 Discussion, conclusion and limitations

The first findings of our research show that AI adoption among craft entrepreneurs in Southern Italy is still at an early, emerging stage. While entrepreneurs are beginning to explore AI tools, widespread use remains limited. Their current engagement places them at the initial phase of Rogers' (2003) innovation diffusion curve, characterised by early exploration rather than broad acceptance.

This hesitation seems to stem from uncertainty about AI's relevance and immediate benefits for their specific business activities. This cautious behaviour aligns with Davis' (1989) Technology Acceptance Model, which emphasises that perceived usefulness is a critical factor in technology adoption. However, the interviewed entrepreneurs are only likely to adopt AI when they clearly recognise its practical application within their business context.

Learning practices among these entrepreneurs are predominantly informal. They rely heavily on peer learning, self-directed training, and affordable online courses (Lave & Wenger, 1991; Eraut, 2004). This preference for flexible, socially rooted, and low-cost learning methods suggests that formal training initiatives must be adapted to fit their actual learning habits if they aim to encourage broader AI adoption.

The analysis of digital competencies (Carretero, 2017) among these entrepreneurs revealed fragmented and limited engagement with AI, mainly focused on basic content creation tasks. Competencies in areas such as Information and Data Literacy, Communication and Collaboration, and advanced Problem-Solving using AI tools were either underdeveloped or largely absent. Notably, Safety competence emerged as a relatively stronger area, with entrepreneurs demonstrating a cautious approach to data sharing.

These findings suggest that future training programs should aim to expand technical competencies and build entrepreneurs' confidence in using AI across a broader range of business functions. Educational initiatives should prioritise improving perceived ease of use and demonstrating the practical relevance of AI to everyday entrepreneurial activities. Tailored, hands-on programs that integrate real-world business scenarios could help close competence gaps, foster greater trust in digital tools, and support a more holistic digital transformation among craft entrepreneurs.

This research is at an embryonic stage, and although interesting emerging insights are arising from the interviews, the work presents some limitations. First, there are some generalisability issues. Since this is a qualitative study, the findings may not be broadly generalisable to all entrepreneurs, and this limitation is even more severe if we consider that we reached a minimum part of the sample. Results are not generalisable, especially for entrepreneurs outside the targeted business sectors or regions. Secondly, due to time and resource constraints, we have targeted a small sample, limiting the diversity of perspectives. Completing the interviews and enlarging the sample is necessary to improve the research quality and the robustness of the analysis.

6 Ethics declaration

The ethical clearance was not required for our research.

7 AI declaration

For this research, we applied Sonix for the transcription of the interviews and ChatGPT for the translation. Both AI services are also introduced in the methodological section.

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Empowering Disadvantage Entrepreneurship: The Role of New Technologies for People With Disabilities

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Abstract

The intersection of sustainability, inclusion, and entrepreneurship is increasingly recognised as a strategic priority for contemporary businesses and societies. Among underserved groups, people with disabilities (PwDs) present both a significant entrepreneurial potential and unique barriers to business creation and operation. While self-employment offers a promising pathway towards economic inclusion for PwDs, research into the specific mechanisms enabling this form of disadvantage entrepreneurship remains fragmented and under-theorised (Klangboonkrong and Baines, 2022; Bhardwaj et al., 2023). This paper critically reviews the business and management literature to examine how emerging digital technologies can act as affordances facilitating entrepreneurial activity among PwDs.

Drawing upon affordance theory (Gibson, 1979; Leonardi, 2011), this study employs a qualitative, problematising literature review methodology (Alvesson and Sandberg, 2011, 2020), sourcing peer-reviewed articles across entrepreneurship, business, management, and disability studies. A theoretical framework is developed by synthesising the findings, identifying four key technological affordances: communication and interaction, business creation and operation, learning and capability development, and community and identity formation.

The analysis demonstrates that digital technologies are not neutral enablers but dynamic socio-material actors whose affordances depend on user capability and institutional context. It reveals how digital solutions can meaningfully reduce systemic barriers, enhance market access, and foster entrepreneurial identity among PwDs. This study contributes to extending the understanding of inclusive entrepreneurship within a digital economy, proposing that inclusive technology strategies must be embedded in policy and education, digital platform design, and business support services.

The paper advocates for future empirical research to validate and refine the proposed framework across diverse PwD populations and socio-economic contexts. It emphasises the need to account for intersectional factors and to evaluate the long-term sustainability of technology-enabled ventures. Ultimately, enabling entrepreneurs with disabilities through technology is not merely an ethical imperative but a strategic investment in unlocking innovation, diversity, and sustainable growth.

Keywords: Entrepreneurship, Disability, Technologies, Affordance theory.

Paper type: Academic Research Paper

1 Introduction

The intersection of sustainability, inclusion, and entrepreneurship has garnered growing scholarly and practical interest in recent years. Accessibility and inclusion, once regarded primarily as ethical imperatives, are now recognised as strategic assets for businesses and society. New technologies are pivotal in advancing these objectives, offering innovative solutions that enable firms and entrepreneurs to navigate growing complexities (Millar et al., 2008). In this context, people with disabilities (PwDs) emerge as a critical focus, representing not only an underserved customer segment to whom tailored products and services (Baker et al., 2007; Tuli et al., 2023), and marketing communication can be directed (Kearney et al., 2019) but also as valuable contributors to organisational activities. This is particularly evident in PwDs' roles as employees (Jammaers et al., 2016), especially in social entrepreneurship initiatives (Kalargyrou et al., 2020).

Therefore, one of the most compelling challenges is the inclusion of PwDs in the labour market (Jammaers et al., 2016; Renko et al., 2016; Klangboonkrong and Baines, 2022). While work is acknowledged as a fundamental right, defined as "*the opportunity to gain a living by work freely chosen or accepted in a labour market and work environment*" (UN, 2008, p. 19), statistics from the OECD (2022) show that nearly 40% of PwDs in the EU are excluded from active labour force participation. This exclusion is a social and economic issue and a missed opportunity to harness a rich vein of entrepreneurial potential.

In response to structural barriers in traditional employment pathways, many PwDs turn to self-employment or entrepreneurship, which the literature refers to as *entrepreneurs with disabilities* (EwDs) or *disadvantaged entrepreneurs* (Pagán, 2009; Maalaoui et al., 2020; Martinez Dy, 2020). However, despite increasing attention, research in this domain remains fragmented and under-theorised (Klangboonkrong and Baines, 2022; Bhardwaj et al., 2023), particularly concerning how digital and emerging technologies can alleviate barriers and unlock new opportunities for this cluster.

This paper aims to address this gap by applying technology affordance theory (Gibson, 1979; Leonardi, 2011) to study disadvantage entrepreneurship. Originating from psychology and defined as "*something that refers to both the environment and the animal* […] (and) *implies the complementarity*" (Gibson, 1979, p. 119), affordance is useful to explain intricate relationships between humans and technologies (Leonardi, 2011; Majchrzak and Markus; 2012) and even more the entrepreneurial agency as social processes enabled by digital technologies (Nambisan, 2017).

So, our research question is how digital technologies can serve as affordances for entrepreneurial activity among PwDs? Through a critical review of the business and management literature, we develop a theoretical framework explaining how new technologies can serve as affordances for entrepreneurial activity among PwDs. By doing so, the paper contributes to a more inclusive and sustainable view of entrepreneurship, where digital transformation is leveraged to reduce disadvantage (Klangboonkrong and Baines, 2022; Bhardwaj et al., 2023).

2 Literature review

2.1 Disadvantage entrepreneurship and PwDs

The concept of disadvantage entrepreneurship refers to entrepreneurial activity initiated by individuals facing systemic or structural barriers, including but not limited to race, gender, socio-economic status, and disability (Maalaoui et al., 2020). PwDs have emerged as a distinct category of disadvantaged entrepreneurs within this framework. As noted by Klangboonkrong and Baines (2022), few studies have analysed the self-employment issues for PwDs, also called entrepreneurs with impairments or EwDs (Pagán, 2009; Hsieh et al., 2019; Renko et al., 2016; Parker Harris et al., 2014).

Nevertheless, the existing body of research has been criticised for lacking theoretical depth and limited geographical scope (Hwang and Roulstone, 2015; Caldwell et al., 2016; Maritz and Laferriere, 2016). However, the debate on disadvantage entrepreneurship has grown in recent years, particularly regarding EwDs (Maalaoui et al., 2020; Santoro et al., 2020; Kašperová, 2021). Scholars have explored various facets of this phenomenon: from gendered experiences (Williams & Patterson, 2019), identity formation (Jammaers and Zanoni, 2020), and psychological outcomes (De Clercq and Honig, 2011; Martinez Dy, 2020). The latter have been analysed looking at the self-image value of 'doing' through self-employment (Martin and Honig, 2020) and the lived experience of EwDs through the critical theory of freedom, emphasising improvements in self-efficacy and self-esteem (Martinez Dy, 2020; Hidegh et al., 2022). More recently, Bhardwaj et al. (2023) highlighted the lack of management literature addressing disadvantaged entrepreneurs, particularly on "*'invisible disabled entrepreneurs' as an umbrella term referring to underdog entrepreneurs who are faced with disability that does not have any physical manifestation and interferes with day-to-day functioning*" (p. 2). Further, Norstedt and Germundsson (2023) have underscored how the motives for starting a new venture by PwDs are a topic that can be further analysed.

2.2 Technology and entrepreneurial inclusion

Technological innovation, particularly digital technologies, has been a powerful force in reshaping business models, operational structures, and value creation processes (Nambisan, 2017; Troise et al., 2022a). Digital transformation enables overcoming the volatility, uncertainty, complexity and ambiguity (VUCA) of contemporary competitive environments (Bennett and Lemoine, 2014; Troise et al., 2022b). For entrepreneurs, especially those operating at the margins of traditional markets, the opportunities offered by technology are amplified as they can be considered both new tools and new terrains for action.

In the context of digital technologies, the "*affordance (or a constraint) is defined as an action potential*" (Nambisan, 2017, p. 1046), and these inherent potentialities are even more relevant for PwDs. Originating in ecological psychology (Gibson, 1979), affordance theory was introduced into organisational and information systems research to explain how users perceive and act upon the action possibilities offered by technological artefacts. Leonardi (2011) and Majchrzak and Markus (2012) refined this concept to include not only perceived affordances but also actualised outcomes depending on the user's context and capabilities.

In the entrepreneurial domain, Nambisan (2017) defines affordance as an "action potential" that arises from the interaction between an entrepreneur and a technological artefact. For PwDs, these affordances may include remote communication, asynchronous collaboration, digital prototyping, and even marketplace access through e-commerce platforms. All these actions may be constrained in a traditional business context due to physical or social barriers.

Emerging research has begun to explore how AI-driven applications, such as image and speech recognition algorithms, voice-to-text software, automated transcription, screen readers, and intelligent assistants, can facilitate entrepreneurial activities for PwDs, enhancing labour market accessibility and fostering employment (Touzet, 2023). However, most existing studies focus on technology as an enabler for employees with disabilities, rather than as a catalyst for self-employment or venture creation. Consequently, the well-documented tendency of PwDs to pursue self-employment could benefit significantly from such technological advancements.

3 Methodology

This study employs a qualitative research design based on a critical literature review on disadvantage entrepreneurship, leveraging the lens of technology affordance theory (Gibson, 1979; Leonardi, 2011; Majchrzak and Markus, 2012) to highlight the opportunities technologies offer to PwDs in starting and sustaining ventures.

Following the suggestions on problematising review by Alvesson and Sandberg (2011; 2020), instead of aggregating extant findings, we seek to challenge implicit assumptions and identify conceptual gaps regarding disadvantage entrepreneurship and technology. We critically selected 21 peer-reviewed articles from top-tier journals in business, management, entrepreneurship, and disability studies. Our data sources include journals such as *Entrepreneurship & Regional Development, European Management Review*, *Disability & Society, International Journal of Entrepreneurial Behavior & Research, International Small Business Journal, Journal of Business Ethics, Journal of Business Research*. The literature was selected based on relevance to three intersecting themes: entrepreneurship by PwDs, digital technologies in entrepreneurship, and theoretical frameworks addressing socio-technical systems or affordances. The exclusion criteria applied concerned both topics and publication types: we excluded articles focusing on disadvantage entrepreneurship in relation to gender or ethnic minorities, as well as papers published in less relevant journals or outlets primarily addressing disability from a medical or rehabilitation perspective.

The review was coded inductively to identify recurring concepts and themes. The articles were categorised according to emergent themes related to entrepreneurial barriers, motivations, technological affordances, and enabling conditions, and were then clustered to build a theoretical framework. This framework explains how new technologies afford entrepreneurial action for PwDs and the conditions under which these affordances can be actualised.

4 Proposed theoretical framework

The critical analysis and synthesis of the selected papers have allowed us to identify two main domains influencing entrepreneurship by PwDs: critical enabling conditions and affordances (or action potentials).

Starting from the critical enabling conditions, the analysed articles mentioned different prerequisites for entrepreneurial effectiveness through digital technologies. We have categorised these in three conditions, opening from the importance of reliable digital tools (e.g., smart devices) and internet connectivity (Access to infrastructure) to the skills to navigate, adapt, and exploit technologies (Digital literacy and training), and finally the regulatory environments and social systems actively promoting inclusion and reducing systemic barriers (Institutional support and inclusive policy frameworks).

The technological solutions promoting entrepreneurship for PwDs have been categorised into four main affordances or action potentials. The first is the opportunity technologies offer for more accessible and effective communication and network circumstances (communication and interaction). Technologies such as speech recognition, real-time translation, and visual description tools afford new ways for entrepreneurs to communicate with clients, suppliers, and partners. For PwDs with hearing, visual, or speech impairments, these tools reduce dependence on intermediaries and open new market interactions. The second affordance is reducing entry barriers by digital platforms (e.g., Shopify, Etsy, Fiverr) that provide low-cost, scalable business models. Automation tools, like customer management systems or invoicing software, can manage operations efficiently without requiring extensive physical infrastructure or manual oversight (business creation and operation). Another change is that online education platforms and AI-driven tutoring tools afford continuous skill development, a key necessity for disadvantaged entrepreneurs seeking to overcome institutional and educational disparities (learning and capability development). Finally, among digital technologies, social media platforms and peer networks afford the creation of supportive communities, reducing isolation and enabling

knowledge exchange. These technologies can also play a critical role in identity construction and validation (Jammaers and Zanoni, 2020), constituting the fourth and last proposed category of affordance (community and identity formation).

Putting together the identified and presented elements, the proposed framework (Figure 1) articulates how digital technologies afford entrepreneurial agency for people with disabilities (PwDs), culminating in creating and sustaining new business ventures. This process is mediated by activating specific affordances across four primary domains and is contingent upon three critical enabling conditions.

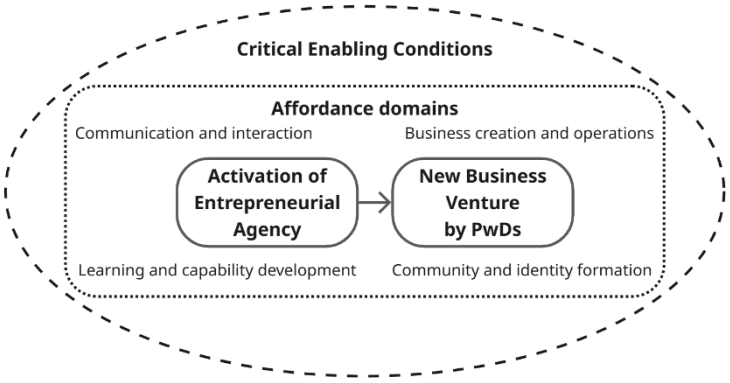


Figure 1: The proposed theoretical framework (Source: author's own elaboration)

While previous applications of technology affordance theory have primarily explored its relevance in organisational behaviour, knowledge management, and IT system design (Leonardi, 2011; Majchrzak and Markus, 2012), these models often assume an implicit universality of access and agency. Our framework diverges by explicitly embedding the social, institutional, and bodily constraints experienced by PwDs. By contextualising affordances within the specific barriers and capacities of disadvantage entrepreneurship, this study contributes a more inclusive and situated extension of affordance theory. Moreover, compared to Nambisan's (2017) digital entrepreneurship perspective, which emphasises opportunity creation through technology, our framework emphasises the conditional actualisation of these opportunities, depending on infrastructure, skills, and support ecosystems.

5 Implications

This paper contributes to the literature by integrating technology affordance theory into the study of disadvantage entrepreneurship. It further highlights that affordances are not universal but conditional and relational as they are shaped by the interplay between user capability, technology design, and institutional context. Moreover, our framework broadens the traditional view of entrepreneurial resources by emphasising the socio-materiality perspective of technologies as dynamic, non-human actors capable of reshaping access, opportunity, and performance.

Additionally, from a more practical standpoint, this framework demonstrates how technology developers, platform providers, and policymakers have a significant influence in empowering PwDs through the design of inclusive business support services, the adoption of universal design principles and disability perspectives in product development cycles, and finally the efforts in bridging the digital divide through targeted infrastructure investment and training schemes. As a practical illustration, an aspiring entrepreneur with visual impairment may utilise voice-activated design software and AI-based product descriptions to manage an e-commerce business on platforms like Etsy. Likewise, an entrepreneur with mobility constraints can participate in virtual incubators or pitch competitions using asynchronous video submissions. These cases show how the proposed affordances can be mapped onto real, functioning business models when enabling conditions are met.

6 Conclusions and future research

This paper advances our understanding of how digital technologies can serve as affordances for entrepreneurs with disabilities, turning exclusion into empowerment. It positions technology not merely as a tool but as a co-actor in the entrepreneurial journey of PwDs. The proposed theoretical framework advances the previous contributions on technology affordance theory (Leonardi, 2011; Majchrzak and Markus, 2012) with a specific focus on digital technologies (Nambisan et al., 2017) and their relationships with PwDs in their action potential in the entrepreneurship context.

As with all conceptual research, this study has several limitations. First, the framework is based on a qualitative critical review of the literature, and its proposed domains have not yet been empirically tested. Second, while the framework aspires to generalisability across various types of disabilities, it may not fully capture the lived experiences of entrepreneurs with intersecting impairments. Third, cultural and regulatory variations across regions are only partially addressed in this review, suggesting that future research should explore localisation and policy adaptation in more detail.

For all these reasons, future research should validate and expand the proposed framework through empirical studies, including case studies and interviews with EwDs across different geographies and types of impairment. Particular attention should be paid to the role of intersectionality (e.g., gender, age, socio-economic status) and the long-term sustainability of technology-enabled ventures. Moreover, future studies could analyse the potential impacts of this framework on several types of stakeholders, besides PwDs.

As technology continues to reshape the business landscape, inclusive entrepreneurship must become a core component of digital strategy and sustainable development. Enabling PwDs to thrive as entrepreneurs is not only a moral imperative but also a wise investment in human potential.

7 Ethics declaration

The authors declare that no ethical approval was required for this conceptual study based on secondary data. No human participants were involved, and there are no conflicts of interest to disclose.

8 AI declaration

This paper has been professionally proofread using AI-based writing assistance (OpenAI ChatGPT), under the supervision and critical validation of the authors. The intellectual content, conceptual development, and final arguments remain the sole responsibility of the authors.

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Institutional Perspectives on Entrepreneurial Education Ecosystems: Fostering Digital Student Startups

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Abstract

The increasing integration of digital technologies (DT)—such as artificial intelligence, big data, and extended reality—is transforming the domain of academic entrepreneurship. Despite the growing interest in digital academic entrepreneurship, extant literature rarely distinguishes the unique institutional challenges faced by student entrepreneurs, whose ventures are typically less resource-intensive, more agile, and deeply embedded in digitally mediated learning environments. Moreover, while studies acknowledge the transformative potential of DT, few have examined their dual interaction with formal and informal university mechanisms, especially from a comparative perspective across institutional ecosystems. Finally, existing frameworks often overlook how students appropriate digital tools and platforms to navigate institutional constraints, thus underestimating student agency in shaping entrepreneurial outcomes in the digital age. This study addresses that gap by investigating how formal and informal university-based mechanisms influence the entrepreneurial motivations and capabilities of student founders in digitally evolving environments.

Grounded in the conceptual frameworks of Rippa and Secundo (2019) and Guerrero and Urbano (2012), the study adopts a qualitative, comparative case-study approach. Six student-led digital startups were analysed across two entrepreneurial universities—University of Naples Federico II (Italy) and Universitat Autònoma de Barcelona (Spain)—using in-depth interviews and documentary analysis. Findings reveal that while formal structures such as entrepreneurship education and technology transfer systems are widely available, they often lack practical alignment with the needs of digital ventures. Informal factors—like cultural perceptions of entrepreneurship, experiential learning practices, and exposure to role models—also play a crucial role, yet their effectiveness varies across institutional contexts.

The study advances two key propositions: first, that universities providing access to advanced digital skills and specialised technical resources are more likely to foster the successful development of digital startups; and second, that institutions facilitating access to online educational resources and entrepreneurial networks significantly enhance the success potential of student-led ventures. These findings demonstrate how DT reshape the interplay between institutional structures and entrepreneurial behaviour, offering theoretical contributions to digital academic entrepreneurship and practical insights for higher education institutions aiming to cultivate inclusive and future-ready innovation ecosystems.

Keywords: Digital Academic Entrepreneurship; Student Entrepreneurship; Entrepreneurial Universities; Institutional Theory; Comparative Case Study

Paper type: Academic Research Paper

1 Introduction

In today's era of pervasive digitalisation, emergent technologies—most notably artificial intelligence, big-data analytics and augmented-reality systems—are recasting industrial value creation logics across virtually all sectors (Lamine et al., 2023). Higher-education institutions are not immune to this transformation; indeed, digital technologies (DT) are penetrating teaching, research and third-mission activities, thereby reconfiguring the landscape of academic entrepreneurship (Rippa & Secundo, 2019). Traditionally, academic entrepreneurship centred on the commercial exploitation of laboratory discoveries through patent licensing or faculty-led spin-offs; yet the diffusion of DT now enables novel entrepreneurial forms that are frequently initiated and managed by students, such as platform-based services, data-driven applications and fully virtual ventures (Lamine et al., 2023; Rippa & Secundo, 2019).

Institutional theory offers a useful lens for unpacking this evolution because the rules, norms and routines embedded in universities condition the behaviours of nascent entrepreneurs (Klofsten et al., 2019). Formal institutional factors encompass codified structures—entrepreneurship curricula, incubators, technology-transfer offices and governance mechanisms—that directly allocate resources and legitimise venturing activities (Guerrero & Urbano, 2012). Informal factors, by contrast, comprise cultural attitudes, pedagogical practices and the availability of credible entrepreneurial role models, all of which shape students' perceptions of feasibility and desirability (Guerrero & Urbano, 2012). Although scholarship has mapped the broad contours of digital academic entrepreneurship (Secundo et al., 2020), empirical clarity is still lacking regarding how DT interact with these formal and informal levers to influence Student Entrepreneurship (SE)—defined here as venture creation

by individuals who simultaneously pursue university studies and operate a business (Primario et al., 2022; Passavanti et al., 2023). Existing investigations seldom disentangle the specific mechanisms through which DT affect motivational drivers, capability development and opportunity enactment among students (Lamine et al., 2021).

Against this backdrop, our study mobilises the frameworks of Rippa and Secundo (2019) and Guerrero and Urbano (2012) to examine how institutional factors at two entrepreneurial universities—the University of Naples Federico II (Italy) and the Universitat Autònoma de Barcelona (Spain)—shape students' abilities and intentions to launch digital ventures. After reviewing the theoretical foundations, we outline a comparative case-study methodology that integrates documentary analysis with in-depth interviews. The findings section explores how DT reconfigure formal supports and informal cultures, while the conclusion discusses theoretical contributions, managerial implications and avenues for future research in digital-age SE.

2 Theoretical Background

2.1 Student entrepreneurship in the digital age

Student Entrepreneurship (SE)—the launch of new ventures by enrolled students or recent graduates—has moved to the forefront of entrepreneurship research because of its demonstrable societal impact, its role in commercialising academic knowledge and its promise for theoretical advance (Colombo & Piva, 2020; Clarysse et al., 2022; Breznitz & Zhang, 2019; Hayter et al., 2017). Digital technologies (DT)—from social media and big-data analytics to AI, 3-D printing and XR—have permeated entrepreneurial practice, prompting a reconceptualisation of academic entrepreneurship as a technology-enabled, platform-mediated phenomenon (Rippa & Secundo, 2019; Nambisan, 2017). Recent scholarship therefore investigates how universities adapt curricula and support structures to meet digitally driven market needs (Garcez et al., 2022; Secundo et al., 2020; Toniolo et al., 2020). Yet the specific influence of DT on SE motivation and capability development remains under-explored (Lamine et al., 2021), despite high-profile student founders such as Zuckerberg, Page, Brin, Dell and Yang fuelling popular interest (Sansone et al., 2021).

SE has already enriched entrepreneurship theory by clarifying the individual–opportunity nexus (Larsson et al., 2017), illuminating the cognitive conversion of intentions into venture actions (Rippa et al., 2020) and mapping how ventures emerge in local ecosystems (Busch & Barkema, 2022; Bock et al., 2021). Nonetheless, granular knowledge of students' activities, contexts and characteristics is still incipient (Clarysse et al., 2022; Passavanti et al., 2023). Scholars call for clearer definitions, noting two prevailing views: students preparing growth-oriented business plans (Katz et al., 2000) versus students simultaneously studying and operating companies (Ridder & Van der Sijde, 2006), sometimes extending to very recent alumni (Wright & Mustar, 2019). Multiple antecedents shape SE—including university ecosystem quality (Busch & Barkema, 2022), social context (Wright & Clarysse, 2020), socio-demographics (Fini et al., 2016) and role models (Abbasianchavari & Moritz, 2022). Institutional-theory research further shows that student founders favour effectuation and bootstrapping relative to non-student entrepreneurs (Politis et al., 2012; Clarysse et al., 2022) and pursue goals distinct from staff spin-offs (Hayter et al., 2017). Because DT are reshaping social norms and motivations, their impact on SE warrants systematic investigation (García-Morales et al., 2020).

2.2 Digital academic entrepreneurship

Rippa and Secundo (2019) argue that the convergence of entrepreneurial-university logic with DT constitutes a paradigm shift. Follow-up studies highlight digital spinoffs, virtual incubators and other adaptive strategies that extend universities' economic reach (Garcez et al., 2022; Secundo et al., 2020; Toniolo et al., 2020; Linzalone et al., 2020). Creating digital products on campus can materially boost regional growth (Ivanović-Đukić et al., 2019). The Rippa–Secundo framework positions DT as core—not peripheral—elements of venture processes, enabling broad stakeholder collaboration, fluid knowledge exchange and online funding access (Bejjani et al., 2023; Kraus et al., 2022; Chan et al., 2022), thereby aligning university activities with global digital-economy demands (Rådberg & Löfsten, 2023).

2.3 Institutional economics and the entrepreneurial university

Institutional Theory distinguishes formal rules—property rights, procedures—and informal norms—values, beliefs—that guide entrepreneurial action across ideation, start-up and growth phases (North, 1990; Davis & Williamson, 2016; Reynolds & White, 1997; Stenholm et al., 2015). Universities have responded by embedding entrepreneurship education, support infrastructure and pro-venture cultures (Guerrero et al., 2020; Secundo et

al., 2021). Contemporary entrepreneurial universities thus integrate competitive strategy with knowledge-transfer missions (Klofsten et al., 2019), complemented by administrative and governance reforms (Redford & Fayolle, 2014). Guerrero and Urbano (2012) synthesise these dynamics into a framework linking formal structures (governance, support, education) and informal levers (attitudes, pedagogy, role-model visibility) to university entrepreneurial capacity, underscoring their role in regional development (Youtie & Shapira, 2008).

By overlaying the digital-entrepreneurship insights of Rippa and Secundo (2019) onto Guerrero and Urbano's institutional matrix, researchers can analyse how DT reconfigure both formal and informal factors, thereby shaping student entrepreneurial motivations and outcomes (Garcez et al., 2022; Secundo et al., 2021). The present study adopts this integrated perspective to assess how two universities leverage DT to orchestrate their entrepreneurial ecosystems and foster student-led digital startups.

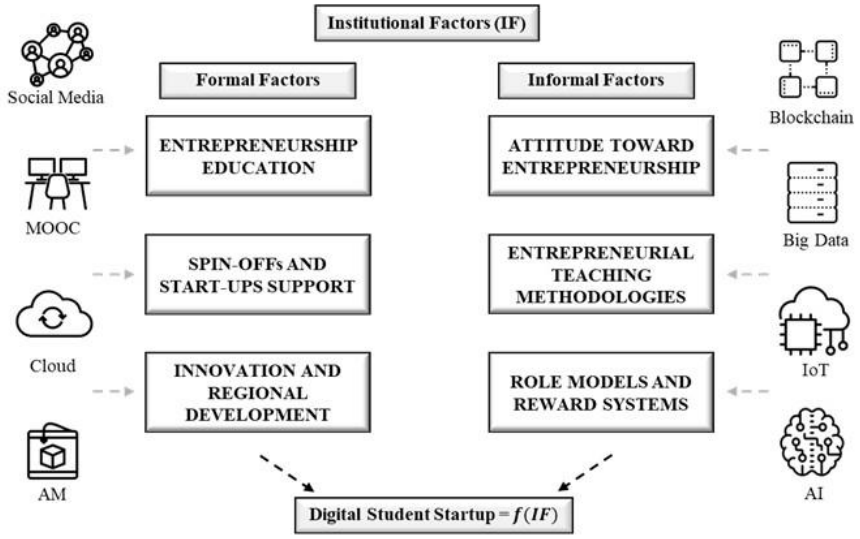


Figure 1: Formal and Informal Institutional Dimensions Shaping Student-Led Digital Start-ups in Entrepreneurial Universities

3 Methodology

To explore the complex and context-dependent dynamics of how digital technologies (DT) influence student-led entrepreneurship within universities, this study employs a qualitative research design. This approach is particularly suitable for investigating processes that unfold in real-life contexts and require attention to depth, meaning and interpretation (Good et al., 2020; Gartner et al., 2002). Because the central aim is to compare institutional factors across university ecosystems, a comparative multiple-case study method was adopted. This strategy offers both rich contextual insights and theoretical generalisability through replication logic (Guerrero et al., 2012; Yin, 2013). Case-study research is especially appropriate when addressing "how" and "why" questions related to contemporary phenomena (Secundo et al., 2020).

Following a literal-replication strategy, cases were selected based on theoretical criteria that enhance learning about digital academic entrepreneurship (Yin, 2013). The two focal universities—University of Naples Federico II (Italy) and Universitat Autònoma de Barcelona (Spain)—have strong regional engagement but differ in institutional maturity and ecosystem characteristics (Guerrero et al., 2012). Both institutions explicitly promote entrepreneurial initiatives and are situated in regions with high startup activity, meeting commonly accepted case-selection benchmarks in SE research. Within each university, three student-led digital startups were purposefully chosen, resulting in six rich cases—labelled ITA and ES respectively—for cross-case comparison and analytical depth (Eisenhardt, 1989).

This comparative logic is further supported by the distinctive characteristics of the two university ecosystems selected, which provide meaningful variation in institutional settings relevant to student-led digital entrepreneurship. Federico II is the oldest public university globally, with over 4,000 researchers across STEM and management disciplines. It has launched more than 90 spin-offs in the past decade and actively incorporates DT into its entrepreneurial strategies. Its strategic orientation toward third-mission activities and its ties with more than ten local industrial districts make it an ideal case for studying university-driven innovation dynamics. UAB, located in Catalonia—Spain's leading entrepreneurial region—benefits from a diverse economic base and institutional infrastructure that supports tech-based startups, positioning it as an agile and innovation-driven institution. The regional context is marked by a high concentration of new enterprises and a GDP per capita

significantly above the national average, which further enhances UAB's capacity to serve as an anchor institution in a dynamic entrepreneurial ecosystem.

Fieldwork occurred over four months between 2023 and 2024. Eight semi-structured interviews were conducted; one was used as a pilot and one was excluded for limited relevance, leaving six interviews (≈ 11 hours; > 90 pages of transcripts). Interviews were structured in three sections: general startup information, organisational features, and institutional influences—based on Guerrero and Urbano's (2012) framework. Complementary data sources included policy documents, startup websites, university brochures and press materials, in line with prior studies (Good et al., 2020; Guerrero et al., 2014; Secundo et al., 2020). This triangulation enhances construct validity and provides a multi-perspective view (Yin, 2013).

To analyse the data, we applied content analysis across three iterative phases: open coding (to identify recurring concepts), axial coding (to group related codes), and selective coding (to extract theoretical categories). ChatGPT-4 was used to assist in consistent labelling and to identify emergent themes, an increasingly recognised practice in qualitative entrepreneurship research (Forsström-Tuominen et al., 2019). Cross-case matrices were developed to identify patterns and inform propositions about how DT shape institutional enablers and constraints for student ventures (Eisenhardt & Graebner, 2007).

Finally, to ensure the trustworthiness of our findings, coding decisions were peer-reviewed, and a clear audit trail linking raw data to interpretations was maintained. The use of theoretical replication across distinct university contexts strengthens the external validity of the results while retaining the depth and interpretive richness characteristic of qualitative research (Yin, 2013; Rasmussen et al., 2014).To ensure trustworthiness, coding decisions were peer-reviewed and a clear audit trail linking raw data to findings was maintained. The use of theoretical replication across distinct university contexts strengthens the external validity of the results while retaining the depth and interpretive richness characteristic of qualitative research (Yin, 2013; Rasmussen et al., 2014).

4 Findings and Discussion

This study investigates how formal and informal institutional factors influence the emergence of student-led digital startups, comparing two university ecosystems—Naples and Barcelona. The results reveal differentiated impacts of digital technologies (DT) on both types of institutional elements, offering insight into how universities can foster digitally-enabled academic entrepreneurship.

4.1 Formal Institutional Factors

The role of formal institutional mechanisms—entrepreneurship education, technology transfer structures, and regional innovation policies—emerged as pivotal yet inconsistently effective across the cases. Entrepreneurship education was generally acknowledged as foundational, yet its execution often lacked practical relevance. Students reported that courses were overly theoretical, lacking hands-on components essential for digital venture development (Secundo et al., 2021). As one Italian founder noted, despite learning useful project management principles, practical application was minimal.

The increasing adoption of DT in educational programming has enhanced accessibility and interactivity, using digital platforms, simulations, and online content to prepare students for real-world challenges (Primario et al., 2022; Secundo et al., 2021). Nonetheless, several respondents—particularly from Spain—emphasised the insufficient integration of advanced digital competencies into entrepreneurship curricula. This echoes Wright et al. (2017), who argue for the urgent adaptation of academic programs to meet the specific demands of technology-intensive entrepreneurship.

Another critical gap identified was in the area of technology transfer. Across both countries, students described university support for patenting and intellectual property as slow, bureaucratic, and ill-suited to the needs of agile digital startups. Entrepreneurs had to resort to external legal support to navigate the patenting process—underscoring findings by Guerrero et al. (2020), who advocate for more responsive and tailored tech-transfer mechanisms within universities.

Nonetheless, regional institutions often compensated for university-level deficits. In Spain, entities such as Barcelona Activa and Acció were praised for offering streamlined legal support, financial resources, and strategic mentoring, facilitating startup formation and early-stage growth. Similar support was found in the Campania region, albeit to a lesser extent. These findings align with Bergmann et al. (2016), who highlight the importance of regional actors in bridging knowledge gaps for nascent entrepreneurs.

Formal university structures have also evolved through DT. Administrative digitisation—through tools for resource management, virtual incubators, and online mentoring—allowed more responsive and student-centric

innovation support systems. However, this transformation remains uneven across institutions, often constrained by legacy governance models or limited digital readiness.

A key insight concerns the strategic value of providing access to high-level technical infrastructure. In several cases, access to anonymised datasets and proprietary university resources enabled critical stages of product validation. This leads to the first proposition:

Proposition 1: Universities that provide access to advanced digital skills and specialised technical resources are more likely to foster the successful development of digital startups.

4.2 Informal Institutional Factors

Informal institutional factors—such as entrepreneurial attitudes, pedagogical practices, social norms, and the presence of role models—proved equally influential in shaping students' entrepreneurial trajectories. A recurrent critique was the persistence of traditional, lecture-based teaching formats. Students expressed a preference for experiential approaches involving simulations, case studies, and collaborative learning environments—methods that foster entrepreneurial competencies and digital literacy (García-Morales et al., 2020; Primario et al., 2022).

University cultures were often perceived as risk-averse or sceptical towards student entrepreneurship. Particularly in Naples, some founders reported that their peers and academic staff did not take entrepreneurial initiatives seriously, reinforcing a conservative career outlook prioritising job security. This mirrors broader socio-cultural dynamics identified in SE literature, where institutional conservatism can deter entrepreneurial action (Passavanti et al., 2023).

Encouragingly, digitalisation is beginning to shift these cultural logics. Universities increasingly celebrate entrepreneurial achievements, especially those leveraging digital innovation, thus enhancing legitimacy and motivation for prospective student entrepreneurs (Chan et al., 2022). However, the presence of effective entrepreneurial role models remains uneven.

Many students—especially in Italy—noted that their universities did not expose them to successful digital entrepreneurs during their studies. This lack of visible role models within the academic environment is widely cited as a barrier to entrepreneurial self-efficacy (Bergmann et al., 2016; Passavanti et al., 2024). To overcome this void, students often turn to digital sources, drawing inspiration from podcasts, YouTubers, and online mentorship platforms.

This evolution of mentorship practices—away from traditional in-person figures towards globally accessible digital influencers—underscores the growing significance of digital platforms in shaping entrepreneurial identity and aspiration (Secundo et al., 2021). For example, students cited Massive Open Online Courses (MOOCs) and entrepreneurial content creators as instrumental to their learning journeys. This finding is particularly pronounced in the Italian context, where informal digital mentorship often substitutes for institutional support (Primario et al., 2022).

A related theme is the value of digital networking. Founders emphasised that beyond institutional structures, connections forged via online communities and peer-to-peer platforms played a vital role in their startups' early development. As one Spanish founder stated, these networks were crucial for navigating bureaucratic challenges and accessing market insights.

Based on these insights, the second proposition is offered:

Proposition 2: Universities that facilitate access to online educational resources and foster networking opportunities with experienced entrepreneurs significantly enhance the success potential of student-led digital startups.

A comparative view reveals distinct strengths and weaknesses across the two ecosystems. In Naples, while regional support is active, university-based formal structures—especially technology transfer and practical education—remain underdeveloped. In contrast, Barcelona's institutions exhibit a more integrated ecosystem, with stronger alignment between formal and informal supports and better incorporation of digital tools.

Digital startups appear to benefit disproportionately from these institutional configurations compared to non-digital ventures. Enhanced scalability, data-driven product models, and online visibility mean they are more sensitive to the quality of digital and entrepreneurial infrastructure. Table 15, which synthesises these differences, confirms that digital ventures receive greater support when universities embrace digital transformation across teaching, mentoring, and administrative processes.

5 Conclusions

This study has examined how digital technologies (DT) reshape institutional conditions within universities and, in turn, influence student entrepreneurship (SE). By integrating the frameworks of Rippa and Secundo (2019) on digital academic entrepreneurship and Guerrero and Urbano (2012) on entrepreneurial universities, the research underscores the transformative role of DT in reconfiguring both formal (e.g., entrepreneurship education, support structures) and informal (e.g., pedagogical approaches, cultural attitudes) factors that foster SE.

The comparative case analysis between the University of Naples Federico II and the Universitat Autònoma de Barcelona reveals that DT have enhanced access to tools, mentorship, and learning environments, thereby reducing barriers to entry and stimulating student engagement. The findings call for a recalibration of educational programs to align with digital learner expectations—particularly by incorporating MOOCs, simulations, and non-traditional mentorship via digital influencers and online communities.

Theoretically, this work expands our understanding of how institutional environments mediate digital entrepreneurship. Practically, it offers strategic insights for universities aiming to create inclusive, innovation-ready ecosystems. Future research should broaden geographic scope, incorporate quantitative methods, and assess the economic contributions of student-led ventures, particularly as DT and digital pedagogies continue to evolve.

6 Ethics Declaration

The authors declare that they have complied with all ethical standards required for this research. No human participants or animals were involved in the study. No conflict of interest exists.

7 AI Declaration

The authors declare that no generative artificial intelligence (AI) tools were used in the writing, editing, or content development of this manuscript.

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AI and Entrepreneurship: A Bibliometric Exploration in the Post-ChatGPT Era

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Abstract

The pervasive integration of artificial intelligence (AI) is fundamentally reshaping societal and business landscapes, presenting both significant opportunities and challenges, particularly within the entrepreneurial sphere. AI's potential to alter venture conception, development, scaling, market entry, and competitive dynamics necessitates a re-evaluation of traditional entrepreneurship theories. As a key enabling technology, AI revolutionises core entrepreneurial processes, from ideation to market expansion, fostering novel forms of value creation and opportunity identification. However, despite acknowledging the influence of digital technologies, a comprehensive understanding of specific research trends concerning AI's role, especially following the widespread adoption of generative AI tools like ChatGPT, remains underdeveloped. This study addresses this gap through a bibliometric systematic literature review. Utilising the Web of Science database and the "bibliometrix" R-package, we employ thematic evolution analysis to map the trajectory of research topics at the intersection of AI and entrepreneurship, specifically comparing the pre- and post-ChatGPT periods. We aim to visualise the field's structure, identify influential contributions, and track thematic shifts. Anticipated findings include the emergence of research streams focused on generative AI's impact on venture creation, ethical considerations, evolving decision-making processes, and the new skills required for AI-driven entrepreneurship. This analysis seeks to provide practical insights for entrepreneurs leveraging AI tools and highlight knowledge gaps and future research directions for academics, ultimately contributing to a deeper understanding of how AI is shaping the future of entrepreneurship.

Keywords: Artificial Intelligence, Entrepreneurship, ChatGPT, Bibliometric Analysis, Thematic Evolution

Paper type: Academic Research Paper

1 Introduction

The accelerating integration of artificial intelligence (AI) across various sectors is fundamentally reshaping numerous aspects of society and business, creating unprecedented opportunities and challenges (Dwivedi et al., 2021; Upadhyay et al., 2022). The entrepreneurial landscape, in particular, appears to be undergoing a significant transformation. AI possesses the potential to profoundly alter how new ventures are conceived, developed, and scaled, potentially expediting market entry, forging new competitive dynamics, and challenging established business models (Giuggioli and Pellegrini, 2023). As a pivotal enabling technology, AI is actively revolutionising core entrepreneurial processes – ranging from the complexities of market entry and international expansion (Huang and Rust, 2018; Liu et al., 2024) to the crucial initial stages of idea generation and validation (Chalmers et al., 2021; Shepherd and Majchrzak, 2022). This fosters innovative forms of value creation and enhances opportunity identification capabilities (Leone et al., 2021; Broekhuizen et al., 2023).

This profound technological shift demands a critical re-evaluation of established entrepreneurial theories. It necessitates a deeper understanding of how AI is not merely assisting but fundamentally transforming the essence of entrepreneurship in the digital era, creating novel opportunities that extend beyond simple automation or efficiency gains (Nambisan, 2017; Mayanja et al., 2024). Given the transformative potential of AI, comprehending its evolving impact on entrepreneurship within today's dynamic business environment is crucial (Warner and Wäger, 2019; Di Vaio et al., 2021; Biloslavo et al., 2024). While existing research acknowledges the broad influence of digital technologies on entrepreneurial processes and behaviours (Andriole et al., 2017), a comprehensive grasp of the specific research trends, thematic clusters, and intellectual structure related to AI's specific role remains underdeveloped (Ancillai et al., 2023). The advent and rapid diffusion of powerful generative AI tools like ChatGPT, with their sophisticated capabilities for content creation, automation, analysis, and personalisation, further complicates and enriches this evolving research landscape, adding new layers of inquiry (Kraus et al., 2019; Goel and Nelson, 2024).

Therefore, this study addresses the identified gap by employing a bibliometric systematic literature review. Our objective is to investigate how scholarly research focusing on AI's impact on entrepreneurship has evolved, placing particular emphasis on the period following the widespread adoption of ChatGPT. By mapping the shifting thematic patterns and identifying future research directions within this critical field (De Bem Machado

et al., 2022; Duong, 2024), we aim to provide a structured analysis of research trends, thematic shifts, and emerging areas of focus. While the publication trend indicates a surge in interest, the core of the bibliometric analysis involves mapping the thematic content. The subsequent sections will present the results from the keyword co-occurrence analysis (Aria and Cuccurullo, 2017), and strategic diagram mapping (Cobo et al., 2011) for both the Pre-ChatGPT and Post-ChatGPT eras. This will allow for a detailed comparison and identification of specific thematic shifts, emerging topics (e.g., related to generative AI, ethics, specific entrepreneurial processes), and changes in the core research foci within the field. This research seeks to understand whether significant changes have occurred in the intellectual structure and thematic focus of AI and entrepreneurship research in the post-ChatGPT era, offering valuable insights for both academic researchers and practitioners navigating this rapidly changing domain.

2 Methodology

The study's dataset was compiled from the Web of Science (WoS) Core Collection database, chosen for its extensive coverage of high-quality academic publications. The literature search targeted documents combining concepts related to Artificial Intelligence (AI) and Entrepreneurship.

The search query included a broad range of terms within the "Topic" field that includes the Title, the Abstract, the keywords provided by the author(s), and those created automatically by WoS looking at each article references and listed as Keywords Plus.

To capture a comprehensive view of AI, we have used terms encompassing general AI concepts as well as specific techniques and recent developments: "Artificial Intelligence", "Intelligent Automation", "Cognitive Computing", "Machine Reasoning", "Augmented Intelligence", "Smart System", "Synthetic Intelligence", "Machine Intelligence", "Computational Intelligence", "Cognitive System*", "Intelligent System*", "Machine Learning", "Deep Learning", "Connectionist System*", "Parallel Distributed Processing", "Neurocomputing", "LLM*", "Large Language Model*", "ChatGPT",* and "GPT". Similarly, to identify relevant entrepreneurship literature, the query targeted the "Topic" field for keywords such as "entrepreneur*" (to capture keywords such as entrepreneur, entrepreneurial, entrepreneurship, etc.), "enterp"* (capturing enterprise, etc.), "startup", and "start-up".

The search logic was designed to retrieve documents discussing AI in the context of either general entrepreneurship/enterprise or specific startup activities.

To ensure the relevance and quality of the retrieved literature, specific constraints were applied during the search process. The timeframe was restricted to publications indexed between January 2018 to nowadays, capturing significant developments both before and after the advent of widely accessible generative AI. Furthermore, the document selection focused exclusively on peer-reviewed journal contributions by including only those classified as "Article", while explicitly excluding "Proceeding Paper" and "Book Chapters" to make the corpus more internally coherent. In particular, we have filtered all the articles marked as "Retracted Publication". Finally, to align the dataset with the study's focus, the search was limited to articles indexed within the "Management" subject category in the Web of Science database.

For each document included in the final dataset, standard bibliographic information (including authors, title, source, abstract, keywords, references, and publication year) was exported from WoS to facilitate the subsequent analysis using the bibliometrix R-package.

Before the analysis we looked at each article abstract to confirm it was related to our SLR main objective – i.e., To understand how scholarly research focusing on AI's impact on entrepreneurship has evolved in the last years. For example, we have deleted previous literature reviews, and those studies using machine learning to predict enterprise outcomes or similar effects.

2.1 Data analysis techniques

The data analysis have been performed using the "bibliometrix" R-package (Aria and Cuccurullo, 2017), a widely used tool for comprehensive science mapping analysis. The analysis will encompass several stages, with a core focus on thematic structure and evolution to understand the intellectual landscape of AI and entrepreneurship research.

3 Systematic literature review: performance analysis

After the screening phase, the final corpus was composed by 132 articles coming from 65 journals. The articles in the corpus have usually more than 3 authors (the average is 3.3 co-authore per article).

The next figure 1 show the growth of the corpus over the years.

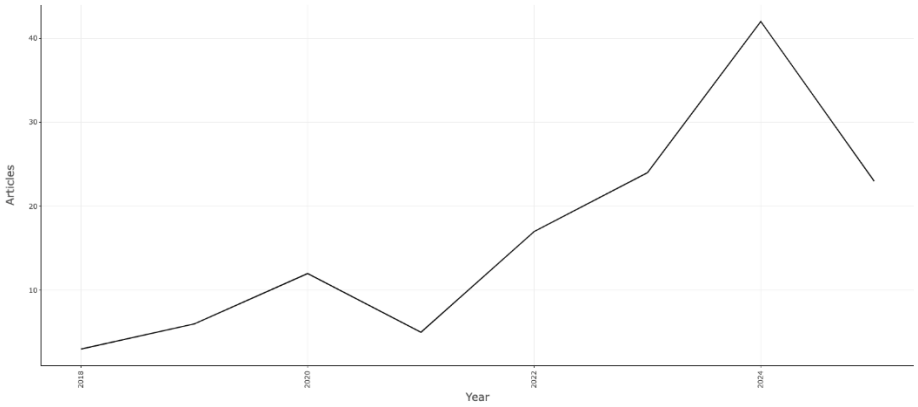


Figure 1 – Scientific Production over the years

Overall, the publication trend analysis reveals a clear and accelerating growth trajectory in research at the intersection of AI and entrepreneurship since 2018. Following an initial phase of rapid expansion with publication counts doubling in both 2019 and 2020, and after overcoming a transient dip in 2021, the field experienced an exponential surge in activity. This is further highlighted by the substantial increase in articles published in 2023 and particularly in the first half of 2024, which alone surpassed previous annual totals. Furthermore, the significant number of articles already assigned to the 2025 (there are 23 articles published in the first three months of this year) underscores the sustained high momentum and highlights the prevalence of rapid online dissemination practices in this dynamic research area, indicating intense and continuously growing attention for these topics.

These articles have been published in a total of 65 journals. The ten most used journals are shown in the following figure 2.

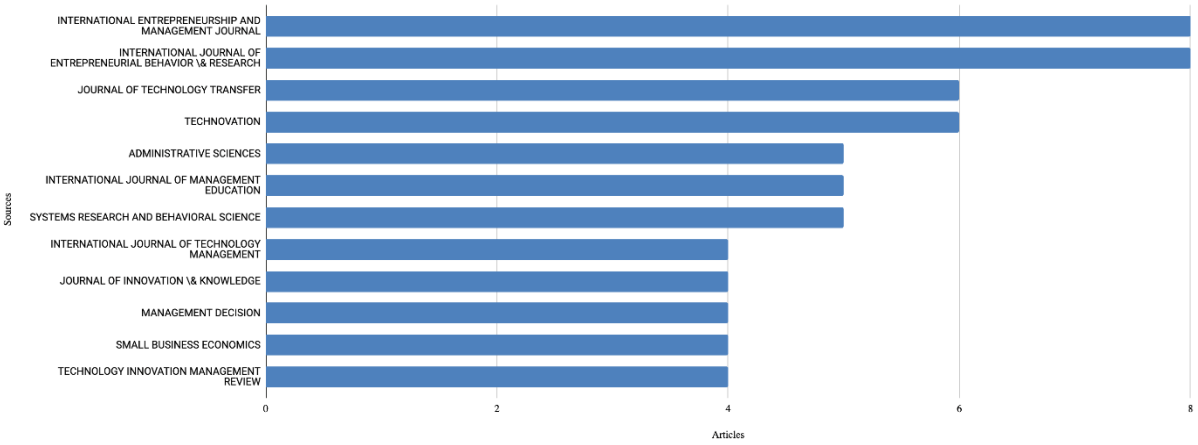


Figure 2 – Ten most used journals in our corpus (showing all the journal with 4 articles for a total of 12 journals)

The *International Entrepreneurship and Management Journal*, and the *International Journal of Entrepreneurial Behavior & Research* are the most prolific sources, each contributing 8 articles to the dataset. Following closely are the *Journal of Technology Transfer*, and *Technovation*, both with 6 articles. These top four journals account for 28 articles, representing approximately 21% of the total dataset. It is interesting to note that apart from the two top journals, that are more related to the topic of entrepreneurship, there are 5 journals related to innovation and/or technology (that is the other side of the query we have carried on), but there are 5 more that cannot be easily classified in one of the two research areas, highlighting the broad scope of these results. In general, the presence of journals like *Small Business Economics* (4 articles) highlight the relevance of AI for smaller firms, while outlets such as *Management Decision* (4 articles), *Journal of Innovation & Knowledge* (4 articles), and *Systems Research and Behavioral Science* (5 articles) suggest connections to broader management related topics.

The next figure 3, report the author's production, limited to our corpus, over the year.

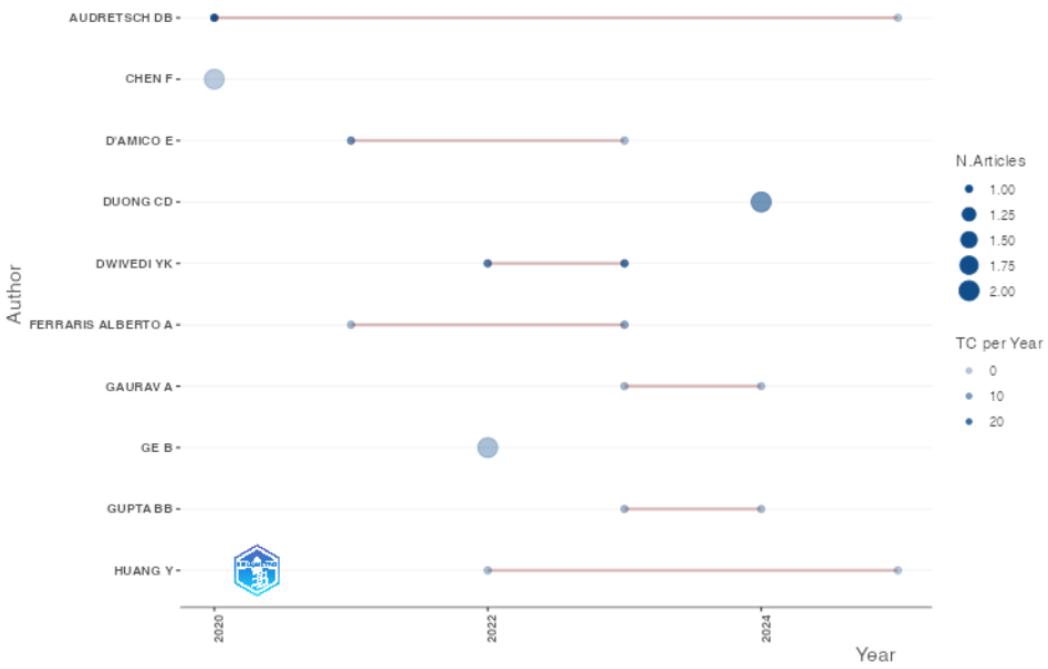


Figure 3 – Author's Production Over Time

The analysis of leading author contributions over time provides a nuanced view of the scholars shaping the AI and entrepreneurship field within our corpus. It highlights a dynamic interplay between recent productivity surges and sustained citation impact. Interestingly, the authors demonstrating the highest average citation impact per year (Audretsch, Dwivedi, Ferraris, and Huang) appear to be recognized relatively quickly by the field, garnering higher citation rates. This could indicate that their work might address more foundational aspects, provide influential reviews, or tackle particularly resonant topics within the AI-entrepreneurship nexus. The sustained activity of established scholars like Audretsch (authors of the seminal paper "Artificial intelligence and big data in entrepreneurship: a new era has begun" with Obschonka, in 2020) and Dwivedi (author of many articles on Artificial Intelligence and its impact in various fields of management studies, such as the highly cited manifest on *International Journal of Information Management* even before the diffusion of ChatGPT – Dwivedi et al., 2021).

Then, there are impactful contributions from younger scholars as Ferraris and Huang, suggests a combination of established expertise and newer influential voices building the field's intellectual core during its rapid expansion phase. This dynamic reflects a field that is both maturing, with recognized influential works, and simultaneously experiencing rapid expansion driven by recent entrants or shifting focus.

4 Thematic evolution

Next, we look into the evolution of this field at the intersection of AI and entrepreneurship research intellectual structure. To achieve this, we employ the thematic evolution analysis approach defined by Cobo López-Herrera, Herrera-Viedma, and Herrera (2011), specifically by mapping and comparing the thematic landscapes of the Pre-ChatGPT era (2018-2022) and the Post-ChatGPT era (2023-onwards).

This analysis utilizes the strategic diagram model (Callon et al., 1991; Cahlik, 2000; Cobo et al., 2011), a powerful tool for visualizing the structure of a research field. This model positions identified research themes (clusters of co-occurring keywords) onto a two-dimensional map based on two key metrics derived from the keyword network:

- **Callon's Centrality** (used for the X-axis of the diagram) – it reflects the strength of a theme's connections to other themes, indicating its importance and integration within the broader research field. Higher centrality suggests a more transversal or foundational role.
- **Callon's Density** (used for the Y-axis of the diagram): it reflects the strength of connections within the theme itself, indicating its internal coherence, conceptual development, and maturity. Higher density points to a well-defined and focused research area.

The position of a theme on this diagram allows for its classification into one of four quadrants: Motor Themes (high centrality, high density - central and developed drivers), Basic Themes (high centrality, low density - important but less developed or transversal), Niche Themes (low centrality, high density - specialized and peripheral), and Emerging or Declining Themes (low centrality, low density - marginal and underdeveloped).

4.1. Pre ChatGPT period: from 2018 to 2022

In the Pre ChatGPT Period, we have found 43 articles that adopting the thematic evolution may be divided in 7 themes as reported in the following figure 4.

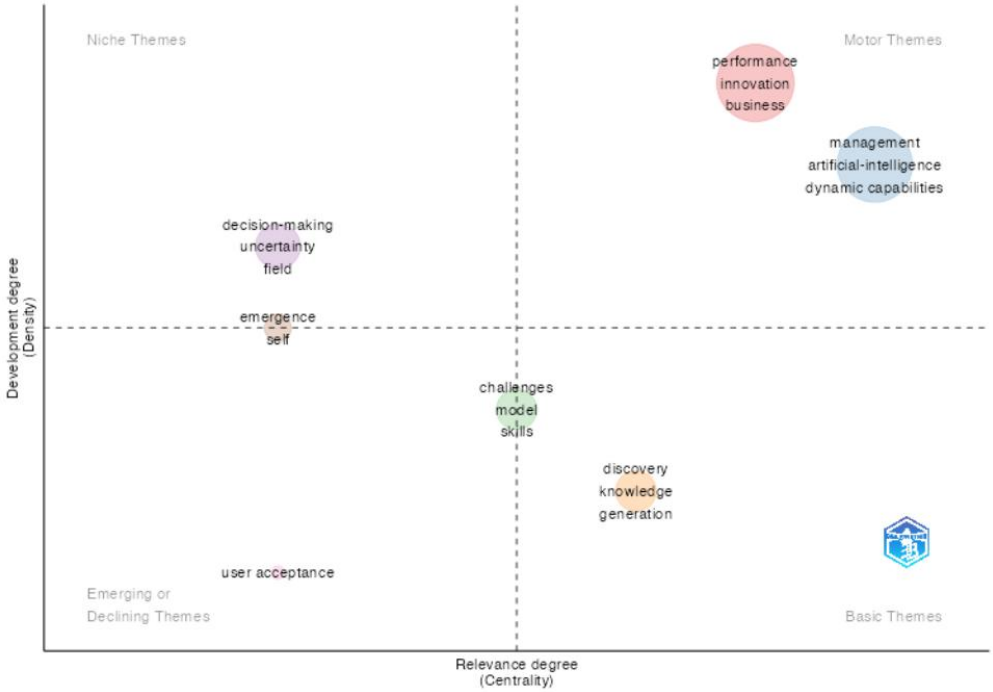


Figure 4 - Pre ChatGPT Period Clusters

The Motor Themes quadrant is dominated by two highly central and developed clusters. The first, represented by the label 'performance', 'innovation', 'business', highlights research investigating the tangible outcomes of AI/digitalization, such as impacts on internationalization speed (Neubert, 2018) and the development of dynamic capabilities for transformation (Warner & Wäger, 2019). The second motor theme, using the label 'management', 'artificial-intelligence', 'dynamic capabilities', underscores the strategic necessity of integrating AI, exploring topics like digital transformation building blocks (Lichtenthaler, 2020) and AI's role in leveraging human capital (Popkova & Sergi, 2020). These themes indicate that core research aimed at understanding how to manage AI strategically and what performance effects to expect.

In the Basic Themes quadrant, the cluster labeled 'discovery', 'knowledge', 'generation' demonstrates high relevance (centrality) but lower development (density). Anchored by studies on AI for identifying emerging business models (Garbuio & Lin, 2019) and validating them (Dellermann et al., 2019), this theme represents the fundamental, yet still developing, application of AI to the crucial entrepreneurial task of opportunity discovery.

The Niche Themes quadrant contains more specialized topics. Labels such as 'decision-making', 'uncertainty', 'field' point to focused research on AI's influence on entrepreneurial cognition, while 'emergence', 'self' likely covers specific areas like ecosystem dynamics or self-efficacy in relation to AI. These themes, though internally developed, had limited connection to the broader field.

Finally, the Emerging or Declining Themes quadrant hosts underdeveloped and marginal topics for this period. Themes identified by labels like 'challenges', 'model', 'skills' suggest nascent discussions on practical hurdles and required competencies, while 'user acceptance' indicates that behavioral adoption theories, though present (Upadhyay et al., 2022), were not yet a central concern within this literature stream.

Overall, the pre-ChatGPT research prioritized understanding the strategic and performance dimensions of AI adoption, underpinned by its connection to opportunity discovery. Foundational cognitive aspects were niche topics, while practical challenges and user acceptance remained peripheral, setting a clear stage for potential shifts in the subsequent era.

4.2. Post ChatGPT period: from 2023 onwards

The strategic diagram for the post-ChatGPT era presents a notably transformed thematic landscape compared to the previous period, reflecting the surge in research activity and potentially shifting priorities (See Figure 5).

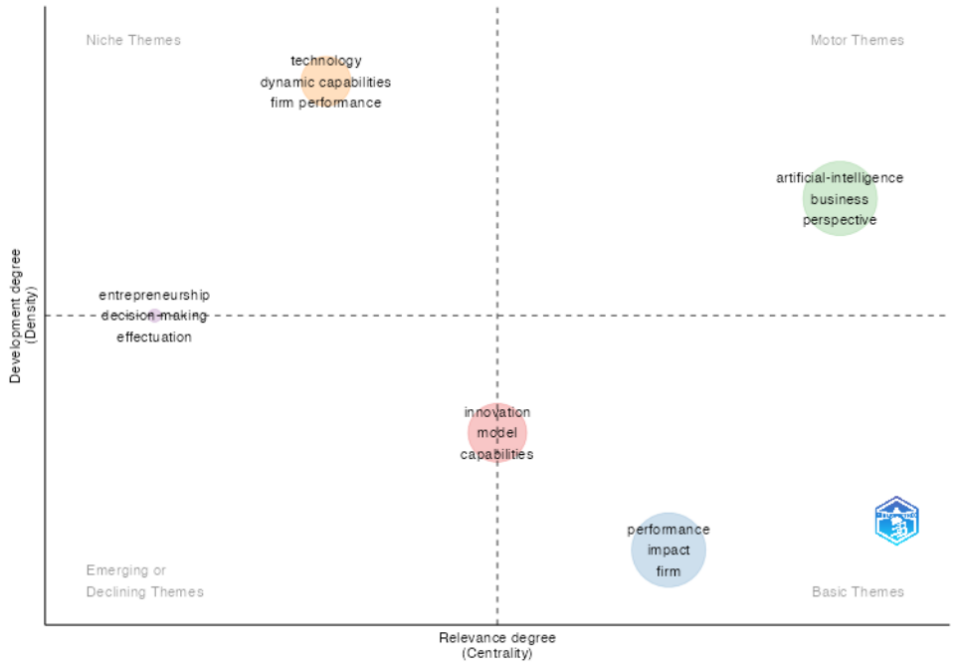


Figure 5 - Post ChatGPT Period Clusters

The Motor Themes quadrant now features a single, dominant cluster labeled 'artificial-intelligence', 'business', and 'perspective'. This theme's high centrality and density indicate that AI itself, viewed from a business perspective, has become the core, well-developed driving force. Articles associated with this label directly address AI's role in the digital economy (Si et al., 2023), its potential for driving sustainable innovation (Govindan, 2024), and its specific application in the venture creation process (Schiavone et al., 2023). This consolidation around the 'artificial-intelligence' label suggests a maturation and direct focus on AI as the central object of study.

Occupying the Basic Themes quadrant is a cluster using the label 'performance', 'impact', 'firm'. Its high relevance (centrality) but lower development (density) indicates that assessing the impact of AI on firm performance remains a crucial, transversal concern, though perhaps explored through diverse, less integrated methodologies. Studies related to this label include SME default prediction (Altman et al., 2023), the potential of generative AI (Norback & Persson, 2024), and AI in entrepreneurial finance (Giuggioli et al., 2024).

In the Niche Themes quadrant, we find two clusters. One uses the label 'technology', 'dynamic capabilities', 'firm performance', suggesting a specialized focus continuing from the previous period. The other, labeled 'entrepreneurship', 'decision-making', 'effectuation', points to a persistent niche examining AI's influence on core entrepreneurial theories.

Finally, a cluster represented by the label 'innovation', 'model', 'capabilities' resides near the center but in the Emerging or Declining quadrant. Its position suggests that while innovation and capabilities remain relevant, this specific thematic configuration, as represented by its label, denotes a less developed and potentially transitional focus in this new era.

Overall, the post-ChatGPT landscape is characterized by a strong, unified focus on 'artificial intelligence' (as the primary motor theme label), while 'performance' and 'impact' evaluation remains a central underlying concern. Specific theoretical lenses ('decision-making') and technology management aspects ('dynamic capabilities') persist as niche areas.

5 Conclusion and implications

This study employed a bibliometric systematic literature review combined with science mapping techniques to investigate the evolution of research at the intersection of Artificial Intelligence (AI) and entrepreneurship,

with a specific focus on comparing the thematic landscape before (2018-Nov 2022) and after (Dec 2022-Mid 2024) the widespread emergence of generative AI tools like ChatGPT. Our analysis confirmed a significant surge in publication activity in the latter period, coinciding with a notable restructuring of the field's thematic priorities.

The thematic evolution analysis (Figure 6) revealed a clear shift.



Figure 6 – The evolution of the themes

In the pre-ChatGPT era, the research landscape was driven by two core motor themes "performance/innovation/business" on the outcomes of AI/digitalization and the more strategic one labeled "management/artificial-intelligence/dynamic capabilities" looking at the enterprise needs for integrating AI in their activities. Foundational concepts of "discovery/knowledge" acted as a basic theme, with niches and emerging topics for the other two.

In stark contrast, the post-ChatGPT era shows a significant consolidation around a single dominant motor theme explicitly labeled "artificial-intelligence/business/perspective". This cluster absorbed key aspects from previous themes, including the one on management (as shown by the evolution of keywords like 'artificial-intelligence;big data;future') on performance (see keywords as business and perspective), decision-making (keywords such as field and opportunities), and even from niche theme of discovery, signifying that AI itself, viewed from a holistic business perspective, has become the central driving force and object of study.

The theme "performance/impact" persists as a highly relevant basic theme, indicating continued interest in outcomes, but it now incorporates knowledge aspects and look into specific industry contexts, themes previously less relevant. A distinct theme labeled "innovation/model/capabilities" has emerged with notable connections, drawing from previous period in themes as the one on performance (keywods innovation, firms, and growth), from the management one (looking at the keyword capabilities), and from the emerging theme on the 'challenges' highlighting innovation as a key area reshaped by new AI possibilities.

Concurrently, 'technology' emerged as a distinct theme, consolidating previous management and performance aspects related to technology itself.

Finally, the new theme on entrepreneurship, drawing mainly from previous "decision-making" and "management" themes, signifies a continued, perhaps more focused, examination of core entrepreneurial processes within the new AI paradigm.

5.1 Academic Contributions

This study offers several contributions to the academic community. Firstly, it provides a structured, quantitative overview of the rapid growth and evolving intellectual structure of the AI and entrepreneurship research field. Secondly, by employing a thematic evolution analysis contrasting pre- and post-ChatGPT periods, it offers empirical evidence of the significant impact generative AI has had on reshaping research agendas, moving AI from a topic *within* management and performance discussions to the central organizing *perspective*. Thirdly, it identifies the specific thematic shifts: the consolidation around AI, the heightened focus on innovation, the persistence of performance impact evaluation, and the reconfiguration of technology and core

entrepreneurship themes. This map serves as a valuable guide for researchers seeking to position their work within this dynamic landscape.

5.2 Practical Implications

The findings also hold important implications for practitioners. On one side, it highlights that entrepreneurs and managers must recognize that AI, particularly generative AI, is no longer a peripheral technology but a central element impacting business models, strategy, and operations. Staying informed about AI developments is crucial. Then, looking at the emerging 'innovation' theme we may get that there are significant opportunities in leveraging AI for novel products, services, processes, and business models. Practitioners should actively explore how AI can drive innovation within their ventures. Taking into consideration that overcoming implementation hurdles and developing AI-related skills are now integrated aspects of technology management and innovation, requiring continuous attention.

At the same time, there are plenty of opportunities in the debate on measuring the real Impact AI investments and initiatives and that the shift in the themes implies that AI tools are actively changing how opportunities are perceived, decisions are made, and ventures are managed.

5.3 Limitations and Future Research

This study is subject to limitations common in bibliometric analyses. Its scope is confined to the Web of Science Core Collection (Management category, Articles only), potentially omitting relevant work from other sources or disciplines. The reliance on keyword analysis provides a structural overview but cannot capture the full theoretical depth of individual papers. The definition of the post-ChatGPT period captures the initial wave but is still a relatively short timeframe for observing long-term stable shifts.

These limitations suggest several avenues for future research. Longitudinal studies tracking thematic evolution over a longer post-ChatGPT period are needed. Deeper qualitative reviews or case studies could explore *how* specific AI tools are impacting the identified themes (e.g., decision-making, innovation models). Research explicitly addressing the ethical implications of AI in entrepreneurship, seemingly underrepresented in the current thematic structure, is crucial. Investigating the specific skills and competencies required by entrepreneurs in this new era warrants further attention. Comparative studies using different databases or including other document types could provide a broader perspective. Finally, research moving beyond identifying impacts towards developing actionable frameworks for AI integration and capability building in entrepreneurial contexts would be highly valuable.

In conclusion, this bibliometric exploration illuminates the dynamic evolution of the AI and entrepreneurship field, accelerated and reshaped significantly in the post-ChatGPT era. By mapping this changing landscape, we provide a foundation for researchers and practitioners to navigate the opportunities and challenges presented by AI's transformative potential.

6 Ethics declaration

This works does not need ethical clearance for the kind of research adopted.

7 AI declaration

We have not used AI tools to develop the paper.

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Artificial Intelligence and Knowledge Management in Healthcare: A Pathway to SDGs Achievement

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Abstract
The integration of Artificial Intelligence (AI) and Knowledge Management (KM) in healthcare is transforming decision-making, resource allocation, and service efficiency, aligning with the United Nations' Sustainable Development Goals (SDGs). AI-driven KM systems enhance clinical decision-making, optimize disease detection, and expand medical access, particularly in underserved areas, supporting SDG 3 (Good Health and Well-being) and SDG 10 (Reduced Inequalities). Additionally, AI contributes to SDG 4 (Quality Education) by improving medical training and SDG 13 (Climate Action) through energy-efficient healthcare solutions. Despite its potential, the adoption of AI in healthcare faces significant challenges, including data privacy concerns, algorithmic biases, and regulatory uncertainties. The lack of comprehensive studies assessing AI's measurable impact on sustainability further limits its large-scale implementation. This study addresses these gaps by analyzing how AI-driven KM systems support SDGs and identifying key obstacles to their integration. The research conducts a bibliometric and thematic analysis and examines 1,095 peer-reviewed papers from the Scopus database. Findings highlight AI's role in enhancing efficiency, enabling knowledge-sharing, and improving resilience in healthcare systems. However, concerns regarding ethical governance, equitable access, and technological disparities underline the necessity of strong policy frameworks to ensure responsible AI deployment. This study contributes to the discourse on AI's role in healthcare by providing a structured analysis of its impact on SDG achievement. Finally, the article addresses future research perspectives as joint scholars' and practitioners' analyses.

Keywords: Artificial Intelligence, Knowledge Management, Healthcare, Sustainable Development Goals

Paper type: Academic Research Paper

1 Introduction

The attention on sustainability has grown exponentially in recent years due to emerging global threads, such as climate change, air pollution, intensification of land use and water depletion (Morioka et al., 2017). Achieving environmental, social and economic sustainability is now a worldwide challenge. Therefore, sustainable development, defined by the World Commission on Environment and Development (WCED, 1987) as "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs", has become an important focus for the general public, governments and health systems (Biason & Dahl, 2016; Mosca et al., 2017). Previously, the concept of sustainability was predominantly associated with environmental aspects (Rogers et al., 2013). However, in addition to encompassing a broad spectrum of environmental issues, sustainable development faces diverse and intricate challenges that evolve alongside human societies and natural ecosystems around the world (Robert et al., 2005). Nowadays, its meaning has evolved to encompass a more holistic perspective, incorporating dimensions such as social equality, economic development and health well-being (Marimuthu & Paulose, 2016). This change is reflected in global initiatives like the Sustainable Development Goals (SDGs) established by the United Nations in 2015 as a global framework to address new emerging challenges (Sparviero & Ragnedda, 2021). The SDGs, comprising 17 interconnected goals, aim to address issues ranging from poverty eradication and climate action (Koebe, 2025). SDG 3, specifically dedicated to promoting well-being for all, underscores the importance of equitable healthcare access and the development of resilient healthcare systems (Nunes et al., 2016). Thus, improving global health stands as one of the most relevant objectives within the United Nations' SDGs (Koebe, 2025).

In recent years, digital transformation has revolutionized multiple sectors, including healthcare. The integration of new technologies, such as Artificial Intelligence (AI), has significantly influenced medical practices, from diagnosis and treatment to healthcare system efficiency (Kraus et al., 2021). AI has also emerged as a key enabler of Knowledge Management (KM) by enhancing the ability to collect, process, and analyze vast amounts of data for improved decision-making and operational efficiency (Taherdoost & Madanchian, 2023). Within the healthcare sector, AI-driven KM systems facilitate the automation of data processing, enable pattern recognition, and generate actionable insights by improving disease detection, optimizing resource allocation, and ensuring access to healthcare services, particularly in underserved areas (Jarrahi et al., 2023). Although the

pandemic period (COVID-19) has identified potential implementations in healthcare related to prevention and decision-making processes, studies investigating the impacts and outcomes of the advanced adoption of AI and KM are currently absent (Taherdoost & Madanchian, 2023; Vishwakarma et al., 2023). While AI-based KM systems have demonstrated substantial benefits in automating knowledge-sharing processes and supporting decision-making frameworks, their role in advancing sustainability in healthcare remains an underexplored research avenue. This study aims to bridge this gap by analyzing how AI and KM contribute to SDG achievement in healthcare and by assessing the associated challenges that could hinder their full integration.

Given the increasing relevance of AI and KM in shaping the healthcare sector's sustainability and resilience, this study seeks to answer the following research questions:

RQ1: How does Artificial Intelligence in healthcare contribute to Sustainable Development Goals achievement?

RQ2: What are the key challenges in integrating AI for a resilient healthcare system?

To explore the role of AI in healthcare, this study adopts a structured methodological approach combining bibliometric and thematic analysis. The bibliometric analysis, conducted through Bibliometrix, examines research trends, collaborations, and knowledge diffusion, while the thematic analysis, conducted using Leximancer, identifies key conceptual relationships. Data were collected through a systematic search in the Scopus database, resulting in a final dataset of 1,095 papers, ensuring a comprehensive understanding of AI's contributions and associated challenges. The findings indicate that AI-driven KM systems enhance healthcare efficiency, optimize resource allocation, and improve patient outcomes, significantly advancing SDG 3, SDG 4, SDG 10, and SDG 13. Nonetheless, challenges related to data privacy, algorithmic biases, and ethical governance necessitate careful policy considerations to ensure responsible AI adoption.

The rest of the paper reviews previous literature in Section 2 and details the Methodology in Section 3. Then, the study presents the findings in Section 4, discusses them, and concludes with future research directions in Section 5.

2 Literature review

In the context of the ongoing digital transformation, the incorporation of new technologies has the potential to contribute significantly to the achievement of these goals. In particular, among these new technologies, AI emerges as a transformative tool to accelerate progress toward health-related issues (Kraus et al., 2021). Furthermore, AI has emerged as a transformative factor within KM, particularly within the healthcare system (Taherdoost & Madanchian, 2023). KM, broadly defined as the process of creating, storing, sharing, and applying knowledge to enhance organizational decision-making and innovation, plays a pivotal role in modern healthcare organizations (Abubakar et al., 2019; Alavi & Leidner, 2001). Indeed, effective KM practices ensure that every employee has access to the appropriate and highest quality of information available at the time when a decision needs to be undertaken. Knowledge can be categorized as either individual or organizational. Individual knowledge refers to an individual's ability to make judgments and decisions based on their knowledge, whereas organizational knowledge encompasses knowledge as a resource that enables a workforce to make decisions based on collectively constructed knowledge. This collective knowledge is acquired by organizations through KM processes (Merali, 2000; Tsoukas & Vladimirou, 2001). Between the early 2000s and 2018, studies on this research field have often been focused on social networks, autonomous media, and human-computer interactions, underscoring the strategic importance of KM for organizations (Gaviria-Marin et al., 2018). Considering healthcare, by leveraging AI, KM is greatly enhanced, as AI automates data analysis, identifies patterns, and generates actionable insights. This capability allows organizations to process vast amounts of health data and uncover correlations that were previously inaccessible through manual processes (Jarrahi et al., 2023). Indeed, advanced AI algorithms enable deep-learning models to support clinical decision-making, policy planning, and the efficient integration of electronic health records, ensuring a continuous knowledge exchange across different healthcare settings (Rajkomar et al., 2018). AI-driven KM systems have the potential to reduce knowledge loss, optimize resource utilization, and enhance global collaboration through advanced knowledge-sharing platforms (Jarrahi et al., 2023; O'Leary, 1998).

AI contributes significantly by enhancing disease detection, streamlining resource allocation, and expanding access to medical services through telemedicine and mobile health applications (Aceto et al., 2020). For example, predictive AI algorithms support early identification of disease outbreaks, enabling timely and targeted responses in vulnerable regions (Panch et al., 2018). AI-driven automation of administrative tasks, such as scheduling and documentation, allows healthcare providers to focus more on patient care, further maximizing the efficiency of KM processes within healthcare systems (Bose, 2003). Furthermore, AI facilitates the integration of electronic health records and big data analytics, providing insights that optimize healthcare

planning and improve patient outcomes (Koebe & Bohnet-Joschko, 2023). These advancements not only foster progress toward universal health coverage but also exemplify how technology-driven innovation can bridge healthcare disparities, particularly in underserved areas (Olu et al., 2019). Therefore, the implementation of AI-based KM systems within the healthcare arena also aligns with wider sustainability principles by addressing inefficiencies and supporting preventive care (Choy et al., 2018). The integration of AI and KM within healthcare extends its impact beyond direct health improvements, enhancing progress across multiple SDGs (Table 1).

Table 1. The role of AI and KM in advancing SDGs

AI and KM	**Effects of AI and KM on SDGs**
AI enhances KM by automating data analysis, identifying patterns and generating actionable insights (Jarrahi et al., 2023).	Advances SDG 3 (Good Health and Well-being) through improved healthcare delivery, early warning systems and universal health coverage (Koebe & Bohnet-Joschko, 2023).
KM supported by AI facilitates seamless integration of electronic health records and big data analytics (Rajkomar et al., 2018).	Supports SGD 10 (Reduced Inequalities) by optimizing medical resources allocation, ensuring underserved regions receive adequate care (Rajan et al., 2020).
AI-based KM systems prevent knowledge loss and enable global collaboration through advanced knowledge-sharing platforms (Jarrahi et al., 2023; O'Leary, 1998).	Contributes to SDG 4 (Quality Education) by promoting health literacy and lifelong learning through AI-driven educational platforms (Holmner et al., 2012).
Advanced KM systems supported by AI improve organizational decision-making practices and innovation by effectively managing vast health data (Taherdoost & Madanchian, 2023).	Drives progress toward the achievement of SDG 9 (Industry, Innovation and Infrastructure) by fostering technological innovation and developing resilient healthcare infrastructures (Koebe, 2025).
AI-enabled KM streamlines administrative and clinical workflows, allowing healthcare providers to focus on patient care (Bose, 2003).	Promotes SDG 8 (Decent Work and Economic Growth) by increasing occupational health and safety through predictive maintenance and reducing workplace hazards (Jarrar et al., 2024).
AI-driven KM systems enhance energy management by utilizing monitoring systems to optimize resource allocation, improve energy efficiency, and integrate renewable energy technologies in healthcare infrastructures (Holmner et al., 2012).	This supports SDG 13 (Climate Action) by fostering sustainable healthcare delivery, reducing environmental impact, and ensuring continuous operations in environments where specific resources are limited (Aceto et al., 2020; Holmner et al., 2012).

Source: Authors' elaboration

3 Methodology

The literature review approach represents a structured method for analyzing scientific sources, ensuring a rigorous and reliable evaluation of existing research (Hulland & Houston, 2020). The literature review method is a technique employed to examine a collection of academic works, aiming to generate insights, critical reflections, and future research directions on a specific research topic (Massaro, Dumay, et al., 2016). In recent years, bibliometric analysis has surged in popularity within the various scientific literature review methods due to the accessibility, advancements, and availability of modern software and scientific databases (Ruggieri et al., 2018). These tools enable handling large volumes of scientific data and contribute to producing high-impact research, uncovering emerging trends, collaboration patterns, and research constituents (Donthu et al., 2021). Given the research gap, the authors consider that an in-depth thematic analysis can complement bibliometric analysis while applying a rigorous and systematic research protocol (Furrer et al., 2020). Combining these two analytical approaches can provide a comprehensive overview of specific research trends and limit the results' subjectivity (Donthu et al., 2021).

According to the literature (Massaro, Dumay, et al., 2016; Secundo et al., 2020), to explore the role played by AI within the healthcare sector, the researchers adopt five rigorous steps, namely:

1. Defining RQs that the study seeks to answer.
2. Writing the research protocol.
3. Determining the research sample for the analysis.
4. Developing a coding framework.
5. Conducting a critical analysis and discussion on the findings obtained, identifying future research directions.

The initial step involves defining the research questions that the study aims to answer (Massaro, Handley, et al., 2016). After defining the RQs, it would be essential to write a research protocol including the definition of

information sources, the methodology adopted, the mean and tools utilized for analyzing the studies constituting the sample (Petticrew & Roberts, 2008). Table 2 illustrates the already known concepts, the motivation that drove the authors to write this review, the research topic, the dataset creation, and the tools used to implement the analysis.

Table 2. Research review protocol

Research protocol elements	**Author's considerations**
What is already known?	In the context of the ongoing digital transformation, the incorporation of new technologies has the potential to contribute significantly to the achievement of these goals. Among these new technologies, AI emerges as a transformative tool to accelerate progress toward health-related issues (Kraus et al., 2021). Additionally, AI has emerged as a transformative factor within KM in healthcare environments (Taherdoost & Madanchian, 2023).
Motivation	Although the pandemic period (COVID-19) has identified potential implementations in healthcare related to prevention and decision-making processes, studies investigating the impacts and outcomes from the advanced adoption of AI and KM are currently absent (Vishwakarma et al., 2023). The study intends to respond to the gap through the SDGs lens. AI-driven KM systems play a crucial role in advancing multiple SDGs within the healthcare sector. There is a potential for a bibliometric and thematic analysis examining the relationships between AI and KM and their impact on SDGs achievements.
Research topic	RQ1: How does Artificial Intelligence in healthcare contribute to Sustainable Development Goals achievement? RQ2: What are the key challenges in integrating AI for a resilient healthcare system?
Journal's research (Villiers et al., 2023)	The decision was made not to restrict the research to individual scientific journals due to the relatively nascent nature of the study's purpose (Secinaro et al., 2021). The analysis included articles and peer-reviewed journals (Easterby-Smith & Lyles, 2012). Additionally, the studies of the sample were selected within "medicine" and "business, management and accounting" areas from Scopus database to extract all relevant information sources (Villiers et al., 2023).

Source: Authors' elaboration

The third step consists of defining resources using the scientific database Scopus, the largest citation database for peer review with social sciences titles from more than 4,000 publishers (Burnham, 2006). The study was conducted using the following research string:

TITLE-ABS-KEY ("artificial intelligence" OR "machine learning" OR "data processing") AND ("healthcare" OR "medical centre") AND ("environmental, social and governance" OR "ESG" OR "environmental" OR "social" OR "governance").

The initial search using the above research string provided 5,300 results. By filtering the results only to include the subject areas of "medicine" and "business, management and accounting," the number of documents was reduced to 2,164. Selecting only articles and peer-reviewed journals, the total results amount to 1,160. After eliminating documents in languages other than English, the final set comprised 1,095 papers. After a one-to-one abstract screening, 75 papers were removed because they were considered irrelevant to the research topic. Figure 1 represents the complete process of paper selection.

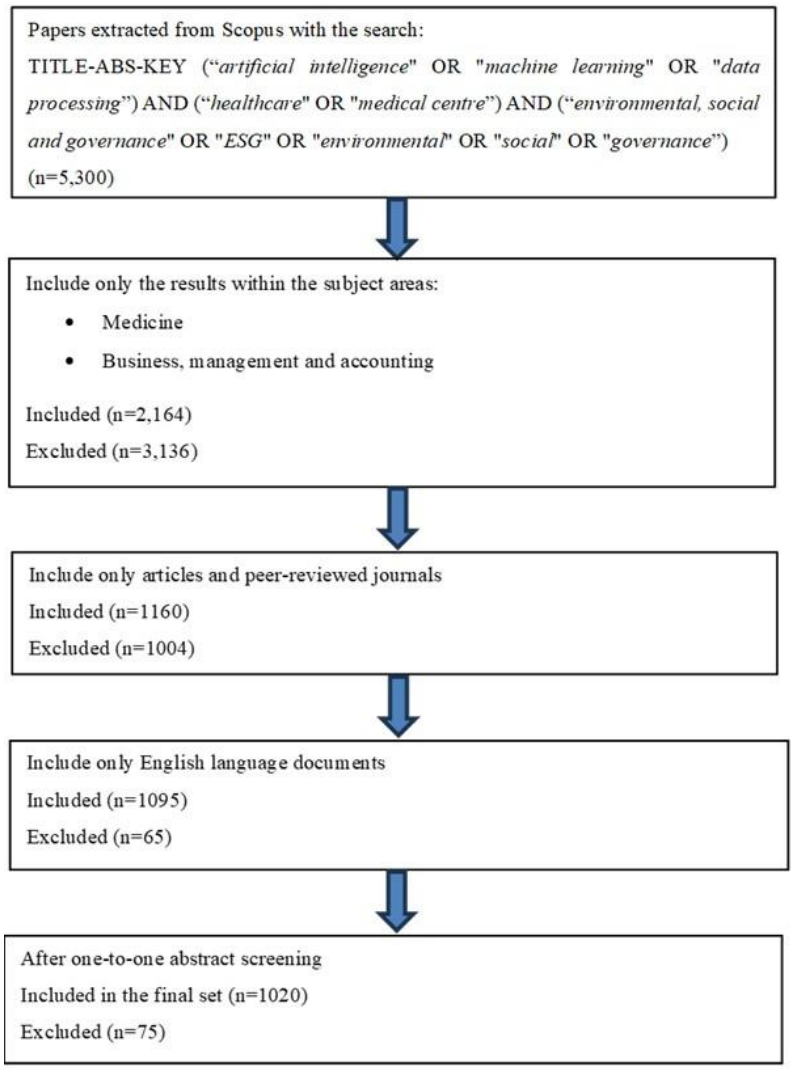


Figure 1. Paper selection process
Source: Authors' elaboration

Subsequently, the fourth phase aims to define the items to be examined in the selected papers by establishing a coding framework focusing on the following nodes:

- Number of sources.
- Sources' production over time: the evolution over the time of the number (Nr) of papers.
- Most relevant sources: distribution of papers among journals and citations received.
- Geographical scientific production distribution: papers distribution among countries.

To gather these data on the flow of relationships between countries and identify the leading contributors on the topic, the authors utilized Bibliometrix, a statistical package available on R-Studio (Radha & Arumugam, 2021). This software compiles bibliometric information such as authors, citations, countries of production, and keywords. Finally, critical analyses have been made through a thematic analysis of the documents selected. This evaluation was conducted using Leximancer 4.0, a software that provides a form of automated analyses based on the properties of texts with trustworthy results demonstrating high reliability and reproducibility (Sotiriadou et al., 2014).

4 Results and findings

The first part of this section provides an overview of the research topic of AI in healthcare, derived from a bibliometric analysis conducted using Bibliomterix. The second part describes the thematic analysis performed through Leximancer software.

The dataset includes 1,075 papers published between 1983 and 2024 from 557 different journals. Table 3 summarizes the key information of the dataset, showing an annual growth rate of 15,18%. Figure 2 illustrates the annual scientific production on the topic, revealing a significant increase in research interest over the last decade. While early publications in the 1980s were intermittent, a steady increase in scholarly output is observed from 2011, reflecting the growing relevance of AI applications in healthcare. Concurrently, European and global regulatory initiatives began emphasizing the integration of AI-driven technologies in medical practice. The introduction in 2016 of the General Data Protection Regulation (GDPR) established robust data-sharing policies while safeguarding patient privacy, a fundamental prerequisite for AI-driven healthcare applications (European Parliament, 2016). More recently, in 2022, the European Health Data Space (EHDS) has facilitated cross-border data exchange, allowing AI to leverage larger datasets for medical research and decision-making (European Commission, 2022). Then, the approval of the EU AI Act (2024) further underscores the importance of ethical and transparent AI deployment in healthcare, reinforcing compliance with European values (European Commission, 2024). The number of publications observed at the end of 2024 aligns with advancements in deep learning, natural language processing, and clinical decision-support systems, further demonstrating the field's maturation.

The dataset includes 3,282 keywords, demonstrating the vast thematic scope of AI in healthcare.

Table 3. Main information about the dataset

Description	Results
Timespan	1983:2024
N° of journals	557
N° of articles	1,075
Annual Growth Rate %	15.18
Document Average Age	3.48
Average citations per doc	20.5
Keywords Plus (ID)	6,991
Author's Keywords (DE)	3,282
Authors	5,969
Authors of single-authored docs	58
Single-authored docs	61
Co-Authors per Doc	6.14
International co-authorships %	32.65

Source: Author’s elaboration using Bibliometrix.

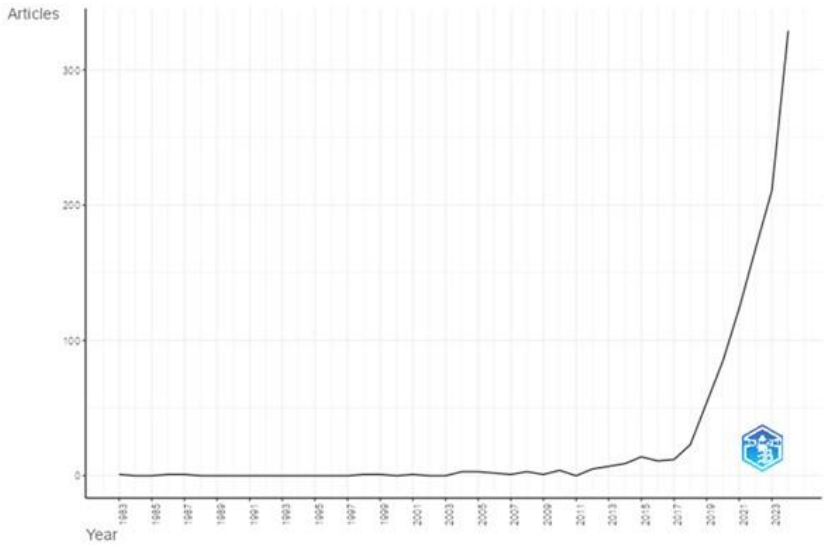


Figure 2. Annual scientific production
Source: Author’s elaboration using Bibliometrix

As shown in Figure 3, the United States leads AI research in healthcare with 1,209 publications, followed by the UK (568) and China (236), driven by strong institutional support and funding. Other key contributors include India, Canada, Australia, and several European nations, reflecting global engagement, with future advancements likely dependent on cross-border collaboration and policy frameworks.

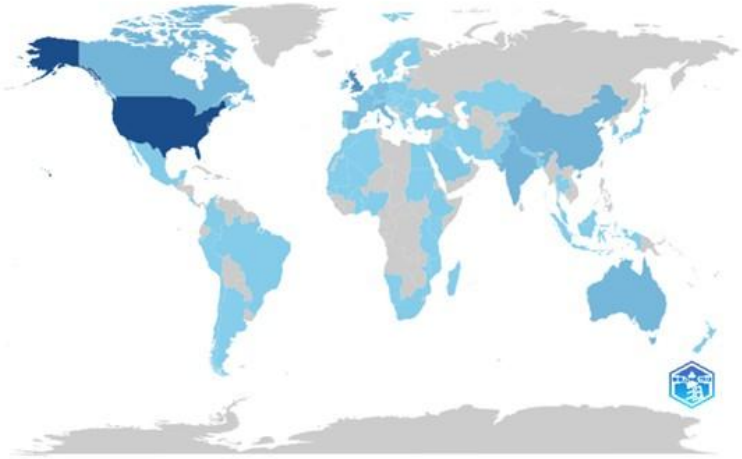


Figure 3. Country scientific production
Source: Author's elaboration using Bibliometrix

The thematic analysis conducted using Leximancer shows that previous studies questioned the issues of AI and SDGs in healthcare. As shown in Figure 4, key topics are related to macro concepts such as "healthcare", "patients", "social", "learning", "data" and "environment".

In the "healthcare" sector, the role of AI appears to be relevant for the individual treatments of "patients", translating from physical to digital care, increasing cost-efficiency and quality of services (Barbieri et al., 2023). Its implementation can daily support the patients through digital care assistance which helps to improve contact-reduced healthcare on site and enable interpersonal interaction that is conducive to maintaining high health conditions. A clear example of these applications is given by Gangl and Krychtiuk (2023) which propose several wearable health sensors and digital biomarkers with useful functionalities such as Photoplethysmography (PPG)-based detection and electrographic signals remote control.

Another cluster obtained from the analysis is related to "data". It connects with the role of increasing algorithm learning and contributing to the vertical and horizontal network reconfiguration, adapting the AI capabilities for new required tasks (Caserta & Romero, 2024). Hammond (1986) defines networks as "an aggregation of structural arrangements due to the belief that structure, horizontal or vertical, affects outcome". Vertical networks represent hierarchical structures where data flow through different levels of authority, while horizontal networks enable collaboration across different entities. In the field of diagnosis, for instance, AI can emulate doctors' predictive capabilities, enhancing accuracy by comprehensively analyzing patients' electronic health records both horizontally and vertically in a very short time (Guo et al., 2020). The results also highlight that data have been a primary resource during the COVID-19 pandemic, providing public administrations access to timely and reliable information through automated systems that have made it possible to manage the traceability and course of sick patients, guiding territorial policies (Tuzii & Bottari, 2022).

The critical nature of managing and processing clinical data, essential for optimal healthcare delivery, brings out the need to secure all the several stages, ensuring privacy and security (Thantilage et al., 2023).

The paradigm of the Internet and new surveillance technologies, such as drones, cameras, smartphones, and the Internet of Things, brought the ethics of privacy protection to the top of every decision-making agenda, emphasizing the ethical aspects of AI in medicine (Dabla et al., 2021). Privacy issues are related to the risks of invasive monitoring technologies, which make daily permanent monitoring, surveillance, and collecting data imply a massive intrusion into the patient's life (Mittelstadt & Floridi, 2016). Moreover, big data and AI require vast amounts of data, which may be stored indefinitely. This creates the risk that users might lose track of how their data is being used, increasing the chances of data leaks or loss (Luxton et al., 2016). For example, in mental healthcare, despite iHealth has great potential, the ambivalence of autonomy and the question of how technology can meet the needs and resources of individual patients, the threats to personal and data privacy, and the risk of datafication and bias create several concerns about suicide prevention (Rubeis, 2022). Datafication could be defined as the procedure's simplification, reduction, and coding with the risk of undermining the uniqueness patients experience (Becker et al., 2018). Bias could arise from the data pre-

processing, especially in the variable's derivation from the data collected phase. In synthesis, AI is perceived as a technology with the potential to assist public data management, reducing current staff shortages, but, for many people, it may pose a threat since it is seen as something that can represent an increase in unemployment and ethical privacy problems in healthcare (Mwase et al., 2023).

We can see the pandemic as an unprecedented boost for many transformations disrupting several of our traditional approaches (Gangl & Krychtiuk, 2023). From one perspective, data and technologies can have a positive impact on healthcare and society. However, we must also consider the potential downsides. The new digital technologies show a strong impact on social aspects. Their adoption and implementation generally produce social, economic status, and class-based inequalities in health, despite some studies claiming the opposite, believing that they could reduce inequalities over time (Weiss et al., 2018). In healthcare, empathy plays an imperative role in improving patient satisfaction and treatment adherence, but AI and especially large language models (LLMs) lack this quality, with the risk that decisions can be undertaken without considering the impact on others (Sorin et al., 2024).

AI is clearly connected to "learning", which has been cited 13,925 times within the documents considered in the sample, with a double reading. On one side, algorithms, processes, and performance measurement concepts are used for classification and regression tasks to emulate human intellect. In this ecosystem, the network platforms are continuing to transform and reconfigure, considering the crucial role played by data and AI but still bearing that learning is one of the most critical factors for successful implementations. Platform24 gives a case developed and utilized to create automated triage engines, which partially replaced the need for human resources in the triage process, namely the prioritization and referral of new patients to medical professionals (Björkdahl et al., 2024). On the other side, AI is a powerful tool for facilitating knowledge sharing, leading to the discovery of innovative solutions (Hajian et al., 2024), especially in the case of semi-supervised learning. Some examples of recent technological advancements in healthcare are chatbots, conversational agents, and metaverse applications, which can promote the transfer of knowledge in clinical settings (Lazarus et al., 2024). In radiography, machine learning algorithms are used for detection, localization, assessment of prediction, classification, and density estimation tasks, but they could be enhanced by investigating the features that drive the prediction task, leading to knowledge discovery (Rainey et al., 2023). These are perfect examples of artificial and human intelligence integration in medicine, showing that AI does not have to replace medical specialists or scientists and, rather, needs such expert human knowledge. Based on these considerations, KM plays a fundamental role. It could be considered as an umbrella term for a variety of interchangeable terms such as knowledge creation, knowledge valuation and metrics, knowledge mapping and indexing, knowledge transport, storage and distribution, and knowledge sharing (du Plessis, 2007). Hospitals should foster a knowledge-sharing environment to maximize patient care value (Karamitri et al., 2017).

"Social" is an important theme of this analysis and it has been cited 7,445 times within the studies under analysis. This criteria represents one of the ESG aspects, that constitute a very relevant evaluation in the academic and corporate world (Clément et al., 2023). In this context, the COVID-19 pandemic shows a relevant impact on the results; social media usage exponentially increased during this period, affecting even the population's mental wellness in a very stressful situation (Pappa et al., 2020). In the social distancing isolation, which causes several problems, some applications use digitalization with the aim of increasing physical, social, and mental well-being. An example is given by the "adapt-cafè project", a mobile application created to encourage positive nutrition, physical activity, and social interaction during the lockdown situation (Meinert et al., 2020).

There is a clear connection between AI and "Environment", which has been cited 3,223 times. Green digital learning involves motivating internal stakeholders to enhance their understanding of environmental issues, which can be beneficial for the business by providing valuable data and information (Halbusi et al., 2024). In healthcare, it plays a moderating role in the relationship between AI, machine learning, and green supply chains, promoting both environmental and financial sustainability (Benzidia et al., 2021). A green or environmental supply chain refers to a series of organizational activities aimed at managing the supply chain system - from sourcing materials to delivering customer service - in an environmentally responsible manner (Jabbour et al., 2015). This concept should always be linked to financial sustainability. It involves managing firms in a way that ensures current financial success does not jeopardize future financial success, including the well-being of future generations, aiming to create a mutually beneficial relationship (Gleißner et al., 2022). Within the hospital's context, new technologies implementation permits both real-time monitoring and assimilation of knowledge on environmental sustainability with the opportunity to exploit learning resources such as e-learning and m-learning (Benzidia et al., 2021).

Environmental and social aspects are two of three ESG criteria, and they are strictly connected to AI and SDGs in healthcare. The healthcare sector must address new sustainable business challenges by integrating ESG

factors into the actual business models. ESG criteria align closely with sustainable healthcare, promoting a responsible approach towards the environment (e.g., reducing greenhouse gas emissions, conserving water, and using renewable energy sources), ensuring social responsibility (e.g., implementing policies to fight workplace discrimination, upholding human rights, and maintaining occupational hygiene and safety), and enforcing robust corporate governance (Leung & You, 2023). Although “Governance” has not been mentioned in the main clusters, there is a clear connection between “Healthcare” and “Management”. Several components of the management field, such as management structure, management remuneration, transparency, business integrity, rights of and relations with shareholders, long-term strategy, internal control, audit, and risk management, are essential corporate governance factors with primary importance within the modern healthcare industry (Sepetis et al., 2024). This is due to the increasing complexity of healthcare, which necessitates management approaches that consider multiple perspectives to improve decision-making practices (Cagliano et al., 2011).

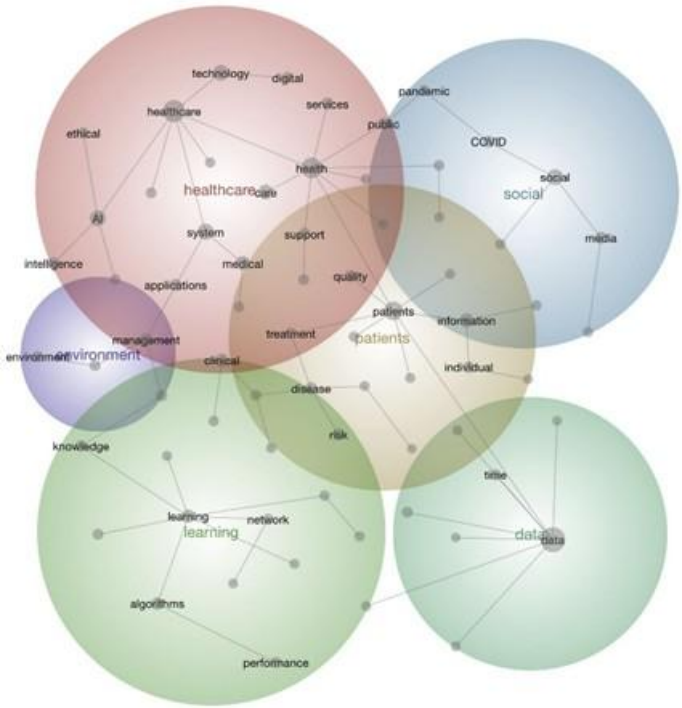


Figure 4. Key themes and results of the analysis
Source: Authors' elaboration based on Leximancer

5 Discussion and Conclusions

This analysis provides a comprehensive picture of the evolving landscape of AI in healthcare, underscoring its role in advancing SDGs. The bibliometric analysis highlights the exponential growth in scientific production over the last decade, with an increasing number of international collaborations and contributions from different countries. This growth is driven by regulatory frameworks such as the EHDS (European Commission, 2022) and the AI Act (European Commission, 2024), which have incentivized AI adoption in medical research and clinical applications. The thematic analysis conducted through Leximancer has identified key conceptual clusters such as “healthcare,” “patients,” “social,” “learning,” “data,” and “environment,” demonstrating the different roles that AI plays in improving healthcare efficiency, decision-making, and sustainability practices.

Another significant aspect that emerged from these analyses is that the role of AI is also particularly relevant within KM.

The ability of AI to automate data analysis and generate actionable insights supports clinical decision-making and policy planning (Rajkomar et al., 2018), promoting greater resilience in healthcare infrastructures.

The study's results also underline the significant contribution of AI to the achievement of several SDGs. AI applications in healthcare directly align with SDG 3 (Good Health and Well-being) by improving diagnostic accuracy, enhancing healthcare accessibility, and optimizing resource allocation (Koebe & Bohnet-Joschko, 2023). In addition, AI-facilitated automation and predictive analytics contribute to SDG 8 (Decent Work and Economic Growth) by increasing operational efficiency and reducing the workload of healthcare professionals (Jarrar et al., 2024). AI-driven monitoring systems promote sustainability in healthcare infrastructures,

supporting SDG 13 (Climate Action) by improving energy efficiency and reducing environmental footprints (Holmner et al., 2012). Lastly, by enabling equitable healthcare access through AI-supported telemedicine and mobile health applications, AI fosters the achievement of SDG 10 (Reduced Inequalities), ensuring that underserved populations benefit from advanced medical technologies (Rajan et al., 2020).

These findings reinforce the transformative potential of AI in enhancing resilient and sustainable healthcare systems on a global scale.

However, despite its numerous advantages, AI in healthcare also raises concerns regarding data privacy, algorithmic bias, and the ethical implications of automation (Mittelstadt & Floridi, 2016). These concerns highlight the necessity for robust governance mechanisms and ethical frameworks to ensure responsible AI deployment. The reliance on AI-driven decision-making raises problems of transparency and accountability, which can undermine trust in healthcare (Rubeis, 2022). Disparities in AI adoption and digital infrastructure between high-income and low-income countries risk exacerbating global healthcare inequalities by limiting access to AI-enhanced medical services in underserved countries (Olu et al., 2019). Despite the existing challenges, the continued advancement of AI-driven KM systems, combined with ethical governance and interdisciplinary collaboration, presents a significant opportunity to create more resilient and inclusive healthcare systems at the global level.

5.1 Theoretical and practical implications

Several theoretical and practical implications emerged from the research. From a theoretical perspective, this study contributes to the existing literature on AI and KM in healthcare by offering a dual analytical perspective (through bibliometric and thematic analysis), allowing for a holistic understanding of how AI-driven KM intersects with sustainability objectives. It reinforces the notion that AI is not merely a tool but a strategic enabler of knowledge dissemination, decision support, and healthcare transformation (Taherdoost & Madanchian, 2023). Furthermore, this research highlights the increasing importance of interdisciplinary collaboration in AI research. The prevalence of international co-authorships and multi-sectoral contributions suggests that AI in healthcare is an inherently cross-disciplinary field requiring expertise from medicine, data science, and policymaking. The study expands the discourse on AI governance by underlining the importance of regulatory frameworks in shaping technological adoption, thereby contributing to the broader theoretical debate on responsible AI implementation.

From a practical standpoint, the findings suggest several implications for healthcare policymakers, practitioners, and industry stakeholders. First, AI-driven KM systems can optimize resource allocation, particularly in underserved regions, supporting SDG 10 by ensuring equitable healthcare access (Rajan et al., 2020). Second, according to Jarrar et al. (2024) AI can contribute to SDG 8 by enhancing workplace efficiency and minimizing occupational hazards through predictive analytics. Third, in alignment with climate change actions and, in particular, SDG 13, AI-driven monitoring systems can promote energy efficiency and environmental sustainability in healthcare infrastructures (Holmner et al., 2012). These implications demonstrate that AI is revolutionizing healthcare and catalyzing broader socio-economic and environmental transformation.

5.2 Limitations and future research avenues

Despite offering valuable insights, this study presents some limitations. First, the bibliometric analysis relies on structured metadata from scientific databases, which may not fully capture qualitative insights regarding AI implementation in real-world healthcare settings. Future research could complement this approach with other methodological approaches, such as case studies and expert interviews, to provide a more comprehensive understanding of AI adoption. Second, the thematic analysis conducted using Leximancer effectively identifies conceptual relationships but does not account for sentiment analysis or contextual variations in AI applications. Future studies could integrate Natural Language Processing (NLP) techniques to analyze discourse surrounding AI in healthcare, particularly in terms of patient perceptions, ethical concerns, and regulatory challenges. Moreover, future research should explore AI's role in addressing disparities in healthcare access, particularly in developing regions where digital infrastructure remains limited. While AI has the potential to bridge gaps in healthcare delivery, the digital divide may hinder equitable AI implementation. Future studies should investigate strategies for overcoming barriers to AI adoption in underserved areas, including capacity-building initiatives, funding models, and public-private partnerships. Lastly, as AI regulations continue to evolve, there is a growing need to assess the long-term impact of emerging policies such as the EU AI Act on healthcare systems. Future research should examine how regulatory developments shape AI adoption, data governance, and trust in AI-driven decision-making.

6 Ethics declaration

This research did not involve collecting personal data, experimentation on human subjects, or any activity requiring ethical approval. Therefore, no ethical clearance was necessary for the study presented in this paper.

7 AI declaration

No AI tool was used in the development, drafting, or editing of this paper. All content is the result of original human authorship and academic research.

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Human-Centered Factors in Generative Artificial Intelligence Adoption: Implications for Employee Well-Being

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Abstract

In recent years, Artificial Intelligence (AI) has gained significant attention across disciplines and industries, with the adoption of Generative Artificial Intelligence (GenAI) in organizations accelerating, particularly through the introduction of user-friendly conversational chatbots. While numerous studies have investigated either the factors influencing AI adoption within organizations or the effects of AI adoption on organizational performance, the role of human-centered factors in shaping its adoption and their subsequent impact on employee quality of working life remains largely unexplored. To address this gap, and drawing on socio-technical systems theory, this study proposes a theoretical model investigating the interplay between key human-centered factors, GenAI adoption, and employee quality of working life. Specifically, employee trust in GenAI is identified as a key human-centered antecedent of GenAI adoption. GenAI adoption is conceptualized through two main constructs: GenAI use and GenAI hedonic experience. Workplace well-being is used as the indicator of employee quality of working life. The model is tested using Partial Least Squares Structural Equation Modeling on survey data collected from 214 Italian professionals with experience in using GenAI in their work activities. The findings demonstrate that employee trust in AI positively influences both GenAI use and GenAI hedonic experience, and that these two factors, in turn, strongly impact workplace well-being. Additionally, while trust in AI also directly affects workplace well-being, its impact is weaker compared to the effects of GenAI use and GenAI hedonic experience. This study provides important practical implications for organizations aiming to improving employee well-being through the adoption of GenAI. Additionally, limitations of the study are discussed, along with suggestions for future research directions.

Keywords: Human-Centered Factors, Generative Artificial Intelligence Adoption, Employee Well-Being, Socio-Technical Systems Theory, Trust in Artificial Intelligence

Paper type: Academic Research Paper

1 Introduction

Artificial Intelligence (AI) is one of the most transformative innovations for organizations (Zhang et al., 2025). Recent developments in AI have been largely driven by advancements in Generative Artificial Intelligence (GenAI) (Sengar et al., 2024). Both AI and GenAI have garnered considerable attention across various industries and academic disciplines (Hyder et al., 2019). The McKinsey Global Institute projects that AI could add up to $13 trillion annually to the global economy by 2030 (Bughin et al., 2018). As AI plays an increasingly central role in business environments, research efforts in this area have intensified. The existing scientific literature can be broadly categorized into two main research streams: the first examines the key factors influencing the adoption of AI within organizations, while the second investigates how AI adoption impacts organizational performance. Within the first research stream, prior studies have identified a variety of influencing factors, which can be broadly grouped into five major categories: organizational capabilities (Aroyable et al., 2024; Cimino et al. 2024), management factors (Aljarboa, 2024; Chen and Tajdini, 2024), technological factors (Magno and Dossena, 2022; Al-Emran et al., 2024; Felicetti et al., 2024), external environmental factors (Aroyable et al., 2024; Chen and Tajdini, 2024; Felicetti et al., 2024), and human-centered factors (Cimino et al. 2024; Felicetti et al., 2024). The second stream of research has focused on the organizational impacts of AI adoption. These impacts can be broadly categorized into innovation outcomes (Wael AL-Khatib, 2023; Khan et al., 2024), operational outcomes (Belhadi et al., 2021; Nayal et al., 2021; Necula et al., 2024;), and financial outcomes (Abrokwah-Larbi and Awuku-Larbi, 2023). Despite the growing body of literature examining the factors influencing AI adoption and its organizational impacts, a significant gap remains regarding how AI adoption affects employee quality of working life (Lozie et al., 2024). This study aims to address this gap by integrating the two research streams. Specifically, we focus on human-centered factors that drive AI adoption and explore how this adoption influences employee working life quality. Additionally, we investigate the direct impact of human-centered factors on working life quality and compare the mediating role of AI adoption in this relationship in order to get a holistic view of the interplay among these elements. In particular, the study focuses on GenAI Chatbots adoption, as this represents a recent and significant advancement in AI technology (Sengar et al., 2024).

The remainder of the paper is structured as follows: Section 2 presents the theoretical background, including the proposed model and hypotheses guiding the research. Section 3 outlines the methodology employed. Section 4 discusses the study's results. Section 5 highlights the key findings, while Section 6 presents the practical implications of the work. Finally, Section 7 concludes the paper by addressing its limitations and suggesting avenues for future research.

2 Theory

2.1 Theoretical Background

This study is grounded in Socio-Technical Systems (STS) theory, originally developed by Trist and Bamforth (1951), which explores the interdependencies between the social and technical components of an organization. The social system encompasses individuals and their interactions, while the technical system includes technology, tools, and equipment (Thomas, 2024). According to STS, the successful achievement of organizational goals depends on the effective integration of both systems, ensuring that the technical components align with and support the social aspects. This integration contributes to organizational success as well as plays a crucial role in improving employee working life quality (Davis and Cherns, 1975). Aligned with this perspective, the present study specifically examines how the adoption of GenAI affects employee workplace well-being. Additionally, since AI systems are inherently sociotechnical in nature (van de Poel, 2020), applying the STS perspective enables to understand their dual impact, both technical and social. Specifically, we explore how the social elements (human-centered factors), such as employee trust in AI, interact with the technological dimensions of GenAI, including its use and hedonic experience with the ultimate goal of understanding their impact on employee quality of working life.

2.2 Theoretical Model

This study proposes a theoretical model that investigates the interplay between key human-centered factors, GenAI adoption, and employee quality of working life. Specifically, GenAI Trust (AIT) is identified as a central human-centered antecedent of GenAI adoption, and it is defined as employees' positive perceptions of AI and its potential impacts on their roles and responsibilities (Chowdhury et al., 2022; Kong et al., 2023). GenAI adoption is conceptualized through two distinct dimensions: GenAI Use (AIU), which captures the frequency and intensity of employees' interactions with GenAI chatbots (Al-Emran et al., 2024), and GenAI Experience (AIE), which reflects the hedonic aspects of technology use, emphasizing emotional engagement and enjoyment (Magno and Dossena, 2022). Finally, employee quality of working life is operationalized through the construct of Workplace Well-Being (WWB), defined as employees' perceptions and emotional states regarding their overall satisfaction with their work environment (Pradhan and Hati, 2009). The model examines how AIT influences GenAI adoption through AIU and AIE, and how, in turn, GenAI adoption impacts WWB. Furthermore, it explores the direct effect of AIT on WWB. By analyzing these relationships, the study aims to provide a holistic understanding of the dynamics among all variables included in the model. The proposed theoretical framework is illustrated in Figure 1.

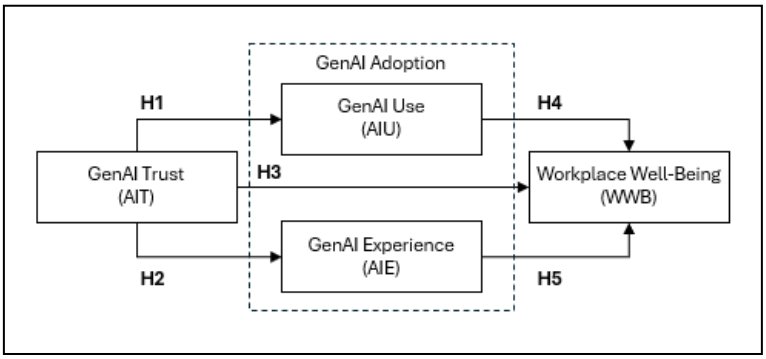


Figure 1: Theoretical Model

2.3 Hypothesis Development

2.3.1 GenAI Trust and GenAI Adoption

GenAI Trust refers to employees' positive perceptions of AI and its potential impact on their roles and responsibilities (Kong et al., 2023). Trust forms the foundation of individuals' interactions with technology (Hoff and Bashir, 2015). Additionally, trust in AI has been increasingly recognized as a key factor for successful AI adoption within organizational settings (Yu et al., 2023; Polisetty et al., 2024). Building on these findings, this study hypothesizes that GenAI Trust positively influences GenAI Adoption across the two identified dimensions: GenAI Use and GenAI Experience.

- H1: GenAI Trust (AIT) positively influences GenAI Use (AIU)
- H2: GenAI Trust (AIT) positively influences GenAI Experience (AIE)

2.3.2 GenAI Trust and Workplace Well-Being

When employees trust AI systems, they are more willing to accept advice and recommendations from these systems (Hughes et al., 2019), which can assist them in making more effective decisions (Kong et al., 2023). The supportive role of technology in decision-making processes has been shown to contribute positively to employees' workplace well-being (Hertel et al., 2019). Furthermore, trust in AI has been linked to increased job engagement (Wang et al., 2021), which fosters proactive working behaviors. These proactive behaviors, in turn, help satisfy employees' motivations (Yu, 2013), and higher levels of motivation are positively associated with improved employee well-being (Van den Broek et al., 2013). Based on these findings, we hypothesize that GenAI Trust positively influences employee Workplace Well-Being.

- H3: GenAI Trust (AIT) positively influences Workplace Well-Being (WWB)

2.3.3 GenAI Use and Workplace Well-Being

GenAI Use can be defined as the extent to which individuals engage with a given technology (Al-Emran et al., 2024). Although Lozie et al. (2024) provide insights into the potential impact of GenAI on employee well-being, they highlight that there is insufficient literature that investigates the effects of a synergy of GenAI use and employee well-being. However, prior research has demonstrated that technology use is positively associated with work engagement (Fujimoto et al., 2016) and job satisfaction (Díaz et al., 2012), both of which are well-established predictors of workplace well-being (Sen and Khandelwal, 2017; Damianus et al., 2020). Based on these findings, we hypothesize that GenAI Use positively impact to employees' workplace well-being.

- H4: GenAI Use (AIU) positively influences Workplace Well-Being (WWB)

2.3.4 GenAI Experience and Workplace Well-Being

GenAI Experience is associated with the hedonic goal of using technology, which refers to engaging in an emotional experience (Magno and Dossena, 2022). Previous studies have provided evidence that technology use is associated with positive emotional experiences (Lu et al., 2019), which are known to enhance job satisfaction (Schiopu, 2015; Fischer, 2000). As job satisfaction represents a key element of workers' well-being (Gordon and Matthew, 2011; Sen and Khandelwal, 2017), it follows that emotionally rewarding experiences with GenAI may contribute to improve the quality of employee working life. Based on this reasoning, we hypothesize that GenAI Experience positively influences employees' Workplace Well-Being.

- H5: GenAI Experience (AIE) positively influences Workplace Well-Being (WWB)

3 Methodology

3.1 Measurement Instrument

To achieve the research objectives, we conducted a questionnaire-based survey. The questionnaire was initially developed in English and then translated into Italian using a standard forward and back translation process to ensure linguistic equivalence and cultural adaptability for the Italian version. To ensure that only relevant participants were included in the study, a filter question asking whether the respondents actively used GenAI in their work activities. The items of each constructs were derived from the scientific literature and, where necessary, slightly adapted to align with the specific research context of this study. The complete set of scale items is provided in Table 1. The questionnaire consisted of 21 items, measured on a 7-point Likert scale ranging from "strongly disagree" to "strongly agree".

Table 1: Theoretical model constructs and items

Variable	Items	Measurement items	Source
GenAI Trust (AIT)	AIT-1	I have confidence in the use of Generative AI Chatbots	Adapted from Kong et al. (2023)
	AIT-2	I believe Generative AI Chatbots can facilitate with routine and trivial tasks through automation	
	AIT-3	I believe that Generative AI Chatbots will consistently operate providing adequate and efficient results within a broad spectrum of processes	
	AIT-4	I believe Generative AI Chatbots adoption will result in creation of new jobs	
	AIT-5	I have a positive attitude towards adoption of Generative AI Chatbots	
	AIT-6	I believe Generative AI Chatbots will positively change employee dynamics within the organization	
GenAI Use (AIU)	AIU-1	I use Generative AI Chatbots frequently	Adapted from Al-Emran et al. (2024)
	AIU-2	I spend a lot of time using Generative AI Chatbots	
	AIU-3	I exerted myself to use Generative AI Chatbots	
GenAI Experience (AIE)	AIE-1	I enjoy using Generative AI Chatbots	Adapted from Magno and Dossena (2022)
	AIE-2	The experience of using Generative AI Chatbots is interesting	
	AIE-3	I am happy with the experience of using Generative AI Chatbots	
Workplace Well-Being (WWB)	WWB-1	I am quite satisfied with my job	Adapted from Pradhan and Hati (2019)
	WWB-2	I enjoy meaningful work	
	WWB-3	I attach lots of value to my work	
	WWB-4	My work achievement often acts as a source of motivation	
	WWB-5	My workplace is very conducive	
	WWB-6	My job provides ample scope for career growth	
	WWB-7	I used to maintain a balance between work and home life	
	WWB-8	My employer does care a lot about their employees	
	WWB-9	My work offers challenges to advance my skills	

3.2 Data collection and data analysis

The questionnaire was distributed between December 15, 2024, and February 28, 2025, via email and major social media platforms. To minimize social desirability bias, participants were assured of complete anonymity. Additionally, a statement outlining the academic purpose of the study was included to help reduce common method bias. A total of 238 Italian professionals responded to the survey. However, 24 participants were excluded because they did not use GenAI in their work activities, making their responses irrelevant to the study's objectives. Consequently, 214 responses were retained for analysis. No anomalies were detected in the data, such as repetitive or incoherent answers. The research model and hypotheses were tested using Partial Least Squares Structural Equation Modeling, which was selected due to its appropriateness for studies with relatively small sample sizes (Willaby et al., 2015) and its robustness in exploratory research contexts (Hair et al., 2019).

4 Results

The evaluation process followed a two-step approach: first, the measurement model was assessed to ensure the reliability and validity of the constructs used in the study; second, the structural model was analyzed to examine the hypothesized relationships between variables and to assess their statistical significance.

4.1 Measurement Model

Indicator reliability was assessed by computing indicators loadings, all of which exceeded the recommended threshold of 0.70 (Hair Jr et al., 2021). Internal consistency was assessed using Cronbach's alpha (Hair Jr et al., 2017), the rho_A coefficient (Dijkstra, 2014), and composite reliability rho_C (Hair Jr et al., 2017), with all values exceeding the established thresholds (Hair Jr et al., 2021). Convergent validity was verified through the Average Variance Extracted (AVE), with all constructs exceeding the 0.50 threshold (Hair et al., 2019). These results are reported in Table 2. Furthermore, discriminant validity was evaluated using the Fornell-Larcker criterion (Fornell and Larcker, 1981). The analysis confirmed that each construct shared more variance with its own indicators than with other constructs, thereby supporting the discriminant validity of the model (see Table 3).

Table 2: Reliability, consistency and validity measures

Construct	Item #	Indicators loadings	Cronbach's alpha	$Rrho_A$	Rho_C	AVE
AIT	6	0,739-0,863	0.903	0.906	0.926	0.676
AIU	3	0,773-0,909	0.826	0.860	0.896	0.742
AIE	3	0,909-0,942	0.914	0.915	0.946	0.854
WWB	9	0,740-0,847	0.931	0.933	0.943	0.646

Table 3: Discriminant validity

Fornell-Larcker				
	AIT	AIU	AIE	WWB
AIT	0.822			
AIU	0.640	0.861		
AIE	0.696	0.708	0.924	
WWB	0.668	0.727	0.793	0.804

4.2 Structural Model and hypothesis testing

Collinearity among constructs was assessed using the Variance Inflation Factor (VIF). All VIF values ranged from 1.0 to 2.5, remaining well below the recommended threshold of 5, thus confirming the absence of multicollinearity concerns (Hair et al., 2011). Following this, the significance and relevance of the structural model relationships were examined. As presented in Table 4, the results indicate that AIT has a significant positive effect on AIU, AIE, and WWB. In turn, both AIU and AIE positively influence WWB. Specifically, AIT demonstrates the strongest effect on AIE (0.696), followed by AIU (0.640), and a smaller direct effect on WWB (0.144). Among the two adoption dimensions, AIE has a stronger impact on WWB (0.488) compared to AIU (0.289). Notably, the indirect effects of AIT on WWB, via AIU and AIE, exceed its direct influence, underscoring the mediating role of GenAI adoption. Statistical significance of all path coefficients was confirmed through bootstrapping procedures, with all t-values exceeding the critical value of 1.96, indicating robust significance (Hair Jr et al., 2021).

Table 4: Path coefficients - mean, Standard deviation, T values, p values

Path coefficient	Original sample (O)	Sample mean (M)	Standard deviation	T values	P values	Result
AIT → AIU (H1)	0.640	0.643	0.047	13.565	0.000	Supported
AIT → AIE (H2)	0.696	0.697	0.048	14.581	0.000	Supported
AIT → WWB (H3)	0.144	0.148	0.071	2.033	0.042	Supported
AIU→ WWB (H4)	0.289	0.289	0.063	4.594	0.000	Supported
AIE → WWB (H5)	0.488	0.484	0.069	7.036	0.000	Supported

5 Discussion

The findings of this study offer valuable insights into the dynamics between AIT, GenAI adoption and WWB. First, the significant positive effects of AIT on both AIU (H1) and AIE (H2) underscore the central role of trust as a foundational human-centered factor driving the adoption of AI technologies in the workplace. These results are consistent with prior research highlighting trust as a critical enabler of AI acceptance (Yu et al., 2023; Polisetty et al., 2024), suggesting that employees are more inclined to engage with AI tools, both functionally and emotionally, when they perceive them as reliable, beneficial, and aligned with their professional roles. In addition, the stronger influence of AIT on AIE compared to AIU indicates that trust is more closely tied to the emotional and experiential dimension of GenAI adoption. This implies that beyond simply using the technology, employees who trust AI are more likely to derive positive emotions from their interactions with it (Lu et al., 2019).

Second, both AIU (H4) and AIE (H5) significantly contribute to employee WWB, with AIE exerting a stronger influence than AIU. This indicates that while frequent and intense interaction with GenAI tools contributes positively to workplace well-being, the emotional quality of that interaction plays an even more important role. In other words, beyond how often employees use GenAI, it is how they feel during its use that has a greater impact on their overall work-related well-being. This supports prior findings that positive emotional experiences with technology are closely linked to the improvement of the employee working life quality (Gordon and Matthew, 2011; Schiopu, 2015; Sen and Khandelwal, 2017; Fischer, 2000).

Interestingly, the direct effect of AIT on WWB (H3) is weaker than the indirect effects mediated through AIU and AIE. This suggests that trust alone does not automatically translate into improved well-being; rather, its

impact is realized primarily through how employees engage with (AIU) and experience (AIE) the technology. This finding reinforces the relevance of the socio-technical systems perspective, which posits that optimal outcomes arise from the alignment and interaction between social and technical subsystems (Trist and Bamforth, 1951; Davis and Cherns, 1975).

6 Implications

The results of this study offer several important practical implications for organizations seeking to adopt GenAI technologies in ways that support employee workplace well-being. First, the strong influence of AIT on both AIU and AIE highlights the foundational role of trust in successful AI integration. Organizations should prioritize transparent communication and training initiatives that demystify GenAI systems. By addressing concerns about job displacement and emphasizing the supportive role of GenAI in work activities, companies can improve higher trust levels among employees, which is an essential precursor to meaningful adoption. Second, the finding that AIE exerts a stronger impact on WWB than AIU suggests that the quality of user experience with GenAI is more influential than the frequency and duration of use alone. This underscores the importance of user-centered design and intuitive interfaces that make interactions with GenAI effective as well as enjoyable and emotionally satisfying. Organizations should consider involving employees in feedback loops when deploying GenAI tools to tailor experiences that align with user needs and preferences. Third, since both AIU and AIE significantly affect WWB, companies should adopt a holistic AI integration strategy that balances productivity-focused implementation with psychological and emotional dimensions of use. For example, providing time for employees to experiment creatively with GenAI, beyond task execution, could enhance their engagement and contribute to more positive work experiences. Finally, given that AIT also has a direct positive effect on WWB, trust in GenAI should be recognized as a key contributor to employees' well-being. Therefore, organizations should implement trust-building strategies, such as involving employees in AI-related decisions, establishing transparent and ethical guidelines for AI use, and clearly communicating AI's intended role. These efforts contribute to a work environment where employees feel respected and empowered, directly supporting their overall well-being.

7 Conclusions

This study contributes to the growing body of research on AI in the workplace by examining the interplay between human-centered factors, GenAI adoption, and employee workplace well-being through the lens of STS theory. By proposing and testing a model that integrates GenAI Trust, Use, and Experience, the study provides empirical evidence on how trust in AI facilitates its adoption as well as both directly and indirectly (through GenAI Use and Experience) enhances employee well-being. The findings highlight that while both the functional use and the emotional experience of GenAI tools positively impact workplace well-being, the experiential dimension exerts a stronger influence. This underscores the importance of promoting effective AI usage and ensure as well, that interactions with AI are satisfying, and psychologically enriching. Furthermore, the direct effect of AI trust on well-being suggests that building a culture of trust around AI systems is critical to fully realizing their potential benefits for employees.

7.1 Limitations and future research

Despite its valuable contributions, this research study has certain limitations that need to be acknowledged. First, the sample consists of Italian professionals, which may limit the generalizability of the findings to other cultural or organizational contexts. Cross-cultural studies could explore how national and organizational cultures influence these dynamics. Second, the use of self-reported questionnaires may introduce common method and social desirability bias, despite efforts to mitigate these through anonymity and clear academic framing. Future research could incorporate multiple data sources, such as interviews or behavioral data, to reduce these biases. Furthermore, the study uses cross-sectional data, capturing relationships at a single point in time and overlooking the evolving nature of GenAI use. Future longitudinal research could explore how employee perceptions and well-being shift as familiarity and proficiency with these tools grow.

8 Ethics declaration

The authors declare that this study did not require formal ethical approval.

9 AI declaration

The authors declare that generative AI tools were used exclusively for language proofreading.

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Navigating the Digital Challenge: A Bibliometric Analysis of Talent Management in the Public Sector

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Abstract

In an era of rapid technological advancement, digital transformation has emerged as a critical driver reshaping human resource management in public sector organizations. While talent management has long been a cornerstone in the private sector, the public sector faces unique challenges—including bureaucratic rigidity, limited resources, and evolving workforce expectations—that complicate efforts to attract, retain, and develop skilled personnel. Today, talent management strategies must strike a balance between technological innovation and human-centric approaches that prioritize employee well-being, engagement, and ethical considerations. Despite growing scholarly interest, research on talent management in the context of digital transformation within the public sector remains fragmented across disciplines and methodological approaches.

To address this gap, the present study employs a bibliometric analysis, using the Bibliometrix R package, to systematically map the literature on digital transformation and talent management in public administration. Findings reveal a significant acceleration of academic output from 2020 onward, coinciding with the pandemic-driven digitalization of public services.

Thematic analysis highlights innovation, sustainable development, leadership, and perception as core emerging themes, alongside rising interest in AI and knowledge management. However, areas such as employee well-being, lifelong learning, and digital inclusion remain underexplored.

This paper offers a comprehensive overview of the evolving academic landscape, underscoring the need for future research to integrate both technological and human dimensions of talent management in the public sector. In doing so, it contributes to advancing a more resilient, agile, and inclusive public workforce capable of navigating the challenges of digital transformation while enhancing public value and citizen trust.

Keywords: Talent Management, Public Sector, Digital Transformation, Bibliometric Analysis

Paper type: Academic Research Paper

1 Introduction

In recent years, digital transformation (DT) has emerged as a crucial force reshaping public sector organizations, challenging traditional operational models and calling for innovative approaches to human resource management (HRM) (Enaifoghe et al., 2024). As governments and public institutions grapple with rapid technological advancements, talent management (TM) has gained strategic importance, becoming pivotal to ensuring an agile, skilled, and resilient workforce capable of navigating ongoing changes (Mapuranga et al., 2024).

While the private sector has long adopted sophisticated TM strategies to maintain competitiveness and foster innovation, the public sector faces distinct challenges. Bureaucratic rigidity, limited financial resources, and shifting workforce expectations complicate efforts to attract, retain, and develop talented personnel (Berman *et al.*, 2021). In this context, TM in the public sector transcends the goals of efficiency and organizational performance; it also contributes to the creation of public value, enhances citizen satisfaction, and supports effective policy implementation (Ananthan et al., 2019).

According to Armstrong (2007, p. 390), TM can be defined as "an integrated set of activities to ensure that the organization attracts, retains, motivates and develops the talented people it needs now and in the future." In public administration, this definition takes on added complexity, as technological innovations such as artificial intelligence (AI), big data analytics, and e-learning platforms increasingly permeate HRM processes (Guerra et al., 2023).

Despite the growing relevance of these dynamics, research on TM in the context of DT within the public sector remains fragmented (Kravariti & Johnston, 2020). A systematic and comprehensive overview is needed to consolidate knowledge, uncover prevailing trends, and guide future research and practice.

Therefore, the present study employs a bibliometric analysis to systematically investigate the literature on DT and TM in the public sector. Leveraging the bibliometrix R package (Aria & Cuccurullo, 2017), this study aims to map the conceptual, intellectual, and social structures of the research field, thereby providing a thorough understanding of how DT is redefining TM practices in public organizations.

Specifically, the objectives of this study are: (i) to identify key scholarly contributions and trends in TM within the public sector; (ii) to examine how DT has impacted TM strategies; and (iii) to highlight dominant research themes on the topic.

2 Literature review

TM has traditionally been associated with the private sector, where organizations pursue competitive advantage through the strategic attraction, development, and retention of talented individuals (Ariss et al., 2014; Collings & Mellahi, 2009; van Zyl et al., 2017). In the public sector, however, TM assumes a broader societal role, contributing not only to organizational performance but also to the delivery of public services, citizen trust, and overall public value (Ananthan et al., 2019; Osborne et al., 2016). The unique characteristics of public organizations—such as bureaucratic processes, budgetary limitations, and political influences—create distinct challenges for the design and implementation of TM strategies (Berman et al., 2021).

Historically, public administrations have prioritized equal employment opportunity and merit-based recruitment over proactive talent identification and development (Poocharoen & Lee, 2013). Nonetheless, recent reforms aimed at modernizing public services emphasize the need for strategic human resource (HR) practices that can enhance flexibility, responsiveness, and innovation in public sector workforces (Reina & Scarozza, 2021).

In this context, DT is profoundly altering the way public organizations manage HRs. Technologies such as AI, big data, cloud computing, and digital collaboration platforms have introduced new methods for recruitment, training, performance evaluation, and employee engagement (Enaifoghe et al., 2024; Guerra et al., 2023). These innovations offer opportunities to enhance efficiency, personalize career development pathways, and foster continuous learning ecosystems within public institutions.

At the same time, DT presents significant challenges, including issues related to data privacy, algorithmic bias, and the digital divide among employees (Shahi & Sinha, 2021). Successful integration of digital tools into HRM requires not only technological infrastructure but also a cultural shift toward greater openness, agility, and trust in digital processes.

As digital technologies become embedded in public sector HRM practices, TM strategies must evolve accordingly. In this respect, the literature suggests that TM must balance technological adoption with human-centric approaches that prioritize employee well-being, engagement, and ethical considerations (Sadeghi, 2024).

Although studies have examined specific aspects of DT and TM in public organizations, a fragmented research landscape persists (Kravariti & Johnston, 2020). Existing contributions are dispersed across diverse disciplines, theoretical frameworks, and methodological approaches, making it difficult to obtain a coherent understanding of the field. Therefore, there is a need for a systematic synthesis that identifies dominant research themes, theoretical underpinnings, and methodological trends. Addressing these gaps will be critical to building a robust body of knowledge that can inform both theory and practice.

3 Methodology

A bibliometric analysis is a quantitative approach that investigates academic literature by analyzing bibliographic data, with the aim of describing, assessing, and tracking research outputs (White & McCain, 1998; Garfield, 2004).

The process was divided into two main phases: the first involved data collection and refinement, while the second consisted of a bibliometric analysis of the collected data.

3.1 Data Collection and Refinement

The research has been divided into sub-phases (Figure 1).

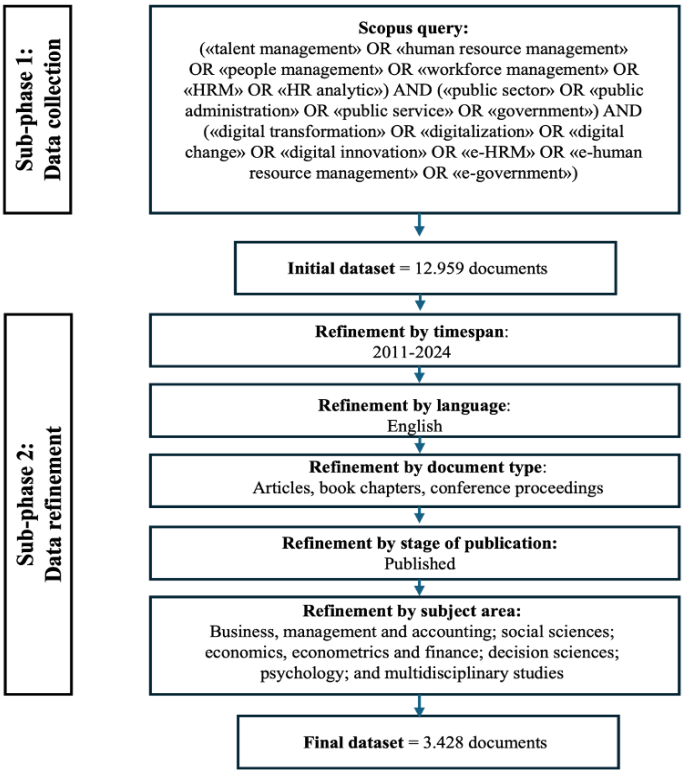


Figure 1: The Data Collection and Refinement Phase

Source: authors' elaboration

In the initial sub-phase, data were retrieved from Scopus, one of the most comprehensive and widely utilized databases among researchers (Singh et al., 2021). The search was carried out on January 10, 2025, employing targeted keywords and Boolean operators.

Compound expressions were placed in quotation marks to maintain their semantic unity, while "AND" and "OR" operators were used to refine results and include synonyms, reducing the risk of excluding relevant studies.

In the field of titles, abstracts, and keywords on Scopus, the following search string was esmployed: "talent management" OR "human resource management" OR "people management" OR "workforce management" OR "HRM" OR "HR analytic" AND "public sector" OR "public administration" OR "public service" OR "government" AND "digital transformation" OR "digitalization" OR "digital change" OR "digital innovation" OR "e-HRM" OR "e-human resource management" OR "e-government".

This query yielded 12,959 documents.

In the second phase, several exclusion criteria were applied.

First, it was considered a thirteen-year research period (2011-2024). This choice is due to the fact that the topic has gained traction since 2011, the year in which the first articles were published.

Second, only English-language articles, book chapters and conference proceedings that have already been published and in open access were included, while excluding other types of papers.

Third, categories unrelated to the focus of this study were excluded, such as mathematics, medicine, and energy. Instead, the following subject area were included: business, management and accounting; social sciences; economics, econometrics and finance; decision sciences; psychology; and multidisciplinary studies.

The final dataset comprised 3,428 documents. Finally, the data were downloaded in CSV format, then analyzed using the Bibliometrix tool (Aria and Cuccurullo, 2017). This open-source tool facilitates comprehensive bibliometric analysis by employing specialized tools for bibliometric and scientometric research.

3.2 Data Analysis

Scientific output of publications was analyzed, considering both annual output and country-specific contributions. The analysis of annual production provided insight into the development of the topic over time, while the analysis by country highlighted the global scope of the topic.

3.2.1 Trend topic

Trend topic analysis made it possible to reconstruct the evolution of research topics on TM in public administration in relation to DT. After keywords were extracted, a time distribution was constructed for each term, calculating its median, first and third quartiles. Each word was thus associated with a reference year (the median). The results were represented in a scatter plot, where the horizontal axis indicates time, the vertical axis indicates the most frequent terms, the size of the bubbles reflects frequency, and a gray bar shows the time span of term use.

3.2.2 Conceptual structure

The conceptual structure of the publications was analyzed through bibliometric techniques, generating clusters that provide a broader understanding of the diversity of research within a specific scientific domain (Börner et al., 2003). The methodological foundation of this analysis lies in the premise that the co-occurrence of key terms (e.g., author- or journal-assigned keywords) reflects the content of documents within a dataset (Callon et al., 1991). The greater the number of shared keywords between two documents, the higher the likelihood that they belong to the same research field or specialty. Keywords appearing together in a document are connected in a co-word network.

By applying the Louvain clustering algorithm to this network, distinct thematic areas within a given domain can be identified. This thematic network is visualized on a two-dimensional matrix, where the axes are defined by the centrality (Callon centrality) and density (Callon density) of the thematic map.

The two-dimensional matrix identifies four thematic quadrants (Callon et al., 1991; Courtial, 1994; Coulter et al., 1998):

1. Motor themes (upper-right quadrant): highly relevant and well-developed.
2. Basic themes (lower-right quadrant): highly relevant but underdeveloped.
3. Emerging or declining themes (lower-left quadrant): less or very relevant and underdeveloped.
4. Niche themes (upper-left quadrant): less relevant but highly developed.

Each theme represented on the matrix corresponds to a cluster in the network. The name of the bubble denotes the term with the highest frequency in the cluster, while the size of the bubble is proportional to the term's occurrences within the cluster.

4 Findings and discussion

This study conducted bibliometric analyses to assess the research performance and thematic evolution of TM within the public sector.

4.1 Research Performance

The analysis of annual production traces the evolution of scientific interest over time, while the analysis by country reveals the geographic distribution of research and the areas of greatest academic significance. The integration of these two perspectives provides a comprehensive view of the phenomenon, combining temporal dynamics and spatial spread.

4.1.1 Annual production

The analysis of scientific annual output (Figure 2) revealed a dynamic and uneven growth pattern. In the early years (2010–2017), the output remained relatively modest. This period can be associated with the "emergence phase" of the topic, characterized by sporadic contributions and the gradual establishment of a scholarly base.

From 2018 onwards, the number of publications began to increase significantly, indicating a transition to a "growth phase", with a notable acceleration after 2020.

The analysis highlights that the scientific production on TM in the public sector, particularly within the context of DT, has accelerated significantly, reaching its peak in 2024. This trend appears to be the result of a set of factors that intensified in 2020, decisively shaping the research landscape.

The year 2020 marked a turning point for the public sector, which was compelled to undergo rapid digitalization due to the global pandemic. This abrupt shift renewed scholarly interest in understanding how public administration can adapt to a new digital reality, particularly in terms of managing the talent required to lead such transformations (Brunetti et al., 2020). Thus, the surge in scientific output can be a response to the growing need for modern and effective HRM strategies to support digitalization in the public sector.

The acceleration of digitalization also redirected research efforts towards topics such as the development of advanced digital skills within the public sector (Chinn et al., 2020), an area that had previously received limited attention. Consequently, researchers have increasingly focused on exploring the implications of TM in this new context, aiming to identify models and best practices for attracting, developing, and retaining digital talent essential for successful transformation (Gilch & Sieweke, 2021).

The year 2024 marks the peak of the production curve, reaching over 1,100 articles and situating it within the highest quartile (Q4) of the observed period. This finding suggests a moment of maximum maturity and widespread attention in the academic community, generating new insights and opportunities for investigation.

The intensification of funding and investment initiatives, particularly in digital skill development (Eichhorst et al., 2022), also likely played a role in boosting scientific output. These investments had a notable impact on HR policies within the public sector, reinforcing the need for evidence-based approaches to guide political and administrative decision-making (Berman et al., 2021).

The 2024 peak represents the culmination of a critical phase of reflection and knowledge consolidation, with scientific research playing and continuing to play a fundamental role in identifying practical and theoretical solutions for effective TM in the public sector.

However, 2025 shows a sharp decline in the number of publications. This abrupt drop could be partially explained by the data collection cut-off in early 2025, which means that the contraction represents an incomplete yearly dataset. Further investigation is needed to confirm whether the decline in 2025 is structural or contingent.

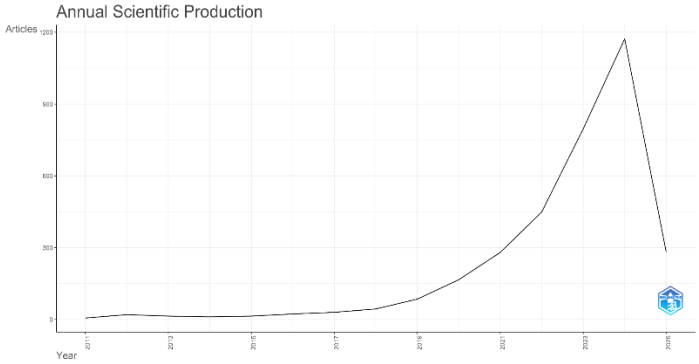


Figure 2. Annual scientific production
Source: authors' elaboration through Bibliometrix software

4.1.2 Country-specific production

Geographical analysis of scientific production reveals a highly heterogeneous distribution of literature on TM in the public sector. The map shows that the countries with the most intense production (darker shading) are primarily China, followed by the United Kingdom, Australia, India and United States.

China has emerged as the leading country in terms of publication volume, confirming its prominent role in managerial and organizational research in recent years.

The United Kingdom and the United States also display a significant concentration of articles, reflecting their longstanding focus on HRM in the public sector. Australia follows, suggesting a strong academic specialization in public management (Bleiklie, 2020). India is an emerging contributor, securing a position among the top five countries in terms of scientific output on this topic.

A more dispersed yet less intense presence (lighter shading) is observed across several European countries (Italy, Germany, France, and Spain), parts of Latin America (Brazil and Mexico), and Southern Africa. In contrast, large areas, such as sub-Saharan Africa, Central Asia, and the Middle East, show either minimal or nearly absent scientific production.

The concentration of scientific output reflects a combination of institutional and strategic factors. Countries such as China, the United States, and the United Kingdom benefit from robust academic systems, strong publication pressures (Tennant et al., 2016), and well-established traditions of applied research in public management. The growing involvement of emerging economies such as India highlights the increasing importance of TM in the contexts of administrative transformation and institutional modernization (Zolak Poljašević et al., 2025).

Moreover, Australia's notable presence suggests a particular sensitivity to human capital management in the public sector, likely driven by national reforms inspired by New Public Management (MacDermott, 2008) and

strategic HRM policies. Conversely, the limited output from many African and Middle Eastern countries may be attributed to weaker research infrastructure, lower levels of science funding, or differing academic priorities.

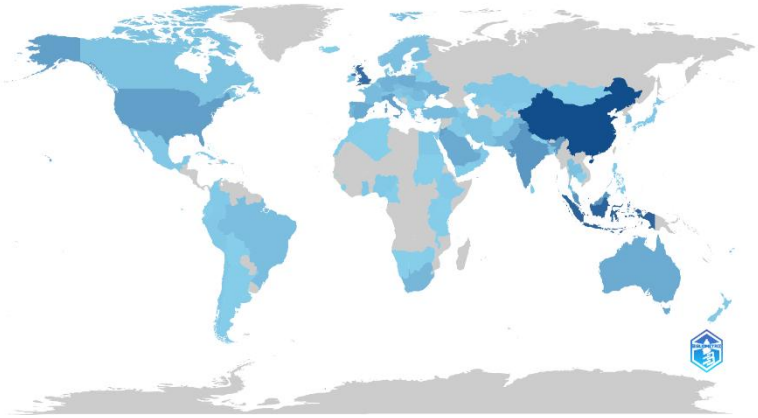


Figure 3. Country scientific production
Source: authors' elaboration through Bibliometrix software

4.2 Key themes and topics

4.2.1 Trend Topic Analysis

The Trend Topic Analysis reveals a clear evolution of research priorities over time. The horizontal axis represents the temporal reference (based on the median use of terms), while the grey bars indicate the duration of concept usage.

The analysis identified three main phases. In the first phase (2020–2021), the focus was on structural topics such as "knowledge management", "organizational framework", and "information and communication technology." These themes display earlier medians and relatively long duration bars, suggesting a systematic reflection on preparing the public sector for TM in the digital age through organizational restructuring and technological modernization (Hildreth et al., 2021; Porrúa et al., 2021).

From 2022, a second thematic wave emerged, characterized by terms such as "innovation", "sustainable development", "Covid-19", and "human capital". These topics showed more recent medians and shorter duration bars, indicating intense but temporally concentrated attention. Particularly notable is "Covid-19" positioned between 2021 and 2022, reflecting the immediate and time-bound academic response to the pandemic's impact on public workforce management (Azizi et al., 2021). Simultaneously, "innovation" and "sustainable development" gained prominence, highlighting the growing awareness of the need to integrate TM strategies with sustainability and organizational innovation challenges (Mujtaba and Mubarik, 2022).

In the most recent period (2023–2024), the emergence of forward-looking themes such as "artificial intelligence" and "green economy" is evident. These topics, with very recent medians and relatively short duration bars, represent emerging areas of scientific interest. The strong focus on AI suggests a new phase of DT, one that not only updates technologies and practices but also redefines decision-making models and human capital development processes (Fenwick et al., 2024).

Themes such as "complexity", "learning systems", and "information systems" appeared early but have remained less frequent. Their positioning suggests that these are either specialized or transversal concepts that serve more as theoretical frameworks than the central research foci.

Overall, the analysis illustrates how the field of TM in the public sector evolved from an initial phase of infrastructural development to a reactive phase addressing external shocks (such as the pandemic), and finally to a forward-looking phase focused on innovation, sustainability, and the management of new technologies.

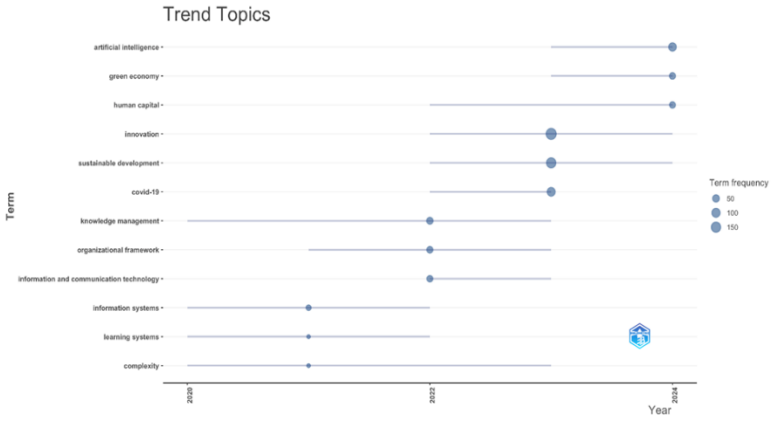


Figure 4. Trend topic analysis
Source: authors' elaboration through Bibliometrix software

4.2.2 Thematic analysis

The thematic map of the keywords extracted from the article sample (Figure 5) illustrates the conceptual dynamics shaping the field, distinguishing the clusters distributed across the four quadrants. In Figure 5, "innovation", "sustainable development", "leadership" and "perception" are positioned close to the line separating the Motor Themes from the Basic Themes quadrant. Their borderline placement indicates high centrality, marking them as fundamental nodes within the keyword co-occurrence network. However, their moderate density suggests that their internal coherence and theoretical/methodological development have not yet been fully consolidated. These themes are thus crucial to the debate but remain explored in diverse or fragmented ways. For instance, "leadership" is central to TM in the public sector but is studied from multiple perspectives, such as transformational, distributed, or innovative leadership, without strong theoretical convergence (Haricharan, 2023). Similarly, while "sustainable development" enters the discussion as a key political objective, its operational and managerial linkage to TM still requires consolidation. In short, they represent both established foundations and fertile grounds for new research and model development.

Additionally, the cluster including "decision making", "artificial intelligence", "digital transformation", and "knowledge management" is located near the boundary between the Niche and Motor Theme quadrants. Their high density indicates a rich and well-structured conceptual base with numerous interconnected studies and solid theoretical underpinnings. Although these themes currently show slightly lower centrality compared to the core concepts, they are gaining prominence and could soon evolve into full Motor Themes if their relevance continues to grow. In particular, the proximity of "artificial intelligence" and "digital transformation" to the Motor Themes quadrant suggests that the DT of the public sector, and its implications for TM, is an emerging and promising frontier for future research (Damar et al., 2024; Shava & Ndebele, 2024).

Conversely, the keywords "human", "social media", "learning", and "working conditions" appear in the lower-left quadrant and are typically associated with either emerging or declining topics. Their low centrality (limited connections with dominant themes) and low density (weak internal development) suggest that they are emerging areas of interest. For example, references to "social media" may point to a nascent but growing focus on the use of digital platforms to attract and manage public sector talent (Mihalcea, 2017). Despite their current marginality, these topics touch upon "soft" and cultural dimensions of HRM, such as well-being, learning, and digital identity, which could become increasingly critical as workplaces continue to evolve into more hybrid and digital environments.

Looking forward, more attention to these aspects could foster a more holistic approach to public sector TM, integrating both hard skills (technology and performance) and the relational and social dimensions of work.

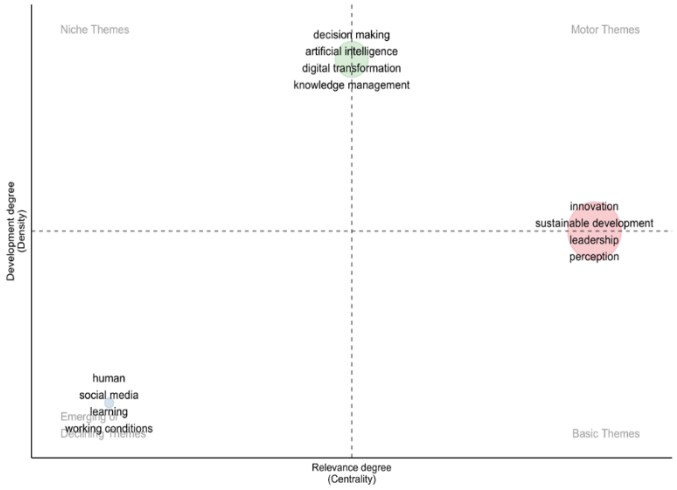


Figure 5. Thematic map
Source: authors' elaboration through Bibliometrix software

This analysis provides a detailed overview of the literature on TM in the public sector, highlighting that areas such as innovation, sustainable development, leadership, and perception have emerged as consolidated and strategic themes. This suggests that talent is often framed not merely in terms of competencies and HR, but as a critical driver for organizational innovation and the advancement of sustainable development goals within the public sector (Tunio et al., 2024; Mohammed et al., 2018).

Similarly, domains such as decision-making, AI, DT, and knowledge management exhibit high density but lower centrality. This pattern indicates that while digitalization and technological innovation are progressively reshaping TM paradigms, these topics have not yet been fully integrated as core themes in the literature. Conversely, concepts such as human, social media, learning, and working conditions appear underdeveloped and less central. This could reflect either underexplored research areas or practical dimensions, such as organizational well-being and continuous education, that have yet to be systematically addressed in academic studies.

Overall, the literature on public-sector TM is strongly oriented toward strategic and leadership aspects (Thunnissen & Buttiens, 2017), with growing attention paid to DT processes. At the same time, it reveals a significant potential for future research on more "human-centred" topics, such as working conditions, lifelong learning, and the role of social media, which currently remain marginal or underrepresented.

5 Conclusions

This study provides a comprehensive bibliometric analysis of the evolving field of TM in the public sector during the era of DT. The findings illuminate a rapidly expanding and diversifying body of knowledge, marked by a surge in academic production following the COVID-19 pandemic and the consequent acceleration of digitalization. The thematic analysis reveals that while core concepts such as innovation, leadership, and sustainable development have gained substantial scholarly attention, more human-centered themes—such as employee well-being, social media, learning, and working conditions—remain comparatively underexplored.

Conceptually, the literature reflects a growing awareness that TM in the public sector is no longer limited to administrative efficiency or traditional HR functions. Instead, it is increasingly perceived as a strategic enabler of digital transition and public value creation. This reconceptualization calls for a deeper integration of technological advancements—such as AI and knowledge management systems—with ethical, inclusive, and development-oriented approaches to managing human capital.

For practitioners, these findings underscore several actionable implications. First, public sector managers must adopt a dual approach that integrates digital competencies with the promotion of employee engagement and well-being. DT should not merely be a technological upgrade but a catalyst for rethinking organizational culture, leadership models, and career development pathways.

Second, investment in continuous learning systems and digital literacy programs is crucial to sustaining workforce adaptability. Public administrations should institutionalize lifelong learning as a core element of TM, enabling employees to navigate evolving digital tools while fostering innovation and resilience.

Third, the increasing relevance of AI in HRM processes necessitates a careful balance between algorithmic efficiency and human oversight. Ethical guidelines and transparent governance mechanisms should accompany

any digital deployment in recruitment, performance evaluation, or workforce planning to prevent bias and protect employee trust.

Finally, the underrepresentation of topics such as social media use in recruitment and the nuanced exploration of hybrid work conditions suggests that practitioners can benefit from expanding their HR strategies to include newer, more flexible, and participatory approaches. These tools can help attract younger digital-native professionals while enhancing internal communication and collaboration.

By highlighting emerging and underdeveloped themes, this study offers a roadmap for public administrators, policymakers, and HR professionals to design more robust, inclusive, and future-oriented TM strategies. In doing so, it contributes to building a resilient public workforce equipped to deliver sustainable public value in a rapidly digitizing world.

6 Ethics declaration

This study did not require ethical approval as it did not involve experiments with human participants, personal data collection, or any procedures requiring formal ethical clearance according to the relevant institutional and national guidelines. No ethical authorization was therefore necessary for the research described in this paper.

7 AI Declaration

The authors acknowledge the use of the AI-based translation tool DeepL in the preparation of this paper. DeepL was employed to support the linguistic translation of parts of the manuscript from Italian to English. The authors reviewed, revised, and edited all AI-generated translations to ensure accuracy, clarity, and appropriateness of academic tone and content. No AI tool was used to generate original ideas or conduct data analysis.

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Corporate Governance, Human-Centric Approaches, and AI Adoption: Does Organizational Size Matter?

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Abstract

The adoption of artificial intelligence (AI) has become a strategic priority for organizations of all sizes, driven by pursuit of process optimization, efficiency gains, and enhanced decision-making. Yet, the effectiveness of AI depends not only on technological implementation but on how organizations integrate it with human-centric values –a challenge that remains underexplored in the context of corporate governance and innovation ecosystems.

This paper explores how corporate governance functions as an instrumental factor in institutionalizing human-centric AI adoption, comparing practices across large organizations, SMEs, and startups within the Rome Technopole (RT) innovation ecosystem. We argue that governance plays a critical role in fostering ethical AI adoption, yet human-centricity should not be treated merely as an afterthought. Instead, it must be a constitutive principle, embedded in the design of the innovation ecosystem itself. Using data from the Rome Technopole Observatory on AI, this exploratory study investigates how organizational size shapes AI strategies and perceived alignment with human-centric values. Findings reveal that structural changes (e.g., dedicated AI teams in large organizations) do not necessarily lead to more human-centric practices or perceptions that AI is aligned with human values. This underscores a critical gap: widespread AI adoption does not guarantee alignment with human-centric principles, which highlights the need for governance that fosters human-centricity at a foundational level.

To address this, based on Sangiovanni Vincentelli's meet-in-the-middle principle, we outline the necessary conditions for developing an innovation ecosystem grounded in human-centric principles. Furthermore, we consider organizations as social, dynamic, and adaptable systems and the RT innovation ecosystem as a context-dependent ecosystem responsible for interactions between its organizations. This theoretical exploratory study paves the way for future empirical research into RT and others innovation ecosystems.

In conclusion, this study posits that corporate governance can be an instrumental mechanism for sustaining an innovation ecosystem in which human-centricity is constitutive. These insights are particularly relevant for organizations operating within collaborative innovation ecosystems, and the innovation ecosystem itself, as they emphasize the alignment between technological progress and societal values as a prerequisite for sustainable and integrative innovation.

Keywords: Artificial Intelligence, Human-Centricity, Organizational Structure, AI Governance Practices, Innovation Ecosystems

Paper type: Academic Research Paper

1 Introduction

This study explores AI and human-centricity in organizational contexts. It is important because the effectiveness of AI cannot be measured solely by its capacity to optimize processes and enhance decision-making, but must also align with human-centric principles, such as ethics and social responsibility (Arrieta et al., 2020). While AI adoption is critical for competitiveness, implementation alone does not ensure responsible outcomes. Individual perception significantly influences the development of responsible AI practices. For instance, while algorithmic trading enhances efficiency in finance, lack of oversight can raise concerns about transparency and fairness. Similarly, AI recruitment tools streamline hiring processes yet may introduce bias, underscoring the risks of neglecting human values in AI deployment. Bias remains a risk in AI systems (Agarwal and Mishra, 2021). These cases underscore the need to embed human-centricity as a foundational governance principle in AI's development, implementation, and societal impact —not an afterthought.

To examine how organizations and innovation ecosystems can address AI's development while leveraging human-centric approaches, this study first contextualizes the corporate governance not only as a foundational factor but as an instrumental element, alongside human-centricity as a constitutive one. It then analyzes different organizations approaches in exploiting AI and human-centricity within an innovation ecosystem. Additionally, examining how different organizations approach AI through corporate governance and integrate human-centric approaches into their organizational practices can provide critical insights.

The study focuses on private companies within Rome Technopole (RT), an innovation ecosystem (see Section 3.1), and aims to:

- *Objective 1*: Investigate corporate governance's role in institutionalizing human-centric AI adoption within innovation ecosystems.
- *Objective 2*: Compare AI governance practices and human-centric approaches across organizations of varying sizes (large and SMEs/startups) in RT.
- *Objective 3*: Outline conditions for developing a human-centric innovation ecosystem.

The following research questions guide this work:

- *Question 1*: How can corporate governance instrumentalize the institutionalization of human-centric approaches (e.g., in AI adoption) within innovation ecosystems?
- *Question 2*: What differences exist in AI governance practices and human-centric approaches among organizations (large and SMEs/startups) within RT?

2 Theoretical background

2.1 Corporate Governance as an instrumental factor in an innovation ecosystem

Adner (2017) argues that innovation ecosystems thrive when multilateral actors align around shared objectives and governance structures that incentivize interaction for a focal value proposition to materialize. Granstrand and Holgersson (2020) define innovation ecosystems as an evolving set of actors, activities, and artifacts, and the institutions and relations, including complementary and substitute relations, that are important for the innovative performance of an actor or a population of actors.

From these definitions, the corporate governance of each actor can be seen as an important mechanism in mediating interactions between actors and plays a pivotal role in the effectiveness of the ecosystem. For example, when an actor decides between the complementary or substitutive relation of an artifact within an innovation ecosystem, this decision can lead to the replacement of that artefact, as defended by Granstrand and Holgersson (2020) according to the Schumpeterian creative destruction, potentially causing the decline of established businesses.

This understanding brings us close to the definition of natural/biological ecosystems. While some authors argue that biological metaphors are limited (e.g., Oh et al., 2016; Adner, 2017), Granstrand and Holgersson (2020) revitalize this perspective by systematically incorporating competition and substitution –core dynamics observed in natural ecosystems. This refined conceptualization proves essential for operationalizing the inherent complexity of innovation ecosystems. Management studies should transcend reductionist frameworks to adequately account for systemic heterogeneity, thereby enabling a more nuanced understanding of organizational complexity and the challenges inherent in representing or explaining their emergent characteristics and evolution (Bertolaso, 2022).

Therefore, viewing the ecosystem as an affiliation should not preclude the possibility of also regarding it as a structure. Affiliation pertains to the act of recognizing the system and its symbiotic relationships, whereas structure refers to defining the alignment framework of the multilateral set of partners that must interact for a focal value proposition to materialize. Ecosystem governance hinges on resolving asymmetric interdependence among actors, where success depends on partner alignment. This underscores the necessity of deliberate structuring, not merely organic growth.

Traditional corporate governance frameworks, particularly those rooted in Agency Theory (Jensen and Meckling, 1976), prioritize mechanisms that align managers' actions with shareholder interests. However, this reductionist approach overlooks the complex, relational, and systemic nature of governance in contemporary organizations.

Governance should move beyond pure economic efficiency to incorporate broader, human-centric considerations. This shift passes through aligning both stakeholder theory (Freeman, 1984; Parmar et al., 2010) and institutional theory (DiMaggio and Powell, 1983; Scott, 2008), which emphasize the interdependent and socially embedded nature of organizations, to have a better understanding of the system in its complexity.

This cross-fertilization and integration are important because, as argued by Parmar et al. (2010), stakeholder theory can help address why organizations in similar institutional environments may be structured differently or have different systems and processes; meanwhile stakeholder theory foregrounds how managers across firms differentially interpret the role of the same institutions and thus create different roles for them in the value creation process. For example, the relationship of different stakeholders within an ecosystem can be shaped also by institutional pression.

Thus, while governance establishes the formal structures and rules that shape organizational roles within an ecosystem, its effectiveness ultimately depends on the deeper institutional processes that guide behavior, decision-making, and strategic action. Stable social and economic systems are maintained not only by explicit governance mechanisms, but also by underlying norms, belief systems and cultural traits.

In this sense, an effective innovation ecosystem requires more than defined corporate governance structures but a collective mindset, aligning the determined governance with the institutional force. Such alignment enables governance to support not only adaptation but also sustained innovation and creating long-term values in complex and dynamic ecosystems.

2.2 Human-centricity as a constitutive condition

An innovation ecosystem involves human, social, intellectual, and financial capital, as well as culture and technology (Carayannis and Campbell, 2009). The lives of the people who compose it are the driving force behind the innovation ecosystem; furthermore, histories and relationships form its properties (Bertolaso and Sangiovanni-Vincentelli, 2024). Thus, the human factor is a foundational element of organizations and innovation ecosystems, on which governance and decision-making processes are based.

The *meet-in-the-middle* principle (Sangiovanni-Vincentelli, 2007) translated to innovation management (Bertolaso and Sangiovanni-Vincentelli, 2024) represents the most effective governance mechanism for innovation ecosystems pursuing collective objectives –e.g., promoting regional economic growth and sustainability. This efficacy stems from its capacity to create strategic interfaces where institutional top-down initiatives (e.g., policy frameworks, mission-oriented programs) productively intersect with organic bottom-up responses (e.g., entrepreneurial experimentation, grassroots solutions). By creating a collaborative dynamic, this principle enables high-level demands are not only imposed but inspire adaptive and creative solutions. Consequently, innovations are inherently sustainable, relational, and holistic.

Human beings are inherently relational (Bertolaso, 2022). By examining these relational dynamics –including axiological reference points– we can better understand interactions among individuals, teams, and leaders, as well as the impact of strategic interventions for the construction and pursuit of a common good/common aim. We are particularly interested in exploring how organizations perceive human-centric approaches. Following Bertolaso (2024), we define human-centricity as an epistemic and operational paradigm that places human principles and therefore values, lived experiences, and participatory co-creation at the core of innovation processes. This approach prioritizes the systemic/dynamic integration of human values, cognitive and affective experiences, and co-design principles, ensuring that solutions are not only functional but also ethically and socially meaningful. Unlike user-centered design, which prioritizes usability, the human-centric paradigm addresses broader systemic needs (e.g., ethical, social) and emphasizes co-creation, making it integral to sustainable innovation.

Within innovation ecosystems, human-centric approaches prioritize regional or communal inhabitation as a primary determinant of design (Bertolaso and Sangiovanni-Vincentelli, 2024), emphasizing human needs and values. In contrast, systems driven exclusively by organizational growth trajectories adopt a fundamentally different paradigm –one that often subordinates socio-cultural contexts to efficiency or scalability.

2.3 The role of governance in the adoption of human-centric AI

AI itself is not human-centric. Its alignment with human values depends on deliberate design choices –from algorithmic transparency to governance frameworks– that prioritize explicability and ethical accountability. Algorithms cannot fully justify their reasoning; even if they could, human explanations are not merely causal but embedded in social, linguistic, and cultural contexts (Capone and Bertolaso, 2020). This is why people resist "black box" systems: we demand interpretability, reliability, and meaningful justifications (Arrieta et al., 2020).

To make AI human-centric, solutions must address how users interact with machines and their need to understand algorithmic decisions (Capone and Bertolaso, 2020). This aligns with the principle of explicability as a core ethical requirement for AI which combines intelligibility (how the system works) and accountability (who is responsible for its outcomes) (Floridi and Cowls, 2019). For example, AI models must balance performance (e.g., prediction accuracy) with explainability to foster trust and collaboration between humans and machines (Arrieta et al., 2020).

Within an organization, the value of AI largely depends on how organizations adopt and integrate it into their processes (Alsadi and Miller, 2023). Comparative studies suggest that AI enhances decision-making when paired with human expertise (Barcaui and Monat, 2023; Felicetti et al., 2024). Here, corporate governance becomes critical: it translates ethical principles into practice through mechanisms like AI ethics boards (accountability)

and user feedback loops (diversity). Governance also ensures AI aligns with the broader innovation ecosystem's values.

The European Commission's AI High-Level Expert Group outlines seven ethical principles –human agency, safety, transparency, fairness, and others (European Union, 2024)– mirroring Floridi and Cowls' (2019) five-principles framework (beneficence, non-maleficence, autonomy, justice, explicability). Corporate governance must operate these principles by enforcing data protection, risk mitigation, and human oversight and values.

Ultimately, governance bridges the gap between AI's technical potential and its human-centric adoption. By institutionalizing ethical principles, organizations can navigate trade-offs while fostering trust. Challenges require adaptive governance, but the foundation is clear: without structured accountability and human participatory design, AI risks remaining a tool of efficiency rather than a partner in progress.

3 Research design

3.1 Context: the Rome Technopole (RT) innovation ecosystem

The RT is an innovation ecosystem strategically designed (Oh et al., 2016), dynamic, and multi-stakeholder (Granstrand and Holgersson, 2020) in Italy's Lazio region, funded by the National Recovery and Resilience Plan (PNRR). It fosters cutting-edge research in energy, digital transition, and health technologies in Central and Southern Italy through university-industry-government collaboration by a hub-and-spoke model (O'Kelly, 1998). Its stakeholders pursue shared value creation (Porter and Kramer, 2018) via six strategic spokes and eight flagships, for instance related to green energy, AI, health, and digital technologies, which enable competitive–collaborative dynamics (Bengtsson and Kock, 2000; Bacon et al., 2020).

3.2 Methodology

The analysis is based on a sample of 60 respondents, collected through a structured questionnaire administered by the Rome Technopole Observatory on AI (2025) between November and December 2024. Although the questionnaire targeted stakeholders within the RT network, it was anonymous and may have been shared beyond the original audience. Despite this, the responses form two balanced groups:

- *Large organizations* (28 respondents): typically, with more structured internal processes, larger teams, and wider experience in digital and AI implementation;
- *SMEs and startups* (32 respondents): are often characterized by smaller scale, agility, and a focus on innovation and experimentation.

Responses from public administration stakeholders were excluded to maintain alignment with the study's focus on corporate organizational differences. The questionnaire covered topics such as human-centric AI applications, governance policies, and responsible AI practices. Statistical tests were conducted to assess whether response distributions differed significantly between the two groups. The analysis highlights topics where significant or non-significant differences were identified.

4 Findings

4.1 Governance practices and human centricity approaches by organization size

The findings underscore the key role of AI not only in technological solutions but also in shaping organizational structure and competitiveness. These insights are valuable for informing future corporate governance strategies within the innovation ecosystem. Table 1 below presents the responses and the statistical significance of the perceptual differences between large organizations and SMEs/startups.

Table 1: Differentiating between large organizations and SMEs/startups by topic

Topic	**Large organizations**	**SMEs and startups**	**Statistical significance of the difference**
I. Data management tools for AI implementation*	Hybrid (local + cloud) (≈68%)	Cloud only (≈31%) Hybrid (local + cloud) (≈31%) On-premises only (≈28%)	Chi-squared test: p-value = 0.031
II. Presence of a dedicated AI team**	Yes (≈67%)	No (≈63%)	Chi-squared test: p-value = 0.0037

Topic	Large organizations	SMEs and startups	Statistical significance of the difference
III. Number of AI projects developed by the organization***	Majority “more than 20” (≈43%)	Majority “1 to 5” (≈58%)	Chi-squared test: p-value = 0.0002 Mann-Whitney U test: p-value = 0.0008
IV. Perceived process structure for AI adoption*	Not structured (≈3%) Partially structured (≈36%) Well structured (≈36%) Very well structured (≈25%)	Not structured (≈19%) Partially structured (≈34%) Well structured (≈38%) Very well structured (≈9%)	Mann-Whitney U test: p-value: 0.851

* 28 large organizations and 32 SMEs/startups answered this question.
** 27 large organizations and 32 SMEs/startups answered this question.
*** 23 large organizations and 31 SMEs/startups answered this question.

Among the tests presented in Table 1, IV is the only one that does not show statistical significance (p=0.851), indicating that organizational size may not reliably predict how employees perceive process readiness for AI. In other words, both large organizations and SMEs/startups report similar levels of perceived process adoption, regardless of actual resources (I and II) or project volume (III). This perception gap may result from the actual absence of such processes —given that the topic is still relatively new—; or a lack of organizational culture around AI, which leads employees to not being aware of or knowing how to apply existing processes to this domain; or self-reporting biases. Addressing this disconnect may require a human-centric paradigm to (re)design structured processes that align more closely with employees' actual understanding, needs, and practices —thus playing a constitutive role in shaping how organizations approach AI integration.

In contrast, other indicators —the number of AI projects implemented (III), the presence of dedicated AI teams (II), and investment in hybrid data management infrastructure (I)— show statistically significant differences between large organizations and SMEs/startups.

These results suggest that organizational size appears to significantly influence investment in human capital and infrastructure for AI development, as large organizations, compared to SMEs/startups, are more likely to have flexible data management solutions (I) and formalized AI teams (II) due to greater internal resources, operational scale, and strategic focus.

Finally, considering the number of AI projects (III), the findings indicate that large organizations are significantly more advanced than SMEs/startups in terms of AI implementation. The gap is both quantitatively and statistically significant, indicating that organizational size and resource availability play key roles in AI project maturity. For example, large organizations were more likely to report the existence of structured approaches to data management and AI deployment, whereas SMEs/startups often reported plans and intentions rather than current implementations. Nevertheless, this structural maturity does not necessarily translate into a widespread perception among them regarding being ready for AI adoption (IV).

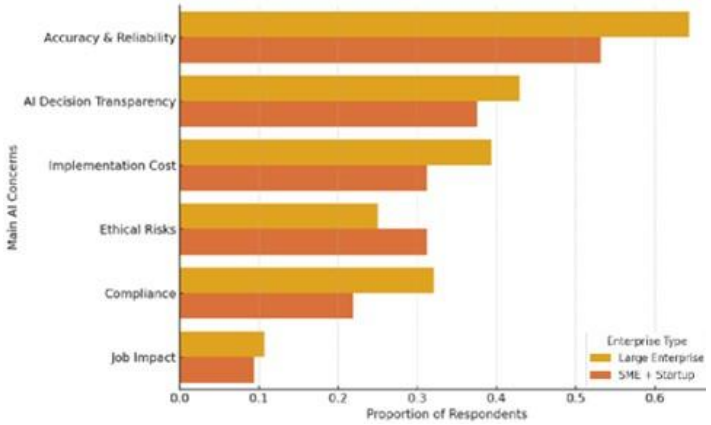


Figure 1: Main concerns regarding AI adoption by organizations

Figure 1 above presents the main concerns organizations have about AI adoption, based on a multiple-response question. There is no statistically significant difference between the perceptions of large organizations and SMEs/startups, indicating a consistent level of concern across both groups. In particular, the concern over “Accuracy & Reliability” reflects a shared underlying issue of trust in AI outputs. In this study, SMEs/startups also reported slightly higher concern about “Ethical Risks,” though this difference is not statistically significant. Most

organizations recognize the need for governance mechanisms to ensure AI is used accurately, transparently, ethically, and responsibly.

Regarding human-centric approaches, although large organizations tend to have more structured AI initiatives (Table 1), this does not result in significantly different views on human-centricity across organization types (Figure 2). When asked about human-centricity (Table 2), organizations consistently acknowledged the benefits of developing human-centered products and services, showing a shared aspiration regardless of organizational size (Figure 2). This suggests that AI adoption alone does not guarantee a human-centric approach, but an effort of understanding and application is needed by organizations. Related findings are presented in the figure and table below.

Table 2: Human-Centric Focused Questions

Human-Centric Focused Questions	**p-value**
Q1 – Stakeholders inclusion & considering social impact of products/services	0.938
Q2 – Developing human-centric products/services as competitive advantage	0.440
Q3 – Designing products/services to adapt to environmental changes	0.704
Q4 – Ensuring equal access to public and private stakeholders	0.503
Q5 – Use of AI to improve user interaction and accessibility	0.802
Q6 – Adapting products/services to market changes & user needs	0.981

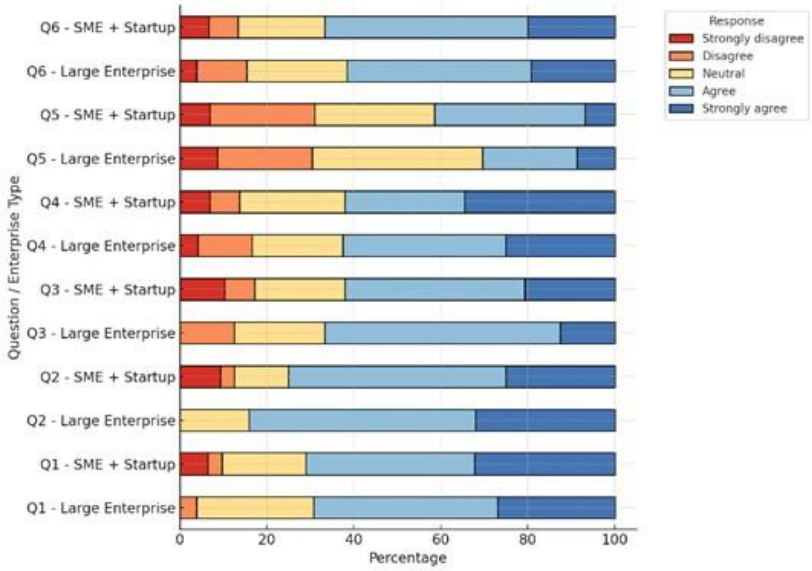


Figure 2: Perceived organizational alignment regarding human-centricity

5 Discussion

5.1 Theoretical contributions

5.1.1 Corporate governance as instrumental

Governance should transcend control, encompassing adaptation to complexity, interdependence, and societal demands. Within innovation ecosystems, organizations should integrate human-centric principles –e.g., grounding the relationship between technology and society in ethics and stakeholder values– into their governance frameworks. This integration responds to both stakeholder demands (Freeman, 1984; Parmar et al., 2010) and institutional legitimacy pressures (DiMaggio and Powell, 1983; Scott, 2008). RT's evidence shows that most organizations view human-centric approaches as beneficial for the business and necessary for the system.

To instrumentalize human-centricity, such as in AI adoption, organizations' governance mechanisms should:

- Mandate participatory design, such as stakeholder inclusion in AI ethics boards or user feedback loops, ensuring AI systems reflect diverse societal needs.
- Enforce transparency, requiring explainability standards for AI outputs (e.g., auditing tools for bias detection) to address the prevalent concern over "Accuracy & Reliability" (Figure 1).
- Incentivize adaptive oversight, such as "human-in-the-loop" policies for high-stakes AI applications, aligning with the finding that 67% of large firms already formalize AI teams (Table 1).

This alignment with human-centricity is critical because technology adoption is socially shaped, as technologies achieve greater impact when implemented through governance that prioritizes epistemic (relational) centrality of individuals (Bertolaso and Sangiovanni-Vincentelli, 2024).

The shift toward ecosystem innovation further necessitates distributed authority, as ecosystem-based innovation models require governance supporting dynamic, adaptive, and relational decision-making, including the establishment of ethical requirements and feedback loops. This means that governance mechanisms should be designed to facilitate trust, collaboration, and co-creation rather than merely enforcing compliance. Given the heterogeneity of actors, we argue that distributed authority and participatory mechanisms enhance ecosystem resilience by aligning incentives and reducing power asymmetries. For instance, divergences in expectations of value creation and value distribution to third parties (Adner, 2017) should be addressed by the *meet-in-the-middle* principle between the RT's actors. For example, RT could adopt tiered governance and integrated communications/training systems, i.e., processes of tailored communication that, while reaching everyone, take into account the local (for companies, institutions, or universities) necessities and the disciplinary sensitivity.

Empirical evidence underscores these challenges: two out of four companies report difficulties in AI integration, with reliability emerging as the primary concern. Yet, this also reveals an opportunity –the potential for innovation and process improvement when governance mechanisms actively address such friction points. From this shift from static to adaptive dynamics, follows that human-centric governance mirrors the institutional evolution towards practices that emulate not hierarchical but complex and dynamic systems, taking into account the epistemological features that intrinsically characterize them.

5.1.2 Human-centricity as constitutive

From section 2, we infer that organizations can integrate human-centric principles into governance due to stakeholder demands but also through institutional legitimacy. From section 3, we argued that human-centricity must be embedded as a constitutive condition of the innovation process, requiring adaptive governance models that account for organizational complexity.

Furthermore, the research reveals that AI alone does not inherently lead to a human-centric approach, but achieving this objective requires deliberate and strategic efforts that go beyond technological adoption. For example, even as part of the same innovation ecosystem, varied sizes of organizations may find diverse types of challenges to exploit AI tools. Thus, we infer that structural or cultural factors could lead human-centric approaches to become constitutive in innovation ecosystem, which can be addressed by the governance.

Innovation ecosystems require governance that is both structured and flexible to accommodate emergent behaviors. In the context of AI adoption, this translates to frameworks that set minimum ethical standards while allowing organizations autonomy to adapt these standards to their specific contexts and communities. In this regard, we argue that the corporate governance of organizations part of the same innovation ecosystem should, to a minimum degree, agree on shared principles.

5.2 Limitations and future research

Other contextual factors, in addition to company size, may influence the findings within the RT innovation ecosystem. Future research could deepen this analysis, including longitudinal studies, public sector analysis, or qualitative investigations to better understand AI adoption dynamics, governance, and human-centric approaches. For instance, examining whether organizations evolve towards greater human-centricity alongside AI maturity could reveal critical insights about governance adaptability. The widespread adoption of AI governance frameworks –four out of five large organizations in RT have already implemented an AI governance model– presents a timely opportunity to assess the quality and effectiveness of these frameworks. Research could identify whether adoption translates into robust human-centric practices or merely procedural compliance, exploring how these models align with stakeholder-centric values, and what governance gaps persist despite high adoption rates. Qualitatively investigating corporate strategies that integrate AI and human-centric principles, as well as the role of organizations and culture in shaping AI ethics, could further bridge theory and practice within innovation ecosystems.

6 Conclusion

First, this paper correlates stakeholder and institutional theories through epistemological theories; to do so, it relates to the literature on human-centricity, AI, and innovation ecosystems.

Second, it points out that the RT data revealed the potential of corporate governance to be instrumental in maximizing innovations created and used through human-centric approaches within innovation ecosystems. To

achieve this, AI adoption should prioritize human-centricity as a foundational principle, rather than reducing it to an instrumental checkbox in service of efficiency gains that perpetuate unsustainable economic models. Adopting AI is not sufficient to ensure workers develop a proper understanding of associated risks and the importance of human proximity. These discussions —essential for sustainable and effective innovation— can be more appropriately fostered within innovation ecosystems, which allow shared reflection and collective development of ethical principles, especially in contexts where individual organizations may lack the internal capabilities or cultural grounding to do so.

Overall, the study evidence that corporate strategies within innovation ecosystems would benefit from a tailored approach and leveraging the *meet-in-the-middle principle*. Along with that, treating the relational dimension of human beings as the foundation of relationships would benefit the ecosystem. Finally, accounting for the cultural impact and respect for diverse communities should benefit stakeholder engagement and ensure the ecosystem's longevity.

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8 Ethics declaration

Ethical clearance was not required for the research.

9 AI declaration

AI tools were used to enhance the clarity and accuracy of the English language in this document.

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Sustainability and Well-Being in Industry 5.0: A Systematic Literature Review

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Abstract

This study proposes a systematic literature review aimed at analyzing three key thematic areas: the conceptual and operational adoption of new operational paradigms related to the use of technology in the business environment (Industry 5.0), sustainability strategies in new business models (sustainability) and the concept of well-being in the workplace. The study examined 21 scientific articles selected from the Scopus and Web of Science databases, published in the period 2020-2024, considering the following keywords: industry 5.0, sustainability and well-being. The results highlight the crucial role of advanced technologies - such as artificial intelligence, collaborative robotics and the Internet of Things - in fostering safer, more efficient and well-being-oriented production environments for workers, with a positive impact on the overall sustainability of industrial systems. The ‘Industry 5.0’ phase is an evolution of the previous Industry 4.0, shifting the focus from pure automation to the enhancement of human capital, the ethical integration of technologies and the promotion of human-machine cooperation. It moves towards a society that is based on the use of technology for a more human, inclusive and resilient society, where technology is at the service of human well-being (Society 5.0). Findings reveal that technology is configured not as an end, but as a means for the improvement of collective well-being and quality of life and lastly for production systems that evolve by placing the person at the center: the goal is to reach the ethical integration of technologies through the human-machine collaboration.

Keywords: sustainability – well-being – Industry 5.0 – systematic literature review

Paper type: Academic Research Paper

1 Introduction

The acceleration of technological progress has profoundly transformed multiple sectors, with significant impacts on social and economic dynamics (Kumar et al., 2024). The main challenge will therefore be to promote a sustainable balance between technological innovation and human capital enhancement, through retraining, professional development and employment resilience strategies.

This study proposes a literature review, aiming to map the main academic contributions, identify emerging trends, and detect possible knowledge gaps. The focus is on three key thematic areas:

1. digitalization (as emerging technologies, and strategic levels for business model transformation and organizational innovations);
2. human capital (as contribution in a work context where digital skills, adaptability and continuous learning capacity become crucial for business competitiveness);
3. sustainability (as an integrated perspective that combines economic performance, environmental impact and social responsibility, outlining new models of shared value creation).

This study will be divided into several stages: in the first part, the three themes of the literature review - sustainability, Industry 5.0 and organizational well-being - will be illustrated and the research questions defined. This will be followed by an illustration of the methodology adopted and the presentation of the main results that emerged. The work will conclude with a critical discussion aimed at highlighting the theoretical and practical implications of the results, as well as proposing ideas for future investigation.

2. From digitalization to the relevant role of human capital in the sustainable development era: literature review

Numerous academic researches have amply highlighted and confirmed that the key factors that have shaped the economic and social scenario in recent years, particularly ‘reinforced’ by the needs that emerged during the Covid-19 pandemic, have been, among others, the advent of digital transformation, sustainable development and human capital, with a focus on organizational and occupational well-being.

2.1 Industry 5.0

The concept of Industry 5.0 (I5.0) emerges as a natural, though not merely incremental, evolution of the Industry 4.0 (I4.0) paradigm, shifting the focus from mere automation and technological connectivity to a more holistic and anthropocentric view of production (Breque et al., 2021). While I4.0 targeted efficiency and productivity through the interconnection of cyber-physical systems, Big Data and Artificial Intelligence (Schwab, 2016), I5.0 integrates these advanced technologies to achieve broader social and ecological goals.

Research in this area explores how digital technologies can facilitate sustainable business models and more environmentally friendly production practices. Finally, resilience addresses the need for industries to be robust and flexible, able to absorb external shocks (such as pandemics or geopolitical crises) and to adapt quickly to unforeseen changes in demand or supply chains. Although the concept is still relatively new and being defined, the existing literature explores its technological, social, economic and ethical implications, highlighting both the immense opportunities for shared value creation and the significant challenges related to implementation, required investments, data governance and the need for an appropriate regulatory framework. If, with I4.0, technology had already profoundly influenced the functioning of organizations (Lasi et al., 2014), with the advent of I5.0 the focus shifts to building a balance between human intervention and intelligent machines, placing greater emphasis on sustainability. The current approach no longer sees technology as a mere substitute for human labour, but rather as a complementary element, capable of fostering an effective collaboration between artificial intelligence and human skills, promoting person-centered innovation (Melnyk et al., 2021).

2.2 Sustainability

Corporate sustainability has undergone a profound transformation, evolving from a niche concept focused primarily on regulatory compliance and philanthropy to a strategic imperative embedded in the core business (Bansal & DesJardine, 2014; Eccles et al., 2014). There is broad agreement in the academic literature that companies can no longer operate by pursuing short-term profit maximization alone, but must consider their environmental and social impact (Elkington, 1998). The Triple Bottom Line (TBL) framework - People, Planet, Profit - proposed by Elkington (1998) remains a key reference point, although its operationalization and measurement still present significant challenges (Norman & MacDonald, 2004). More recently, the focus has crystallized on Environmental, Social and Governance (ESG) criteria, which provide a more structured framework for investors and stakeholders to assess companies' non-financial performance (Gillan et al., 2021; Serafeim, 2020). The research highlights multiple drivers driving companies towards sustainability: increasing pressure from stakeholders (investors, consumers, employees, local communities) (Freeman et al, 2010; Clarkson, 1995), the need to manage emerging risks related to climate change and resource scarcity (Linnenluecke & Griffiths, 2010), the opportunity to gain competitive advantages through eco-sustainable innovation and improved corporate reputation (Porter & Kramer, 2006; Hart & Milstein, 2003), and increasing environmental and social regulation globally.

The literature therefore underlines how the transition towards truly sustainable business models requires a systemic change involving strategy, operations, organizational culture and stakeholder dialogue. In fact, the advent of digitalization has become a key ally to these ends: it pursues greater efficiency in production processes (Ching et al., 2022) and contributes to the development of new ‘cleaner’ business practices with a lower environmental impact (Amjad et al., 2021). Ultimately, there is an increasing move towards a new corporate structure that promotes concrete improvements in its operations from a sustainability perspective (Porter & van der Linde, 1995; Elkington, 2018). There has been growing attention to the application of blockchain technologies in the agri-food sector, highlighting the potential for addressing sustainability issues (Dal Mas et al., 2023). The adoption of sustainable supply chain practices, based on criteria of transparency, traceability and environmental responsibility of suppliers, is also crucial. Ongoing staff training, aimed at developing green skills and promoting a sustainability-oriented corporate culture, is a further strategic element. Finally, the integration of environmental assessment metrics (e.g. LCA - Life Cycle Assessment) into management control systems makes it possible to monitor the impact of activities and guide conscious decisions towards continuous improvement (Wagner, 2010; Rosa et al., 2020; Shi et al., 2024).

2.3 Employee Well-being

Employee well-being has become a central theme in management and organizational studies, evolving from a narrow focus on occupational health and safety to a broader, multidimensional perspective (Guest, 2017). It is now understood not merely as the absence of illness, but as the presence of positive psychological states such as job satisfaction, engagement, purpose, and psychological flourishing (Bakker & Demerouti, 2007; Keyes, 2002;

Seligman, 2011). Empirical evidence has linked high levels of well-being to key organizational outcomes, including improved performance, higher productivity, greater engagement, and reduced absenteeism and turnover (Wright & Cropanzano, 2000; Harter et al., 2002; Lyubomirsky et al., 2005). Moreover, in competitive labor markets, prioritizing employee well-being serves as a strategic advantage for talent attraction, retention, and corporate reputation (Edmans, 2011). However, scholars caution against superficial or instrumental approaches (well-being washing') and stress the importance of authentic leadership commitment and structural integration of well-being into organizational culture and practices (Spicer, 2020). The current challenge lies in designing and implementing well-being strategies that are effective, sustainable, and genuinely human-centered.

In light of these premises, this study aims to answer the following research questions:

- ***RQ1***: What is the current state of research on the three different topics: Industry 5.0, sustainability and employee well-being, investigated 'jointly'?
- ***RQ2***: How does the concept of work and corporate well-being change with the introduction of sustainability-oriented Industry 5.0?
- ***RQ3***: What findings arise from the present study, and what are the prospective avenues for future research?

3 Research design

On the basis of RQs, the authors explore the existing literature and decided to work with a systematic literature review, as according to numerous studies (Calandra et al., 2023; Page et al, 2021) it is an organised, transparent and above all replicable methodology (Tranfield et al., 2003). The purpose of this study is to identify current research trajectories and potential research topics, gaps in existing research and to highlight further and future research topics and suggest a framework. Therefore, it is intended to provide an interdisciplinary and international overview of the current academic debate focused on the proposed topics.

With the present work, the following steps were observed:

1. the first phase consists of the "planning of the review process", as the definition of the objective and purpose of the research (carried out in sections 1 and 2 above) and the description of the review project;
2. the second phase consists of the "conduct of the review process", as the identification, selection, evaluation, and synthesis of the relevant research studies;
3. the third and final phase consists of the "reporting and dissemination of the overall research results", as the descriptive presentation of the findings and the thematic analysis of the journal articles.

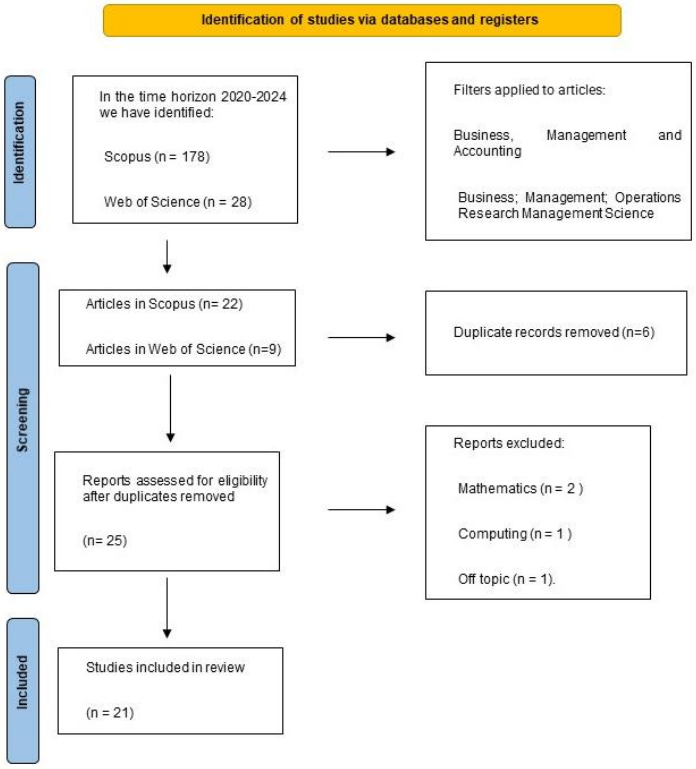


Figure 1: Summary of PRISMA flowchart

4 Results

In order to answer the first research question (RQ1), a summary of the 21 articles identified by the systematic literature review was carried out, first offering a summary table of the articles examined:

Table 1: Selected articles

Author	Year	Title	Journal	Main content	Type of research	Geographic research contest (potential)	Sectoral context of research
Brauner, P., Ziefle, M.	2022	Beyond playful learning – Serious games for the human-centric digital transformation of production and a design process model	Technology in Society	Serious games as key tools for a human-centric digital transformation of industrial production, aligned with I5.0 principles.	EmSt	Germany	Manufacturing and production sector
Chin, S.T.S.	2021	Influence of emotional intelligence on the workforce for industry 5.0	IBIMA Business Review	To examine the impact of emotional intelligence (EI) on organizational performance in the context of I5.0.	CaseSt	Malaysia	Case study: plastic manufacturing company
D'souza, C.P., Tapas, P.	2024	Diversity 5.0 framework: managing innovation in Industry 5.0 through diversity and inclusion	European Journal of Innovation Management	To identify the dimensions of I5.0 that foster innovation through gender diversity.	TCS & EmSt framework "diversity 5.0"	India	Manufacturing
Dacre, N., Yan, J., Frei, R., Al-Mhdawi, M.K.S., Dong, H.	2024	Advancing sustainable manufacturing: a systematic exploration of Industry 5.0 supply chains for sustainability, human-centricity, and resilience	Production Planning and Control	The shift to Supply Chain 5.0 entails technical, organizational, cultural, and ethical challenges, calling for integrated approaches based on responsible innovation, resilience, and human-centered values.	SLR framework "supply chain 5.0"	United Kingdom	Manufacturing (Supply chain)
Destouet, Candice; Tlahig, Houda; Bettayeb, Belgacem; Mazari, Belahcene	2023	Flexible job shop scheduling problem under Industry 5.0: A survey on human reintegration, environmental consideration and resilience improvement	JOURNAL OF MANUFACTURING SYSTEMS	Flexible scheduling in I5.0: a review of resilience, sustainability, and human-centric approaches; identification of research gaps; and proposal of a new SFJSSP (Sustainable Flexible Job Shop Scheduling Problem) model and framework.	SLR	France	Manufacturing
Dolgui, A., Ivanov, D.	2023	Metaverse supply chain and operations management	International Journal of Production Research	To identify how the Metaverse will impact supply chain and operations management	TCS	France – Germany	Cross-sectoral (supply chain)

Author	Year	Title	Journal	Main content	Type of research	Geographic research contest (potential)	Sectoral context of research
Fernández-Miguel, A., García-Muiña, F.E., Settembre-Blundo, D., Tarantino, S.C., Riccardi, M.P.	2024	Exploring Systemic Sustainability in Manufacturing: Geoanthropology's Strategic Lens Shaping Industry 6.0	Global Journal of Flexible Systems Management	To investigate the role of geoanthropology-supported systemic sustainability in advancing manufacturing toward Industry 6.0, and to develop practical tools for sustainability governance in industrial districts.	CaseSt	Italy	Industrial district (Sassuolo ceramics)
Ferreira, A.C.D., Titotto, S.L.M.C., Akkari, A.C.S.	2022	Urban Agriculture 5.0: An Exploratory Approach to the Food System in a Super Smart Society	International Journal of Mathematical, Engineering and Management Sciences	Urban Agriculture 5.0: a systemic model integrating technology, environment, and society to strengthen resilience, food security, and sustainability in smart cities.	SLR	Brazil	Agriculture
Gamberini, L., Pluchino, P.	2024	Industry 5.0: A comprehensive insight into the future of work, social sustainability, sustainable development, and career	Australian Journal of Career Development	Redefining work in the age of technology, highlighting the need for inclusive upskilling, continuous learning, and human-centric collaboration with cobots, placing worker well-being at the core.	LitRew	Italy	Cross-sectorial (job market)
Ivanov, D.	2023	The Industry 5.0 framework: viability-based integration of the resilience, sustainability, and human-centricity perspectives	International Journal of Production Research	To identify thematic clusters around resilience, sustainability, and human centrality, proposing a new "triple bottom line": resilient value creation, human well-being, and social sustainability.	TCS	Germany	Manufacturing
Kumar, U., Kaswan, M.S., Kumar, R., Rathi, R., Joshi, R.	2024	A systematic review of Industry 5.0 from main aspects to the execution status	TQM Journal	Industry 5.0 and the SDGs: overview of key technologies, applications, challenges, and mitigation strategies, with a proposed mapping of I5.0 technologies to the Sustainable Development Goals.	SLR	India	Cross-sectorial (Manufacturing, Medicine, Electronics and Informatics; Construction, Agri-food and Other Minors)

Author	Year	Title	Journal	Main content	Type of research	Geographic research contest (potential)	Sectoral context of research
Laddha, S., Agrawal, A.	2024	Unveiling barriers to Industry 5.0 adoption in supply chains: a DEMATEL approach	RAUSP Management Journal	To identify the barriers to I5.0 in Indian supply chains: identifying key obstacles, analyzing their interdependencies, and supporting a sustainable, human-centric implementation pathway.	SLR & EmSt	India	Manufacturing (supply chain)
Leng, Jiewu ; SSha, Weinan ; Wang, Baicun ; Zheng, Pai; Zhuang, Cunbo ; Liu, Qiang ; Wuest, Thorsten ; Mourtzis, Dimitris; Wang, Lihui	2022	Industry 5.0: Prospect and retrospect	JOURNAL OF MANUFACTURING SYSTEMS	To provide a comprehensive and systemic theoretical foundation for understanding I5.0 as an integrated human-centric ecosystem—beyond technological evolution—combining technology, ethics, resilience, and sustainability.	TCS	China – Europe	Cross-sectorial
Narkhede, Ganesh Bhoju; Pasi, Bhavesh Nandanram; Rajhans, Neela; Kulkarni, Atul	2024	Industry 5.0 and sustainable manufacturing: a systematic literature review	BENCHMARKING-AN INTERNATIONAL JOURNAL	Exploring the link between I5.0 and sustainable manufacturing: challenges and opportunities within the Triple Bottom Line, and an operational framework for implementation in Indian industry.	SLR	India	Manufacturing
Nguyen, T., Duong, Q.H., Nguyen, T.V., Zhu, Y., Zhou, L.	2022	Knowledge mapping of digital twin and physical internet in Supply Chain Management: A systematic literature review	International Journal of Production Economics	Mapping the research landscape on Digital Twin (DT) and Predictive Intelligence (PI) in Supply Chain Management: identifying current and emerging research fronts and proposing future directions within the Industry 4.0–5.0 context.	SLR	United Kingdom	Supply chain management

Author	Year	Title	Journal	Main content	Type of research	Geographic research contest (potential)	Sectoral context of research
Oeij, P.R.A., Lenaerts, K., Dhondt, S., Sorko, S.R., Warhurst, C.	2024	A Conceptual Framework for Workforce Skills for Industry 5.0: Implications for Research, Policy and Practice	Journal of Innovation Management	To develop a conceptual framework for workforce competencies in Industry 5.0, integrating its three pillars—human centricity, resilience, and sustainability—across individual, organizational, sectoral, and societal levels.	TCS	Europe	Cross-sectorial
Ojstersek, R., Javernik, A., Buchmeister, B.	2024	Integrating simulation modelling for sustainable, human-centred Industry 5.0: ESG-based evaluation in collaborative workplaces	Advances in Production Engineering and Management	Developing an ESG-based simulation model to assess the efficiency and sustainability of collaborative workplaces.	EmSt	Slovenia	Manufacturing
Rahman, N.A.A., Mohammad, M.F., Ghafar, N.H., Moin, M.I.A., Ali, A.	2020	The salient motives for Malaysia aviation industry sustainability: An explorative study on business, management and technology components in aviation management program in Malaysia	International Journal of Supply Chain Management	A practical and theoretical model is provided to support academia–industry integration in the aviation sector, contributing to the sustainable development of Malaysia's aviation talent pipeline.	EmSt	Malaysia	Civil aviation sector
Tian, G., Sheng, H., Zhang, L., Zhang, X., Feng, Y.	2024	Enhancing end-of-life product recyclability through modular design and social engineering optimiser	International Journal of Production Research	An innovative model is introduced to support sustainable and modular end-of-life product design, directly contributing to the core objectives of5.0: resilience, sustainability, and human centricity.	EmSt	China	Manufacturing-Automotive
van Erp, T., Carvalho, N.G.P., Gerolamo, M.C., Rytter, N.G.M., Gladysz, B	2024	Industry 5.0: A new strategy framework for sustainability management and beyond	Journal of Cleaner Production	An innovative I5.0 manufacturing strategy built on core values—modularity, flexibility, and seamless digital integration—is proposed.	TCS	International	Cross-sectorial

Author	Year	Title	Journal	Main content	Type of research	Geographic research contest (potential)	Sectoral context of research
Vesperi, W., Gagnidze, I., Sobolieva, T.	2024	Industrial revolutions and human capital for the new normal: a cross-country analysis of the university system	International Journal of Organizational Analysis	Supply chain resilience and sustainability in Industry 5.0: mapping the scientific landscape, identifying emerging themes, and outlining future research and managerial directions for human-centric supply chains.	LitRew	India	Supply chain Management

For this literature review, the selected articles were categorized according to the following criteria: (1) the type of study conducted; (2) the country or geographic region in which the research was carried out (where identifiable); and (3) the sectoral context relevant to the study (where identifiable).

With regard to the type of study, the following four categories have been identified:

1. Theoretical/Conceptual Studies - TCSt (propose models, frameworks, perspectives, discuss concepts) - STC;
2. Literature Reviews - LitRew (they systematically analyze and synthesize existing research on a topic, e.g. systematic literature review SLR, mapping, survey of literature, ...);
3. Case Studies- CaseSt (single or multiple): in-depth investigations on one or more specific cases referring to companies, projects, contexts, in order to understand complex phenomena in their real context. They can be 'exploratory');
4. Empirical Studies - Non Case Study / Applied Methodology - EmSt (collect and analyze primary or secondary data through surveys, experiments, quantitative analysis (e.g. cross-country analysis), or apply/develop specific methodologies with data, without necessarily adopting the depth or holistic approach of a traditional case study.

As far as the country is concerned, it can be stated that the country of reference is not always 'traceable', particularly in Literature Reviews, but it is possible, in general, to outline the nationality of the researchers who have addressed their research interests on these topics. It can be said that, albeit with a good approximation, the articles refer to the following geographical contexts: Europe (Italy, Germany, France), United Kingdom, Brazil, India, Malaysia, Slovenia. Finally, the research showed more reference to companies operating in the manufacturing sector, however there is no lack of curious and interesting research referring, for example, aviation (in Malaysia), automotive (China), the training of students and workers including diversity and soft skills as strategic leverage, transition to supply chains 5.0, the context of the Metaverse and the integration of Urban Agriculture in smart urban environments.

5 Discussion

To answer the second research question (RQ2), the topic of human-robot collaboration (HRC) needs to be analyzed, as it integrates mechanical efficiency with human cognitive, decision-making and relational capabilities. The introduction of collaborative solutions has already shown interesting results such as increased productivity, improved worker well-being and higher product quality, and simulations of human-robot interactions have revealed strategic tools for optimizing task allocation and assessing ESG (environmental, social and governance) impacts. However, current models privilege economic variables, neglecting crucial aspects such as safety, worker motivation and energy efficiency (Ojstersek et al., 2024).

The transition from I4.0 to I5.0 has directed the interests of academia and business towards the topics of sustainability, humanization of production processes and skills development. This has fostered the emergence of new professions in robotics and advanced automation (e.g. mobile robot managers, intelligent machine programmers, robotics assistants, process supervisors) (Kumar et al., 2023).

In this scenario, human capital is at the heart of this transition, as training becomes crucial to combine technical skills with soft skills, such as communication, critical and creative thinking. In particular, emotional intelligence emerges as a crucial competence to foster collaboration in teams and effectively manage complex

situations (Chin, 2021): indeed, an empirical study in Malaysia shows that the integration of experience, corporate loyalty and emotional intelligence qualifies as a strategic lever to enhance organizational resilience and facilitate adaptation to changes induced by industrial evolution. In the I5.0 era, education and training emerged as strategic levers for achieving an innovative, sustainable and inclusive economy. This requires flexible, digitally integrated and continuous learning-oriented training paths throughout the entire working life: dynamic learning environments must be promoted and the creative and innovative potential of employees must be enhanced (Oeij et al., 2024).

The graph elaborated with VOSviewer highlights the evolutionary directions of I5.0, oriented towards the integration of Society 5.0 values and the reaffirmation of the centrality of the human being in innovation processes (Figure 2).

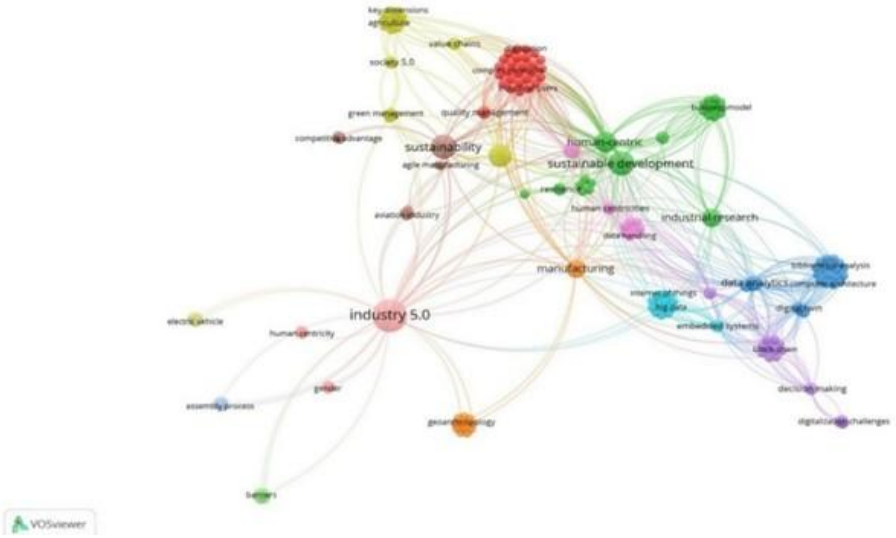


Figure 2: Co-occurrence analysis of keywords

In conclusion, three core aspects characterizing I5.0 (RQ3) are identified:

1. the new modes of training and learning;
2. the obstacles limiting the adoption of modern technologies;
3. the evolutionary trends of the future that introduce I6.0.

Digital serious games represent an interesting innovation in education, as they combine educational purposes with playful dynamics. They offer realistic and safe simulated environments and deal with complex scenarios without incurring concrete risks, developing, on the one hand, motivation and educational effectiveness and, on the other, the acquisition of practical skills (Brauner & Ziefle, 2022).

Among the main barriers to the spread of I5.0 emerge high implementation costs, followed by market uncertainty, lack of technological knowledge, limited access to reliable information and data security concerns, all of which hold back investment (Laddha & Agrawal, 2024).

Looking beyond the current paradigm, research begins to outline the contours of I6.0, characterized by even more advanced human-machine integration, extensive use of artificial intelligence and a more systemic approach to sustainability (Fernández-Miguel et al., 2024).

6 Conclusion

In the I5.0 era, organizational well-being emerged as a critical enabler of sustainable and inclusive transformation. Organizations are thus called to invest in the development of human capital, foster dynamic and continuous learning environments, and promote the integration of technology in a way that is conscious, ethical, and human-centered. The keyword co-occurrence analysis conducted through VOSviewer highlights how digitalization (including digitization), green management, and sustainability converge along the evolutionary trajectory of I5.0, aligning with the values of S5.0 and reaffirming the central role of the human being in innovative processes.

Empirically, despite the emergence of valuable insights and promising approaches, the practical implementation of these innovations remains hindered by significant challenges. Tools such as serious games, performance measurement indices, and other potentially impactful frameworks remain underutilized, often due

to the substantial investments required and the lack of organizational readiness and cultural maturity to embrace them. Additionally, the development of well-structured public policies is crucial to facilitate the integration of advanced technologies and sustainability goals—an integration that is ultimately shaped by human capabilities, which continue to represent the foundational asset of I5.0.

Despite this study is based on a limited body of literature derived from the intersection of selected keywords, this field of research is quickly evolving and needs for the development of integrated quantitative models, new performance metrics (e.g., ethics, well-being), and empirical research—particularly at the different specific sectoral —as well as deeper investigations into human-centered governance practices.

7 Ethics declaration

Ethical clearance was not required for this article, and no application for ethical clearance was submitted.

8 AI declaration

The preparation of this article did not involve the use of artificial intelligence in any form.

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Fostering Knowledge Management to Enhance Innovative Work Behaviour in Public Healthcare Organizations

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Abstract

Innovative work behaviour (IWB) may be crucial to enable middle managers of public healthcare organizations (PHOs) to effectively fulfil their hybrid role of doctor-managers. However, psychological and cognitive boundaries associated with role hybridization can inhibit IWB. To overcome these criticalities, knowledge should be dynamically managed within PHOs. Grounded in the social identity theory, the present study aimed to explore the development of knowledge transfer at the individual-level of analysis by investigating the influence of doctor-managers' organizational identification (OI) on their IWB, through the indirect effect of satisfaction with the managerial role. A survey was administered to doctor-managers working in Italian PHOs. A linear regression analysis was performed to test the research design. The findings demonstrated that doctor-managers' OI address a greater satisfaction with the managerial role; in turn, this latter positively influences doctor-managers' IWB. This study provides new insights into the individual determinants of IWB in knowledge-intensive public organizations like PHOs. In doing so, it contributes to the ongoing discussion on the pivotal role of knowledge transfer dynamics as a precursor of IWB by unleashing the potential of OI. PHOs' top management should regulate doctor-managers' identity by providing an environment fostering the transfer of knowledge supporting them in performing their hybrid role. This may be achieved through managerial practices that facilitate vertical and horizontal integration and knowledge exchange.

Keywords: Innovative Work Behaviour, Knowledge Management, Public Healthcare Organizations, Hybrid managers

Paper type: Academic Research Paper

1 Introduction

Innovative Work Behaviour (IWB), as a dimension of innovation processes, has become increasingly relevant in high complex and knowledge-based organizations, such as public healthcare organizations (PHOs)(Richard and Duxbury, 2014). In fact, IWB is a multifaceted concept that involves a set of individual behaviours aimed at intentionally generating and implementing new useful ideas, products, services, or procedures within the organization (Janssen, 2004; De Jong and Den Hartog, 2010)

Managers' IWB plays a key role, as their propensity to innovate has the potential to drive the organization towards innovative outcomes (Damanpour and Schneider, 2009). This is particularly true for healthcare middle management within publicly funded universalistic health systems, like that of Italy. In these systems, the NPM reforms have altered the traditional professional responsibilities and duties of doctors heading operational units (OUs) who have enrolled in middle management positions (Morandi, Angelozzi and Di Vincenzo, 2021). Such enrolment has created "doctor-managers" with clinical–professional autonomy and new tasks as budget holders (Paolini et al., 2025). Therefore, these hybrid managers must strike a balance between the quality of treatments and cost containment. IWB may be crucial to enable doctor-managers to effectively fulfil their dual role.

Nevertheless, psychological and cognitive boundaries can inhibit IWB of these professionals. Indeed, the hybridization of healthcare middle managers (Sartirana, Prenestini and Lega, 2018), combined with a lack of interest in managerial issues and inadequate knowledge and skills to cope with them (Morandi, Angelozzi and Di Vincenzo 2021), exposes these physicians to interpretative ambiguities regarding their dual role responsibilities. Such challenges may lead to harmful psychological responses, which threaten doctor-managers' role satisfaction (Pandey and Raney, 2006) and have the potential to negatively impact their approach to the managerial role. This, in turn, can inhibit their search for IWB.

Among the emerging studies investigating the drivers of IWB, relevant attention has been devoted to the characteristics of individual actors, such as their personal knowledge, skills (Phelps, Heidl and Wadhwa, 2012), and creativity (Tierney and Farner, 2002), as well as to knowledge sharing mechanisms (Mura et al., 2012). Positive organizational scholarship approaches (Cameron et al., 2003; Roberts, 2006; Cameron and Spreitzer,

2011) has highlighted individual and collective strengths (attributes and processes) and how such strengths enable human flourishing (e.g. goodness, growth, and resilience).

However, there are few studies (Lee and Choi, 2003; Avital and Carlo, 2004; Pinho et al. 2011) that analyse these strengths as facilitators of knowledge management (KM) processes, which, in turn, are able to foster IWB.

Knowledge is a valuable intangible resource that should be dynamically managed especially by knowledge-intensive organizations like PHOs, to increase the alignment of individual beliefs, values and goals with the organizational ones. Socio-organizational features represent crucial facilitators affecting KM via several processes supporting knowledge creation, acquisition or distribution to the various organizational actors (Pinho et al., 2011). In this regard, Nonaka and Takeuchi (1995) underscore the pivotal function of socialization mechanisms in facilitating internalization processes and knowledge transfer within organizations.

At the individual level, social identity theory (Tajfel & Turner, 1979) may offer a valuable lens for understanding how knowledge transfer develops. One such form of social identity is organizational identification (OI), defined as the aspect of an individual's self-concept that derives from the perceived oneness with or the sense of belongingness to the organization (Mael & Ashforth, 1992). OI allows individuals to feel themselves as a part of organization (Bergami and Bagozzi, 2000). Being embedded in organizations that encourage the progressive homogenization of beliefs, values, and goals increase doctor-managers' understanding, learning and interiorization of organizational expectations (Ravishankar & Pan, 2008) about how to cope with the responsibilities linked to their dual role. These intangible processes of knowledge transfer, by mitigating role ambiguities, make doctor-managers more psychologically empowered in their hybrid role (Salvatore, Numerato and Fattore, 2018; Di Vincenzo, Angelozzi and Morandi, 2021). These cognitive-psychological benefits, coupled with the enhanced knowledge of their role, may induce doctor-managers to seek and adopt IWB. In particular, along the lines of knowledge transfer, OI may induce a greater satisfaction with the managerial role (De Vries, Bekkers and Tummers, 2016; Fischer & Doring, 2022), which may boost the willingness of search innovation sources and engage with IWB (Radaelli et al., 2014; Di Vincenzo and Iacopino, 2021; Usmanova et al., 2021).Based on this reasoning, this study explores the positive influence of doctor-managers' OI on their IWB, through the indirect effect of satisfaction with the managerial role.

A survey was conducted on 98 doctor-managers working in Italian PHOs.

The remainder of the paper is structured as follows: section 2 presents the background and hypotheses development; section 3 outlines the methodology; section 4 presents the findings; section 5 provides discussion and conclusions.

2 Background and hypotheses development

Among the studies investigating the antecedents of IWB, relevant attention has been devoted to the characteristics of individual actors. A significant amount of research has been dedicated to examining the influence of individual attributes at various stages of the innovation process, from idea generation (Björk & Magnusson, 2009) to the implementation and use of new products, services and processes (Iacopino, Mascia and Cicchetti, 2018). The antecedents of IWB refer to cognitive aspects, such as trust in the superior, openness to new ideas, vitality at the workplace and the development of learning processes (Carmeli and Spreitzer, 2009). Additionally, they pertain to employees' characteristics, including personal knowledge, skills (Madjar, Oldham and Pratt, 2002; Phelps, Heidl and Wadhwa, 2012), empowerment, professionalism, problem-solving capabilities, demographic aspects and satisfaction in the work environment (De Vries, Bekkers and Tummers, 2016). Moreover, the management literature has associated IWB determinants with informal norms and attitudes in organizations, including creativity (Tierney and Farner, 2002; Kessel, Hannemann-Weber and Kratzer, 2012), engagement and knowledge sharing (Mura et al., 2012; Alfes et al., 2013). Only a handful of studies have sought to examine the factors influencing IWB in PHOs. Oppi, Bagheri and Vagnoni (2020) investigated the influence of clinical managers perceived creative self-efficacy and creative collective efficacy on IWB. Di Vincenzo and Iacopino (2021) explored the impact of professional network on physicians' IWB.

Positive organizational scholarship approaches (Cameron, 2003; Roberts, 2006; Cameron and Spreitzer, 2011) highlight individual and collective strengths (attributes and processes) and how such strengths enable human flourishing (e.g. goodness, growth, and resilience). However, there are few studies (Lee and Choi, 2003; Avital and Carlo, 2004; Pinho et al. 2011) that analyse these strengths as facilitators of knowledge management (KM) processes, which, in turn, are able to foster IWB.

Knowledge is a valuable intangible resource that should be dynamically managed especially by knowledge-intensive organizations like PHOs, to increase the alignment of individual beliefs, values and goals with the organizational ones. Socio-organizational features represent crucial facilitators affecting KM via several processes supporting knowledge creation, acquisition or distribution to the various organizational actors (Pinho

et al., 2011). In this regard, Nonaka and Takeuchi (1995) underscore the pivotal function of socialization mechanisms in facilitating internalization processes and knowledge transfer within organizations.

At the individual level, social identity theory (Tajfel & Turner, 1979) may offer a valuable lens for understanding how knowledge transfer develops.

Social identity is defined as the perception of oneness with or the sense of belonging to a group (Mael and Ashforth, 1992). It is that aspect of an individual's self-concept that derives from the awareness of the affiliation with a group, along with the value and emotional significance attached to this affiliation (Tajfel & Turner, 1979).

One form of social identification is OI, which is the extent to which an individual's self-concept contains attributes that are identical to those of the perceived organizational identity. Identification arises when an individual and an organization share common interests that outweigh their differences, and when the individual perceives that their relationship with the organization forms an 'us' (Salvatore, Numerato and Fattore, 2018).

From a cognitive perspective, this intrinsic bond with the organization allows individuals to feel and recognize themselves as a part of organization and to engender a sense of pride, distinctiveness, and enhanced self-esteem (Bergami and Bagozzi, 2000).

OI is correlated with a wide range of work-related positive attitudes and behaviours such as commitment, organizational citizenship behaviours, and job turnover (Van Dick et al., 2006; Salvatore, Numerato and Fattore, 2018). Indeed, individuals who strongly identify with their organization, embodying its values, goals and role organizational expectations, are more likely to positively contribute to its success through positive individual role and extra-role behaviours and performance. According to the IWB construct, being embedded in organizational contexts favouring the progressive homogenization of beliefs, values and goals increase doctor-managers' understanding, learning and interiorization of organizational expectations (Ravishankar & Pan, 2008) about how to cope with the responsibilities linked to their dual role. These intangible processes of knowledge transfer, by mitigating role ambiguities, make doctor-managers more psychologically empowered in their hybrid role (Salvatore, Numerato and Fattore, 2018; Di Vincenzo, Angelozzi and Morandi, 2021). These cognitive-psychological benefits, coupled with the enhanced knowledge of their role, may induce doctor-managers to seek and adopt IWB. In particular, along the lines of knowledge transfer, OI may induce a greater satisfaction with the managerial role (De Vries, Bekkers and Tummers, 2016; Fischer & Doring, 2022), which may boost the willingness of search innovation sources and engage with IWB (Radaelli et al., 2014; Di Vincenzo and Iacopino, 2021; Usmanova et al., 2021).

Based on this reasoning, we elaborated the following research hypotheses:

- *Hp 1: Doctor-managers' organizational identification positively affects their satisfaction with the managerial role*
- *Hp 2: Doctor managers' satisfaction with the managerial role positively affects their innovative work behaviour*

3 Methodology

3.1 Setting

To test the hypotheses, an empirical study was conducted among doctors heading OUs of PHOs situated in two regions in central Italy (Abruzzo and Lazio). The Italian National Health Service is a publicly funded universalistic healthcare system, where the central government provides universal coverage by allocating resources to its 21 regions; the regions, in turn, design the strategic plans and the financing of health services, delegating to PHOs, namely Local Health Authorities (LHAs), the local provision of health services. LHAs have a substantial degree of financial and decision-making autonomy regarding the pursuit of their objectives, in accordance with the principles of effectiveness, resource consumption, appropriateness and quality of health services provided. They are accountable to the regional government for the achievement of these objectives. LHAs' management is entrusted to General Directors, who are appointed by the Region's government. LHAs are organized in departments, which in turn are structured in several OUs, complex and simple, headed by doctor-managers having both clinical and managerial responsibilities.

3.2 Data collection and sample

A questionnaire was administered to doctors heading complex OUs and simple OUs with departmental value. The survey was conducted in person on-site during university courses on managerial training which involved doctor-managers as students. Indeed, the Italian regulation requires the attendance of these managerial annual courses for doctors heading complex OUs and simple OUs with departmental value. Confidentiality and privacy

were guaranteed to prevent the potential for bias, including the possibility of being inclined to report in a more or less complete manner due to social desirability concerns. The participants were provided with a description of the study's purpose and were requested to sign an informed consent form in accordance with the Italian data protection laws. Based on an overall number of 139 participants to the managerial courses, we collected 98 responses, yielding a 70% overall response rate. Most of the respondents identified as male (57%), with the remaining 43% comprising female participants. The mean age was found to be 56 years, with a range from a minimum of 38 years to a maximum of 69 years. The average of tenure in managerial positions was found to be approximately 8 years, with a range from a minimum of 0 years to a maximum of 44 years. 16% of respondents declared having held an academic position.

3.2.1 Questionnaire

The questionnaire collected attributional data from respondents (including their age, gender, and tenure in the managerial position), their sense of OI, satisfaction with the managerial role and IWB. The measurement scales are described below.

Organizational identification. This measure was developed according to the Bergami and Bagozzi's (2000) graphic scale used in healthcare settings (Salvatore, Numerato and Fattore, 2018; Di Vincenzo, Angelozzi and Morandi, 2021). The scale conceptualizes identification in terms of cognitive distance between an individual and a collective. It is articulated in two circles with a degree of overlap that varies within a range of eight potential alternative responses, ranging from complete separation to complete overlap.

Satisfaction with the managerial role. A single item scale reproducing the job satisfaction scale of Warr, Cook and Wall (1979) was used to measure doctor-managers' satisfaction with the managerial role ("Taking everything into consideration, how do you feel about your managerial job?'') . The response range has been from 1 = extremely dissatisfied to 10 = extremely satisfied.

Innovative work behaviour. Doctor-managers' IWB was measured using a 9-item scale developed by Janssen (2000). The scale measures the self-perceived capabilities in the generation and implementation of new ideas (e.g., "I create new ideas to solve challenging problems", "I transform innovative ideas into useful applications", "I introduce ideas into the work environment in a systematic way"). Respondents rated their degree of agreement on a 7-point Likert scale (1 = strongly disagree, 7 = strongly agree). The Cronbach's alpha reliability coefficient for this scale was 0.84 (falling within the acceptability threshold of .70). The Kaiser-Meyer-Olkin (KMO) test for sampling adequacy value was 0.80 (falling within the threshold of .60).

4 Findings

The findings of the descriptive analysis demonstrated that the mean values for all the scales exceeded the neutrality threshold. Given the extension of the measurement scales, the highest mean values were observed in satisfaction with the managerial role (7.23), indicating that doctor-managers exhibited a tendency to hold a favourable attitude towards their managerial role. The standard deviation of IWB (0.64) was found to be the lowest compared to OI and satisfaction with the managerial role, both of which exhibited moderate standard deviations (1.62 and 1.50, respectively). Results are reported in Table 1.

Table 1: Descriptive statistics

Variables	**Mean**	**SD**	**Min**	**Max**	**1.**	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**
1. Organizational Identification	5.35	1.62	1	8	1						
2. Satisfaction with the Managerial Role	7.23	1.5	1	10	.239**	1					
3. Innovative Work Behaviour	5.82	.64	4	7	.165	.418***	1				
4. Age	55.8	7.66	38	69	.039	.149	.152	1			
5. Gender	.43	.50	0	1	-.028	-.280**	-.083	.059	1		
6. Tenure	7.82	7.55	0	44	-.056	-.245**	-.042	-.106	-.006	1	
7. EBM	3.95	1.02	1	5	.036	.246**	.424***	.084	.128	.008	1

Note. Number of observations = 98. SD = standard deviation. Min = minimum value. Max = maximum value.
*$p \leq .05$; **$p \leq .01$; ***$p \leq .001$

Correlation analysis presents significant preliminary evidence, showing that organizational identification correlated positively with satisfaction with the managerial role (r = .239, $p \leq 0.01$), which correlated positively with gender (r = -.280, $p \leq .001$), tenure (r = -.245, $p \leq .001$), EBM (r = .246, $p \leq .01$) and IWB (r = .418, $p \leq .001$).

Consistent with the methodological approach of previous studies (Di Vincenzo, Angelozzi and Morandi, 2021; Cifalinò, Mascia and Vendramini, 2020; Morandi, Angelozzi, and Di Vincenzo 2021), a linear regression analysis was performed to test the research hypotheses. Indeed, when specific assumptions are met, linear regression provides the most accurate estimates (Barclay et al., 1995).

As suggested by previous studies (Oppi, Bagheri and Vagnoni, 2020; Di Vincenzo and Iacopino, 2021), personal and contextual characteristics have the potential to influence IWB. In response to this, the analysis controlled for the role of respondents' personal characteristics in terms of age, gender, tenure in managerial position (number of years as head of OU) and EBM (frequency of evidence-based management), as well as for the region in which the hospital of each respondent is located.

In accordance with the guidelines of Osborne and Waters (2019), the requirements of linear regression analysis were examined.

The results of linear regression analysis are reported in Table 2.

Table 2: Regression analysis

Dependent Variables	**Independent Variables**		**Control Variables**					**Prob > F**	**Hp**
	Organizational identification	Satisfaction with the Managerial Role	Age	Gender	Tenure	EBM	Region		
Satisfaction with the Managerial Role	.277** (.08)		.116 (0.17)	-.313*** (.27)	-.074 (.02)	.348*** (.13)	-.117 (.31)	.001	1
Innovative Work Behaviour		.295** (.04)	.095 (.01)	-.016 (.13)	.045 (.01)	.298** (.06)	-.076(.14)	.001	2

Note. Number of observations = 98
Reported coefficients are Beta estimations with standard errors in parentheses.
*$p \leq .05$; **$p \leq .01$; ***$p \leq .001$
R^2 = .25 for Hp 1; R^2= .21 for Hp 2

As hypothesized, the degree of organizational identification is significantly associated with the satisfaction with the managerial role, confirming the research hypothesis Hp 1 (β = .277, $p \leq .01$). In this path the control variables gender (β = -.313, $p \leq .001$) and EBM (β = .348, $p \leq .001$) were also found to be statistically significant.

Furthermore, satisfaction with the managerial role was found to predict doctor-managers' IWB, providing support for research hypothesis Hp 2 (β = .295, $p \leq .01$). It also emerged the significance of the control variable EBM (β = .298, $p \leq .001$).

4.1 Discussion and conclusions

The assumption of new managerial responsibilities by heads of OUs in PHOs gives rise to significant challenges in balancing their dual role as physicians and managers (Kurunmaki, 2004; Di Vincenzo, Angelozzi and Morandi, 2021). IWB may represent a key factor in enabling doctor-managers to effectively fulfil their role as hybrid managers. However, the hybridization of healthcare middle managers may result in unclear organizational expectations of their new role and decreased satisfaction with the managerial role. These mental and attitudinal states have the potential to negatively impact IWB.

This study examined the influence of OI on doctor-managers' satisfaction with their managerial role and IWB. Along the lines of social identity theory, the results confirmed the hypothesized paths by demonstrating that doctor-managers' OI, through the indirect effect of increased satisfaction with the managerial role, fosters an increase in their IWB. These findings align with prior studies suggesting that enhancing OI in doctor-managers leads to increased psychological empowerment in their role as hybrid managers (Salvatore, Numerato and Fattore, 2018; Di Vincenzo, Angelozzi and Morandi, 2021). The study findings are also consistent with previous research on the role of the characteristics of individual actors, such as satisfaction in the workplace, including satisfaction with the job role, in predicting IWB (De Vries, Bakkers and Tummers, 2016).

This research provides new insights on the individual determinants of IWB, thus contributing to the ongoing discussion on the antecedents of IWB in knowledge-intensive public organizations like PHOs (De Vries, Bakkers and Tummers, 2016). Particularly, this study contributes to the few healthcare studies exploring doctor-managers' attributes that influence their IWB, by focusing on the Italian public healthcare setting, which is still scarcely explored (Oppi, Bagheri and Vagnoni, 2020; Di Vincenzo and Iacopino, 2021). In doing so, this study adds to the ongoing discussion on the pivotal role of knowledge transfer dynamics as a precursor of IWB by unleashing the potential of OI.

PHOs' top management should regulate doctor-managers' identity that is strengthen their oneness with the organization, by providing an environment fostering the transfer of knowledge necessary to support them in performing their hybrid role and facilitating the interiorization of their hybrid nature. This may be achieved through managerial practices that facilitate vertical and horizontal integration and knowledge exchange opportunities, which make more likely to have doctor-managers who are willing to address IWB. These practices could translate managerial recommendations into concrete and actionable policies, such as AI-enhanced mentorship programs, and improve the monitoring of IWB through the adoption of innovation performance metrics.

Nevertheless, the study has some limitations that provide opportunities for future research. Firstly, the study design implemented a single-source, cross-sectional survey. Consequently, the results may be subject to common method bias. Secondly, the study does not consider any change over time. Further research is encouraged to explore the effects of OI on IWB through longitudinal models showing possible difference in doctor-managers' IWB when particular environmental criticalities or shocks occur or does not occur. Thirdly, the present study focused on self-reported data of doctor-managers working in PHOs of two Italian regions; consequently, the results may be influenced by the investigated context. Cross-country or comparative studies that also examine whether and how contextual factors affect the associations that emerged between the constructs in this study are highly recommended. Exploration into the interplay between other personal attributes and IWB within this dynamic could also prove beneficial.

Despite these limitations and the needs for subsequent improvements, it is believed that the problem addressed remains of general interest and relevance for PHOs' managers and healthcare policy makers.

5 Ethics declaration

Ethical approval was not necessary for this study.

6 AI declaration

The Authors declare that no AI tool was used in developing the paper.

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SMEs AI Investments and Resilience: a Knowledge Risk Perspective

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Abstract

This paper aims to investigate how investment in artificial intelligence interacts with automation-related knowledge risks to shape the resilience of small- and medium-sized enterprises in the Italian context. The rapid advancement of digital transformation requires an extensive understanding of the link between innovative technologies, such as artificial intelligence, and the management of knowledge risks linked to automation, notably related to improving the competitive advantage of small- and medium-sized enterprises. This study employs knowledge risk theory to investigate how investments in artificial intelligence, alongside the challenges introduced by automation, collectively influence organizational resilience and innovation capacity. The empirical foundation of this research is based on secondary data collected across 20 Italian regions and various industries. The dataset was obtained from Confartigianato, a leading association of small- and medium-sized enterprises in Italy. The data were then analyzed using a quantitative approach. The results showed that areas with elevated automation-related knowledge risks are more inclined to invest in artificial intelligence, suggesting a reactive rather than proactive investment approach. The results also highlight varied geographical patterns related to investment levels, risk exposure, and digital readiness, with significant discrepancies in digital adoption and the critical role of knowledge risk as an intermediary factor in the link between artificial intelligence investment and organizational resilience, suggesting that beneficial outcomes are contingent on proficient risk management. This study aims to make a substantial contribution to the current literature on knowledge risk by investigating its application in the context of artificial intelligence and automation deployment in small- and medium-sized enterprises, thereby informing management and regulatory approaches.

Keywords: Artificial Intelligence, Knowledge Risk, Automation Risk, SMEs, Organizational Resilience.

Paper type: Academic Research Paper

1 Introduction

Artificial Intelligence (AI) is profoundly reshaping competitive dynamics across various economic sectors by promoting new practices, improving operational efficiencies, and offering strategic benefits (Muto et al., 2024). In contrast to conventional technologies limited by rigid codes and unchanging directives, AI systems possess the capacity to learn from data, evolve over time, and enhance independently (Durst et al., 2023). This distinctive self-learning ability positions AI as a transformational entity capable of disrupting conventional business models and redefining industrial dynamics. Nonetheless, adopting AI into business workflows encounters challenges, particularly regarding knowledge risks. These risks relate to the management, loss, or theft of knowledge within an organization, hence undermining performance and resilience. Durst and Zieba (2019, p. 2) define knowledge risk as "a quantification of the likelihood and intensity of detrimental impacts stemming from activities associated with knowledge that may influence the operational efficacy of an organization at any level." In the realm of escalating automation, these hazards are becoming increasingly evident. The automation of jobs through AI may lead to the deterioration of human capabilities, especially tacit knowledge—the experiential, often unrecorded insights held by individuals. This information is crucial for maintaining operational flexibility and fostering innovation; its lack can result in inefficiencies and diminish an organization's ability to adapt to change (Moreira et al., 2024). Furthermore, organizations may become dependent on outdated technologies or fail to adapt due to gaps in digital capabilities. Without effective knowledge management, AI adoption may ultimately weaken rather than strengthen organizational performance.

Nevertheless, AI and automation also represent major opportunities for small- and medium-sized enterprises (SMEs), particularly those seeking to enhance competitiveness under constrained resources. The intersection of AI implementation, automation requirements, and increasing knowledge issues in SMEs remains insufficiently studied. Much of the existing research concentrates on large enterprises, overlooking the distinct challenges and conditions faced by SMEs (Oldemeyer et al., 2024; Khan et al., 2024).

This paper examines the relationship between AI investments and automation risks, along with their influence on knowledge risk dynamics in SMEs. The focus is on Italian SMEs, which are embedded in a national context marked by substantial regional disparities in digital infrastructure, AI adoption, and digital literacy. These disparities, combined with sector-specific issues such as labor shortages and uneven innovation capacity, provide a rich context for analyzing how technology-related risks affect organizational resilience.

Due to the lack of research on this point of view, we hypothesize:

- H1: Regions with higher exposure to automation-related knowledge risks tend to invest more in AI, reacting to digital transformation pressure.
- H2: AI investment and knowledge risk levels are different across regions, and these patterns form distinct groups that reflect different levels of digital readiness.
- H3: AI investment helps improve SME resilience, with knowledge risks managed.

This study examines the role of knowledge risk as a mediating element in the relationship between automation demands and organizational resilience and creativity. It contends that heightened regional AI adoption mitigates operational and technological knowledge risks, enabling SMEs to adapt and innovate more effectively in unstable or high-risk environments (Muto et al., 2024; Zieba, 2017).

The study simultaneously investigates the role of organizational attributes, such as business size and regional digital competencies, on the effects of automation and AI on these risks. The investigation uses a quantitative methodology, utilizing two secondary datasets that represent a diverse array of Italian SMEs across various sectors. This research explores the influence of various contextual factors, including business size, industry characteristics, and the level of regional digital maturity, on the interplay between AI, automation, and knowledge risk. It also recognized the necessity of training and development in providing personnel with the competencies required to proficiently utilize AI solutions. The study emphasizes the relevance of knowledge management systems in capturing and spreading tacit knowledge, so converting it into managed organizational assets. This will also provide guidance to expand literature on knowledge management by integrating the dual function of AI as both a potential risk exacerbator and a tool for mitigating knowledge loss. For SMEs, especially in contexts with limited institutional capability, such strategies are essential for the effective management of digital changes. A successful strategy may be providing for governments and corporate leaders the importance of including knowledge risk factors into holistic digital transformation initiatives. Regional differences in infrastructure and digital literacy must be mitigated by targeted, context-specific policy measures to promote equitable AI dissemination across regions. In the absence of such restrictions, the benefits of AI may intensify existing inequities instead of mitigating them. Comprehending these processes may enhance the efficacy of support measures for SMEs striving to maintain creativity and resilience in an increasingly automated environment.

2 Literature Review

2.1 Regional Exposure to Automation and AI Investment

Digital transformation pressures are unevenly dispersed across regions, owing to differences in digital infrastructure, AI use, and knowledge risk management (Schwaeke et al., 2024). Regions that face greater risks related to automation knowledge often counteract by increasing their AI investments as a strategic adaptation measure. In fact regions with a high level of AI integration tend to have lower operational risks, whereas those slow to adopt AI face greater knowledge vulnerabilities (Borgia et al., 2022). Clustering methodologies have been used to categorize regional digital transformation patterns, confirming that AI adoption and knowledge risk degrees align into distinct regional typologies (Badghish and Soomro, 2024). The degree to which regions are exposed to automation and AI investments is determined by structural factors such as the focus of their industries, their capacity for research and development, their productivity, and the skill levels of their workforce. In Europe, regions are categorized into clusters like high-tech service centers and advanced manufacturing hubs, which stand to benefit more from AI as it amplifies their current capabilities. In contrast, peripheral areas may encounter structural obstacles, potentially increasing regional disparities (Guarascio et al., 2024). In the agricultural sector, rural areas face heightened automation risks due to limited labor markets and fewer alternative job opportunities for displaced workers (Rijnks et al., 2022).

2.2 Variations in AI Investment and Knowledge Risk Across Regions

Investment in AI and the associated knowledge risks vary significantly across different regions, resulting in the emergence of unique clusters based on their level of digital preparedness. Studies on regional digital transformation emphasize the importance of local factors such as policy backing, economic frameworks, and technological environments in shaping AI adoption patterns (Schwaeke et al., 2024). Empirical studies reveal that digital transformation trajectories differ significantly, with some regions demonstrating proactive AI adoption strategies, while others struggle with knowledge retention challenges (Borgia et al., 2022). Furthermore, classification techniques used to analyze SMEs digital readiness have identified systematic patterns in AI-related investments and their correlation with knowledge risk exposure (Badghish and Soomro,

2024). Investment preferences at the regional level play a crucial role in shaping AI adoption trends. In China, region-specific investments have been shown to alleviate corporate financial risks, although their effectiveness is dependent on factors such as industry competition and policy uncertainty (Wang, 2023). Moreover, regions with strong technological cohesion are better positioned to withstand economic recessions, as they possess the capability to forge new growth paths and tackle external disruptions (Rocchetta et al., 2020). In addition, venture capital investments contribute to strengthening regional economic resilience by promoting product diversification, although they may not fully address the structural issues in less developed regions (Sheng et al., 2024).

2.3 AI Investment, Knowledge Risk, and SME Resilience

For SMEs, especially in industries such as construction, AI investment can boost competitiveness and sustainability. Nevertheless, the rate of adoption tends to be slow due to perceived knowledge deficiencies and performance expectations. The integration of knowledge plays a crucial role in moderating AI adoption and influencing SME resilience (Khan et al., 2024). In addition, in industries such as agriculture and forestry, increasing AI investments introduce systemic risks like algorithmic bias and unequal access, which can affect sustainability and resilience (Lu et al., 2024). Although AI-driven automation has the potential to bolster SME resilience, its success depends on how effectively knowledge risks are managed. The literature suggests that merely adopting AI does not automatically lead to better organizational outcomes. Instead, it necessitates complementary strategies such as employee upskilling, the establishment of knowledge retention systems, and digital knowledge-sharing initiatives (Durst et al., 2023; Zieba, 2017). Prior research establishes that knowledge risk serves as a crucial mediator between AI investment and firm performance. Organizations that fail to mitigate knowledge disruptions caused by automation may experience operational inefficiencies despite investing in AI technologies (Durst and Zieba, 2019; Borgia et al., 2022).

3 Research Framework and Hypotheses

The integration of AI into business processes is increasingly viewed as a strategic advantage for SMEs pursuing innovation and competitive advantage. However, alongside these benefits, AI adoption and the automation of processes bring challenges for the organization, particularly in the form of knowledge risks. These risks arise when automation processes interrupt traditional knowledge flows, displace skilled employees, or lead to overreliance on digital systems with limited transparency or adaptability. This study is based upon the framework of knowledge risk theory (Durst and Zieba, 2019) and extends it by exploring how AI investments interact with automation-related challenges and changes to influence organizational resilience and innovation capacity.

Knowledge risks refer to the likelihood and impact of adverse results arising from the mismanagement, loss, or low utilization of organizational knowledge assets. Knowledge risks are conceptualized into three dimensions: human risks (e.g., loss of tacit knowledge, knowledge hiding), technological risks (e.g., reliance on outdated systems or inefficiencies in AI knowledge transfer), and operational risks (e.g., breakdowns in workflows or knowledge misuse) (Durst and Zieba, 2019). In this study, knowledge risks are interpreted through automation risk indicators, including both the number of businesses and employees subjected to automation, as well as the amount of risk across specific industries and regions.

AI investments, including both already invested and planned investments in AI technologies, are theorized to minimize knowledge risks by enabling better knowledge management practices, improving system integration, and encouraging employee engagement through training and upskilling initiatives. However, the ability of AI investments to effectively reduce knowledge risks is likely to be influenced by regional and organizational factors, such as the level of digital infrastructure, regional planning, and workforce readiness.

This study develops and tests a research model by taking knowledge risks as a mediating variable between AI adoption and key organizational outcomes such as resilience and innovation. Furthermore, regional disparities in digital development are taken as a moderating variable that influences the strength of these relationships.

3.1 Hypotheses

Building on the presented literature review, we formulated the following hypotheses:

- *H1: Regions with higher exposure to automation-related knowledge risks tend to invest more in AI, reacting to digital transformation pressure.*

- *H2: AI investment and knowledge risk levels are different across regions, and these patterns form distinct groups that reflect different levels of digital readiness.*
- *H3: AI investment helps improve SME resilience, with knowledge risks managed.*

4 Research Methodology

This study examines the relationship between AI investment, automation-related knowledge risks, and SMEs resilience in the Italian regional context through quantitative methods. Due to the increasing role of AI in reshaping business operations, this study adopts an explanatory research approach, with the goal to uncover causal relationships between digital transformation initiatives and risk exposure of organizations. Regional-level analysis is done from secondary data taken from Confartigianato of 20 Italian regions and multiple industries.

In this study, knowledge risks are taken as mediating variables between AI adoption and organizational resilience (Durst and Zieba, 2019). To test the hypotheses of the study, a combination of descriptive statistics, correlation analysis, regression modeling, clustering (via K-means), and mediation analysis are used. This analytical framework ensures the study examines AI-driven digital transformation and its implications for SMEs across regions with different levels of technological readiness.

4.1 Data Collection

In this study, secondary data was used from Confartigianato Italy, which is a leading Italian association that monitors SMEs performance, digital transformation, and regional business risks.

4.2 Descriptive Statistics

The descriptive statistics were computed to assess the distribution and variation of AI investment levels and automation risk exposure across Italian regions. The results are summarized in Table 1.

Table 1: Summary of Key Variables (n = 20 regions)

Variable	Mean	Std. Dev.	Min	Median	Max	Range
Total Investment (%)	6.82	1.53	4.7	6.3	10	5.3
Planned Total (%)	13.92	2.13	10.5	13.7	17.3	6.8
Medium Risk	401,118	533,239	6,239	191,799	2,223,292	2,217,053
High Risk	178,426	263,647	1,871	63,516	992,638	990,767
Low Risk	167,723	223,575	3,027	78,846	1,068,508	1,065,481

Looking into Table 1, AI investment levels vary widely, as they range from 4.7% to 10% of firms per region. Planned AI adoption has a mean of 13.9%, which reflects progressive digital transformation efforts and is on the higher side. There is more variance in Medium and High automation risks, Lombardy having many of high-risk firms and regions like Molise having fewer firms. Low Risk or resilience also varies sharply, reflecting that there are high regional disparities in digital readiness.

4.2.1 Correlation Analysis

Testing our first hypothesis, we performed correlation analysis (Cohen, 2013). Which shows that it is not because AI reduces risks in the short term, as it is a response to the existing risk, and not because AI reduces risk in the short term; rather, AI investment is a response to existing risk.

The study challenges traditional assumptions, but it is aligned with recent literature (Durst et al., 2023; Muto et al., 2024) suggesting that AI adoption often follows pressure, not anticipation, particularly in SMEs directing the automation-driven disruptions.

Table 2: Correlation Coefficients (r) Between Investment in AI and Regional Knowledge Risk Typologies

Variables	Correlation (r)	Description
Total investment ↔ Medium Risk	0.36	Regions with medium risk tend to invest more in AI showing a weak but positive correlation.
Total investment ↔ High Risk	0.34	Regions with higher risk tend to invest more in AI showing a weak but positive correlation.
Total investment ↔ Low Risk	0.43	There is moderate correlation
Medium Risk ↔ High Risk	0.98	Knowledge Risk types co-occur regionally with a strong correlation

There is a weak but consistent positive relationship between automation risk and AI investment. AI investment is positively correlated with medium risk (r = 0.36) and high-risk (r = 0.34) firm concentration as shown in Table 2. These results support the hypothesis (H1) that regions experiencing higher levels of automation-related knowledge risks are more likely to invest in AI, which suggests a reactive investment rather than a proactive investment pattern. Moreover, AI investment shows a moderate positive correlation with firm resilience (r = 0.43), indicating a potential long-term benefit in reducing risk exposure.

For testing our second hypothesis, Principal Component Analysis (PCA) was used to reduce the dataset's five dimensions (AI investment, planning, and three types of automation risk) into two components for visualization (AK Jain et al., 2010). Principal Component 1 (PC1) is to capture variance in knowledge risk exposure, while Principal Component 2 (PC2) shows differences in AI investment intensity. These two components together explain most of the variance in the dataset and show clear regional clustering based on digital maturity.

In Figure 1, in the scatter plot, each point represents a region outlined into two principal components (capturing most variance in investment and risk features). Colors shown as groups indicate three different clusters, derived using K-means clustering. As green are lagging behind regions, blue representing digitally advanced and orange representing transitioning regions.

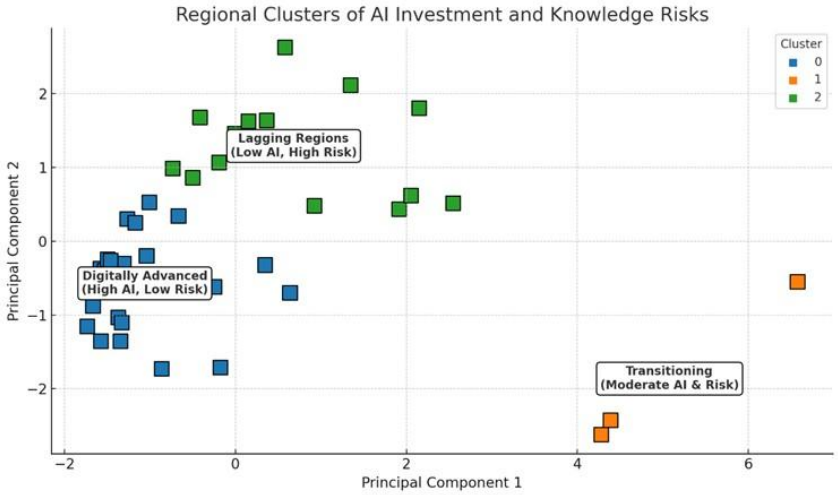


Figure 1. Regional Clusters: AI Investments and Knowledge Risks

K-means clustering grouped Italian regions into three different clusters based on AI investment, automation risk levels, and resilience. The cluster analysis was shown using a Principal Component Analysis (PCA) projection. Cluster 0 has digitally mature regions with high AI investment and low risk; Cluster 1 reflects moderate investment and mixed risk profiles; while Cluster 2 represents digitally lagging regions with low AI investment and high-risk exposures, as shown in table 3. These groupings support the H2 AI investment, and knowledge risk levels are different across regions, and these configurations form distinct groups that reflect different levels of digital readiness.

Table 3: Cluster Groups

Clusters	**Descriptions**	**Regions**
Cluster 0	High AI investment, lower risks	Lombardy, Emilia-Romagna
Cluster 1	Moderate AI investment, mixed risk levels	Lazio, Marche
Cluster 2	Low AI investment, high risk exposure	Molise, Basilicata

To test the third hypothesis of this study, i.e., "AI investment helps improve SME resilience, with knowledge risks managed", we used a causal step mediation model as shown in Table 4.

Table 4: AI Investment, Knowledge Risk, and Resilience: Key Regression Findings

	Variable	**Coefficient**	**p-value**	**Interpretation**
AI Investment towards Knowledge Risk	Total investments to High Risk	59,270	0.026	More investment in high-risk regions showing significant relationship.
Knowledge Risk towards Resilience	High Risk to Low Risk	0.79	<0.001	Higher knowledge risk drives more attention to resilient practices with a strong effect.

	Variable	Coefficient	p-value	Interpretation
AI Investment towards Resilience (Direct)	Total investments to Low Risk	63,130	0.004	Showing a significant and positive effect on SME resilience
Investment + High Risk towards Resilience	Total Investments	18,360	0.036	Significant, but reduced
	High Risk	0.755	<0.001	It continues to drive resilience strongly

AI investment = Independent Variable (X)
High Risk (Knowledge Risk) = Mediator (M)
Low Risk (Resilience) = Dependent Variable (Y)

4.2.2 Mediation Results

By looking into the direct effect of AI investment on SMEs resilience, it is significant. However, when knowledge risk (High Risk) is added to the model, the effect of AI investment drops by 70% i.e. from 63130 to 18360. Which shows a partial mediation, where knowledge risk acts as a crucial bridge between investment and actual SMEs outcomes.

To test whether knowledge risk mediates the relationship between AI investment and SMEs resilience, a stepwise mediation analysis was conducted. Results shows that AI investment significantly predicts both high-risk exposure i.e $\beta = 59{,}270$, $p = 0.026$ and SME resilience i.e. $\beta = 63{,}130$, $p = 0.004$. When both AI investment and knowledge risk were entered into the full model, the effect of investment on resilience diminished to $\beta = 18{,}360$ ($p = 0.036$), while knowledge risk remained a strong predictor ($\beta = 0.755$; $p < 0.001$). This shows a partial mediation, suggesting that only AI investment is not sufficient, and its impact on resilience depends on how effectively knowledge risks are managed.

5 Discussion

This study examined how AI investments relate to automation-related knowledge risks and influence organizational resilience in Italian SMEs. The analysis, grounded on knowledge risk theory (Durst and Zieba, 2019), provides new insights into the dynamics of digital transformation and risk exposure in regionally diverse contexts. The findings show that the relationship between AI adoption and risk mitigation is complex than it was expected to be.

The first hypothesis proposed that AI investment would be higher in regions facing greater knowledge risks. The results showed this, but the direction of this challenges conventional assumptions. Instead of AI mitigating risk in a straight way, the data suggests that SMEs in high-risk environments are adopting AI in response. Technological changes are often driven by organizational pressures rather than expectation (Durst, Edvardsson and Foli, 2023; Muto et al., 2024). Therefore, AI acts less as a proactive measure and work more as a strategic tool for managing challenges.

Cluster analysis showed regional disparities. Lombardy and Emilia-Romagna regions are digitally advanced, while other regions such as Molise and Basilicata lagged behind. As there are disparities among different regions according to this study, it requires region-specific AI policies (Schwaeke et al., 2024).

Mediation analysis revealed that knowledge risks significantly influence this relationship. AI adoption only resulted in improved resilience when risk levels were properly considered. This shows the mediating role of knowledge risk and confirms findings in the previous literature (Borgia et al., 2022; Zieba, 2017), which emphasized the important link between knowledge systems and organizational outcomes in the era of automation.

6 Theoretical and practical implications

It shows a new aspect that relations of AI and risk and the investment are the response to it and not ultimately a solution to increasing knowledge risks. This understanding challenges traditional views of technological adoption. Further, by taking knowledge risk as a mediator, the study helps in showing the causal relationships between AI investment and resilience, which is an area often less explored in SMEs contexts. Furthermore, the use of regional clustering demonstrates how structural and digital disparities guide technology adoption, emphasizing the need to insert contextual variables into strategic models of AI integration.

The findings highlight that AI investments alone are not sufficient to reduce knowledge risks or enhance resilience. AI must be included within strong knowledge management strategies, including systems for capturing tacit knowledge, staff training, and cross-functional collaboration.

The regions that are lagging behind require targeted digital infrastructure investments and AI adoption incentives into the specific sectors.

Policy makers, to perform better, need to continuously update workforce training programs and reduce over-reliance on AI systems. In both cases, the study suggests region-specific policies rather than a uniform policy for all the regions.

7 Conclusion

This study investigated how AI investment interacts with automation-related knowledge risks to shape SMEs resilience in the Italian context. The findings challenge traditional assumptions that AI adoption automatically reduces risk, showing that investments are reactive and concentrated in high-risk regions where automation pressures are stronger.

Clustering analysis identified three distinct regional profiles based on AI maturity and risk exposure, highlighting digital adoption disparities in Italian SMEs. Furthermore, mediation analysis showed that AI investments improve SMEs resilience with knowledge risks properly managed, which highlights the need for them to integrate AI within broader knowledge management frameworks.

This research extends knowledge risk theory by linking it to automation risk and AI adoption in SMEs. Practically, the findings stress the need for region-specific digital transformation policies, targeted workforce upskilling, and AI-integrated knowledge retention strategies to ensure that SMEs remain competitive in technological changes.

8 Limitations and Future Research Directions

This study has many limitations along with its contributions, which can be suggested for future research.

The analysis was done at the regional level of Italy, and data was taken from Confartigianato. Future research can do comparative studies of countries with a broader scope of study. The comparison was on a regional basis; future research should look at data from individual SMEs perspectives to better understand their behaviors, knowledge practices, and unique cultural factors.

The data represents a single time frame. Longitudinal research could provide temporal insights into how AI investments and risk profiles evolve over time and in response to policy interventions.

While the study includes main measures of AI investment and risk, it does not have qualitative indicators like employee perceptions, organizational culture, or change management readiness. Mixed-method research can address these dimensions. Although this study is on SMEs, the data includes firms from multiple sectors. Doing the analysis by sector could reveal industry-specific risk responses and adoption.

By integrating AI adoption patterns with knowledge risk theory, this research offers a more grounded understanding of how digital transformation progresses in practice, particularly within SMEs operating in complex and uneven regional environments. Policymakers and organizational leaders are thus appealed to approach AI not only as a technological solution but as part of a strategic knowledge infrastructure essential for resilience, innovation, and equal growth in the digital era.

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10 Ethical considerations

The protection of the privacy of research participants has been ensured. Anonymity of individuals and organisations participating in the research has been ensured. There are no possible conflicts of interests. All the previously published work along with their authors have been duly acknowledged in references. There is no use of offensive, discriminatory, or other unacceptable language in the paper.

11 AI declaration

The authors have not used an AI tool in developing the paper.

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Human Resource Management in Early-Stage Startups: A Qualitative Multiple-Case Study

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Abstract

Early-stage startups face unique challenges in Human Capital (HC) management, as traditional Human Resource Management (HRM) practices, designed for established firms, overlooking the unique organizational dynamics of nascent ventures. This exploratory qualitative case study examines HRM practices in early-stage startups through a cross-case analysis of eight cases: two each from France, Italy, and the United Kingdom, complemented by one case each from Switzerland and Tunisia. We conducted semi-structured interviews with eight startup founders and three early-hire employees, enabling comprehensive perspective triangulation through multiple stakeholder viewpoints within each case organization. Through the theoretical lenses of Resource-Based View (RBV) and contingency theory, this study examines how startups orchestrate their HR resources and adapt their management systems. The findings demonstrate the imperative for adaptive HRM strategies in early-stage startups' dynamic environments during critical phases of hiring, onboarding, and retention. The study's primary contribution is extending the startup HRM literature by introducing a flexible management of a fractional HR management model, which provides startups with a cost-effective, expertise-driven solution for managing essential HR functions, including talent acquisition, onboarding, development, and retention. The research advances both theoretical understanding of HRM in nascent ventures and provides actionable insights for startup founders in optimizing their HC management strategies within resource constraints, particularly during their founding years.

Keywords: Human Resource Management (HRM), Human Capital (HC), Early-stage startup, Fractional Human Resources (HR)

Paper type: Academic Research Paper

1 Introduction

The startup ecosystem has witnessed remarkable growth over the past three decades (Tripathi et al., 2019), emerging as a core driver of economic growth and innovation. These innovative and fast-growing organizations have the potential to revolutionize industries and reshape the global economy. Human capital (HC) forms the foundation of these organizations and, through the Resource-Based View (RBV), represents the most valuable, rare, inimitable, and non-substitutable (VRIN) resources that they can have (Barney, 1991; Nason and Wiklund, 2018). Managing HC effectively presents significant challenges for early-stage ventures (Cardon and Stevens, 2004; Gjerløv-Juel and Guenther, 2019; Eisenmann, 2020; Choi et al., 2023; Rocha and Grilli, 2024). The crucial importance of HC management in early-stage startups is evidenced in empirical research suggesting that internal organizational challenges, rather than external market factors, often become the reason for startup failures. Moreover, the probability of exit rate for younger firms is much higher than for established firms (Zacharakis, Meyer and DeCastro, 1999; Santarelli and Vivarelli, 2007; Marmer et al., 2012; Eisenmann, 2021). Recent research indicates that over 90 percent of startups fail due to internal difficulties, with ineffective team management and employee retention emerging as primary contributors to these failures (Why Startups Fail: Top 12 Reasons l CB Insights, 2021). This aligns with research demonstrating that investment in human resources (HR) correlates strongly with startup success (Pfeifer, 2022; Van Lancker et al., 2022), and effective HRM significantly impacts organizational performance (Cardon and Stevens, 2004; Hoffman and Tadelis, 2018; Chatterji et al., 2019; Jiang et al., 2012; Messersmith and Wales, 2011). From a contingency theory perspective, the unique characteristics of early-stage startups require HRM approaches that differ from those employed by established firms (Dyer and Reeves, 1995; Wood, 1999; Delery and Roumpi, 2017). This theoretical framework demonstrates that practices' effectiveness is contingent upon both internal organizational dynamics and external environmental factors. In the context of early-stage startups, these contingencies manifest primarily through resource constraints, growth needs, and the necessity for maintaining organizational agility. Founding team members and initial employees serve dual roles: they both establish organizational culture and shape operational norms (Choi et al., 2023), in other words, wearing multiple hats on a daily basis. This dynamic interplay between HC deployment and organizational development creates a unique context for HRM implementation in startup environments. Within this context, the loss of HC can prove more detrimental than

the departure of a founder, as it disrupts organizational momentum and increases the startup failure probability. Despite the importance of HRM in startups and its effective management, research in this domain remains limited (Baron, 2003; Cardon and Stevens, 2004; Messersmith and Wales, 2011; Nyström, 2021; Pfeifer, 2022; Van Lancker et al., 2022). Existing literature primarily focuses on established startups, leaving a significant gap in understanding the specific needs of organizations in their early stages (Katz et al., 2000; Leung et al., 2006). This study addresses this gap through an exploratory investigation that combines literature analysis with qualitative interviews to examine how early-stage startups can effectively manage their HC by adapting HRM practices to their unique organizational contingencies. Drawing on the intersection of RBV and contingency theory, we pose three integrated research questions (RQ)

- RQ1: How do early-stage startups strategically manage their human capital within resource constraints, particularly in the hiring, development, onboarding, and retention phases?
- RQ2: What specific organizational contingencies influence HRM practices in early-stage startups, and how do these contingencies impact implementation effectiveness?
- RQ3: How does fractional management emerge as a strategic HRM approach in response to early-stage startups' unique human capital constraints, and what implications does this have for organizational performance?

2 Background

2.1 Theoretical Framework

The emergence and evolution of organizations occur through the sophisticated interplay between opportunity recognition and resource orchestration, with HC serving as a critical mediating mechanism in this relationship (Muñoz-Bullon, Sanchez-Bueno and Vos-Saz, 2015; Yi, Amenuvor and Boateng, 2021; Howell, Bingham and Hendricks, 2022). This theoretical foundation shows organizational success depends not only on identification of opportunities but also on the systematic development and deployment of HC resources that can effectively exploit these opportunities (Leung et al., 2006; Colombo and Grilli, 2010). These relationships operate through interdependent mechanisms, where initial HC investments create trajectories that significantly influence subsequent organizational development and competitive positioning (Eisenhardt and Schoonhoven, 1990; Davila, 2005; Davila and Foster, 2007; Brymer and Rocha, 2023). The RBV provides the theoretical foundation for understanding how organizations develop and maintain competitive advantages through VRIN resources (Barney, 1991; Nason and Wiklund, 2018; Chatterji et al., 2019; Yi, Amenuvor and Boateng, 2021). In the context of HC, VRIN characteristics manifest through the collective knowledge, skills, and capabilities embedded within an organization's workforce. These resources become unique because they emerge through complex social processes that create uncertain cause-effect relationships, making them difficult for competitors to replicate (Becker and Gerhart, 1996; Gerhart and Feng, 2021). Contemporary HRM theory builds upon these RBV perspectives, conceptualizing practices within a comprehensive system of employment relationship management (Jiang et al., 2012; Boon, Den Hartog and Lepak, 2019). The literature identifies three core dimensions of HRM: hiring, development, and retention (Dess and Lumpkin, 2003). The hiring dimension includes strategic recruitment and selection processes to attract and evaluate high-potential candidates. The development dimension focuses on capability enhancement through training programs and performance management systems that align individual and organizational objectives, including the onboarding phase. Retention strategies ensure sustained engagement through compensation strategies and work environment design that supports long-term value creation. Within this theoretical framework, the concept of fractional management has emerged as an innovative response to resource constraints, particularly in early-stage ventures (Birnie et al., 2005; Gatrell, 2007). While academic literature on fractional management remains limited, practitioner insights provide valuable perspectives on its implementation. Research conceptualizes fractional management as a cost-sharing model enabling organizations to access high-level expertise at reduced costs through flexible, part-time arrangements (Kratzer et al., 2022). This model differs from traditional consulting through its emphasis on long-term organizational development rather than project-based interventions. The theoretical analysis of interim management, framed through transaction cost economics and RBV, provides a theoretical foundation for understanding why resource-constrained organizations might opt for flexible management solutions, particularly in HC development. The fractional executive model, where experienced professionals serve multiple organizations on a part-time basis (So and Teckchandani, 2023), has demonstrated effectiveness across various executive functions. However, its application in HRM, especially within early-stage startup contexts, remains relatively unexplored in academic literature, presenting a significant gap in our understanding of alternative management structures in nascent ventures.

2.2 Human Capital and HRM in Startups

In the startup context, the application of HC and HRM theories takes on distinctive characteristics due to the unique challenges and constraints these organizations face. Understanding these dynamics begins with examining the critical role of founding teams as they establish the initial conditions that shape subsequent organizational development.

2.2.1 Strategic Role of Founding Teams

The evolution of entrepreneurship literature demonstrates a shift from individual-centric to team-based theoretical frameworks (Beckman, 2006; Klotz et al., 2014). This theoretical progression reflects growing empirical evidence that organizational success, particularly in high-uncertainty environments, emerges primarily from collective capabilities rather than individual entrepreneurial action. The critical influence of founding teams has emerged as a central theoretical mechanism in determining organizational trajectories during formative stages (Ucbasaran, Westhead and Wright, 2008; Muñoz-Bullon, Sanchez-Bueno and Vos-Saz, 2015). Team formation processes represent a crucial theoretical mechanism linking initial conditions to subsequent organizational outcomes. The composition of founding teams reflects both deliberate strategic choices and path-dependent processes, incorporating varied combinations of knowledge, skills, and competencies. Colombo and Grilli (2010)(Colombo and Grilli, 2010) demonstrate how specific combinations of complementary capabilities within founding teams generate synergistic effects that exceed individual contributions. Moreover, founders usually face the "liability of newness," when hiring and composing their initial team. They typically leverage their existing social capital through shared past experiences and opt for affiliation hires, while in some cases, founders bring previous experience that helps to overcome this liability (Gjerløv-Juel and Guenther, 2019). These founding team dynamics create unique challenges for HRM practices in startups, particularly as organizations transition from founder-centric to more structured organizational forms.

2.2.2 Unique HRM Challenges for Startups

The structural configuration of founding teams in early-stage startups presents unique theoretical considerations that challenge conventional organizational design principles. Despite formal role assignments, team members typically engage in multiple functional areas, a pattern that contrasts with specialized role structures in established organizations (Pratiwi, Ferdiana and Hartanto, 2018). This structural flexibility creates both opportunities and challenges, influencing organizational culture development, routine formation, and the establishment of decision-making processes. Contemporary research indicates that the emergence and complexity of HRM challenges correlate more strongly with organizational growth trajectories than age (Rutherford, Buller and McMullen, 2003; Tocher and Rutherford, 2009). This finding challenges traditional life-cycle models of organizational development and suggests the need for more dynamic theoretical frameworks capable of capturing the temporal evolution of HC development in startups (Choi et al., 2023). Empirical evidence demonstrates this complexity, suggesting the criticality of internal factors, particularly HC management, in determining startup success, with internal factors accounting for over 90 percent of startup failures (Marmer et al., 2012). The integration of early employees represents a critical phase in organizational development, with their departure potentially affecting organizational performance as significantly as the founder's departure (Gjerløv-Juel and Guenther, 2019; Choi et al., 2023). This finding suggests the need for theoretical models that can account for the distinctive characteristics of early-stage HC development, particularly regarding the main HR practices. The composition of founding team experience provides potential competitive advantages through multiple theoretical mechanisms, particularly in overcoming the liability of newness in organizational management (Cardon and Stevens, 2004; Rocha and Grilli, 2024). While earlier research emphasized the advantages of homogeneous team compositions in facilitating rapid decision-making, contemporary scholarship suggests that diverse founding team backgrounds contribute valuable perspectives and capabilities that enhance organizational adaptability and innovation potential (Brymer and Rocha, 2023).

3 Methodology

3.1 Research Design

Our research design follows a qualitative multiple-case study approach to examine HRM practices in startups at their early stages (Yin, 2009). This methodological approach enables a rich, contextual understanding of complex organizational phenomena while enabling systematic cross-case pattern identification (Beach and Pedersen, 2016). Grounded in Resource-Based View theory, our research design investigates how resource

constraints and contingency factors shape HR practices in nascent ventures while exploring alternative HR management approaches.

The investigation proceeded through three distinct phases (Figure 1): Phase 0 comprised theoretical foundation development and data collection protocol establishment; Phase I involved empirical data collection through two sub-phases (I.a and I.b); and Phase II focused on cross-case analysis and theoretical integration. This progressive design enabled theoretical sampling refinement while accommodating the complex, multilayered nature of HR practices in entrepreneurial settings.



Figure 1: Research framework

3.2 Sample and Data Collection

For this investigation, we operationalize "early-stage startups" as ventures in initial growth phases characterized by resource constraints, evolving organizational structures, and emerging market presence. While venture capital literature often constrains this definition to companies with secured funding, our conceptualization deliberately encompasses a broader range of nascent businesses at various developmental stages. Through theoretical sampling, we selected eight cases across five countries (France, Italy, Switzerland, Tunisia, and the United Kingdom) to maximize contextual variation. The deliberate inclusion of startups with varying founding years (2014-2022) and employee counts (5-100) represents a methodological strength rather than a limitation, enabling identification of HR practice evolution patterns across developmental trajectories.

Data collection occurred during 2023-2024 through semi-structured interviews with two stakeholder groups: founders/CEOs (n=8) and early-hire employees (n=3), enabling comprehensive perspective triangulation. Interviews lasting 30-60 minutes followed a protocol combining structured questions addressing core HRM dimensions with open-ended explorations of participants' experiences. Tables 1 and 2 present the descriptive characteristics of participants, demonstrating the sample's diversity across industry sectors and organizational configurations.

Table 1: Descriptive characteristics of startup founders, Group A (N=8)

Startups	**Sloneek**	**Dizzy ink**	**Wiremind**	**Qovoltis**	**Wayout**	**Genuieway**	**Nocciolar**	**Biova Project**
Interviewee role	CEO	CEO/Founder	CEO	President	CEO	COO & Co-founder	CEO	President/Co-founder
Country	United Kingdom	United Kingdom	France	France	Tunisia	Switzerland	Italy	Italy
Industry	Software	Art & printing	Software	Electric Mobility and Energy	Green Infrastructure	Software	Food & Beverage	Food & Beverage
Founded year	2017	2015	2014	2019	2020	2019	2022	2020
Founders at the start	2	1	2	2	3	3	1	2
Current employee (2025)	24	2 to 5	94	70	6	10	5 (+ 3 seasonal)	5

Table 2: Descriptive characteristics of early-hire employees, Group B (N=3)

Organization	Current Position	Entry Position	Tenure(years)	Industry Sector
Wayout	Ex Employee	Sales & Marketing Intern	1 to 2	Green Infrastructure
Nocciolar	Sales and Marketing manager	Sales and Marketing intern	2 to 3	Food & Beverage
BetaGlue Technologies	Head of Manufacturing & Operations	VP	2 to 3	Medical Equipment Manufacturing

4 Findings

4.1 Key HRM Patterns

4.1.1 Hiring Practices and Network Orchestration

Early-stage ventures predominantly employ network-based approaches to talent acquisition, with affiliation-based hiring (ABH) emerging as a strategic response to resource constraints. At Sloneek, "80% of initial software developers were sourced from the previous company," demonstrating how founders strategically leverage existing relationship networks to access pre-validated talent pools. Our analysis reveals systematic adaptation of hiring approaches as ventures evolve. Wiremind's strategic pivot to candidates valuing early-stage involvement after losing prospects to larger companies illustrates how ventures refine their value propositions in response to competitive pressures. Notably, variations in hiring approaches correspond to distinct performance outcomes. Ventures employing high network utilization (Sloneek, Qovoltis, Wayout) achieved stronger cultural alignment and reduced integration costs, while those employing more external approaches (Wiremind, Genuineway) prioritized technical excellence but faced greater integration challenges.

4.1.2 Onboarding and Adaptive Integration

Our cross-case analysis reveals that early-stage ventures implement adaptive integration approaches that selectively prioritize certain onboarding elements while strategically deferring others. Drawing from Bauer's(2010) framework of the four C's (Compliance, Clarification, Culture, and Connection), we observed that startups customize their integration emphasis based on hiring pathways and organizational priorities.

Ventures employing affiliation-based hiring demonstrated less formalized onboarding processes, leveraging pre-existing social connections to facilitate natural integration. In contrast, ventures recruiting externally developed more structured technical assessments, as exemplified by Wiremind's "baptism by fire" approach that simultaneously evaluated problem-solving capabilities and fostered peer connections. These variations represent strategic adaptations to specific organizational contexts rather than developmental limitations.

4.1.3 Development Patterns and Retention Strategies

Our findings reveal a "development paradox" where skill development needs are highest but formal investment capacity is constrained by resource limitations. Early-stage ventures resolve this paradox through adaptive learning mechanisms that evolve along two dimensions: formalization of learning processes and sources of knowledge transfer.

Temporally, development approaches transition from predominantly informal, founder-led instruction toward more structured, peer-based learning systems as ventures mature. Strategic prioritization emerges as a consistent pattern across ventures, with most prioritizing immediate operational skill acquisition over long-term career development, representing strategic resource allocation rather than simply reflecting limitations.

Regarding retention, our analysis reveals a complex interplay between monetary and non-monetary factors, with cultural alignment emerging as a critical determinant. While existing literature emphasizes compensation and job security as primary retention drivers (Rangrez, Amin and Dixit, 2022), our findings indicate that in entrepreneurial settings, mission alignment and cultural fit often complement traditional retention mechanisms. Retention approaches manifest across a spectrum, from predominantly financial (Nocciolar, Genuineway) to predominantly cultural (Sloneek, Wayout), with most ventures employing hybrid approaches that evolve with organizational maturity.

4.2 Fractional HR Management: An Emergent Solution

Our analysis identified fractional HR management as an emergent solution addressing the expertise-resource tension in early-stage ventures. This approach enables startups to access specialized HR expertise through flexible, part-time arrangements without the financial burden of full-time personnel. The early employee from Betaglue Technologies specifically highlighted "lack of HR expertise in the hiring team" as a significant challenge, while Wayout's former employee suggested that fractional HR services "could be the best option not only for Wayout but also similar companies." This solution addresses three critical needs identified across our sample: (1) specialized expertise in compliance and contract management, (2) systematic approach development without full-time overhead, and (3) objective perspective in candidate evaluation. The viability of fractional HR appears contingent upon venture maturity, with ventures at transitional growth stages (approximately 10-50 employees) expressing the strongest interest.

4.3 Cross-Pattern Analysis

Our systematic analysis reveals three core mechanisms through which early-stage startups develop their HR management capabilities: network-based resource orchestration, adaptive capability development, and strategic formalization. Table 3 presents perspectives from early-hire employees, highlighting how their experiences align with these mechanisms and revealing potential value in fractional HR services. One early employee explicitly noted that such services could be "the best option for not only our company but also similar companies."

Table 3: Cross-case summary for Early-hire employees

Early hire employees	**Recruitment**	**Onboarding & professional development**	**Retention**	**HR need**
Early hire employee (Nocciolar)	Network-based recruitment with informal assessment procedures; demonstrated effectiveness despite lack of structured protocol	Structured trial period with clear performance metrics and deliverable comprehension	Attractive compensation, and the company culture, close network and connection with the founders	Current HR needs minimal post-integration; potential value in systematizing founder-level recruitment processes
Early hire employee (Wayout)	Affiliate-network recruitment; informal selection process	Intensive mentorship model via daily founder interactions; hands-on skill development	Career advancement opportunities available but lacking formal structure; emphasis on experiential learning	HR support critically needed during onboarding and development phases despite part-time status
Early hire employee (Betaglue technologies)	Informal recruitment process; details pending further documentation	NA	NA	External HR consultation recommended specifically for recruitment phase optimization

Table 4 extends this analysis by presenting a comprehensive cross-pattern examination of HR capability development across all ventures, demonstrating how the three core mechanisms manifest differently based on contextual factors including founder experience, industry demands, and resource availability.

Table 4: Cross-Pattern Analysis of HR Capability Development

Dimension	**Resource Orchestration**	**Capability Evolution**	**Formalization Strategy**	**Performance Outcomes**
Sloneek	High network utilization, community-based	Organic growth through social ties	Low initial, emerging structure	Strong retention, rapid capability building
Dizzy ink	Medium network use, founder-centric	Experience-based learning	Low formalization maintained	Product-focused development
Wiremind	Low network use, external focus	Systematic technical assessment	High structured approach	Technical excellence prioritized

Dimension	Resource Orchestration	Capability Evolution	Formalization Strategy	Performance Outcomes
Qovoltis	High network activation, hybrid approach	International team development	Medium with formal elements	Successful scaling achieved
Wayout	High community engagement	Impact-driven development	Low with planned evolution	Mission-aligned growth
Biova Project	Medium network use, referral and recommendation based	Different levels of employees as such interns	Low formalization, emerging on the way	Mission alignment, impact product focus
Nocciolar	Medium industry network leverage	Technical expertise focus	Medium technical structure	Strong operational foundation
Genuineway	Low network use, professional approach	Corporate-startup hybrid	High professional structure	Balanced growth model

From this cross-pattern analysis, we derived three key insights regarding HR capability development in early-stage ventures. First, network activation effectiveness is moderated by network-strategy alignment. Ventures demonstrating strong alignment between network utilization and strategic objectives (Sloneek, Qovoltis) achieved superior outcomes compared to those with misalignment, regardless of absolute network utilization levels. Second, ventures that developed systematic adaptation mechanisms early in their lifecycle demonstrated accelerated capability development, as exemplified by Qovoltis's approach: "After the first employees, we learned what we needed and changed the structure." This systematic learning process enables ventures to refine their HR practices as they mature. Third, formalization strategies appear contingent upon growth rate and industry demands rather than reflecting an absolute development trajectory. The variation in formalization levels across ventures with similar employee counts demonstrates that formalization represents a strategic choice rather than simply a developmental stage.

Our analysis further revealed the interconnected nature of HR practices in early-stage ventures, where hiring approaches directly influence retention outcomes. This interconnection manifests through a learning-retention dynamic where early employees view their roles as accelerated learning opportunities. When these learning expectations remain unmet, retention becomes challenging, supporting Cardon and Stevens' (2004) findings. This interconnection suggests that founders should develop coherent HR approaches that maintain consistency across dimensions rather than implementing isolated practices.

5 Discussions and conclusions

5.1 General Discussions

This study investigated HC and HRM practices in startups at their early stages, yielding several important theoretical and empirical insights. Our findings confirm previous research indicating that resource constraints significantly impact HR practices in startups (Bamberger, Bacharach and Dyer, 1989; Cardon and Stevens, 2004; Messersmith and Wales, 2011; Brymer and Rocha, 2023; Roach and Sauermann, 2024; Rocha and Grilli, 2024). Specifically, we found that early-stage startups face similar resource constraints(Davila and Foster, 2007), particularly regarding full-time HR personnel investment.

5.2 Theoretical and Practical Implications

This study makes several significant contributions to HR theory in entrepreneurial contexts. Our findings confirm that resource constraints significantly influence HR practices in early-stage startups (Cardon and Stevens, 2004; Messersmith and Wales, 2011), particularly regarding full-time HR personnel investment. However, we extend existing theoretical frameworks by demonstrating how these constraints drive innovative adaptations rather than merely limiting practice sophistication.

First, we contribute to Resource-Based View theory by illuminating how early-stage ventures orchestrate limited resources while building necessary capabilities for growth. Our findings demonstrate that network-based resource orchestration represents not merely a compensation for resource limitations but a strategic adaptation mechanism that can provide competitive advantages through social capital leverage and enhanced talent alignment.

Second, we extend contingency theory by identifying specific contextual factors that influence HR practice effectiveness in entrepreneurial settings. Our cross-pattern analysis reveals that practice effectiveness is contingent upon alignment with organizational priorities, founder experience, and industry context rather than

reflecting universal best practices. This finding challenges predominant stage-based models of HR development by demonstrating that HR practice evolution follows multiple pathways shaped by venture-specific contingencies.

The practical implications of our research are particularly relevant for startup founders and early-stage investors. Different levels of HR formalization represent appropriate strategic responses to contextual factors rather than developmental deficiencies. The network-dependent informality in hiring and flexible, founder-driven integration approaches appear particularly suited to the dynamic needs of early-stage ventures, suggesting that founders should align HR formalization with their specific organizational context rather than pursuing standardized formalization paths.

5.3 Concluding remarks and future directions

This exploratory study identified a significant gap in the HRM literature regarding strategies specifically tailored for startups. This is particularly evident in the startups at their early stages, as their success heavily hinges on the quality of their initial hires and managing (orchestrating) their primary resource of HC. Our qualitative analysis revealed that founders face unique challenges in managing their initial teams, depending on the various contingents and their resource allocation and limitations. Thus, founders rely on close network hires, or ABHs, as this can be useful in the decision-making and integration of the employees. In the long term, however, recruiting someone with a different background is essential for bringing fresh perspectives and diverse expertise to drive innovation and organizational growth. The emergence of fractional HR as a viable solution addresses these constraints by providing on-demand expertise while accommodating limited resources. Given the unique nature of startups and the complexity of HRM practices, we propose three key directions for future research: First, longitudinal studies should examine the long-term impact of fractional HR on organizational outcomes, including financial performance, employee retention, and innovation metrics. These studies should address the current lack of empirical data on organizations formally implementing fractional HR practices. Second, research should investigate the implementation challenges across different organizational contexts, focusing on both organizational requirements and employee experiences. This includes examining the strategy's sustainability and evaluating its effectiveness from multiple stakeholder perspectives. Third, future studies should expand the scope of team composition analysis in early-stage startups. This expanded framework could examine: (1) vertical analysis across organizational levels to understand how fractional HR addresses varied stakeholder needs, (2) evolution of team compositions and HR requirements through growth stages, e.g., turnover rates, and (3) organizational contingencies such as industry sector, geographic location, and funding stage that influence fractional HR effectiveness. This way, this study could comprehensively analyze the domain of HR not only early but also in startups in general.

5.4 Limitations

Several limitations should be acknowledged when interpreting our findings. First, our sample size was constrained by participant availability during follow-up interviews. Second, our focus on specific European and North African contexts may limit broader applicability to other entrepreneurial ecosystems, particularly in Asian and American contexts. Third, our qualitative methodology, while providing rich contextual insights, has inherent limitations regarding statistical generalizability. These limitations suggest promising directions for future research while acknowledging the boundaries of our current findings.

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7 Ethics declaration

All interviews were conducted following informed consent procedures, with participants being fully informed about the research purpose. The study did not require formal ethical clearance as it involved non-sensitive interviews with professionals discussing their professional experiences rather than personal matters. All data collection complied to General Data Protection Regulation (GDPR) requirements, with spoken consent obtained from all participants for research purposes before the interviews. All data was anonymized in the reporting to protect participant confidentiality while maintaining analytical integrity.

8 AI declaration

No AI tools were used in the development of this paper for the conference IFKAD 2025.

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Inclusive Language in Academia: Evaluating Human and AI-Generated Communications to Students

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Abstract

In recent years, growing societal attention to gender bias and inequality has prompted Universities to reconsider their institutional practices, including the use of inclusive language in formal communication. As central actors in the production and dissemination of knowledge, academic institutions bear a cultural responsibility to ensure that their communication practices reflect principles of equity and inclusion. This study explores the extent to which written communications addressed to students, either by university faculty or generated by artificial intelligence (AI), adhere to inclusive language practices.

The research adopts a qualitative design based on content analysis and evaluates 63 announcements authored by faculty members from two Italian universities, alongside 39 messages produced by three generative AI systems—ChatGPT Basic, Deepseek, and Gemini 2.0 Flash. The analysis is guided by 16 indicators of inclusive language use, drawn from the guidelines developed by Sabatini (1987) and revised by Somma and Maestri (2020). Each message is classified as inclusive, non-inclusive, or partially inclusive, based on the presence or absence of these indicators.

Findings show that inclusive communication practices are strongly gendered: female faculty members display a much higher rate of inclusive language use (48%) compared to their male colleagues (18%). Notably, no male full professor in the sample used inclusive language. Disciplinary differences also emerge, suggesting that the adoption of inclusive language is influenced by specific cultural norms within academic fields. Among AI systems, Gemini 2.0 Flash produced the highest share of inclusive outputs (38%), followed by ChatGPT (23%) and Deepseek (8%). However, the overall low performance of AI models indicates that inclusive principles are not yet systematically embedded in their training.

This paper contributes to the literature by combining human and AI communication analysis under a unified framework and offering empirical insights into how inclusive language is—or is not—implemented in practice. The results underscore the need for targeted interventions, both educational and technological, to promote inclusive communication in academia. By advancing this dual focus on human and AI-generated texts, the study highlights inclusivity not only as an ethical imperative, but also as a strategic priority for fostering institutional credibility and evolution.

Keywords: Inclusive Language; Academia; AI; Content Analysis; Communication

Paper Type: Practical Paper

1 Introduction

In response to growing societal awareness of gender bias and inequality, the academic sector has increasingly re-evaluated its institutional structures and practices. As central actors in the production and dissemination of knowledge, universities bear a significant cultural and political responsibility and have undertaken systematic efforts— through education, research, and policymaking — to promote equity and drive structural transformation beyond the boundaries of academia (Petrolo et al., 2023).

Within this broader context, language represents a powerful tool for challenging entrenched inequalities (Testa et al., 2024). The frequency and modality of communication among organisational members are crucial for fostering an inclusive environment (Trittin & Schoeneborn, 2017; Wolfgruber et al., 2021), while effective faculty-student communication ensures access to essential information regarding courses, exams, and academic events.

As extensively recognised in the literature, language is not a neutral conduit of meaning, but a symbolic and social practice that constructs reality (Butler, 2017), conveys ideologies, and shapes the relationship between identity and power (Giusti, 2022). Grammatical structures, lexical choices, and discursive conventions do not merely reflect existing cultural frameworks, including those related to gender; they also contribute to their reproduction. Therefore, the adoption of gender-inclusive language should not be regarded solely as a matter of formal correctness. Instead, it constitutes a political and cultural act (Butler, 2018), potentially reshaping mechanisms of recognition and exclusion (Pagliara, 2024).

At the institutional level, language has gained increasing legitimacy as a key lever for promoting gender equality. In 2018, the European Union urged Member States to adopt gender-neutral language, identifying it as

a foundational principle in policies such as GEAR and GEP. That same year, the Italian Ministry of Education, University and Research (MIUR) issued *Guidelines for the Use of Gender in Administrative Language*, with the goal of raising awareness within academic settings about the influence of linguistic choices in reproducing gender stereotypes. The document highlights how grammatical and semantic asymmetries—even when unintentional—can shape social perceptions and sustain structural inequalities. Since 2020, several Italian universities have followed suit, adopting institutional guidelines to encourage inclusive language in both academic and administrative communication.

Any investigation of gender-inclusive language in the Italian academic context must reckon with a structural feature of the Italian language: the obligatory marking of grammatical gender (Sabatini, 1987; Somma and Maestri, 2020). Unlike other linguistic systems, Italian requires gender assignment for articles, nouns, adjectives, and pronouns. This grammatical structure poses specific challenges to achieving inclusive communication, as each act of writing entails a gendered choice that may symbolically include or exclude specific subjects (Giusti, 2022). These gendered forms are not neutral: they shape individual and collective imaginaries (Gheno, 2022), influence cognitive representations of social and professional roles (Gygax et al., 2008), and can reinforce hierarchical or exclusionary frameworks (Konnelly & Cowper, 2020).

Nonetheless, Ferrari and Pecorari (2024) noted that the so-called *inclusive masculine* remains dominant in institutional texts. This convention is often justified based on syntactic clarity, readability, and legal-administrative tradition. However, it is rarely subjected to systematic scrutiny, and its application remains unexamined mainly, despite broader cultural shifts. The persistence of the inclusive masculine contributes to the symbolic erasure of women and non-binary individuals, ultimately rendering invisible the very diversity that institutional communication should acknowledge and represent (Maiden & Robustelli, 2014).

In parallel, digital technologies—including the expanding use of artificial intelligence (AI)—are reshaping how organisations manage and disseminate knowledge (Malik et al., 2023). While AI has the potential to support faculty in producing more inclusive and accessible communications, concerns remain about the quality, accuracy, and inclusivity of AI-generated content (Müller, 2024). Whether such messages genuinely reflect inclusive principles is an open empirical question—particularly regarding their capacity to meet the needs of a diverse audience and ensure equitable access to information for all students, including those with specific needs.

This study aims to contribute to this emerging scientific debate by assessing the inclusivity of academic language used in communications authored by faculty members in comparison with those generated by AI. Faculty announcements, disseminated institutional bulletin boards convey operational and technical information that significantly influences students' engagement and participation in academic life (Jalolov, 2024). This justifies the selection of such communications as the empirical focus of our research.

The article is structured as follows: the next section presents the methodological approach and the structure of data collection, analysis and comparison. The results emerging from the surveys carried out are then presented and discussed. Finally, the conclusions, limitations and future research directions are presented.

2 Methodology

This study employs a qualitative research design based on content analysis (Flick, 2014) to evaluate the inclusiveness of language in written academic communications. Specifically, it analyses and compares announcements addressed to students, authored either by university faculty or generated by artificial intelligence (AI), assessing each text against criteria drawn from the existing literature on gender-inclusive language (Graebner et al., 2012).

The study, currently a work in progress, is structured into four main phases: (i) the identification of conceptual drivers from the reference literature; (ii) the data collection, during which announcements from three Italian universities—respectively located in the northern, central, and southern regions—were gathered. For each announcement, they have been recorded: the announcer's gender, university affiliation, subject matter, and the full text of the communication. At the same time, generative AI systems were prompted to produce parallel messages, calibrated to match the topic, institution, and (where applicable) gender of the human announcer. These AI-generated announcements were catalogued using the same variables; (iii) a content analysis of both human- and AI-authored messages to identify potentially non-inclusive language elements; and (iv) a comparative analysis of the findings.

2.1 Data collection

The empirical phase of the study began with the retrieval and selection of announcements issued by faculty members and published on the official bulletin boards of two Italian universities. For each faculty member, one announcement was selected per course, with preference given to the most recent communication available.

Only announcements authored by full professors, associate professors, and researchers were deemed eligible for inclusion. For each communication, the following variables were recorded: gender of the author, academic rank, university affiliation, city, disciplinary field, date, subject of the announcement, and full text.

Upon completing this phase, a comparable set of announcements was generated using three generative artificial intelligence systems— ChatGPT Basic, Deepseek, and Gemini 2.0 Flash. To ensure the generation process was entirely AI-driven and not influenced by human intervention, the systems were instructed to autonomously produce prompts based on the subject matter of the human-authored announcements. Each AI system was tasked with generating a message in the style of a university professor addressing students on the same topic as the original communication. To reduce potential gender bias in prompt formulation, all prompts were generated in English, given its relatively higher degree of grammatical gender neutrality compared to Italian. The final announcements were then produced in Italian. The same variables recorded for faculty-authored texts were systematically documented for each AI-generated communication.

In total, the dataset comprises 63 communications authored by faculty members and 39 generated by artificial intelligence.

2.2 Data analysis

The criteria employed to assess the degree of linguistic inclusiveness were based on the guidelines initially formulated by Sabatini (1987) and later revised and expanded by Somma and Maestri (2020), which represent a key reference for the promotion of gender-inclusive language, both in general discourse and within Italian academic institutions. A deductive content analysis was conducted (Flick, 2014), whereby the predefined set of criteria was systematically applied to both faculty- and AI-generated announcements. The complete list of indicators used in the evaluation is presented in Table 1, which summarises the 16 dimensions adopted in the analysis.

Table 1 - Indicators for Evaluating Gender-Inclusive Language

#	Indicator Name	Description
1	Visibility of feminine forms in roles and titles	Use of the feminine form for roles and titles when referring to women (e.g., *la ministra*, *la professoressa*).
2	Avoidance of generic masculine and inclusion of both genders	Use of inclusive formulas to refer to mixed groups (e.g., *studentesse e studenti*) instead of the overextended masculine; alternation of masculine and feminine in lists.
3	Grammatical agreement with the gender of the subject (or majority)	Grammatical coherence between the subject's gender and the grammatical elements used (articles, adjectives, pronouns).
4	Avoidance of gender-based linguistic stereotypes	Avoiding stereotypical representations of roles or behaviours attributed to men and women.
5	Use of feminine agentive nouns	Use of profession names in the feminine form (e.g., *autrice*, *scienziata*, *relatrice*).
6	Use of grammatically correct feminine forms	Use of regular feminine forms in accordance with Italian morphological rules (e.g., *avvocata*, *ingegnera*).
7	Consistency in gender usage within the text	Avoidance of incoherent gender alternations when referring to the same person or role.
8	Neutralising resistance to feminine forms	Unhesitant use of feminine forms, including for high-status roles, without justifications.
9	Gender parity in institutional titles and use of capital letters	Symmetrical and correct use of titles for both genders.
10	Use of the feminine article with titles and differentiation of epicene forms	Presence of the feminine article before titles and names (e.g., *la professoressa Moretti*); use of forms such as *la giudice*.
11	Consistency in the use of feminine forms	Grammatical gender remains consistent throughout the text when referring to female subjects.
12	Avoiding asymmetry between high- and low-status professions	Use of feminine forms also for senior roles, not only for caregiving professions.
13	Use of title and surname, not first name	Avoid referring to colleagues by first name only (e.g., *Maria*); prefer *Prof.ssa Rossi*.
14	Use of female-firstness in coordinated pairs	Symbolic precedence given to feminine in gender pairs (e.g., *studentesse e studenti*).
15	Preference for marked feminine forms	Use of marked feminine forms (*ministra*) rather than neutral or masculine forms (*ministro*).
16	Use of unmarked expressions	Prefer neutral expressions (e.g., *person* instead of *man*).

Each communication was analysed to assess the overall degree of linguistic inclusiveness. The three authors performed the coding independently, and the results were subsequently compared. Any discrepancies were discussed collectively until a consensus was reached. The presence or absence of the indicators listed in Table 1 was recorded for each announcement. Based on this evaluation, communications were categorised as follows:

1. Inclusive, if all relevant criteria were fully met;
2. Non-inclusive, if none of the indicators were observed;
3. Partially inclusive, if only some criteria were satisfied.

3 Results

This section presents the results of this study. The analysis is structured to highlight how inclusive, non-inclusive, and partially inclusive language patterns emerge across different profiles.

The first result, illustrated in Table 2, concerns the distribution of language styles disaggregated by gender and academic rank, revealing significant differences in language practices and offering a first insight into how inclusive language may vary across institutional roles and gender.

Table 2 - Language styles among university faculty by gender and academic position

	Inclusive language		**Not inclusive language**		**Partially inclusive language**		**Overall**
Female	**12**	**48%**	**8**	**32%**	**5**	**20%**	**25**
Full Professor	3	60%	2	40%	0	0%	**5**
Associate Professor	5	42%	5	42%	2	17%	**12**
Researcher	4	50%	1	13%	3	38%	**8**
Male	**7**	**18%**	**25**	**66%**	**6**	**16%**	**38**
Full Professor	0	0%	9	82%	2	18%	**11**
Associate Professor	4	27%	9	60%	2	13%	**15**
Researcher	3	25%	7	58%	2	17%	**12**
Overall	**19**	**30%**	**33**	**52%**	**11**	**17%**	**63**

First, gender differences are evident. Female academics exhibit a significantly higher proportion of inclusive language (48%) compared to their male counterparts (18%). Conversely, male academics display non-inclusive language patterns (66%), more than double that of female academics (32%). These findings suggest that inclusive language styles are more prevalent among women across academic ranks. Second, when analysing by academic position, male full professors are particularly concerned: none demonstrated inclusive language (0%), and the vast majority (82%) fell into the non-inclusive category. In contrast, female full professors show stronger inclusivity, with 60% using inclusive language styles and none falling into the partially inclusive category, indicating a more polarised but clearly more inclusive profile. Third, among associate professors, both genders display a more balanced distribution. Female associate professors have equal shares of inclusive and non-inclusive language (42%), with a smaller portion falling into the partially inclusive category (17%). Among males in the same rank, inclusive language remains lower (27%) compared to their female colleagues. Notwithstanding, this category has the highest percentage among male academics. Fourth, researchers also show a mixed profile, though female researchers again outperform males in inclusivity (50% vs 25%). This suggests that inclusivity might decrease with seniority among men, while women seem to maintain or even strengthen it. Finally, looking at the overall, only 30% of the total sample demonstrates inclusive language, while 52% falls into the non-inclusive category. This highlights a systemic issue in language practices within academia, particularly among male senior faculty. These patterns, identified through objective coding frameworks, underline the need for targeted training and awareness initiatives to promote inclusive language, especially in senior roles.

The second part of the analysis, presented in Table 3, looks into inclusive language practices depending on gender and scientific disciplinary sector (in Italian: *Gruppi Scientifico-Disciplinari* - GSD). While the gender gap identified earlier remains the same as below, this more granular view reveals how disciplinary cultures shape language styles in distinct ways.

Table 3: Language styles among university faculty by gender and GSDs

	Inclusive language		Not inclusive language		Partially inclusive language		Overall
Female	12	48%	8	32%	5	20%	**25**
ECON-01	1	100%		0%		0%	**1**
ECON-02	1	100%		0%		0%	**1**
ECON-06		0%	2	100%		0%	**2**
ECON-07	2	33%	2	33%	2	33%	**6**
ECON-09	1	50%	1	50%		0%	**2**
GIUR-01		0%		0%	1	100%	**1**
GIUR-02	3	75%		0%	1	25%	**4**
GIUR-03	2	100%		0%		0%	**2**
GIUR-06	1	100%		0%		0%	**1**
STAT-02		0%	2	67%	1	33%	**3**
STAT-04	1	100%		0%		0%	**1**
GEOG-01		0%	1	100%		0%	**1**
Male	7	18%	25	66%	6	16%	**38**
ECON-01	2	50%	1	25%	1	25%	**4**
ECON-02		0%	1	100%		0%	**1**
ECON-06		0%	6	100%		0%	**6**
ECON-07		0%	3	100%		0%	**3**
ECON-08	1	33%	1	33%	1	33%	**3**
ECON-09		0%	2	67%	1	33%	**3**
GIUR-01		0%	1	100%		0%	**1**
GIUR-02		0%	1	50%	1	50%	**2**
GIUR-06		0%	2	100%		0%	**2**
GIUR-08		0%	3	100%		0%	**3**
INF-01	2	67%	1	33%		0%	**3**
MAT-05	1	50%	1	50%		0%	**2**
STEC-01		0%	1	100%		0%	**1**
STAT-02		0%	1	100%		0%	**1**
STAT-04	1	33%		0%	2	67%	**3**
Overall	**19**		**33**		**11**		**63**

Overall, these findings highlight that inclusive language is not only gendered, but disciplinary environments might contextually shape it. Differences within and across fields suggest that interventions aimed at improving inclusive practices should also consider the specific cultural and institutional dynamics of each academic domain. Notably, Economics (ECON) exhibits considerable internal variation. Female academics in ECON-01 and ECON-02 show exclusively inclusive language patterns (100%), while others, such as ECON-06 and ECON-07, display a more mixed or predominantly non-inclusive profile. Among men, the situation is more concerning: language in ECON-06 and ECON-07 is entirely non-inclusive, suggesting the presence of entrenched communicative norms that may resist inclusive practices. The Law (GIUR) area presents a more polarised picture. Female academics show firm, inclusive profiles in GIUR-02, GIUR-03, and GIUR-06, with several cases of fully inclusive language. In contrast, male academics in GIUR-01, GIUR-06, and GIUR-08 exclusively exhibit non-inclusive language, with the sole exception of a partially inclusive case in GIUR-02. This dichotomy suggests that inclusivity in legal disciplines may be gendered and possibly linked to institutional or hierarchical dynamics. In Statistics (STAT), female academics again demonstrate higher inclusivity, particularly in STAT-04. Male academics in the same sectors lean toward either non-inclusive or partially inclusive language, reinforcing the broader gendered trend observed across disciplines. Other fields reveal additional patterns worth noting. In INF-01, male academics demonstrate relatively high levels of inclusive language (67%), emerging as a positive exception. Conversely, in GEOG-01 and STEC-01, language is uniformly non-inclusive, regardless of gender. Fields such as MAT-05 and ECON-08 show a more balanced distribution across all three language types, suggesting variability that individual rather than systemic factors may influence.

In addition to examining human language practices, this study evaluates the outputs of three large language models (LLM) — ChatGPT Basic, Deepseek, and Gemini 2.0 Flash — to assess their alignment with established inclusive communication criteria. Results are shown in the following Table 4.

Table 4: Language styles among large language models (LLMs)

	Inclusive communication		Not inclusive communication		Overall
Gemini 2.0 Flash	5	*38%*	8	*62%*	**13**
ChatGPT	3	*23%*	10	*77%*	**13**
Deepseek	1	*8%*	12	*92%*	**13**
Overall	**9**	**23%**	**30**	**77%**	**39**

The results indicate that all three models predominantly generated outputs that were classified as non-inclusive. In particular, deepseek displayed a low proportion of inclusive communication, with only 8% of its outputs meeting the criteria for inclusivity. ChatGPT achieved a higher percentage of inclusive communication (23%), suggesting some ability to produce outputs aligned with inclusive communication models, although non-inclusive responses remained the majority. Gemini 2.0 Flash recorded the highest proportion of inclusive outputs among the three models (38%), indicating a relatively greater presence of inclusive linguistic patterns within its responses, even though a substantial share of non-inclusive communication persisted. Overall, only 23% of the 39 outputs analysed across the three systems were classified as inclusive. These findings highlight a broader limitation in current LLMs, suggesting that inclusive communication principles are not yet systematically embedded in model training.

When considering the results as a whole, a ranking of inclusive language emerges across the groups and systems analysed. Female academics demonstrate the highest proportion of inclusive communication, confirming their leading position in adopting language styles aligned with inclusive language models. Following them, Gemini 2.0 Flash ranks second, showing a greater tendency toward inclusive patterns among the evaluated language models. ChatGPT occupies the third position, with a moderate share of inclusive communication. At the same time, male academics come fourth, highlighting a substantial gap in communication practices when compared to their female colleagues. Finally, Deepseek ranks fifth, with the lowest proportion of inclusive outputs observed.

4 Conclusion

The overall analysis highlights a clear ranking in the adoption of inclusive communication patterns. Female academics emerge as the group most aligned with inclusive models, followed by Gemini 2.0 Flash, which demonstrates the highest degree of inclusivity among the large language models evaluated. ChatGPT basic occupies the third position, while male academics are placed fourth, and Deepseek ranks fifth, showing the lowest level of inclusive language. This combined picture reinforces the idea that human factors, such as gender and disciplinary culture, play a decisive role in fostering inclusive communication, but also reveals that technological systems have not yet systematically integrated inclusive principles into their outputs. There is still a significant gap between the aspirations of inclusive language and the practices observed both in human and machine language.

4.1 Limitations and contributions

Several limitations must be acknowledged. First, the human data were collected from only two faculties at two different Italian universities, limiting the generalisability of the findings. Expanding the study to include a broader and more diverse academic population would provide a more nuanced and representative understanding of language practices across institutions. Second, the analysis of LLMs was restricted to three systems. Involving a wider range of models could reveal whether different training approaches or architectures produce varying patterns of inclusive communication.

Despite these limitations, the study offers important theoretical contributions by integrating human and machine communication analysis under a common framework derived from the literature. This approach enables a cross-contextual understanding of inclusivity and highlights the persistent barriers that affect communication dynamics. On a practical level, the findings underline the urgent need for targeted interventions—both educational and technological—that promote inclusive practices in academic contexts and encourage the development of AI systems better attuned to diversity-sensitive communication. Future initiatives should prioritise inclusive communication not merely as an ethical requirement, but as a strategic component for enhancing institutional quality, social cohesion, and innovation.

5 Ethics declaration

This study is based exclusively on publicly accessible institutional communications and content generated by artificial intelligence. It did not involve human participants or the collection of personal or sensitive data. Therefore, no ethical approval was required.

6 AI Declaration

Use of Artificial Intelligence as an object of study

This study employed three generative artificial intelligence models—ChatGPT (OpenAI, basic version), Deepseek, and Gemini 2.0 Flash — to autonomously produce simulated academic announcements addressed to students. These texts, generated without human intervention, were analysed and compared with communications authored by university faculty members to assess the degree of linguistic inclusivity based on pre-established criteria. The generation process ensured that each AI system created messages independently, thereby preserving the integrity of the dataset used in the analysis.

Use of Artificial Intelligence as a writing support tool

During the development of this article, ChatGPT (OpenAI, GPT-4 version) was used exclusively for linguistic and stylistic support, such as sentence rephrasing and abstract revision. All AI-generated content was critically reviewed and edited by the authors to ensure consistency with the research objectives, terminological accuracy, and adherence to the empirical data collected. The tool was not used for data generation or analysis, nor did it influence the coding process or the interpretation of results. All analytical and editorial decisions were made autonomously by the research team.

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Unlocking Innovation in SMEs Though Transformational Leadership and Commitment-based HRM Practices

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Abstract

The purpose of this research is to examine transformational leadership impacts open innovation through the mediating role of commitment-based human resource management practices. A quantitative survey was conducted to collect data from a sample of 169 SMEs. The findings indicate a considerable positive correlation between transformational leadership and inbound open innovation in SMEs, as demonstrated by the quantitative survey analysis conducted with SmartPLS version 4.1.0.9. Furthermore, commitment-based human resource management methods work as a significant mediator between transformational leadership towards and innovation and the acquisition of knowledge within a company, referred to as inbound open innovation. The results underscore the imperative of developing organizational leadership that promotes change, creativity, trust, and employee commitment to enhance organizational openness. Open innovation is a recognized organizational approach that promotes transformation, enhances the competitiveness of SMEs, and stimulates overall economic growth. The results compel policymakers and decision makers to concentrate more on a transformational leadership style that can facilitate transformation and boost employee loyalty to the firm. Consequently, a culture of openness will be fostered, resulting in a more favorable impact on the performance of SMEs.

Keywords: Transformational leadership, HRM, inbound open innovation, competitiveness, SMEs

Paper type: Academic Research Paper

1 Introduction

Due to rapid changes and technological advancements changes, , there has been a major shift on the ways how firms innovate (Majchrzak *et al.*, 2023; Puliga *et al.*, 2023). Internal innovation is no longer a sustainable strategic option for introducing novelty and maintaining competitiveness in a market where innovation is essential for long-term growth and profitability (Camilleri *et al.*, 2023; Chesbrough, 2006, 2003; Van De Vrande *et al.*, 2009). Conversely, openness to external knowledge and the establishment of partnerships and collaboration beyond the borders of the organization is an important driver of innovation (Puliga *et al.*, 2023; Wiroonrath *et al.*, 2024). Consequently, contemporary organizations must embrace open innovation (OI) to satisfy the demand for innovation (Fatima and Masood, 2023; Puliga *et al.*, 2023). Chesbrough (2006) defines OI as *"the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively*". This research indicates that internal resources are crucial for executing organizational activities, while external knowledge and collaboration with stakeholders such as customers, suppliers, other companies, universities, and research centers are essential for attaining the desired level of innovation and sustaining competitive advantage (Chesbrough, 2006; Engelsberger *et al.*, 2023; Fatima and Masood, 2023; Majchrzak *et al.*, 2023)

According to (Chesbrough and Crowther, 2006), open innovation is a concept employed to enhance organizational competitiveness through a bidirectional process of information sharing and resource exchange. Open innovation encompasses inbound open innovation, which emphasizes information inflows through the construction and development of new collaborations and partnerships with external entities to enhance organizational innovation capabilities (Chesbrough and Crowther, 2006). In contrast, knowledge outflows, referred to as outbound open innovation, pertain to the process of open innovation that emphasizes the exploitation of an organization's expertise and skills through commercialization (Chesbrough, 2006).

OI has attracted significant attention from researchers across all company sizes, however, this study focuses specifically on SMEs and inbound open innovation. Parida et al. (2012) say that outbound OI is more problematic for SMEs to undertake owing to their "liability of smallness," which arises from a deficiency in internal resources. Therefore, they should prioritize inbound OI to address their knowledge deficiencies before pursuing outbound OI. This study concentrates on inbound OI, as this strategy provides SMEs the option to adopt the notion of openness gradually and progressively. Extensive study is conducted on the openness of SMEs, examining several elements such as human resource management (HRM) (Naqshbandi *et al.*, 2023), leadership (Naqshbandi and

Jasimuddin, 2018; Naqshbandi and Tabche, 2018) organizational culture (Popa *et al.*, 2017) etc, which are acknowledged as the "human side" of open innovation (OI).

One of the most intriguing variables in this regard is the influence of leadership. Leadership is a crucial element in organizations adopting openness. Leaders focused on change, transformation, and innovation assist organizations in embracing adaptability, hence enhancing overall innovativeness (Naqshbandi and Tabche, 2018; Wiroonrath *et al.*, 2024). In this regard, transformational leadership (TL) has attracted the attemtion of organization innovation literature (Su *et al.*, 2020). Through consistent support and fair treatment, transformational leadership aims to inspire and motivate people to surpass predetermined goals, as a result, employee behavior fosters organizational innovation (e.g. open innovation) (Su *et al.*, 2020). Simultaneously, HRM systems have demonstrated beneficial effects on organizational results (Huselid, 1995). Consequently, it is plausible to assert that HRM systems implemented in firms may emerge from leadership ideologies. Leadership may impact the firm's actions through the implementation of HRM practices. This study specifically investigates the impact of transformational leadership on organizational outcomes, particularly inbound innovation, using commitment-based human resource management. Commitment-based HRM is characterized as a collection of HRM policies and practices that enhance trust, knowledge sharing, collaboration, and knowledge exchange (Collins and Smith, 2006). It aligns with the fundamental principles of TL, which emphasize shared interests. Consequently, TL seeks to cultivate commitment through HRM practices that promote the appropriate behaviors in employees, which are crucial for organizations engaged in open innovation.

This study constructs and evaluates a research model that examines the direct impact of transformational leadership on inbound OI, as well as the mediating effect of commitment based human resource management practices in SMEs. The primary objective of this study is to further the comprehension of open innovation dynamics in SMEs, specifically examining transformational leadership, commitment-based HRM, and inbound open innovation among Albanian SMEs. The significance of transformational leadership in various innovation outcomes is acknowledged, yet, its influence on inbound OI through the mediation of commitment-based HRM practices remains limited.

2 Literature review

Interrelations between transformational leadership, commitment-oriented human resource management (HRM), and inbound open innovation represent a compelling yet underexplored quest in contemporary organizational science. Extant literature has established isolated dyadic relationships between these constructs; however, the integrative mechanism through which transformational leadership fosters inbound open innovation via commitment HRM remains insufficiently theorized and empirically unverified. As demonstrated by Cao and Le (2024), transformational leadership has been extensively studied as “one of the most effective leadership styles contributing to positive and key outcomes for most organizations in the context of rapid change of business environment”. Their research has highlighted how transformational leaders inspire their followers to follow the change strategy and motivate them to achieve the change goals beyond expectations through their positive impacts on employee trust. Similarly, García-Morales *et al.* (2008) have conceptualized transformational leadership as “the engine and transmitter” of innovative culture and of the dissemination of knowledge, specifically pertinent to organizational performance improvement. Despite these valuable insights, the specific pathways through which transformational leadership influences open innovation processes, particularly through HRM systems, remain underdeveloped in the literature, constituting a significant knowledge gap that warrants further investigation.

The mediating role of commitment HRM in the relationship between transformational leadership and inbound open innovation can be theoretically substantiated through multiple complementary perspectives. Zhu *et al.* (2005) have empirically demonstrated that “human-capital-enhancing HRM fully mediates the relationship between CEO transformational leadership and subjective assessment of organizational outcomes”, which suggests that transformational leaders operationalize their vision primarily through HR systems. This finding aligns with Chiang *et al.* (2011) assertion that “high-commitment HRM was positively related to perceived organizational support”, which subsequently enhances knowledge-sharing behavior, which per se represents a critical antecedent of inbound open innovation. The convergence of these empirical findings suggests that commitment HRM serves as a principal intermediary mechanism through which transformational leadership influences innovation outcomes. Furthermore, Cao and Le (2024) have identified the mediating role of employee trust between transformational leadership and organizational change capability, noting that “transformational leaders are capable of providing a positive vision and actualize necessary changes for organization due to paying much attention to promoting a climate of collaboration among individuals, fostering emotions and a trustworthy

culture". This parallel mediating relationship suggests that commitment HRM might similarly function as a mediational pathway through which transformational leadership facilitates inbound open innovation.

A pronounced knowledge gap exists in understanding the tripartite relationship between transformational leadership, commitment HRM, and inbound open innovation within a unified theoretical framework. While several authors(Cao and Le, 2024; Cera and Abbas, 2023) have established that transformational leadership has a significant relationship with developmental culture and open innovation and that developmental culture mediates the relation between transformational leadership and open innovation, the specific role of commitment HRM in this relationship remains generally obscure. Similarly, Gad David *et al.* (2021)G have demonstrated that transformational leadership positively impacts the outbound open innovation and enhances a firm's innovation culture, which encourages the inbound open innovation, but have not explicitly examined the mediating role of commitment HRM in this process.

This theoretical cavity is particularly significant given that commitment HRM, with its emphasis on enhancing employee engagement and knowledge sharing (Chiang et al., 2011), conceptually aligns with both the inspirational aspects of transformational leadership and the collaborative requirements of inbound open innovation. Moreover, Lei *et al.* (2019), have argued that "organizations can only follow and implement change initiatives successfully if their leaders get the involvement of employees through fostering their trust in leadership", suggesting that commitment-based approaches to HRM might be essential for translating transformational leadership into innovation outcomes. The identified knowledge gap is further amplified by Su *et al.* (2020) observation that transformational leadership can affect organizational and individual outcomes through the establishment of a collaborative HRM system, which implies but does not explicitly verify the mediational role of commitment HRM in innovation processes.

Based on the foregoing theoretical analysis and the identified knowledge gaps, there is compelling rationale to hypothesize that commitment HRM mediates the relationship between transformational leadership and inbound open innovation. This mediation hypothesis is supported by several theoretical threads: first, transformational leaders create conducive environments for knowledge acquisition and sharing (García-Morales *et al.*, 2008); second, these leaders implement commitment-oriented HRM practices to operationalize their vision (Zhu *et al.*, 2005); third, commitment HRM enhances employee engagement and knowledge-sharing behaviors (Chiang et al., 2011); and fourth, such knowledge-sharing behaviors are fundamental to inbound open innovation processes (Cera and Abbas, 2023; Gad David *et al.*, 2021). The integration of these theoretical perspectives suggests that transformational leadership does not directly influence inbound open innovation but rather operates through the mediating mechanism of commitment HRM. We believe that this hypothesis addresses a significant gap in the literature by shedding light on the complex interrelationships between leadership styles, HR systems, and innovation processes, thereby contributing to a more nuanced understanding of how organizations can effectively leverage external knowledge sources through appropriate leadership and HRM configurations.

In consideration of the conceptualizations explored above, as well as in view of the knowledge gap identified, we hypothesize the following relationships:

- ***H1:*** *Transformational leadership is positively associated with inbound open innovation.*
- ***H2:*** *Transformational leadership is positively associated with commitment-based HRM.*
- ***H3:*** *Commitment-based HRM practices mediates the link between transformational leadership and inbound open innovation.*

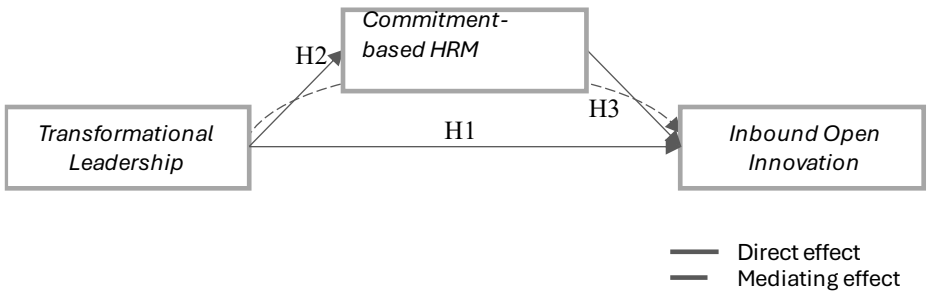


Figure 1. Conceptual framework
Source: Authors' own

3 Methodology

3.1 Data and sample

This study employed a quantitative methodology. Creswell and Creswell (2017) claim that this methodology is more accurate since it can derive the characteristics, beliefs, and/or behaviors of a population from a limited sample size. The current study's outcomes are carried out via surveys. Saunders *et al.* (2009) contend that the suggested research methodology involves executing extensive quantitative research and examining the interconnections among diverse variables inside a defined research framework. Participants in the study were from a variety of different fields, including the manufacturing and service industries. There were 169 respondents in all. It was determined that the sample size in question was sufficient to Hair *et al.* (2017). In this study, the respondents were firm owners, managers, or chief executive officers. This type of research requires the inclusion of participants who hold a high managerial role in order to guarantee that they have a comprehensive understanding of the organization activities, which is consistent with the methodologies that have been applied in earlier studies (Martinez-Conesa *et al.*, 2017).

3.2 Variable measurement

The independent variable *transformational leadership* was measured by four items adopted by the researchers García-Morales et al., (2008). Example of the items used to measure the construct: TL1 - "The organization's management has a clear common view of its final aims and is able to transmit them and achieve the commitment of the rest of the organization's members". The mediation variable construct of commitment-based HRM was measured by a scale of 10 items adopted by Collins & Smith, 2006. One sample item of the measured construct is: "Internal candidates are given consideration over external candidates." The dependent variable of this research, inbound open innovation, was assessed using a six-item construct developed from the work of Cheng and Shiu (2015). An example of a sample item is provided in the following statement: "Our organization constantly scans the external environment for inputs such as technology, information, ideas, knowledge, etc".

4 Analysis of results

4.1 Analysis of reliability and validity

The measurement model's validity and reliability must be assessed before proceeding with the structural model analysis. Table 1 demonstrates that all average variance extracted (AVE), Cronbach Alpha (CA), and composite reliability (CR) values are above the established thresholds of 0.508 and 0.709, confirming the achievement of convergent validity and reliability (Hair *et al.*, 2022) In evaluating the discriminant validity of the study construct, the researchers employed the HTMT and the Fornell-Larcker criterion, which are widely proposed by prior literature (Fornell and Larcker, 1981; Henseler *et al.*, 2015). Table 2 is a presentation of Fornell-Larcker and HTMT's output. The HTMT values are less than 0.85 to show the attainment of discriminant validity; the square root of the AVE for every variable is higher than the correlations of the other variables (Hair *et al.*, 2022).

Table 1: Assessment of reliability and convergent validity

Constructs	Code	CR	CA	AVE
Inbound Open Innovation	OPEN-INNO	0.915	0.891	0.645
Transformational leadership	T-LEAD	0.915	0.876	0.729
Commitment-based HRM	COM-HRM	0.926	0.908	0.612

Source: Author's construct.

4.2 Assessment of quality measures

The study employed the coefficient of determination (R-squared) and the Q-squared to evaluate the model's anticipated accuracy. The R^2 for COM-HRM is 0.403, indicating that T-LEAD accounts for about 40.3 per cent of the overall distinctions in COM-HRM. Also, the findings suggest that T-LEAD and COM-HRM account for about 39 per cent of the overall distinctions in inbound open innovation, as indicated in Table 3. All the R^2 values suggest that the constructs have acceptable justifications as they exceeded the values of 0.26 proposed by Cohen (1988) to achieve an acceptable R^2.

Table 2: The Fornell-Larcker criterion and HTMT values

Fornell-Larcker	COM-HRM	OPEN-INNO	T-LEAD
Commitment-based HRM	**0.782**		
Inbound Open Innovation	0.516	**0.803**	
Transformational leadership	0.635	0.600	**0.854**
HTMT			
Inbound Open Innovation	0.537		
Transformational leadership	0.699	0.643	

Source: Author's construct.

Moreover, as per the Hair et al. (2017) heuristic, the model has a substantial predictive significance, evidenced by Q^2 values of 0.389 and 0.345 for COM-HRM and OPEN-INNO, respectively. The SRMR indices were also used to determine the model's fitness. An SRMR value above 0.08 is acceptable (Diamantopoulos and Siguaw, 2000). Hence, an SRMR score of 0.081 signifies that the model is well-fitted. Further, the F^2 value of 0.050 suggests the removal of the construct, COM-HRM, will have a small impact on the model. Last, the removal of T-LEAD from the model will significantly influence the model as its highest F^2 value, 0.68, is greater than the moderate value of 0.35 (Cohen, 1988).

Table 3: Results of R^2 and Q^2

	R^2	R^2 Adjusted	Q^2
Commitment-based HRM	0.403	0.400	0.389
Inbound Open Innovation	0.391	0.383	0.345
F^2 values	**OPEN-INNO**		**COM-HRM**
Commitment-based HRM	0.050		
Transformational leadership	0.203		0.676

Source: Author's construct.

5 Discussions

According to the results displayed in Table 4, T-Lead has a positive relationship with Open-Inno. The relationship was significant at the 5 per cent level, as it yielded a T-statistic of 4.681, which exceeds the threshold of 1.96. Additionally, a path coefficient of 0.456 indicates that a one-unit increase in T-lead characteristics will result in a 46 per cent increase in Open-Inno. Furthermore, the CI values between 0.248 and 0.628 suggest that this relationship is not due to chance. Hence, the $H1_a$ is supported. This indicates that T-Lead enhances Open-Inno. The reason has been that transformational leaders foster a visionary culture, encouraging collaboration and information integration from external sources. They empower teams, build trust, and create a comfortable environment for implementing ideas from outside sources. Previous studies suggest that the characteristics of transformational leadership serve as a basis for skill acquisition, knowledge enhancement, expertise development, and innovation cultivation (Awan and Jehanzeb, 2022; Gad David *et al.*, 2023).

Table 4: Direct and indirect results

Hyp	Path	Beta	Confidence Interval	T stat	P value	Support
H1	T-lead-> Open-Inno	0.456	[0.248, 0.628]	4.681	0.000	Yes
H2	T-lead-> Com-HRM	0.635	[0.523, 0.737]	11.566	0.000	Yes
H3	T-lead-> Com-HRM-> Open->Inno	0.144	[0.033, 0.294]	2.189	0.029	Yes

COM-HRM - Commitment-based HRM; T-LEAD - Transformational leadership; OPEN-INNO - Inbound Open Innovation;

Source: Author's construct.

Again, T-Lead has a positive and significant relationship with Com-HRM (H2). The result suggests that Com-HRM is expected to increase by 63.5 per cent when the T-Lead unit is enhanced. According to prior studies, T-Lead facilitates HRM practices on employees' organizational commitment (Lin *et al.*, 2012). Using their great emotional connection to the goals of the firm and shared vision, which motivates them, T-Lead improve Com-HRM(Jiatong *et al.*, 2022). The basis of commitment-oriented activities includes internal career advancement, democratic decision-making, and employee development are empowering and helpful acts that serve to establish trust and motivation (Jun and Lee, 2023). This kind of leadership suits the HRM policies prioritising corporate civic behaviour and long-term employee participation. Moreover, constant motivation and inspiration stimulate subordinates' commitment towards the organisation ((Ausat *et al.*, 2022). The result confirms the findings of Ausat *et al.* (2022) who revealed that T-Lead significantly impact Com-HRM among organizations.

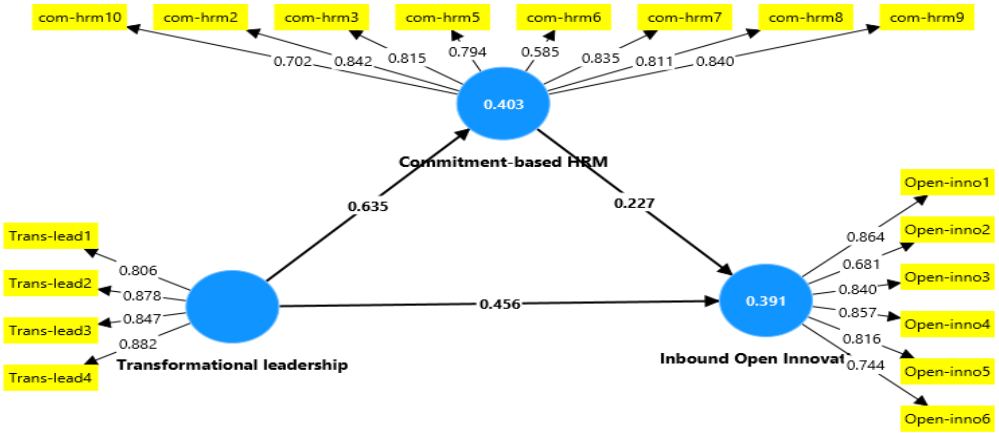


Figure 1: Structural model showing direct and indirect paths

Lastly, the study evaluated the mediating function of Com-HRM, revealing that it has a partial role in the T-Lead and Open-Inno connection (β=0.144; p<0.029). The study highlights the importance of T-Lead in improving Com-HRM to promote Open-Inno, making Com-HRM a valuable mediating variable. The VAF of 24.02 suggests that T-Lead and Com-HRM account for a substantial proportion of the variability in inbound open innovation. The value of 24.02 also indicates that Com-HRM partially mediates the relationship between the T-Lead and Open-Inno connection. The result supports a prior study that posits Com-HRM can facilitate the link between transformational leadership and inbound open innovation by fostering trust, engagement, and communication with external knowledge sources (Jun and Lee, 2023). This approach, utilising techniques like empowerment, training, and participatory decision-making, promotes transparency and initiative, enabling organisations to effectively embrace external innovations.

6 Conclusions

The objective of this study was to examine the mediating role of commitment-based HRM in the relationship between transformational leadership and inbound open innovation in SMEs. The distributed survey garnered responses from a total of 169 participants. The hypothesis was developed utilizing SmartPLS version 4.1.0.9. The results demonstrated that transformational leadership exerted a substantial beneficial influence on inbound open innovation. Transformational leadership had a favorable correlation with commitment-oriented HRM strategies. Given that commitment-based HRM is documented in existing literature to have a significant direct relationship with inbound open innovation, the study posited it as a mediating variable. The successful assignment of commitment-based HRM as a mediating variable in the link between transformational leadership and inbound open innovation metrics was achieved.

This study presents some practical implications for SMEs aiming to enhance innovation through leadership and HRM. Transformational leadership development may equip leaders to inspire, instill trust, and drive change. Such leaders play a pivotal role in fostering a culture of collaboration and openness. Secondly, implementing commitment-based HRM strategies such as participatory decision-making and internal promotion enhances employee engagement and loyalty. These approaches function as an essential link between leadership and inbound open innovation. Policymakers should also endorse leadership and human resource management training programs to enhance the competitiveness of SMEs. An effective HRM system aligned with innovation objectives promotes knowledge exchange and collaboration. Ultimately, this integrated approach enables SMEs to thrive in dynamic, knowledge-driven environments.

This research possesses multiple limitations. The research is confined to Albanian SMEs, perhaps impacting the generalizability of the findings to other cultural or economic contexts. Furthermore, the study concentrates solely on inward open innovation, neglecting outbound or coupled modalities that could provide a more comprehensive understanding. Furthermore, the utilization of self-reported measurements may inadequately include the intricacies of leadership behavior and innovation processes. Finally, exogenous factors such as market dynamics or technical changes were not controlled, potentially affecting the observed connections.

7 Acknowledgements

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8 Ethics declaration

The study was performed in compliance with ethical norms. The participants were fully apprised of the study's objective and the intended use of the data. No personal or sensitive information was gathered, and participants retained the choice to withdraw at any point during this research.

9 AI declaration

All the parts of this paper are written by authors without using AI tools to generate the content.

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Project "Telediabetolab": Knowledge Gain and AI Data Process Applied in Telediabetology

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Abstract

The goal of the proposed paper is to provide a preliminary Artificial Intelligence (AI) approach addressing the analysis on the prevention of diabetes. The study is performed within the framework of the research project *Telediabetolab* and focuses on the check of the supervised Support Vector machine (SVM) algorithm to define a method to perform a data processing analysis based on predicted diabetes risk. The preliminary study highlights the possibility of defining a multi-parametric approach to prevent the chronic condition of diabetes by considering the pre-diabetes condition. The SVM data processing is executed by analyzing different parameters such as blood pressure, body weight, glucose, and blood ones. The predicted results show that there could be cases of diabetics who might not be diabetic and cases of non-risk that could degenerate.

Keywords: Telediabetology Process, Process Mining, chronic disease management

Paper type: Academic Research Paper

1 Introduction: Telediabetolab framework

The work analyses the preliminary results of a research project. The project addresses the use of a regional telediabetology platform (*Telediabetolab* project) integrating Artificial Intelligence (AI) algorithms scalable on a national level. The proposed model is further integrable with other validated telemedicine systems and applies the process mining approach matching healthcare processes with AI decision making (Rosa et al, 2024; Rosa and Massaro, 2024). The platform is to be tested at the ASL of Bari on an initial sample of 100 patients: the project takes into account the use of telemedicine devices such as glucometers, body weight scales, and blood pressure meters, and fixed point of care including multiparametric capillary blood analyzers and retinographers, with the aim of implementing new management processes for diabetics in terms of primary, secondary and tertiary prevention, care, and remote monitoring. Specifically, the project platform (see the main framework of Fig. 1) is designed to be interoperable and compatible with the information systems of the National Health System (NHS) for the exchange of data with electronic health records and for the use of certified monitoring sensors. Elements of innovation are: (i) the formulation of new clinical/care processes (PDTA) and management of diabetics through the use of AI engines to limit the risks of diabetes, (ii) the digital mapping of diabetics (construction of a Regional database), (iii) the implementation of a procedure for optimizing the dosage of medicines, (iv) the formulation of prevention guidelines based on the correct lifestyle associated with the different classes of diabetics, (v) the optimization of the organizational processes of healthcare personnel using data-driven machine learning approaches. Socio-economic impacts are in a potential reduction in hospitalizations and treatment costs, and in an improvement in the quality of life of diabetics. The novelty of the paper is the full integration of sensor technologies into a telemedicine platform enabling AI algorithms to improve the PDTA decision making in diabetic primary prevention processes.

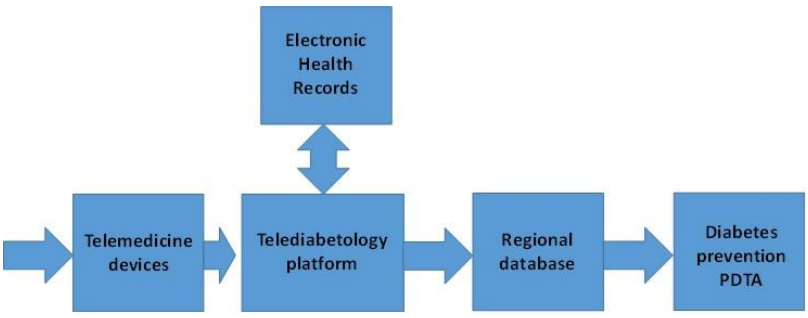


Figure 1: Main framework of the Telediabetology project.

2 Literature Review

In recent years, the landscape of healthcare has undergone a significant transformation, driven by advancements in technology and a growing emphasis on patient-centered care. Among the most promising developments is the integration of telemedicine, digital health, AI, and process mining, which together form a comprehensive approach to enhancing the management of diabetes and other chronic diseases. This innovative synthesis not only holds the potential to improve patient outcomes but also to optimize healthcare delivery systems.

2.1 Telemedicine and Telediabetology

Telemedicine has revolutionized the management of chronic diseases, particularly diabetes, through the specialized field of telediabetology, which prioritizes remote patient care (IDAMA, 2024). Studies by Borgonovi and Ferrara (2022) and Cerf (2020) underscore the transformative impact of telemedicine in enhancing healthcare access for patients facing geographical and financial barriers. This accessibility translates into improved health outcomes, facilitated by real-time monitoring capabilities (Shoeibi et al., 2022). Remote Patient Monitoring Systems (RPMS) have demonstrated effectiveness in reducing hospital visits and mortality rates, while simultaneously improving the quality of life for individuals with diabetes (Kakhi et al., 2022; Nahavandi et al., 2022). Additionally, the advantages of utilizing telemedicine solutions are clear: cost savings from reduced investments and infrastructure expenses, improved efficiency of medical staff's working hours, and enhanced service quality due to quicker diagnosis and treatment monitoring (Stawicka and Parlinska, 2020).

2.2 The Role of Digital Health in Diabetes Management

Digital health (DH) has shown immense potential to revolutionize diabetes prevention and management by leveraging diverse clinical, anthropometric, biochemical, and behavioral data over time. This innovative approach enhances support for individuals at risk of or currently living with diabetes. To fully harness the benefits of DH technologies, it is vital for policymakers, patients, and caregivers to actively engage with these advancements, ultimately fostering improved public health outcomes (Ranjani et al., 2024).

Telediabetology, as a distinct domain within telemedicine, emphasizes the remote management of diabetes through advanced technological interventions. The COVID-19 pandemic has accelerated the adoption of telehealth solutions, highlighting the necessity for continuous monitoring and timely interventions in chronic disease management (Ahmad et al., 2022). Effective management strategies must enhance patient engagement and adherence to treatment regimens, a principle underscored by the World Health Organization (2020).

Recent findings indicate that telediabetology can substantially improve glycemic control and overall health outcomes through real-time data collection and personalized care (Chao et al., 2021). The integration of digital health technologies into diabetes management has shown significant potential for enhancing patient outcomes. Mayya et al. (2024) emphasize the promise of artificial intelligence (AI) for predictive analytics, enabling the identification of high-risk patients and the customization of interventions. This vision aligns with the objectives of the *Telediabetolab* project, which seeks to employ AI for diabetes risk assessment and management via a telemedicine platform.

2.3 Advancing Chronic Disease Management Through Process Mining and AI

The intersection of telediabetology, process mining, and AI presents a dynamic framework for advancing chronic disease management, particularly diabetes prevention and care. The methodologies explored in the literature reveal the potential of predictive analytics to transform healthcare delivery, thereby enhancing patient outcomes while concurrently reducing costs. The *Telediabetolab* project aims to contribute to this evolving landscape through a focus on knowledge acquisition and AI data processing in telediabetology, ultimately enhancing chronic disease management.

2.4 Process Mining in Healthcare

Process mining has emerged as a critical methodology for analyzing and optimizing healthcare workflows, particularly in chronic disease management. Process mining is a technique that extracts valuable insights from event logs, facilitating the discovery, monitoring, and enhancement of actual processes within healthcare settings (Rosa and Massaro, 2024). This capability is essential for identifying inefficiencies and improving patient pathways, especially in telediabetology.

The Process Mining Organization (PMO) model, proposed by Rosa et al. (2023), provides a systematic framework for healthcare systems to analyze existing workflows and design optimized care processes. This model comprises three key phases: analyzing current processes, employing AI-driven data processing for predictive insights, and implementing corrective actions to improve workflows. This structured approach not only identifies bottlenecks but also informs strategic decision-making aimed at enhancing patient care and optimizing resource utilization in chronic disease management.

2.5 AI Applications in Chronic Disease Management

AI, particularly Machine Learning (ML), is increasingly leveraged in chronic disease management. Tools such as Support Vector Machines (SVM) are utilized to predict diabetes risk and support clinical decision-making through predictive analytics (Al-Qatf et al., 2018; Viloria et al. 2020). AI enhances personalized medicine by analyzing extensive patient data to create tailored treatment plans, thereby improving outcomes and fostering patient engagement (Kim et al., 2020).

2.6 Machine Learning and Predictive Analytics

ML has garnered significant attention in chronic disease management, especially for risk prediction and patient stratification. The integration of ML algorithms, such as SVM, enables healthcare professionals to analyze large datasets and identify patterns that inform clinical decision-making (Rosa and Massaro, 2024). This predictive capacity is particularly critical in diabetes management, where glycosylated hemoglobin (HbA1c) levels serve as key indicators of long-term glucose control (Chao et al., 2021). By applying both supervised and unsupervised ML techniques, healthcare providers can classify patients based on risk profiles, facilitating timely interventions and personalized treatment plans. The dual application of these algorithms enhances data interpretation and informs resource allocation and patient management strategies, as demonstrated in the research of Rosa and Massaro, (2024).

The integration of telemedicine, AI, and process mining within the realm of telediabetology signifies a pivotal shift in the approach to chronic disease management, particularly in diabetes care. The application of predictive analytics and digital technologies can significantly enhance healthcare delivery, improve patient outcomes, and reduce costs. By fostering a collaborative environment that embraces innovation and leverages the strengths of these technologies, healthcare organizations can not only optimize their processes but also ensure that patients receive the highest quality of care in managing chronic diseases.

3 AI results: testing of a SVM algorithm

The SVM algorithm tests an open dataset[1] composed of the following attributes matching with the data detectable by the experimental devices of the telediabetology project:

- Id: patient ID;
- Chol: total cholesterol;
- Stab.glu: stabilized glucose;
- hdl: high -density lipoprotein;
- ratio: Cholesterol/HDL Ratio;
- glyhb: Glycosylated Hemoglobin;
- gender;
- height;
- weight;
- frame: body frame
- bp.1s, bp.1d, bp.2s, bp.2d: first/second systolic/diastolic blood pressure.

The dataset is aligned with real attributes of the physiological parameters making the proposed model very similar to the experimental one. In order to estimate the risk of diabetes two thresholds (see Fig. 2) are considered by considering the Glycosylated Hemoglobin (HbA1c) being one of the most critical parameters of diabetes: HbA1c value of 5.7%-6.4% diagnosed as pre-diabetes, and HbA1c ≥6.5% diagnosed as diabetes (Chao et al., 2021).

[1] https://www.kaggle.com/datasets/imtkaggleteam/diabetes?select=diabetes.csv

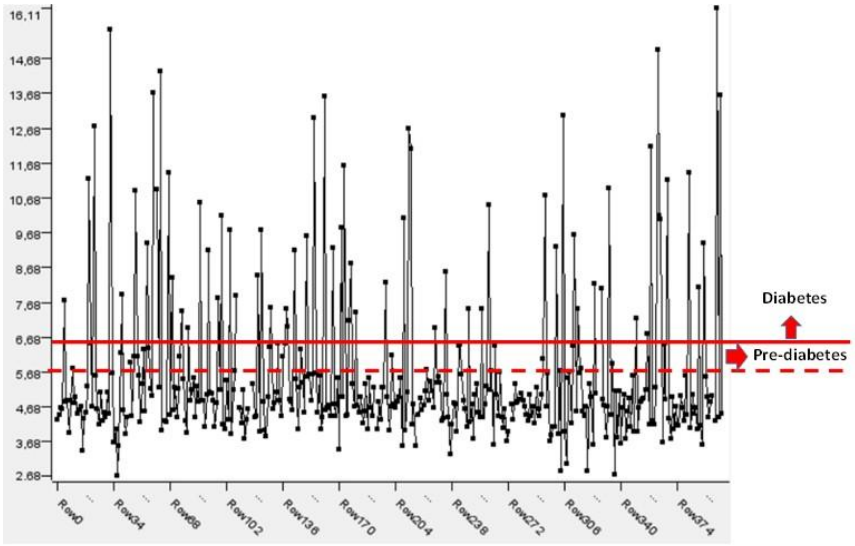


Figure 2: Plotting of the critical parameter of the Glycosylated Hemoglobin defines the threshold of pre-diabetes and diabetes conditions (Chao et al., 2021).

A total number of 403 records are processed by means of the SVM algorithm of the Konstanz Information Miner (KNIME) open - source tool providing the prediction of diabetes risk. The diabetes risk is considered for all the HbA1c values above the threshold of 5.7. For 396 records it is observed a matching between diabetes risk and the predicted one, while for 7 values a discordance is checked. Fig. 3 illustrates a screenshot of the extraction of the 7 records characterized by the mismatching, and Fig. 4 shows the scattering plot of the whole analysis (diabetes risk versus the prediction of the diabetes risk). The predicted values highlight that there could be cases of diabetics who might not be diabetic and cases of non-risk that could degenerate. This aspect suggests that a deeply analysis should be performed to define a possible risk: for example, a value of 4.81 of HbA1c which is considered normal (record 194) could degenerate into diabetes. These cases could be the ones to pay more attention to in order to avoid triggering cases of diabetes. However, a more accurate analysis requires more discordance cases to find possible correlations between other critical conditions due to the combination of other parameters (age, cholesterol, etc.). Cases that could be misclassified could instead be reconsidered as borderline cases requiring further analysis to estimate correctly the diabetes risk.

Row ID	I chol	I stab.glu	I hdl	D ratio	D glyhb	I age	S gender	I height	I weight	S frame	I bp.1s	I bp.1d	S Diabetes Risk	S Prediction (Diabetes Risk)
Row9	263	89	40	6.6	5.78	55	female	63	202	small	108	72	YES	NO
Row44	213	76	40	5.3	5.96	72	female	59	137	large	130	60	YES	NO
Row194	143	371	46	3.1	4.81	68	male	67	158	small	138	82	NO	YES
Row230	174	105	117	1.5	5.53	20	male	70	187	medium	132	86	NO	YES
Row267	195	171	29	6.7	5.68	78	male	66	172	large	130	82	NO	YES
Row309	198	86	66	3	5.68	61	male	74	152	small	138	76	NO	YES
Row347	306	92	56	5.5	5.58	74	male	69	184	large	140	72	NO	YES

Figure 3: Extraction of the predicted results with discordance between diabetes risk and the prediction of the diabetes risk.

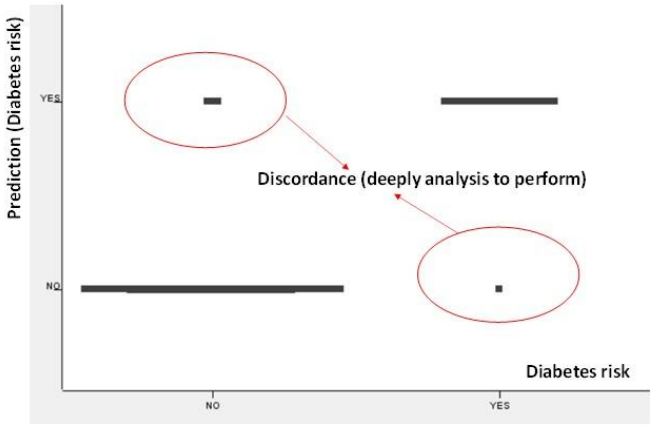


Figure 4: Plot of all the SVM results: diabetes risk versus the prediction of the diabetes risk.

The good performance of the SVM algorithm is proved by the Receiver Operating characteristic ROC curve of Fig. 5 estimating an area under the curve of 0.989. The SVM is performed before by cleaning the dataset[1] (filtering of the not significant attributes such as Id, and neglecting attributes with missing values).

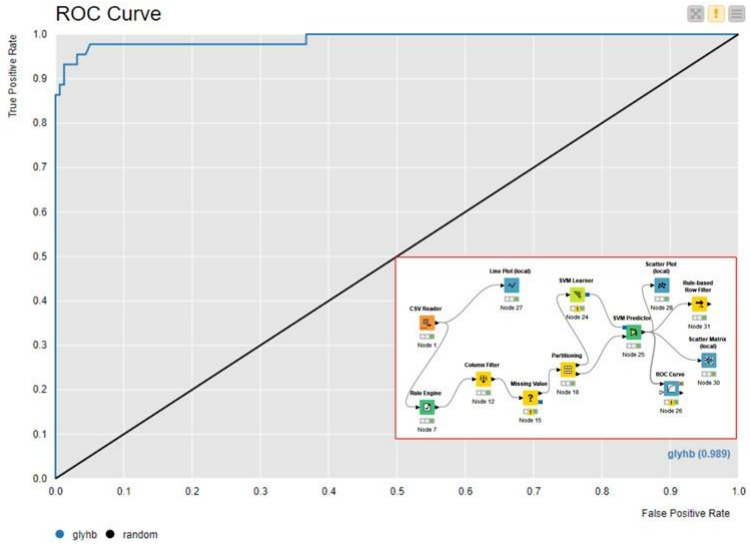


Figure 5: ROC curve indicating the good performance of the SVM algorithm. Inset: KNIME workflow adopted for the SVM data processing.

4 Conclusion

The proposed study is addressed within the existing literature about advanced healthcare methodologies improving clinical processes, by focusing the attention on process mining applications. The integration of AI into the telemedicine framework improves the decision support systems providing the digital knowledge base for the primary prevention of diabetes based on the risk analysis of the chronic condition. This improves the PDTA clinical processes thus supporting the management of the diabetes risk on a large scale. The integration of AI into the PDTA workflow makes processes intelligent adopting decision engines based on AI classification or AI prediction. Specifically, the work highlights the possibility of using AI as a warning tool for diabetes risk with the aim of minimizing chronic cases as much as possible. Due to its performance, the SVM algorithm proves to be suitable for datasets compatible with those that will be created in the activities of the *Telediabetolab* project. Future work will concern the study of correlations between multiple parameters to define more accurate criteria for defining preventive diabetes risk, and the comparison with other AI algorithms such as Artificial Neural Networks (ANNs) that are considered equally suitable for risk classification.

5 Acknowledgments

The paper has been developed within the framework of the project titled: “Telediabetology applied to the optimization of clinical/healthcare processes for monitoring and treating diabetics, through innovative prevention and prediction approaches” (bando PNRR INTERCONNECTED NORD-EST INNOVATION ECOSYSTEM – INEST-M4C2 –investimento 1.5. creazione e rafforzamento di "ecosistemi dell’innovazione per la sostenibilità”, NEXTGENERATIONEU, Spoke 2).

6 Ethics declaration

The research activities presented in this paper are based on the analysis of publicly available datasets and do not involve any experimentation on human participants, personal data collection, or sensitive information. Therefore, ethical clearance was not required for the development of this study.

7 AI declaration

No AI tools were used in the drafting, editing, or development of this paper. All content, analysis, and writing were conducted entirely by the authors.

[1] https://www.kaggle.com/datasets/imtkaggleteam/diabetes?select=diabetes.csv

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Public-Private Co-Creation of Knowledge-Based Open Innovations: Challenges and Opportunities

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Abstract

Efficiency and value creation for citizens, communities, and societies are becoming increasingly important for the public sector. Public sector is continuously seeking for innovative ways to create and provide services, and despite acknowledging the key role of knowledge in innovation processes, the relationship between publicly available knowledge and innovation is still poorly understood. A more unified view of OI and the *public sector originated knowledge* ecosystem, alongside public-private collaboration, is crucial. The private sector's creation of open knowledge-based innovations, such as products or services, for private markets appears to have minimal influence. To achieve successful *knowledge-based* innovation, functional systems are crucial for addressing the identified barriers within *public knowledge* and innovation. This paper investigates the potential of public sector originated knowledge to drive open innovation in partnership with public and private organizations. The potential to gather and use openly available knowledge is now greater than ever due to the possibilities provided by AI. Challenges in innovation are widely explored in existing research. Future studies should focus on developing models for successful open knowledge initiatives, including strategic planning (value realization and resource-based strategic analysis), technical enablers (new digital technologies as AI), sharing platforms (design of public knowledge sources with appropriate APIs), enabling functional *public knowledge* ecosystems, and legal frameworks to support open *public knowledge* sharing and utilization (e.g., knowledge privacy). Research needs to consider social aspects alongside technological and business ones. This includes management models for *public knowledg*e and innovation, knowledge processes and its management to support OI, and organizational cultures that reflect experiences of control or safety, risk management, attitudes and engagement in OI processes. To better comprehend how the private sector can benefit from public *knowledge*, additional empirical studies are crucial.

Keywords: Open innovation; publicly available knowledge; knowledge-based innovation; public-private co-creation

Paper type: Academic Research Paper

1 Introduction

Efficiently providing public services to its citizens and other stakeholders is a pressing concern for the public sector. As research on open innovation (OI) intensifies (Chesbrough 2020), it highlights the need for external problem solvers in the public sector. Private sector actors are increasingly designing new tech solutions and innovations for public services, using their digital platforms and applications. Globally, national governments (Reggi and Dawes 2021) have stressed the importance of open government knowledge, which is produced by the private-based digital applications, for external use. The main concern revolves around the use and subsequent processing of this knowledge. Studies exploring the value of open innovation in the public sector often point to private organizations as key collaborators for enabling value creation through democratization and the public value creation approach (Parrado and Reynaers 2020; Pedersen 2020). Yet, the social implications of companies' potential innovations have been ignored in terms of their economic impact.

The economic potential of open knowledge is significant. Stott (2014) estimates that open knowledge could create an additional €3 trillion to €5 trillion in value annually. An example of public knowledge utilization can be seen in London, where the Transport for London open knowledge source has led to the development of 550 applications, the creation of 5500 jobs, and the use of 25 knowledge sources or platforms (Stone and Aravopoulou 2018). The London transport case, if applied to EU datasets, would generate over 30,000 applications and 5 million new jobs across the EU. But critics argue that the anticipated benefits of open knowledge may be overly optimistic (e.g., Jamieson, Wilson, and Martin 2019).

According to Attard et al. (2015), public or governmental entities are responsible for producing public knowledge. OI commonly starts with open knowledge, which is often seen as a starting point for ideation. While the knowledge's potential is acknowledged, how it connects to innovation is more unclear. Process ideation develops solutions for known problems, but policy or legal concerns may block their actual use or trial. Public

actors have a duty to serve the public and generate value (Hartley, Sørensen, and Torfing 2013), a responsibility that contrasts with the profit-driven logic of the private sector.

Private sector involvement can significantly enhance the OI ecosystem. Nonetheless, private businesses need to explore new concepts and advancements within the framework of social institutions. Evaluating value creation for public services delivered by private companies involves examining the interaction between the public sector, service users, and the companies themselves. Osborne (2018) defines co-creation "as a process characterized by interactive relationships that generate value through their shared engagement". According to service logic, companies are involved in creating customer value, but there is usually a market acting as a mediator between them and the customer. The creation of services within company networks is often facilitated by shared knowledge resources (Sønderskov and Rønning 2021). External resources can be tapped into through the knowledge and resource ecosystem, providing a platform for joint problem-solving between public and private sector actors (Torfing et al. 2019). Despite these suggested value benefits, there are those studies who claim that service users lack the ability to create value (Beck and Bozeman 2007). Meynhardt (2009) takes a different approach than others, arguing that public services should consider not just private sector value, but also group and public value. Supporting factors or actors should be identified and considered by both service users and providers (Grönroos 2019).

This paper emphasizes the public sector's role as a context, suggesting the need to explore opportunities for private market participation in service development. The literature has identified several challenges to using open knowledge and developing open knowledge-driven innovations. These challenges can be categorized as technical design and knowledge quality or integration, knowledge management and policy and legal issues, financial backing for open knowledge programs, or organizational and cultural contexts (Attard et al. 2015; Jetzek 2016; Ruijer et al. 2017; Toots et al. 2017; Ferraris et al. Pellicelli 2020). Smith and Sandberg (2018) argue that challenges in open knowledge operation processes can affect the way knowledge is used and the various stages of its implementation. When platforms lack identification requirements, anonymity in knowledge use poses a challenge (Begany and Martin 2020). Therefore, *this study seeks to explore the potential of public knowledge to spur open innovation via public-private partnerships*.

2 Public-private co-innovation

Open innovation (OI) can consist of open knowledge, organization agile practices or culture, offered digital services or personnel knowledge or other resource visualization capabilities (Lindquist and Buttazzoni 2021). Alternatively, OI can be considered as a resource-based approach or a social exchange and benefits approach (Hopp et al. 2021). Innovation here means new products, services or processes that produce business or non-monetary value (e.g. knowledge or competence or other shared resource) for the organization or end users. Technology solutions with simultaneous competence development seem to be one of the main sources of opportunities for innovations (Di Stefano, Gambardella and Verona 2012; Clausen, Demircioglu and Alsos 2020).

Innovation actions are often focused on proving the effectiveness of public sector services (De Vries et al. 2016; Osborne 2018). The research has identified the factors of innovation; trust seems to be crucial between private-public agencies (Brogaard 2017; Brogaard 2021) and co-operation is needed, when simultaneously formulating ecosystems. Ecosystems around knowledge or accumulated knowledge can be an enriching source for innovations (Pollock 2011). However, an organization's internal capability to utilize external resources to enhance innovations is needed (Di Stefano et al. 2012). Furthermore, public sector personnel's involvement in the innovation activities is essential to improve the performance of the organization (Demircioglu and Audretsch 2017). It is worth noticing how public and private stakeholders together with politicians and policymakers could minimize administrative silos and forward cross-sector collaboration (Torfing, Sørensen, and Røiseland 2019).

In terms of regionality, for administration of the innovation process to succeed, multilevel coordination is needed between regional and local agencies (e.g. Dmitreiva and Guseva 2017; Catala-Perez and de-Miguel-Molina 2021). The governance mechanisms can offer innovation potential, and the public sector can play a major role as a facilitator in the innovation process (Lember et al. 2019; Carbonara and Pellegrino 2020; Hayter and Clapp 2020), especially with public-owned enterprises (Luke, Verreynne and Kearins 2010).

However, the question has been asked whether it is correct to share public developed platforms or acquired knowledge funded by public tax income? Past thinking is that collaborative innovation between public and private actors or shared platforms is a risk because private actors could use the innovation results in their business (Benington and Moore 2011) could be turned into a new approach of shared resources and common obtained value. Another critique can be expressed of the platform owners whose purpose is to be a gatekeeper and whose actions are business-oriented (Cutolo, Hargadon, and Kenney 2021). There is a contrast between open knowledge and value creation, or between the combination of public sector platform and power relations

between all the parties of the value triangle, namely the public sector, private sector and the end customer. Both the barriers to innovation, adoption of innovations and value creation (e.g. Walker 2006; De Vries, Bekkers, and Tummers 2016; Demircioglu and Audretsch, 2017; Meissner 2019) and the drivers that enhance public innovations (Sorensen and Torfing 2011; McLoughlin et al. 2019; Zhenbin et al. 2020) have been identified. Therefore, this article emphasizes the need for consideration of private sector innovations converted from public sector knowledge sources.

3 Knowledge-based innovations

More and more innovations are constructed on the basis of knowledge. When knowledge is utilized, the knowledge utilizers also form networks that can be understood as a knowledge ecosystem. A knowledge ecosystem is quite a new concept, first defined in 2010. Pollock provides the oldest definition: "An ecosystem has knowledge cycles, in which intermediate consumers of knowledge such as builders of apps and knowledge wranglers may share back their cleaned, integrated and packaged knowledge into the ecosystem in a reusable way. This cleaned and integrated knowledge is often more valuable than the original source" (Pollock 2011).

Scholars have represented the content of open knowledge and platforms from the infrastructure or policy aspect or open knowledge ecosystems promoting OI. Barriers or challenges of open knowledge utilization, around knowledge platforms and knowledge per se and human-technology interaction in the innovation process have been considered by researchers while the drivers of open knowledge have received less attention. OI can be between public-public actors or public-citizens or public-private actors (Mu and Wang 2020) as well as private-private actors. The risk of OI with private actors in the public sector has been noted because of the fear of innovation process results that are more beneficial for the private market advantage than offering public value (Hartley et al. 2013). Therefore, new thinking about OI is needed in the public sector to create frameworks for public-private open knowledge co-operation that benefits all parties of the value triangle, namely the public sector, private sector and the customer. It is essential is to identify suitable co-operation partners and to actualize the identified drivers and to obtain transaction flows in OI processes in the private sector (e.g. Torfing, Sørensen, and Røiseland 2019).

Researchers have created different business models from public sector case studies. Ansell and Miura (2020) have considered the possibilities of governance platforms versus business platforms and how governance platforms can promote value creation; however, they mentioned that financial promoters have a minor role. Nambisan, Zahra and Luo (2019) regard platforms as flexible innovation spaces that allow global partners to create value propositions and delivery of products or services, and allow the actors to formulate different business models. Janssen and Zuiderwijk (2014) have identified six different mode-based business models depending for example on access to knowledge or interaction in the platform-knowledge interface: "single-purpose apps, interactive apps, information aggregators, comparison models, open knowledge repositories, and service platforms". However, Feller, Finnegan and Nilsson (2017) have concluded that the financial benefits for companies would seem to be the reverse: costs may increase and revenue models would not be established.

Although technical in nature, the knowledge ecosystem contains social aspects as well. A knowledge ecosystem is built on actors, roles, relationships and resources that aim to exchange knowledge, produce knowledge together or consume knowledge (Oliveira, Lima, and Lóscio 2019). When opening platforms, knowledge or implementing new OI and co-creation practices in the organization, leadership and teams are faced with new challenges; what are the internal effects (e.g. culture, norms) and external effects (e.g. customers, other stakeholders) (Altman and Tushman, 2017). The actors have different interests (for example, focusing on customer and market needs or accumulating knowledge in the ecosystem) that need the consideration of the platform or knowledge ecosystem management (Wareham, Fox, and Giner, 2014). Actors in the ecosystems have different levels of competence, knowledge and maturity to operate in the platform or utilize the knowledge, and they need to identify their roles in the ecosystem.

Open knowledge sources are one pop-up base for innovations at the public-private interface. However, the benefit of opening public knowledge sources is two-fold. Firstly, opening up the knowledge sources for companies and knowledge developers offers public knowledge branding. Companies do not expect to obtain rapid innovations via open knowledge. Secondly, there are challenges in knowledge utilization, e.g. knowledge consistency and integration, the trustworthiness of the knowledge or access rights. Nevertheless, high technology and artificial intelligence is expected to produce innovations during the next few years.

4 Findings and discussion

The field of open knowledge presents complex, multi-dimensional challenges and opportunities. Infrastructure and content use possibilities of public knowledge frameworks have been examined practically and

academically (Conradie and Choenni 2014; Charalabidis, Alexopoulos, and Loukis 2016; Ham, Koo, and Lee 2019), management practices and policies (Smith and Sandberg 2018; Jamieson, Wilson, and Martin 2019; Luna-Reyes et al. 2019) and among value-creation networks (Pereira et al. 2017).

Public and private sectors face challenges in open innovation. OI has open knowledge but there are either insufficient resources for processing or expertise in using knowledge sources (Luna-Reyes et al. 2019; Begany and Martin 2020). Alternatively, access to knowledge is limited (Hellberg and Hedström 2015; Smith, Ofe, and Sandberg 2016). Although OI forms to describe the possibilities of operating OI processes have been designed (e.g., Mergel 2015; Smith and Sandberg 2018; Mu and Wang 2020), whether sharing open knowledge benefits OI is a valid question: Does open knowledge offer value, and if so, is that value societal or economic? To whom does this bring value: the public sector, citizens, or other stakeholders, which includes the private sector?

Studies of OI and public sector open knowledge ecosystems typically ignore their interconnection. This study emphasises that OI is fundamentally rooted in knowledge ecosystems and open knowledge utilization, and that the relationships between the various participants within these ecosystems are not a primary concern and only two partners are required to create commercial innovation. Various open knowledge ecosystem models have been created to demonstrate network development (Dawes, Vidiasova, and Parkhimovich 2016; Bonina and Eaton 2020). Ecosystems are not directly monetizable by private firms, but the actors involved can create innovation and new business models via partnerships within the ecosystem.

The other question is whether the public sector is willing to divide the control of the knowledge to enable the knowledge's further use for commercial value. This dilemma appeared in the selected literature business models as well, which considered the economic benefits of value obtained from the public sector rather than the private sector business side (Feller, Finnegan and Nilsson 2011; Zeleti and Ojo 2019). Business models in the public sector may be based more on value creation for citizens (e.g. promoting governmental program implementation or offering services) that are non-economic, whereas private sector models are often based on technical solutions enabling public sector supply of services via applications (Janssen and Zuiderwijk 2014; Kitsios and Kamariotou 2019). The public-public actor or public-citizens partnership can be challenging for creating business value for private sector companies. Therefore, public sector support for private sector companies is important in knowledge and knowledge sharing to boost innovations (Love, Roper and Bryson 2011).

The identified barriers in public-private OI require models for creating successful open knowledge initiatives. Complexity in the different open knowledge adoption phases is manifested through various barriers to innovations (Attard et al. 2015; Smith and Sandberg 2018). Even though public sector agencies emphasize increased democratization, citizen empowerment and the transparency of public processes by digitalization in open knowledge -based innovation processes, the open knowledge sharing practices are old-fashioned (Zhenbin et al. 2020). However, to enhance open knowledge -based innovations, some crucial enablers for public-private OI that have been identified are policy drivers (McLoughlin et al. 2019), access to knowledge sources as well as private sector competence to utilize open knowledge and identify the benefits of open knowledge (Toots et al. 2017; Wang and Lo 2020).

Some successful open knowledge innovation experiments are illustrated in the literature, for instance, cities as development platforms and OI drivers. The Smart City idea has been piloted e.g. in Helsinki (examples of the pilots: platform for open knowledge utilization, knowledge sets for the metropolitan area covering public transport, decision-making and service points, and tools and support for knowledge utilizers), Manchester (digital services based on open knowledge, tools and support for open knowledge and public transport knowledge for developers), Amsterdam (several applications to developed based on open knowledge), Barcelona (promoting co-creation and innovations leveraging open knowledge), Chicago (knowledge utilization to identify opportunities to improve city operations) (Ojo, Curry, and Zeleti 2015) and Cape Town (open knowledge application helps house-level water consumption monitoring to build drought resilience) (Van Belle, and Hlabano 2019). Besides new innovations by the private sector and business markets, global challenges can be solved with open knowledge but it requires multi-sector co-operation.

5 Conclusions

This research explored the potential of public knowledge to spur open innovation via public-private partnerships. Previous studies highlighted knowledge's crucial role in fostering innovation. While open knowledge is vital for innovation and public participation, the private sector's significant contribution is often overlooked. Limited attention has also been given to the interplay between OI and open knowledge, potentially leading to a lack of shared understanding regarding OI's importance in public-private cooperation. Ecosystem models pinpoint crucial connections between agencies, but they don't yield benefits or income until these links translate into practical collaborations. Open knowledge sharing should not include identifiable information, as

it's neither feasible nor sensible. Despite public organizations releasing anonymized or statistical knowledge, access and use by the private sector are frequently limited, especially in fields like healthcare. A more unified view of open innovation (OI) and the open knowledge ecosystem, alongside public-private collaboration, is crucial. The private sector's creation of open knowledge-based innovations, such as products or services, for private markets appears to have minimal influence. To better comprehend how the private sector can benefit from public open knowledge, additional empirical studies are crucial.

Challenges in innovation are widely explored in existing research. The next step should focus on developing models for successful open knowledge initiatives, including strategic planning (value realization and resource-based strategic analysis), technical enablers (new technologies as AI), sharing platforms (design of public knowledge sources with appropriate APIs), enabling functional public knowledge ecosystems, and legal frameworks to support open public knowledge sharing and utilization (e.g., knowledge privacy). We need to consider social aspects alongside technological and business ones. This includes management models for public knowledge and innovation, knowledge processes and its management to support OI, and organizational cultures that reflect experiences of control or safety, risk management, attitudes and engagement in OI processes.

Ethics declaration

Ethical clearance was not required for the research.

AI declaration

AI tools were not used for the creation of the paper.

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AI-Enhanced Data Platforms: Transforming Knowledge Management in Waste Management Organizations

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Abstract

This paper examines the transformative impact of AI-enhanced data platforms on knowledge management (KM) within waste management organizations, focusing on the case of Alia Servizi Ambientali SpA in Tuscany, Italy. Utilizing a qualitative case study approach that combines on-site observations, stakeholder interviews, and system data analysis, our research demonstrates that AI integration significantly optimizes operational efficiency by consolidating diverse data streams, from IoT sensors monitoring waste receptacles to vehicle fleet metrics, into a unified, high-quality repository. The platform employs a medallion architecture to ensure data quality, enabling predictive analytics that improve route optimization, reduce vehicle movements, and lower carbon emissions. Beyond these practical benefits, the study advances theoretical insights by proposing a framework that situates AI-driven KM within broader governance and ethical contexts, contrasting traditional approaches with the dynamic capabilities of AI technologies. Despite the inherent limitations of a single-case design, our findings provide a strategic blueprint for leveraging AI-enhanced data platforms in waste management. They underscore the critical role of robust governance frameworks, leadership commitment, and targeted training in aligning technological capabilities with evolving KM practices, ensuring the sustainability and scalability of digital transformation initiatives.

Keywords: Artificial Intelligence, Knowledge Management, Data Platforms, Waste Management, Digital Transformation

Paper type: Practical Paper

1 Introduction

In an era defined by rapid digital transformation and mounting sustainability mandates (United Nations, 2015), waste management organizations must contend with ever-growing volumes of operational data while meeting stringent environmental and resource-efficiency targets (European Commission, 2020). Yet many public utilities still rely on legacy systems and siloed information flows, limiting their ability to translate data into strategic insights or to deploy proactive, predictive services (Mårtensson, 2000).

The integration of artificial intelligence into unified data platforms offers a promising, but underexplored, avenue for overcoming these constraints, particularly within the waste management sector, where operational complexity and stakeholder fragmentation pose unique challenges (Rahman et al., 2020). Alia Servizi Ambientali SpA's recent deployment of an AI-enhanced data platform provides a timely case through which to examine how advanced analytics can reshape knowledge management practices in a large-scale public service (Chourabi et al., 2012).

Building on prior work in digital innovation and KM transformation (Shadbolt & Milton, 1999), this study investigates three interdependent dimensions: (1) the technological integration that underpins operational efficiency; (2) the mechanisms by which data platforms catalyze knowledge creation and organizational learning; and (3) the governance structures necessary for ethical, transparent AI deployment. In doing so, we address a gap in both scholarly and practitioner literatures on how AI-driven architectures can be effectively embedded within public utilities.

Beyond technological design, we explore the structural and cultural shifts that the move from manual, reactive processes to data-driven, collaborative problem-solving. By detailing Alia's critical success factors and stakeholder dynamics, our findings yield actionable insights for policymakers and practitioners seeking to align AI-enabled KM systems with sustainability and circular-economy objectives.

In the following sections, we first contextualize the study through a review of relevant literature on digital transformation, knowledge systems and modern data platforms. We then outline the methodological approach adopted to investigate the case of Alia Servizi Ambientali SpA, followed by an in-depth presentation of the

platform's implementation and its multidimensional outcomes. The paper concludes by discussing theoretical implications, practical insights, and avenues for future research.

2 Background and Literature Review

2.1 Digital Transformation and Knowledge Management

KM traditionally involves systematic processes for capturing, developing, and disseminating organizational knowledge to drive performance (Gupta et al., 2000; Shadbolt & Milton, 1999). Historically, KM practices have centered on manual information repositories and intradepartmental communication channels. However, the advent of digital transformation has catalyzed the evolution of KM into a dynamic, data-driven process that leverages advanced technologies, including big data analytics, IoT, and artificial intelligence (Vaio et al., 2021).

Digital transformation facilitates the transition from static, siloed knowledge repositories to interactive, real-time systems where data continuously informs decision-making. As organizations increasingly adopt digital infrastructures, the role of KM shifts from simply storing information to actively generating insights through automated processes and predictive analytics. This evolution aligns with the broader trends in Industry 4.0, where connectivity, machine autonomy, and rapid data processing are redefining operational paradigms (Manesh et al., 2021).

2.2 AI-Enhanced Data Platforms

Central to this digital transformation is the emergence of AI-enhanced data platforms that integrate and analyze large volumes of structured and unstructured data. Traditional data warehouses—often characterized by "schema-on-write" models—have evolved with the advent of data lakes and, more recently, Data Lakehouse architectures that combine the best features of both approaches (Armbrust et al., 2021; Nambiar & Mundra, 2022). The medallion architecture, a layered data processing approach, exemplifies this evolution by ensuring that data is progressively refined through bronze, silver, and gold stages to achieve high-quality, business-ready outputs (Databricks, 2022).

AI integration further enhances these platforms by introducing machine learning algorithms that support predictive analytics, anomaly detection, and real-time data processing. For example, AI-driven predictive models have been applied to forecast waste generation patterns, optimize vehicle routing, and minimize environmental impacts in waste management systems (Rahman et al., 2020). Such innovations streamline operational processes and provide a strategic edge by transforming raw data into actionable insights.

2.3 Ethical Governance and Theoretical Gaps

While many studies focus on the technological and operational aspects of AI-enhanced systems, the literature reveals a notable gap in addressing the ethical and governance dimensions of these transformations. Recent discussions in the field of AI ethics have emphasized the need for frameworks that ensure transparency, data privacy, and accountability in the deployment of AI technologies (Floridi & Cowls, 2019; Jobin et al., 2019). In the context of KM, this involves establishing governance protocols that ensure data integrity and safeguard against biases or misuse. Current research often overlooks how the integration of advanced data platforms influences broader organizational learning and cultural shifts. By addressing these dimensions, this paper contributes to a more holistic understanding of digital transformation. Our study seeks to bridge this gap by proposing an integrated framework that accounts for operational efficiency, organizational learning, and ethical governance in AI-enhanced KM systems.

3 Methodology

3.1 Research Design

This study adopts a qualitative, single-case approach in line with the Gioia methodology to explore how AI-enhanced data platforms reshape KM practices at Alia Servizi Ambientali SpA. By focusing on one well-defined organization, we obtain rich, context-sensitive insights into technological, organizational, and ethical aspects of digital transformation (Gioia et al., 2013; Noy, 2008).

3.2 Data Collection

Data were gathered over six months through a triangulated protocol to ensure breadth and depth of evidence:

- *Semi-Structured Interviews*: Fifteen in-depth interviews (totaling 1005 minutes) with several internal and external professional figures (Table 1) to capture a range of stakeholder perspectives.
- *On-Site Observations*: Direct field observations documented day-to-day workflows and the practical impacts of the new platform on service delivery.
- *Document Analysis*: Internal reports, policy documents, and strategic plans were reviewed to corroborate interview insights and provide an organizational backdrop to the transformation process.

Table 1: Respondent presentation (Authors' elaboration):

Respondent ID	Professional Profile	Interview Length (minutes)
INT-01	IT Manager	55
INT-02	Knowledge Management Manager	75
INT-03	Data Scientist	50
INT-04	HR & Knowledge Management Specialist	70
INT-05	Operations Manager	70
INT-06	Data Engineer	45
INT-07	Digital Transformation Manager	50
INT-08	Data Platform Expert	60
INT-09	Operations Coordinator	65
EXT-01	Academic Expert in Knowledge Management	70
EXT-02	Policy Advisor	70
EXT-03	External Governance Consultant	90
EXT-04	Academic Expert in Waste Management	60
EXT-05	External Business Strategy Consultant	85
EXT-06	External Data Consultant	90

3.3 Data Analysis

The interview transcripts, observation notes, and documents were imported into NVivo software for systematic coding. An inductive coding approach was used to develop first-order codes based on participants' experiences, which were subsequently grouped into second-order themes reflecting broader organizational processes. These themes were then synthesized into aggregate dimensions corresponding to the three components of our theoretical framework:

1. *Operational Efficiency & Technological Integration*: This dimension explores how AI-enhanced data platforms contribute to operational optimization by integrating advanced analytics within centralized data architectures. The structured layering of data processing—such as the medallion architecture—enables scalable automation, real-time decision-making, and predictive modeling capabilities (Databricks, 2022; Armbrust et al., 2021). These technological affordances support the transition from reactive workflows to proactive, data-driven operations. The framework posits that such integration improves efficiency and redefines the role of digital infrastructure in organizational performance.
2. *Knowledge Creation & Organizational Learning*: From a knowledge management perspective, AI-enhanced platforms act as enablers of continuous organizational learning and innovation. By consolidating heterogeneous data into unified repositories, they facilitate cross-functional collaboration, eliminate informational silos, and promote shared knowledge creation (Vaio et al., 2021; Shadbolt & Milton, 1999). The framework emphasizes how data accessibility and interpretability reshape organizational cognition, fostering adaptive learning cycles and evidence-based decision-making. This dimension reframes KM not as static storage, but as a dynamic, iterative process embedded within digital transformation.
3. *Ethical Governance & Cultural Transformation*: The integration of AI systems into organizational contexts necessitates robust ethical and governance structures to address concerns around transparency, accountability, and data integrity. This dimension underscores the importance of embedding principles such as algorithmic transparency, stakeholder inclusion, and privacy protection within the design and deployment of AI systems (Floridi & Cowls, 2019; Jobin et al., 2019). Furthermore, it highlights the reciprocal relationship between governance mechanisms and cultural change, wherein ethical frameworks not only safeguard technology use but also foster organizational values aligned with responsible innovation.

4 Case Study Overview: Alia Servizi Ambientali SpA

4.1 Organizational Context

Alia Servizi Ambientali SpA, established in 2017, is a prominent public utility responsible for waste management across 58 municipalities in Tuscany, serving over 1.47 million residents. Managing approximately 1.5 million tons of waste annually and operating a fleet exceeding 1,800 vehicles, the organization has long faced challenges related to data fragmentation, inefficient information flows, and the limitations of legacy IT systems. These operational challenges were exacerbated by the increasing demands of sustainability and the need to optimize resource utilization.

4.2 Implementation of the AI-Enhanced Data Platform

In response to increasing operational complexity and limitations of legacy IT infrastructure, Alia Servizi Ambientali SpA initiated the implementation of an AI-enhanced data platform in 2021 as a foundational component of its comprehensive digital transformation strategy. The implementation followed a systematic phased approach, with emphasis on scalability, data centralization, and AI-readiness as primary design considerations.

The architectural framework was structured according to the medallion model (Databricks, 2022), a layered data processing methodology that organizes data into hierarchical tiers: bronze (raw), silver (cleaned), and gold (business-ready). This structured approach facilitated progressive enhancement of data quality, consistency, and traceability throughout the processing pipeline. The integration of heterogeneous data sources, including structured and unstructured inputs from IoT-enabled waste receptacles and fleet telematics systems, enabled comprehensive aggregation of high-volume, high-velocity data streams, supporting both real-time data ingestion and the deployment of machine learning pipelines for operational applications (Figure 1).

A critical element of the deployment was the implementation of automated Extract-Transform-Load (ETL) processes, replacing previously fragmented and manual methodologies. These ETL workflows operate under centralized orchestration frameworks and are augmented by AI models that dynamically adapt to data anomalies and optimize processing schedules (Gadde, 2020). This approach standardized the data lifecycle management and ensured consistent availability of high-integrity data for subsequent analytical processing.

From an interoperability standpoint, the platform incorporated open protocols such as Delta Sharing, enabling secure and efficient data exchange with external stakeholders, including municipal authorities and third-party consultants. This architectural decision aligns with emerging industry trends toward data democratization and collaborative intelligence (Abdallah et al., 2020), ensuring the versatility of Alia's data assets across diverse strategic and regulatory contexts.

The implementation incorporated governance-by-design principles to ensure comprehensive data stewardship, algorithmic accountability, and system scalability. Notably, robust lineage tracking mechanisms were integrated across all data pipelines, establishing transparency and auditability throughout the data lifecycle, from acquisition to utilization.

From a technical perspective, the platform utilized cloud-native infrastructure and Machine Learning Operations (MLOps) methodologies to optimize the development and deployment of AI models. These included containerization techniques for computational reproducibility, version control systems for data and code artifacts, and continuous integration/continuous delivery (CI/CD) pipelines for analytics workflows—essential components for maintaining agility in model iteration and retraining processes (Deekshith, 2020).

In aggregate, these implementation characteristics established a flexible, future-oriented data ecosystem capable of supporting both immediate operational requirements and long-term strategic initiatives. While specific benefits are elaborated in subsequent sections, it is significant to note that this technological foundation was deliberately aligned with Alia's strategic vision of integrating AI capabilities into operational and knowledge processes, while maintaining stringent controls over data integrity, security, and governance.

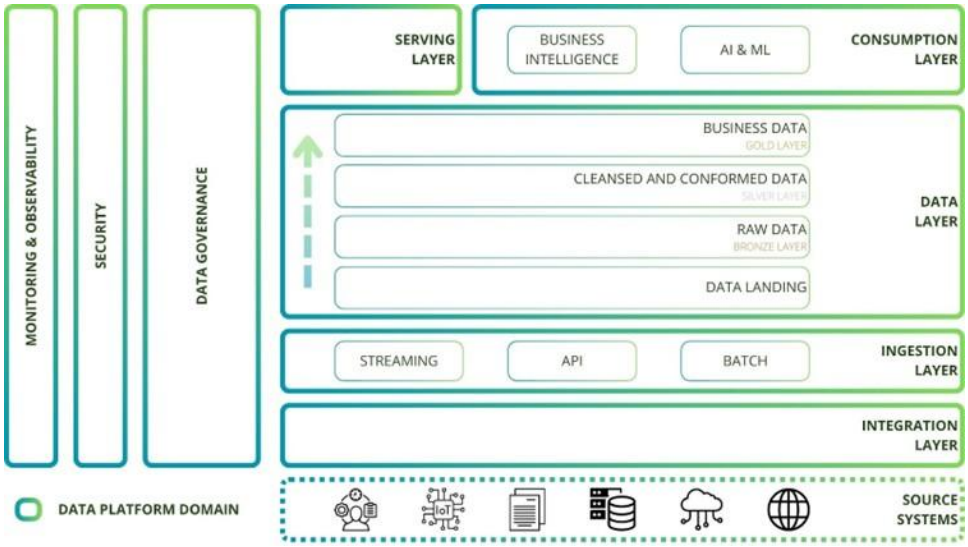


Figure 1: Data Platform Architecture (Authors' elaboration)

5 Outcomes and Discussion

The AI-enhanced data platform implementation at Alia Servizi Ambientali SpA yielded substantive outcomes across technological, operational, and organizational dimensions. These results validate the platform's effectiveness in addressing endemic inefficiencies, integrating heterogeneous data sources, and establishing robust capabilities for data-driven management within a traditionally fragmented sector.

5.1 Operational Efficiency & Technological Integration

The consolidation of disparate data assets into a medallion-based architecture enabled real-time data ingestion, automated ETL processes, and advanced analytics capabilities, significantly reducing processing latency and manual intervention while enhancing data reliability (Databricks, 2022; Armbrust et al., 2021). The integration of AI-driven anomaly detection and predictive routing algorithms transformed conventional static collection schedules into dynamic, demand-responsive operational workflows, demonstrating how embedded ML capabilities enhance operational agility beyond simple cost reduction (Gadde, 2020; Lanzalonga et al., 2024). The deployment of intuitive self-service dashboards empowered operational managers to execute data-informed decisions, consistent with Industry 4.0 principles of system responsiveness and iterative improvement.

5.2 Knowledge Creation & Organizational Learning

The establishment of a centralized data repository with comprehensive lineage tracking effectively dismantled historical information silos, enabling multidisciplinary teams to leverage trusted data assets for collaborative problem-solving initiatives (Vaio et al., 2021; Shadbolt & Milton, 1999). Personnel without technical expertise utilized self-service analytics tools to generate actionable insights independently, thereby accelerating organizational learning cycles. The resultant "knowledge loop," wherein operational feedback continuously refines predictive models, exemplifies how AI-enhanced platforms institutionalize dynamic capabilities, specifically, the systematic creation and application of knowledge, within routine operational processes (Oliva et al., 2019).

5.3 Ethical Governance & Cultural Transformation

The implementation established a comprehensive governance framework that ensured alignment between technical operations and organizational values, addressing critical concerns regarding data quality, security protocols, and algorithmic accountability (Jobin et al., 2019). Strategic investment in targeted training programs combined with democratized data access substantially improved organizational data literacy, facilitating a transition from experiential decision-making to evidence-based experimentation. This governance-by-design methodology not only maintained adherence to AI ethical standards and transparency requirements but also catalyzed a fundamental cultural evolution, fostering responsible innovation practices and strengthening Alia's collaborative partnerships through standardized, secure data exchange protocols (Dhanya et al., 2023).

6 Conclusion

This paper has presented a comprehensive analysis of the transformative impact of AI-enhanced data platforms on knowledge management practices within the waste management sector. Through detailed examination of the Alia Servizi Ambientali SpA case study, we have demonstrated that the integration of artificial intelligence and centralized data architectures produces substantial enhancements in operational efficiency, knowledge integration, and ethical governance frameworks.

The research makes three significant contributions to the existing body of knowledge. First, it provides empirical evidence that AI-enhanced platforms, through mechanisms such as predictive analytics and automated ETL processes, significantly optimize operational performance in resource-intensive industries. Second, it advances a theoretical framework that synthesizes technological, organizational, and ethical dimensions of knowledge management transformation, extending traditional KM models to address the complexities of the digital era. Third, it offers valuable comparative insights by contextualizing the case study within a broader cross-sectoral landscape, thus establishing the transferability of the integrated framework across diverse organizational environments.

Despite these contributions, several limitations warrant acknowledgment. The single-case design methodology, while facilitating in-depth analysis, constrains the generalizability of findings. Future research would benefit from multi-case comparative studies and longitudinal analyses to document the progressive impacts of AI integration on organizational knowledge processes. Furthermore, additional investigation into how AI-enhanced platforms contribute to sustainability objectives and circular economy initiatives would provide valuable insights, particularly given the increasing prominence of environmental responsibility metrics in contemporary digital transformation strategies.

In conclusion, the integration of AI-enhanced data platforms represents a critical evolution in organizational knowledge management practices. The Alia Servizi Ambientali SpA case illustrates that such technological innovations can concurrently enhance operational efficiency, cultivate a culture of continuous learning, and maintain robust ethical governance standards. As organizations across diverse sectors increasingly embrace digital transformation initiatives, the insights and integrated framework presented in this study offer practitioners a strategic blueprint for implementing sustainable and ethically grounded innovation in their knowledge management systems.

7 Ethics Declaration

This research did not involve human subjects or personal data requiring ethical clearance. The case study analysis of Alia Servizi Ambientali SpA was conducted with full organizational consent and in compliance with relevant data protection regulations. All organizational data was provided in anonymized and aggregated form under a formal research agreement. No additional ethical approval was required for this study.

8 AI Declaration

This paper utilized artificial intelligence tools during its development. Consensus was employed for literature review to identify and synthesize relevant scholarly sources. Anthropic Claude 3.7 Sonnet was used for text refinement to improve academic tone and clarity in specific sections. All AI-generated content was thoroughly reviewed and edited by the authors. The research design, data collection, analysis, interpretations, and conclusions were developed independently without AI assistance.

9 Acknowledgments

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The Role of AI and Emerging Technologies in Transforming Knowledge Management

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Abstract

Knowledge is one of the most valuable assets in modern organizations. However, its intangible and evolving nature makes it challenging to capture and leverage. Knowledge management (KM) is the organized, systematic process that acquires, refines, organizes, and applies this knowledge to improve organizational success and secure long-term competitive advantage. As data volume and complexity continue to grow, conventional systems have proven insufficient to harness the full potential of knowledge assets. As a result, emerging technologies have become indispensable, providing agile, scalable, and intelligent solutions. However, much of the existing research often examines these technologies in isolation, considering artificial intelligence (AI) and others as standalone entities, failing to reveal the synergies that emerge from combining them. This limitation is further complicated by the nature of common research approaches: literature reviews, while offering broad theoretical insights, are typically too abstract to inform practical application; meanwhile, case studies, though grounded in real-world scenarios, often lack generalizability due to their strong context-specific focus. This study addresses these gaps by investigating how AI and complementary, emerging technologies redefine KM areas. Drawing on 1,487 documented business practices—comprising case studies, pilot projects, and simulation models—derived from literature, this research focuses on five critical KM phases: knowledge creation, acquisition, organization, transfer, and application. Conceptually, knowledge is created or acquired, then captured, organized, and preserved for the long term, transferred to those who need it, and finally applied to produce value. Finally, these practices are analyzed through association analysis via Cramér's V to quantify the strength of relationships between AI (whether used alone or alongside other technologies), business functions and the different KM areas. Theoretically, the findings advance KM research by demonstrating which technological combinations are more effective in each KM phase. From a managerial perspective, the emerging practices examined in this study offer real-world examples of how these integrated solutions can be successfully deployed, allowing managers to draw from documented practices rather than starting from scratch.

Keywords: Artificial Intelligence, Emerging Technologies, Knowledge Management, Blockchain, Internet of Things.

Paper type: Academic Research Paper

1 Introduction

Data is everywhere. In today's interconnected world, large volumes of data are continuously produced from a wide range of activities and sources. This increasing data availability opens new opportunities for companies. Data consists of raw facts. When these facts are organized and given context, they become information, and eventually mature into knowledge when combined with experience, judgment, and practice (Bhatt 2001). Knowledge needs to be managed to fully realize its value. This is accomplished through knowledge management (KM). KM is the systematic process by which organizations accumulate, disseminate, and effectively use knowledge to secure a sustainable competitive advantage (Caputo et al. 2019). Traditionally, KM depended on document-based repositories and human expertise. While these approaches worked to some extent, recent technological advancements have caused a major transformation in how KM is practiced. Modern KM systems use digital solutions that help users find, share, and apply knowledge more easily (Malik et al., 2024). Notably, artificial intelligence (AI) has emerged as a crucial element in this process.

AI is defined as a system's ability to correctly process and interpret external data, learn from it, and use that learning to perform specific tasks (Liebowitz 2001). In doing so, AI can redefine how knowledge is generated, captured, and applied. AI can quickly analyze large amounts of data, spot subtle patterns that might otherwise remain hidden. AI can also automate repetitive tasks once reserved for human intelligence, freeing employees to spend more time on critical tasks (Iaia et al. 2024).

For KM systems to be truly intelligent and automated, AI needs to work in combination with other complementary technologies, such as the Internet of Things (IoT), blockchain (BC), and immersive environments (IMM). For example, IoT collects and transmit unstructured data from connected devices and sensors (Atzori et al. 2010). However, without AI, this information remains disorganized and hard to interpret. BC provides a secure

and transparent way to store data. Nevertheless, BC alone does not transform the data into knowledge. Moreover, IMM create interactive, multisensory learning experiences that can be tailored by AI to better match each user's needs (Speicher et al. 2018).

Despite the recognized importance of these technologies in KM, existing research still treats them separately. This approach ignores that modern organizations leverage multiple technologies simultaneously to improve their processes (Nascimento et al. 2021). This study aims to fill this gap by investigating how AI interacts with other technologies, including 3D printing (3DP), BC, computing (COM), digital applications (DA), geo-spatial tech (GEO), IMM, IoT, proximity tech (PT), open and crowd-based platforms (OCP), and robotics (ROB), to redefine KM. To this end, KM is broken down into five key processes: knowledge creation, acquisition, organization, transfer, and application. By considering exclusively case studies, pilot projects, and simulation models, this research extracts and classifies 1,487 emerging practices from literature. These practices illustrate real-world business applications in which AI and other technologies are deployed together in specific contexts, with each of them explicitly associated with one or more KM areas. Association analysis is first applied to investigate the linkage between AI, KM, and business functions. Subsequently, this analysis is extended to evaluate the interplay between AI, other complementary emerging technologies, and various KM phases, thereby clarifying the ways in which these technologies collaborate for improving KM strategies. From a theoretical perspective, this research contributes to the evolving discourse on KM by exploring how AI and other emerging technologies work together to redefine KM systems. Practically, the findings offer actionable insights for organizations seeking to implement AI in their KM processes effectively.

The remainder of the paper is structured as follows. The next section provides a theoretical background on KM, with a focus on how emerging technologies have influenced KM practices. The methodology section discusses the framework, and the sequential phases involved, while the results section presents descriptive statistics and key findings, followed by theoretical, methodological, and practical implications. The paper concludes with overall conclusions and limitations.

2 Theoretical Background

Knowledge is widely recognized as one of the most valuable assets an organization can hold. Accordingly, modern businesses are increasingly investing in KM to ensure that knowledge is effectively created, shared, and put to practical use (Davenport and Prusak 1998).

Knowledge manifests in various forms. Tacit knowledge refers to the implicit expertise that is inherently difficult to express or codify, whereas explicit knowledge is more accessible (Liebowitz 2001). Both forms of knowledge are critical to an organization's intellectual capital. Meanwhile, rapid digital transition has changed traditional knowledge flows within and between organizations. As a result, KM now operates across two distinct domains: the "human" space, in which personal experience and organizational interactions occur, and the "digital" space, where data is captured, processed, and stored (Cerchione et al. 2024).

This study views KM as a process consisting of five key phases: knowledge creation, acquisition, organization, transfer, and application. The process begins with creating new knowledge or capturing external knowledge, followed by structuring that knowledge into accessible formats. Whether it is through formal repositories or informal channels, this knowledge is shared and is put to work to solve business problems (Durst and Edvardsson 2012).

Nevertheless, managing knowledge remains an ongoing challenge due to the risk of losing tacit knowledge, information overload and persistent knowledge silos (Jarrahi et al. 2023). This is why emerging technologies have started to play an increasingly important role (Nascimento et al. 2021). Organizations today collect unprecedented volumes of data from transactions, customer information and online interactions. These heterogeneous data can be analyzed to extract valuable insights, effectively becoming a new source of knowledge. Moreover, modern firms increasingly use collaboration platforms and social media internally, expanding the modalities through which knowledge is shared (Nisar et al. 2019), while mobile devices and cloud-based services offer unprecedented connectivity and accessibility, allowing staff to access organizational knowledge anywhere, anytime.

Among these technologies, AI has had the most profound impact on KM in recent years, with scholars and practitioners noting its potential to both augment human capabilities and automate knowledge processes (Iaia et al. 2024). Cognitive augmentation allows AI systems to analyze and process enormous volumes of data at speeds far beyond human capability. At the same time, automation makes it possible for AI to take over routine knowledge tasks that previously required human presence (Jarrahi et al. 2023).

While the importance of AI in KM is widely recognized (Marvi et al. 2024), much of the existing research tends to investigate it in isolation, thereby missing the potential benefits that may be realized through its

integration with other emerging technologies. Previous studies have primarily taken two distinct approaches. On one hand, there are literature reviews and conceptual articles that examine specific technologies, especially AI, and their individual impact on KM processes (Jarrahi et al. 2023, Iaia et al. 2024). Conversely, other conceptual works explore broader themes for KM modernization, focusing on emerging technologies or the phenomenon of Industry 4.0 (Duarte Alonso et al. 2024, Nascimento et al. 2021). While these contributions are important, they tend to be too generic and primarily emphasize the theoretical linkages between technologies and KM, without providing sufficient detail on their practical implementation. On the other hand, numerous case studies have been published that present specific business applications, documenting how these technologies are deployed in real-world settings (Wang et al. 2023). However, these studies are inherently context specific. The practical insights gained from a particular organization or project may not be directly transferable to all companies. This research aims to bridge the gap between these two approaches by conducting a literature analysis that focuses exclusively on case studies, pilot projects, and simulation models. The goal is to examine the interplay between AI and a range of complementary, emerging technologies within KM using a two-step approach. First, an association analysis is conducted considering only the presence of AI. The objective is to evaluate how AI's implementation in certain business functions is linked to different phases of KM. In the second step, this analysis is extended to include all the other emerging technologies, making it possible to evaluate the strength of the associations between these technologies, when combined with AI, and different KM phases.

3 Methods

The primary goal of this study is to examine how AI and other emerging technologies can collaborate and reinforce one another to improve KM processes. The research method consists of three main stages. As illustrated in **Figure 1**, the proposed approach starts with an extensive literature analysis designed to identify emerging practices from literature, in which these technologies have been used to redefine one or more KM areas.

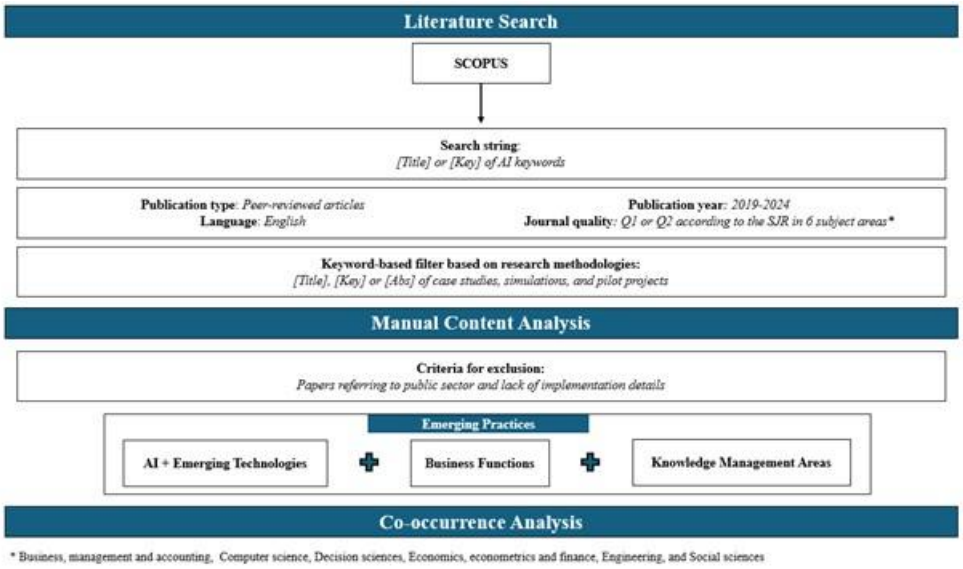


Figure 1 - Methodological steps.

The SCOPUS scientific database serves as the primary source. To cover all relevant articles, the researchers define a series of keywords for AI, using both common names and possible variations or synonyms. These keywords are then combined into search strings that look for the mention of at least one of these terms in either the "Title" or "Keywords" fields of each article. Figure 2 illustrates the complete list of all these keywords, along with the 10 additional emerging technologies that are under investigation in this study.

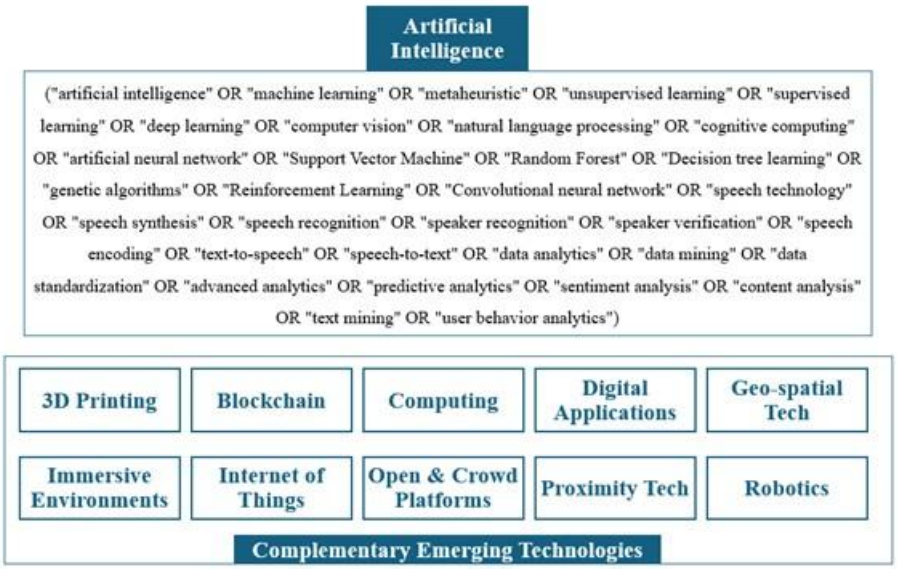


Figure 2 - Search query for AI-related articles and 10 complementary emerging technologies.

The initial SCOPUS search identifies 54,368 papers selected from leading journals in “business, management and accounting”, “computer science”, “decision sciences”, “economics, econometrics and finance”, “engineering”, and “social sciences”, focusing only on those ranked in Q1 and Q2 according to the Scimago Journal Ranking. To maintain relevance, only papers published between 2019 and 2024 are included. Once the initial pool of articles is retrieved, a preliminary filtering step is applied. Literature reviews, conceptual articles, survey-based or interview-based research, and those addressing technical issues are not considered. Instead, the focus is directed toward case studies, pilot projects, simulations, and mathematical models. To further refine the selection, a keyword-based filter is applied, integrating 233 specific strings—such as "case study," "pilot project," "experiment," "simulation," and "empirical evaluation”. Only studies mentioning at least one of these terms in their “Title,” “Abstract,” or “Keywords” are retained, reducing the initial number to 35,738. Subsequently, a team of 3 researchers with expertise in KM and technology management carries out a first evaluation of the remaining papers, discarding those that lack sufficient details or that address public sector issues. This further scrutiny brings the count to 10,988 articles selected for manual content analysis. After a rigorous evaluation, the final dataset results in 1,487 articles that demonstrate a clear connection to KM.

The selected articles are classified according along three dimensions: technologies implemented, business functions involved, and KM phases affected. The analysis encompasses AI and 10 other distinct technologies, which can operate either independently or in combination. Business functions are the activities a business performs to achieve its goals and objectives. Table 1 provides a concise description for all these different functions.

Table 1 - List of business functions considered in this study.

Business Function	Description
Accounting & Finance (A&F)	Covers financial activities such as accounting, budgeting, and investments.
Distribution (DIS)	Oversees transportation, warehousing, and logistics.
Govern. & Admin. (G&A)	Encompasses executive management and strategic business planning.
Human Resources (HR)	Focuses on workforce management and safety, and employee training.
Info. & Comm. Tech. (ICT)	Deals with the deployment and improvement of IT systems.
Marketing (MK)	Involves promotion, advertising, and customer relationship management.
Operations (OP)	Responsible for producing goods or delivering services.
Procurement (PRO)	Encompasses sourcing, purchasing, and supplier relationships.
Research & Develop. (R&D)	Focuses on research, product design and development, and prototyping.

In parallel, the study considers five fundamental KM processes. *Knowledge creation* refers to the generation of original ideas or solutions that did not exist before (Durst and Edvardsson 2012). In contrast, *knowledge acquisition* involves gathering existing knowledge from both internal and external sources (Migdadi 2021). Once collected, *knowledge organization* ensures that this knowledge is structured and categorized, while *knowledge transfer* makes it possible to disseminate this knowledge within or between organizations (Wang and Noe 2010).

Finally, *knowledge application* is the practical use of acquired or created knowledge to solve problems, inform decision-making, or complete tasks effectively (Schniederjans et al. 2020).

Figure 3 illustrates an example of emerging practice. Fang et al. (2024) propose a system that uses advanced AI to build an immersive augmented reality (AR) environment where multiple workers collaborate easily. This seamless integration of AR and AI for both visual and audio inputs help transfer knowledge instantly.

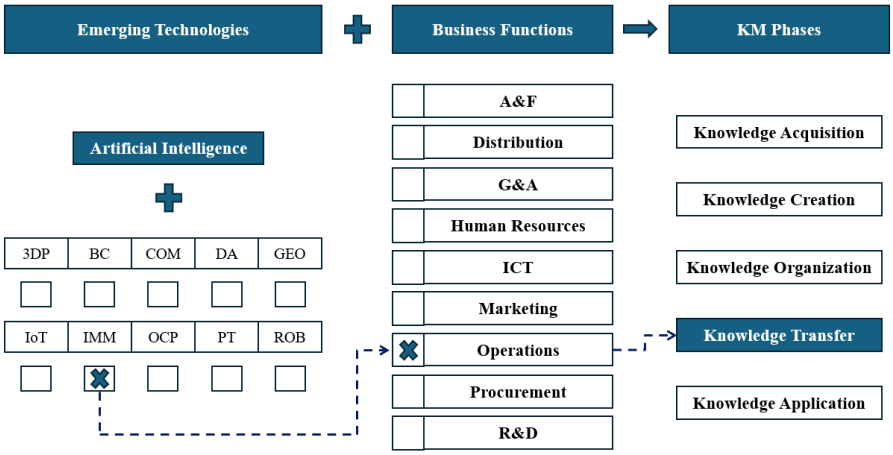


Figure 3 - Example of emerging practice.

Subsequently, the final dataset undergoes an exploratory investigation designed to reveal the connections among KM areas, AI, and the other emerging technologies examined in this study. To this end, an association analysis is conducted. This statistical method is used to uncover hidden associations or dependencies between two or more variables that occur together (Colliander and Ahlgren, 2012). Central to this analysis is the Cramér's V measure, a statistical measure used to assess the strength of the associations among variables.

The Cramér's V measure produces a value ranging from 0 to 1. Values near 0 indicate that there is little to no association between the variables. Conversely, values closer to 1 signify a strong association.

4 Results

4.1 Descriptive statistics

This section presents descriptive statistics for each variable. Table 2 shows the number of practices classified by macro-technology. Nearly half of the cases involve the use of AI in isolation, while the remaining combine AI with other technologies. Among the latter, more than one-third of the total cases incorporate IoT, and a similar share utilizes DA, highlighting the critical role of real-time connectivity and user-centric interfaces in modern KM strategies. In addition, around one in five practices rely on COM to support robust data processing, with even fewer adopting IMM to boost employee engagement or BC for information security.

Table 2 - Emerging practices by macro-technology.

Label	#	%
Artificial Intelligence (only)	**739**	**49.70%**
Artificial Intelligence (in combination)	**748**	**50.30%**
Digital applications	285	38.10%
Internet of Things – 5G	278	37.16%
Computing	154	20.59%
Immersive environments	125	16.71%
Robotics	90	12.03%
Blockchain	70	9.36%
Open & crowd platforms	43	5.75%
Geo-spatial tech	30	4.01%
Proximity tech	19	2.54%
3D printing	16	2.14%
Total	**1,487**	

Table 3 presents the practices distributed by business function. Operations (OP) clearly dominate, with over half of the cases focused on optimizing daily processes where knowledge is actively applied. Research & development (R&D), marketing (MK) and governance & administration (G&A) each hold nearly equal shares, signaling that these functional domains are benefiting from these KM initiatives. The smaller percentages for functions like human resources (HR), distribution (DIS) and accounting & finance (A&F) indicate that, although these areas are not the primary focus, they still receive attention in KM strategies. This reinforces the idea that KM is not confined to a single department but is a cross-functional priority.

Table 3 - Emerging practices by business function.

Label	#	%
Operations	924	62.14%
Research & development	290	19.50%
Marketing	276	18.56%
Governance & administration	274	18.43%
Information & communications technology	222	14.93%
Human resources	53	3.56%
Distribution	49	3.29%
Accounting & finance	28	1.88%
Procurement	9	0.60%
Total	**1,487**	

Table 4 categorizes emerging practices by the phase of KM they influence. Knowledge acquisition is the leading one, suggesting that the primary aim is the gathering of new information and insights from both external and internal sources. The near-equal focus on knowledge organization and transfer demonstrates that companies are equally committed to structure the acquired or created knowledge and ensure it is effectively disseminated across the organization. On the other hand, the lower emphasis on knowledge application and creation point to challenges in pushing the boundaries of current knowledge and translating this into practical actions.

Table 4 - Emerging practices by KM phase.

Label	#	%
Knowledge acquisition	353	23.73%
Knowledge organization	342	23.00%
Knowledge transfer	335	22.52%
Knowledge application	299	20.11%
Knowledge creation	265	17.82%
Total	**1,487**	

4.2 Association analysis

Figure 4 illustrates the Cramér's V values derived from the association analysis in a bubble chart. The size of the bubbles indicates the strength of the association showing which functions are more closely linked to each KM phase.

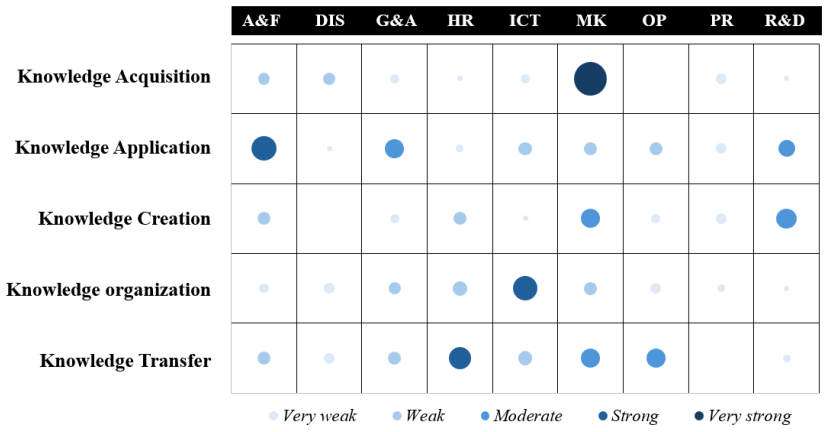


Figure 4 – Associations between KM phases and business functions in AI practices.

Their interpretation follows the guidelines proposed by Akoglu (2018), which categorize these values into very weak, weak, moderate, strong, and very strong levels.

In the *knowledge acquisition* phase, AI plays a major role in actively sourcing and processing new knowledge, especially in MK. Joung & Kim (2023) demonstrate this by proposing an interpretable machine learning approach that analyzes online reviews to extract and quantify product features.

In the *knowledge application,* AI's impact becomes even more evident. Across various organizational functions, AI integrates new knowledge, albeit with varying degrees of impact. Most functions exhibit a weak to moderate association; however, the A&F domain deviates from this pattern. For example, Kwon & Lee (2024) introduce a trading system that combines traditional expert rules with deep reinforcement learning.

K*nowledge creation* shows significant differences among functions, with R&D strongly benefiting from AI's ability to connect dots that might otherwise be missed. For instance, Liu et al. (2022) develop a framework for product design that employs machine learning to construct design-specific knowledge graphs.

In the *knowledge organization* phase, the focus is on structuring and preserving information effectively. ICT stands out in this stage, as demonstrated by Gao et al. (2023) through a relation extraction framework used for drug instructions. Their model accurately captures subtle semantic nuances to build robust medical knowledge bases with limited high-quality annotated data.

Lastly, in the *knowledge transfer* phase, AI proves important for disseminating knowledge, particularly in HR settings. Kakdas et al. (2024) propose a novel 3-D simulation framework that integrates reinforcement learning to train medical staff in proper personal protective equipment protocols.

In the second step of the analysis, the focus shifts to exploring the role of complementary emerging technologies and their contribution to KM. Figure 5 presents the Cramér's V values from the association analysis in the form of five radial charts. Each chart represents a distinct phase of KM and plots various emerging technologies (integrated with AI) along individual axes, with the length of each axis indicating the strength of the association.

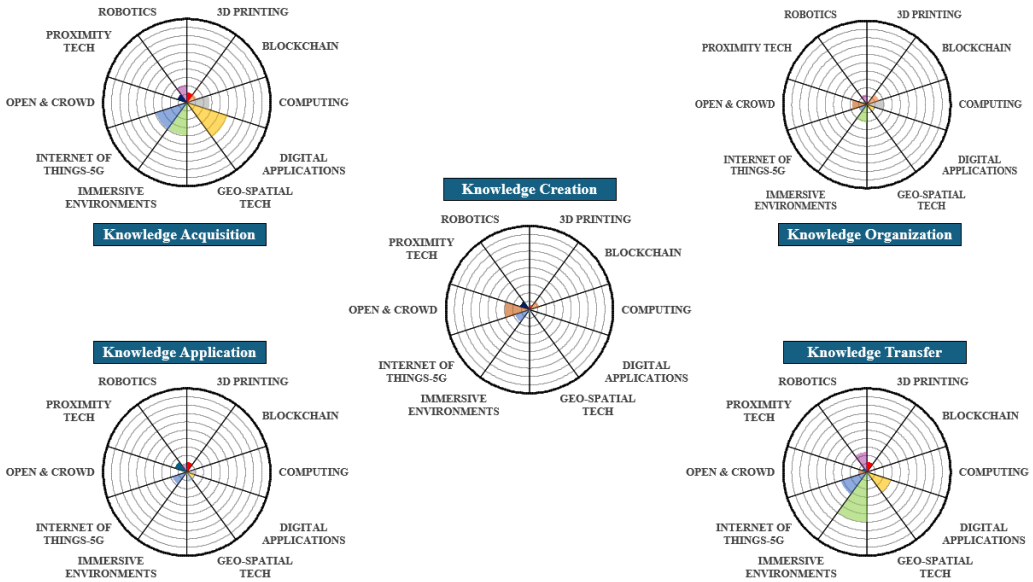


Figure 5 - Associations between complementary technologies and KM phases in AI practices.

The *Knowledge acquisition* phase clearly benefits from DAs that leverage AI to capture, filter, and interpret diverse information streams. For example, Shahzad et al. (2024) propose an AI-chatbot that traduces everyday customer feedback into strategic, actionable knowledge that strengthens e-brand loyalty in the luxury fashion sector.

Knowledge creation is closely associated with open and crowd-based platforms, combining AI with external and internal contributors. For instance, Poser et al. (2022) introduce an AI-based conversational tool that facilitates knowledge creation in open innovation environments.

The *knowledge organization* phase does not depend on a single dominant complementary technology outside od AI. Luo et al. (2023) illustrate this by offering a convolutional neural network–based text classification framework tailored for construction accident reports.

Similarly, *knowledge application* sees no single complementary technology clearly standing out, with AI continuing to be essential in transforming knowledge into concrete practice. For example, Panigutti et al. (2023) propose a co-designed, human-centered explainable AI system for clinical decision support systems.

Knowledge transfer registers the strongest associations with IMM and ROB. For instance, C. Liu et al. (2023) present an integrated human–robot collaboration approach that blends a mixed perception module with online deep reinforcement learning and an AR interface to capture tacit maintenance expertise and transfer that knowledge efficiently between skilled operators and collaborative robots in complex manufacturing environments.

5 Discussion

5.1 Theoretical implications

KM has been widely recognized as one of the critical determinants driving organizational success, particularly in contexts characterized by rapid technological evolution. Despite existing research acknowledging the potential of AI in KM processes (Jarrahi et al. 2023, Iaia et al. 2024), the understanding of how AI interacts with other emerging technologies to impact KM remains limited. Specifically, previous studies have examined these technologies in isolation, neglecting the fact that organizations typically deploy them simultaneously (Nascimento et al. 2021). This research addresses these limitations by examining the intersection of AI with ten complementary, emerging technologies across five essential KM phases. To this end, this study analyzes 1,487 documented business practices derived from literature. Association analysis is then employed to measure the strength of relationships between the various phases of KM and associated business functions, focusing only on AI practices, as well as between specific technological combinations and KM processes.

The analysis reveals that AI is strategically utilized across all business functions in KM strategies. In some cases, AI is implemented in isolation, as highlighted by Jarrahi et al. (2023); in others, its impact is enhanced when integrated with other complementary emerging technologies. Certain combinations are not uniformly beneficial across all KM processes; rather, their impact varies significantly based on the specific KM phase. For example, combining AI with DA effectively streamlines knowledge acquisition from external sources, while the integration of AI with IMM significantly improves knowledge transfer. Similarly, the use of AI alongside open and crowd-based platforms enriches the process of knowledge creation by leveraging the power of collective intelligence.

Notably, in the knowledge application and organization phases, AI tends to exhibit strong standalone capabilities, underscoring its intrinsic ability to organize and apply knowledge effectively, as noted by Marvi et al. (2024). This extends current understandings of AI's role in KM by demonstrating that, while certain technology combinations yield considerable benefits in specific phases, the unique strengths of AI are indispensable in others, further emphasizing its intrinsic value.

5.2 Methodological contributions

The methodology in this study offers significant advantages over traditional approaches in the KM literature by constructing an extensive dataset composed of documented business practices. Following the approach adopted by Cammarano et al. (2024), this study extracts case studies, simulations, and pilot projects from rigorously peer-reviewed academic articles, which inherently ensures a high standard of reliability, originality, and relevance. Business practices are classified along three key dimensions: the specific emerging technologies deployed, the business functions affected, and the KM areas involved. To achieve this, the research builds upon and revisits previous classifications in the KM literature (Marvi et al. 2024, Jarrahi et al. 2023), resulting in the definition five fundamental processes—creation, acquisition, organization, transfer, and application. These processes capture the full spectrum of KM activities. Unlike conventional literature reviews that merely summarize the current state of research, this study explicitly aims to create a practical database that serves as a robust foundation for subsequent analyses. In particular, the study employs association analysis—a quantitative statistical method that measures the strength of relationships between categorical variables— to provide a rigorous empirical basis that moves beyond basic descriptive statistics.

5.3 Recommendations for managers

Given the strategic importance of KM in today's highly competitive environment, this research provides critical insights for managers who contend with so many uncertainties and risks when investing in emerging technologies. To optimize their investment decisions, they require clear and actionable guidance. This study

addresses these problems by first determining which business functions derive the greatest benefit from AI implementation, and then it identifies the most effective technological combinations for improving specific KM phases. Ultimately, the research provides a robust analytical framework that allows managers to benchmark their current KM initiatives against empirically validated emerging practices. By doing so, they can identify gaps in their current approaches, evaluate the effectiveness of their systems, and prioritize investments in areas where the potential for improvements is greatest.

6 Conclusions

This study examines the transformative role of AI and its integration with other emerging technologies in redefining KM. Using a dataset of real-world business applications from scientific literature, the research shows that specific technological combinations lead to significant improvements in KM practices across various phases. For instance, AI paired with DA profoundly improves knowledge acquisition, while IMM and ROB excel in facilitating dynamic knowledge transfer. These findings provide a strong empirical basis for developing tailored KM strategies, as managers can leverage these results to optimize their strategic investments and align their technological choices with the most pressing needs of each KM area.

Nevertheless, several limitations should be carefully acknowledged. The extensive body of literature makes it impractical to comprehensively analyze every potentially relevant academic contribution, resulting in an inevitable partial perspective of the phenomenon. Although rigorous selection procedures are adopted, manual screening and classification remains time-consuming and carries the risk of subjective bias. Furthermore, relying exclusively on SCOPUS-indexed academic journals may exclude relevant studies from non-indexed sources.

Future research might benefit from leveraging AI-based techniques to automate the article classification. Additionally, longitudinal studies will make it possible to track the evolution of these technologies and their long-term impact on KM. In parallel, researchers should explore mixed method approaches that combine advanced machine learning analysis with in-depth case studies.

7 Ethics declaration

This research did not involve human participants, animals, or sensitive data requiring ethical approval. Therefore, ethical clearance is not required.

8 AI declaration

Generative AI tools were used to assist in language editing and improving clarity. The authors reviewed and edited all AI-generated content to ensure accuracy and integrity. The final manuscript reflects the authors' own work and interpretations.

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Do Organizations Struggle to Implement AI in Knowledge Management Systems? Initial Empirical Insights

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Abstract

Previous studies have highlighted the numerous benefits of artificial intelligence (AI) models in enhancing the management of organizational knowledge assets. However, the adoption of AI in organizational settings often encounters significant barriers that hinder its optimal implementation. This paper presents preliminary findings from a timely study that uniquely focuses on the perceived obstacles at the intersection of AI and knowledge management (KM) in organizations. Our objective was to understand the perspectives of employees and managers regarding four dimensions of barriers and challenges in integrating AI technologies into knowledge management systems (KMSs) in business: human, technological, financial, and ethical-regulatory. A voluntary and anonymous online questionnaire was completed by 378 respondents from various industries. The results reveal that financial barriers were reported to be the least significant by both regular employees and managers. Instead, nearly half of the participants expressed concerns about technical barriers, particularly the inadequacy of their organizations' technological infrastructure to support AI applications effectively. A significant percentage of 82.28% of the sample mentioned organizational barriers, specifically noting that employees lack the necessary skills to leverage AI for enhancing organizational KM. Furthermore, nine out of ten respondents indicated that a substantial cultural shift is essential for facilitating AI adoption within their organizations. Concerns about the potential leakage of sensitive information due to AI usage were significant, with approximately two-thirds of respondents highlighting this issue. Additional ethical barriers were prominent, with three out of four participants reporting a lack of clear organizational procedures to ensure information security and privacy in AI applications. These findings have significant theoretical and practical implications for the discipline of KM in general, and for KMSs in particular. These findings lay a fertile ground for future empirical investigations into the relationship between AI and KM.

Keywords: Artificial Intelligence, AI Adoption, Technology Adoption, Challenges, Implementation, Knowledge Management Systems

Paper type: Academic Research Paper

1 Introduction

Artificial intelligence (AI) has emerged as a transformative technology with the potential to revolutionize various industries (Arias-Pérez and Vélez-Jaramillo, 2022; Dwivedi et al., 2021; Kar et al., 2021), capturing the interest of knowledge management (KM) scholars (Jallow et al., 2020; Nakash and Bolisani, 2024). With the rapid advancement, power, and versatility of generative AI (GenAI), its impact on knowledge creation, storage, transfer, and application is becoming increasingly evident (Alavi et al., 2024). Despite the intrinsic link between AI and KM, the symbiotic relationship between these multidisciplinary fields has not been thoroughly explored and remains fragmented (Bencsik, 2021; Nakash and Bolisani, 2024; Pimentel and Veliz, 2024; Jallow et al., 2020; Zbuchea et al., 2019). Consequently, scholars have emphasized the critical need for collaborative and convergent research at the intersection of KM and AI (Melina et al., 2024; Mohammad et al., 2022; Sundaresan and Zhang, 2022; Taherdoost and Madanchian, 2023).

Recent research has underscored the numerous advantages of AI systems in enhancing the management of organizational knowledge assets. AI can automate knowledge discovery, facilitate advanced data analysis, and support decision-making by providing insights derived from large datasets (Alavi et al., 2024; Al Mansoori et al., 2020; Bencsik, 2021; Kirchner et al., 2024; Pimentel and Veliz, 2024; Vadari and Desik, 2021; Zhou, 2022). However, the adoption of AI within organizational contexts can face significant barriers that may hinder its effective implementation (Alsheiabni et al., 2019; Ambati et al., 2020; Dwivedi et al., 2021; Hamm and Klesel, 2021; Kar et al., 2021; Makridakis et al., 2023; Sun and Medaglia, 2019).

AI adoption refers to the process of integrating AI technologies within an organization, that can be a complex phenomenon influenced by various factors (Radhakrishnan and Chattopadhyay, 2020). Extensive literature highlights the multifaceted nature of obstacles to AI adoption (Kar et al., 2021). Additionally, different stakeholder groups may present conflicting views regarding AI, further complicating the adoption process (Sun and Medaglia, 2019). However, there remains a lack of sufficient empirical studies addressing the "inhibitors to

AI implementation" in organizational settings (Alsheiabni et al., 2019). This gap also extends to knowledge management systems (KMSs) (Nakash and Bolisani, 2024), which are technological systems designed to assist in the organization, storage, sharing, and utilization of knowledge within an organization (Al Mansoori et al., 2021). In principle, AI can support companies in their KM processes and can also open new perspectives on how different elements of knowledge, including explicit and tacit contents, can be treated by technologies (O'Leary, 2024; Taherdoost and Madanchian, 2023).

To address the gap in the literature, this paper presents some preliminary findings from a timely study on the perceived obstacles to AI adoption in KM within organizations. Our objective was to explore the perspectives of employees and managers regarding four dimensions of barriers and challenges to integrating AI technologies into KMSs: human, technological, financial, and ethical-regulatory barriers. This understanding is crucial as it provides valuable insights into the practical difficulties of AI integration with KMSs, which can inform the development of more effective implementation strategies.

2 Theoretical Background: Barriers and Challenges to AI Adoption

2.1 Human

Previous studies have emphasized the critical role of human factors in AI implementation, with a recurring theme in the literature being the potential resistance to change, deeply rooted in organizational culture. Employees may fear job displacement or feel threatened by the introduction of intelligent robots, leading to resistance, knowledge hiding, and lack of cooperation (Arias-Pérez and Vélez-Jaramillo, 2022; Malik et al., 2023; Vasiliu and Yavetz, 2024). Concerns extend beyond potential negative impacts on career prospects (Lingmont and Alexiou, 2020) to include doubts about the accuracy and reliability of AI tools, which can hinder their effective use (Alavi et al., 2024; Sun and Medaglia, 2019).

2.2 Technological

Technological challenges encompass the lack of transparency in AI algorithms and the difficulties AI systems face in processing unstructured data (Sun and Medaglia, 2019), as well as in understanding the depth of implied relationships (Nakash, 2024). AI technologies, such as machine learning and natural language processing, require sophisticated algorithms and significant computational power (Alhosani and Alhashmi, 2024; Taherdoost and Madanchian, 2023). Integrating these technologies into existing KMSs can be technically challenging, especially in managing tacit knowledge (Zhou, 2022). Furthermore, AI models heavily rely on large volumes of high-quality data. Ensuring the availability, accuracy, and completeness of data in the organizational systems is a critical challenge, as poor data quality can lead to suboptimal AI performance (Makridakis et al., 2023; O'Leary, 2024; Tarafdar et al., 2019).

2.3 Financial

Economic challenges encompass barriers related to profitability and economic sustainability, which hinder the adoption of AI (Sun and Medaglia, 2019). The widespread implementation of AI technologies could have a significant economic impact on organizations, particularly in terms of the required investments and changes in operational methods (Dwivedi et al., 2021). The development, deployment, and maintenance of AI technologies require substantial financial investment, especially when integrating with other systems. Organizations must invest in advanced hardware, software, and infrastructure to support these technologies (Alhosani and Alhashmi, 2024). Moreover, the cost of recruiting and retaining skilled AI professionals can be high, adding to the financial burden (Tarafdar et al., 2019).

2.4 Ethical-Regulatory

In contrast to humans, AI systems lack self-awareness and the capacity for self-reflection (Jarrahi et al., 2023). Ethical and regulatory concerns are increasingly recognized as major obstacles to AI adoption due to fears of unfair or discriminatory outcomes, and errors in predictions (Feuerriegel et al., 2020). Issues such as data privacy, algorithmic bias, and knowledge misapplication pose significant challenges (Alavi et al., 2024; Alhosani and Alhashmi, 2024; Makridakis et al., 2023; Malik et al., 2023; Pimentel and Veliz, 2024). Furthermore, regulatory frameworks such as the GDPR often lag technological advancements, creating uncertainty and risks for organizations (Feuerriegel et al., 2020). The issue of accountability in the event of errors caused by AI systems has also been a subject of discussion (Dwivedi et al., 2021).

3 Research Framework

A voluntary and anonymous online questionnaire was completed by 378 respondents from various roles in companies of different sizes and sectors (including public and private services, manufacturing, and high-tech industries), all within a single country. Gender-wise, the study included 47.4% men and 52.6% women. Among the respondents, 67.5% held academic degrees, and 56.1% were in managerial positions. Additionally, 57.1% were over the age of 40, and 37.1% had more than 10 years of organizational seniority.

Based on the literature, and alongside the collection of demographic and employment information, the developed questionnaire included four types of barriers and challenges to AI adoption for KM: human, technological, financial, and ethical-regulatory. Each type was assessed through respondents' agreement with five statements on a 6-point Likert scale, ranging from 1 (strongly disagree) to 6 (strongly agree). **Table 1** provides examples of statements for each type of obstacle.

Table 1. Key Examples of Likert Scale Statements, Categorized by the Four Barriers and Challenges

Types of Barriers and Challenges	Example of a Statement
Human	Knowledge managers in my organization fear a loss of personal value with the widespread implementation of AI in KM processes
Technological	AI models are not accurate enough for acquisition, documentation, sharing, and application of the organizational knowledge
Financial	The cost of purchasing, implementing, and maintaining AI solutions for KM is too high for my organization
Ethical-Regulatory	Biases and hidden discrimination may seep into the decision-making process due to mistaken interpretation of reality by the algorithms

The questionnaire underwent reliability and validity testing. It is important to acknowledge that the results presented in this paper are derived from preliminary analysis, that offers a foundational insight into the barriers and challenges associated with AI adoption in the KMSs context. Nonetheless, they constitute merely the initial phase of an extensive research endeavor, which will continue with the application of in-depth statistical analyses to examine the impact of demographic and occupational variables on perceptions.

4 Preliminary Findings and Interpretation

The results indicate that comparatively, financial barriers and challenges to implementing AI in KMSs were reported less frequently than human, technological, and ethical-regulatory obstacles. This finding may initially appear counterintuitive, as financial constraints are traditionally perceived as significant impediments to the adoption of advanced technologies. However, this can be explained by the growing trend towards open-source AI solutions, which have gained substantial traction in recent years, thereby lowering the financial barriers to entry for many organizations. It is possible that this shift allows organizations to leverage advanced AI capabilities without the traditionally exorbitant investment in proprietary technologies.

This trend was also reflected particularly among managers, who perceived fewer financial obstacles compared to employees. This difference can be attributed to the broader strategic perspective of managers, who are likely to focus on long-term benefits and the alignment of AI with organizational goals, rather than immediate financial constraints. Accordingly, a very small minority of respondents—less than 4% (n=15)—completely dismissed the notion that the costs associated with acquiring, implementing, and maintaining AI for KM are prohibitively high for their organizations. This minority viewpoint reflects a forward-thinking approach, where AI is seen as a long-term investment rather than an immediate financial burden.

From a technological perspective, nearly half of the sample (47.62%) expressed significant (n=89) or very significant (n=91) concerns about their organization's inadequate technological infrastructure to support AI applications effectively. This finding emphasizes the critical role that technological readiness plays in the successful implementation of AI-driven initiatives. Insufficient computational power, outdated systems, limited data storage and processing capabilities, or a lack of integration between existing systems and AI platforms could all contribute to these concerns. Inadequate infrastructure may not only hinder organizations from realizing the full value of AI for KM, but could also lead to implementation failures, wasted resources, and a loss of competitive advantage. Therefore, this finding underscores the need for organizations to prioritize infrastructure development as a fundamental prerequisite for AI adoption.

In terms of human capital, a significant majority of respondents (n=311, 82.28%) expressed varying levels of agreement that employees within their organization lack the necessary skills to effectively leverage AI for enhancing organizational KM (see **Figure. 1**).

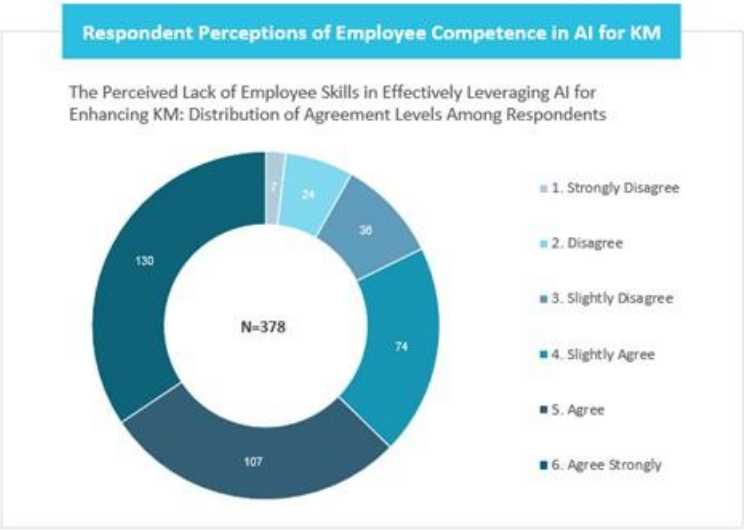


Figure 1: Levels of agreement with the statement:
"Employees currently lack the necessary skills to fully utilize AI for enhancing KM"

The widespread perception of a skills gap underscores the complexity of AI technologies, and the specialized expertise required to harness their full potential for KM. AI's transformative power in KM lies in its ability to automate knowledge discovery, streamline processes, and provide data-driven insights. However, achieving these outcomes depends heavily on the proficiency of the workforce in understanding, interacting with, and applying AI tools. The lack of necessary skills among employees can severely limit the effectiveness of AI implementations, as employees may struggle to navigate the technology, interpret its outputs, or adapt their workflows to maximize its benefits. This finding suggests a broader need for organizations to invest in targeted training and development programs aimed at building AI literacy and technical proficiency among their employees.

Moreover, an overwhelming 9 out of 10 respondents (n=343, 90.74%) indicated that a significant cultural shift is required to facilitate the adoption of advanced AI applications within their organizational environment (see **Figure 2**). This underscores the deep-rooted influence of organizational culture on the successful integration of AI technologies in KMSs, suggesting that more than just technological upgrades or skills development are needed.

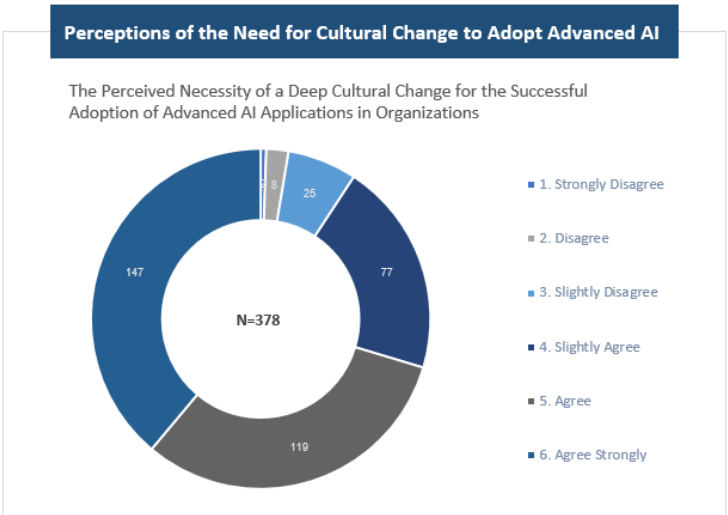


Figure 2: Levels of agreement with the statement:
"A deep cultural change is required to adopt advanced AI applications in the organization"

The call for a profound cultural shift highlights the psychological and emotional barriers that often accompany AI adoption. As indicated in qualitative responses from several participants to an open-ended question we asked, notable apprehension exists regarding job security, with some employees expressing fears that AI could render their roles obsolete or irrelevant. To address these concerns, organizational culture must

evolve to foster an environment where employees feel secure in engaging with AI technologies. Building trust and promoting a sense of inclusion in the AI transition process are essential to mitigating these fears.

Further, approximately two-thirds of respondents (67.20%) expressed significant (n=115) or very significant (n=139) concerns that AI could potentially lead to the leakage of sensitive information from organizational systems. This highlights a critical issue in AI adoption, as it underscores pervasive fears surrounding data security and privacy risks. The finding suggests that trust in AI technologies is not yet fully established within organizational sets. Employees may be uncertain about the robustness of AI security measures or skeptical about the ability of these systems to safeguard critical information. This uncertainty may be exacerbated by a lack of transparency regarding how AI systems operate, how data is protected, and who has access to that data. To address these concerns, organizations must not only implement stronger security protocols for AI systems but also communicate these safeguards clearly and effectively. Building trust in AI technologies is essential for their successful adoption, particularly when handling sensitive data.

In this context, 3 out of 4 respondents (n=273, 72.22%) reported a lack of clear organizational procedures for ensuring information security and privacy in AI applications. This finding underscores a significant gap in AI governance and oversight within many organizations. The absence of well-defined protocols for managing data security and privacy signals that organizations may not yet be fully prepared to mitigate the risks associated with AI implementation. This lack of governance could hinder their ability to deploy AI safely and responsibly, underscoring the need for comprehensive AI governance strategies that address security, privacy, and ethical considerations.

5 Conclusions

The findings presented in this paper are preliminary and highlight several critical obstacles to the successful adoption of AI in KMSs. While financial barriers were reported less frequently than anticipated, human, technological, and cultural challenges emerged as significant impediments. These challenges are deeply interconnected, with each having critical implications for the successful integration of AI technologies into KMSs.

First and foremost, the importance of technological readiness cannot be overstated. A significant portion of respondents reported concerns regarding inadequate technological infrastructure. This highlights the need for organizations to invest in upgrading their existing IT systems, enhancing computational capabilities, and ensuring seamless integration between AI and their KMS platforms. In addition to infrastructure, the human element remains a critical factor in AI adoption. The widespread perception of a skills gap among employees suggests that organizations must prioritize workforce development, emphasizing the importance of building AI literacy and technical proficiency at all organizational levels.

The cultural dimension of AI adoption emerged as a key finding, with the vast majority of respondents recognizing the necessity for a profound cultural shift to embrace AI technologies for enhancing KM. This underscores that AI adoption is not merely a technological upgrade but a transformational change impacting all facets of organizational life. AI challenges existing norms and practices, particularly in KM, where human expertise has traditionally been central. Furthermore, the study highlights significant concerns regarding data security and privacy in AI applications, especially within the context of KMSs, where sensitive organizational knowledge and intellectual property are at stake.

6 Outlook

This is a preliminary study that nonetheless opens the possibility of implementing further analyses. First, extending the analysis to other areas could be useful in highlighting country-specific differences. Second, a more thorough statistical analysis (for example, a cluster analysis) can help identify categories of potential business users based on their perceived challenges. Third, future studies should explore the specific technological requirements for AI integration in KMSs and develop best practices for organizations at various stages of technological maturity.

7 Ethics Declaration

This study was conducted in accordance with the ethical standards of the Institutional Ethics Committee. The participants provided informed consent prior to their inclusion in the study, ensuring confidentiality and anonymity.

8 AI Declaration

The authors confirm that no AI tools were used in the creation of this manuscript. All research, analysis, and writing were conducted manually, adhering to the highest standards of academic integrity.

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AI-driven Value Creation in Innovation Ecosystem, insights from Stakeholder Theory

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Abstract

In the era of Industry 5.0, artificial intelligence offers new opportunities for co-creation, personalization, collaboration and integration. These affect companies' Business Model Innovation strategies, supporting progress in the interactions between sets of actors, populations, activities, institutions and networks impacting the entire innovation ecosystems. Positioning itself in the research stream focused on analysing the impact generated by emerging technologies in the innovation of business ecosystems, this study aims of discussing the impact generated by artificial intelligence in business model innovation, reflecting on the salience of the involved stakeholders. A three-phase methodological approach was used, integrating a systematic literature review with a case study analysis. The related findings were discussed according the stakeholder theory basing on the salience attributes of power, legitimacy and urgency. This approach allowed us to establish a strong theoretical foundation while anchoring our findings in real-world example. Seven artificial intelligence-based value creation innovations were identified, demonstrating how artificial intelligence-based applications are transforming value creation mechanisms. Findings indicate that artificial intelligence has the potential to generate significant added value, primarily by enhancing value creation through data exploitation and the high degree of services customization tailored to customer needs. Moreover, new value streams emerge from artificial intelligence-based applications, driven by the widespread adoption of the technology across innovation ecosystems. This diffusion influences and engages stakeholders at every layer of the ecosystem's structure. Stakeholders are classified as Discretionary (Standards Bodies, Public Bodies), Demanding (Distribution Channels, Research Institutes), Dangerous (other suppliers), Dependent (Suppliers), Definitive (Core Organization, Customers, Complementors). Notably, no stakeholders were identified that align with the Dormant or Dominant categories.

Keywords: Stakeholder Identification and Salience, Society 5.0, Advanced technologies, Business Model Innovation, Value strategies.

Paper type: Academic Research Paper

1 Introduction

In the era of Industry 5.0, in which human involvement within innovation and technological advancement is placed at the forefront (Troisi et al., 2023), firms are increasingly relying on Artificial Intelligence (AI), and managers are trying to leverage on it with the aim of identifying and managing new business models (Wellers et al., 2008). AI is an enabling technology that can be integrated in products and systems and can provide a beneficial service for customers in various parts of the supply chain (SC) (Teece, 2018). For example, AI offers new opportunities for co-creation (Sewpersadh, 2023), personalization (Cao, 2021), collaboration and integration (Latinovic and Chatterjee, 2022), affecting companies' Business Model Innovation (BMI) strategies, and supporting progress in the interactions between sets of actors, populations, activities, institutions and networks that characterise the Innovation Ecosystems (IEs) (Granstrand and Holgersson, 2020). IEs are complex systems of individuals, businesses, governments and institutions in which Society 5.0 strives to foster innovation, generating opportunities for new businesses and stimulating the economic growth (Oh et al., 2020). Therefore, IEs includes actors, activities, and artifacts. Dias Sant´Ana et al., (2020), in their literature review, examine the IE by describing it through a triple-layer structure and mapping the actors operating within each layer. According to them, the first layer of IE is the *core business layer,* which comprises the central entities driving the business. This layer includes actors such as the core organization, suppliers and distribution channels. In traditional models, it is typically managed by a single company or coordinated by a focal organization within the SC. Alternatively, it can consist of a network of multiple organizations, each responsible for different aspects of the core business. The second layer of IEs is the *extended enterprise layer*, which broadens the business perspective to encompass customers, complementors, other suppliers, and regulatory or standard-setting bodies relevant to the field. The third and outermost layer, *other group of actors*, incorporates a diverse range of entities such as trade associations, labor unions, universities, research institutions, investors, and other stakeholders. Although these actors may not be directly involved in day-to-day operations, they can significantly influence the success and the evolution of the business ecosystem. Technology plays a critical role in IEs, particularly in

facilitating the dissemination of information and innovation (Oliveira and Trento, 2021). Disruptive technology, such as AI (Palmié et al., 2020; Barile et al., 2024), have the potential to impact all ecosystem actors, reconfiguring relationship, revitalizing processes, and enhancing the overall resilience of the ecosystem (Burström et al., 2021). Positioning itself within the research stream that investigates the impact of emerging technologies on the business ecosystems innovation, this study aims of exploring how AI influences BMI, with a particular focus on the salience of the actors involved. The study is guided by the following research questions (RQs): *How is AI transforming Value Creation (VC)? How does this transformation affect the actors within the business ecosystem?*

2 Research Methodology

A three-phases research methodology was adopted. In the first phase, a systematic literature review was conducted to define the research boundaries and identify a comprehensive list of AI-based VC innovations. The review followed the PRISMA guidelines, resulting in a final sample of 195 papers analysed through content analysis (Figure 1). In the second phase, the list of AI-based VC innovations, was explored through a case study, aimed at comparing theoretical expectations with real-world practices. The case study, focused on the energy sector, chosen for its intensive adoption of AI technologies (Serban & Lytras, 2020; Lyu & Liu, 2021), and involved a series of interviews with employees from an energy company. A semi-structured interview format was adopted to maintain alignment with the core research themes while allowing flexibility to delve into emerging insights (Adeoye-Olatunde and Olenik, 2021). Finally, in the third phase, the findings were interpreted through the lens of Stakeholder Theory (ST), which emphasize the importance of considering stakeholder interest in organizational decision-making processes (Gilbert and Rasche, 2008). This study focuses on stakeholders within IEs, following the three-layer structure proposed by Dias Sant'Ana et al. (2020). To further examine stakeholder roles, we applied the Stakeholder Identification and Salience theory developed by Mitchell et al., (1997), which assesses stakeholder relevance based on three key attributes: power, legitimacy and urgency (summarized in Table 1). According to this model, stakeholders can be categorized into seven types: Dormant (Power), Discretionary (Legitimacy), Demanding (Urgency), Dominant (Power + Legitimacy), Dangerous (Power + Urgency), Dependent (Legitimacy + Urgency), and Definitive (Power + Legitimacy + Urgency). We then analysed how the actors in our case study align with these categories in relation to the observed impacts of AI on business innovation.

3 Results and Discussions

The findings of this study enabled the identification the key impacts of AI on VC mechanisms within the business model, and allowed for the mapping of these impacts to specific stakeholders group within the IE.

3.1 The impacts of AI on value creation

Seven AI-based value creation innovations were discovered:

Digital Servitization. AI allows companies to expand their product and service portfolios through servitization (Chauhan et al., 2022), dematerializing the offering, and enriching services that enhance company and customers value (Sjödin et al., 2023). Customers are the first involved actor as they choose a company according to its competitiveness, variety and accessibility of services (Burström et al., 2021). The case study highlights involvement of the actors from the extended enterprise layer, particularly other suppliers and complementors, which help the company in implementing software for AI-based integrated services. This enhances customer support by streamlining service and maintenance requests. AI enables faster request submissions, improving response times and satisfaction. The company also introduced AI-based data sensing and tracking services, optimizing electrical device performance and strengthening after-sales.

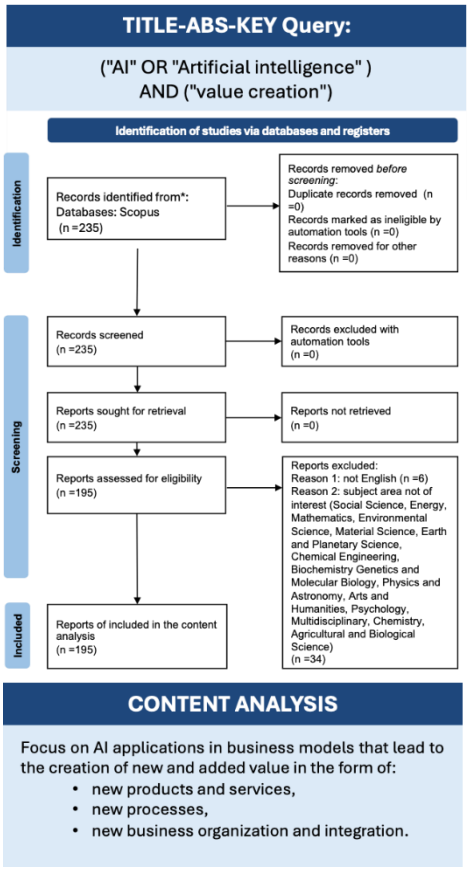


Figure 1 – Search scheme, PRISMA protocol and content analysis details

Table 1 – Stakeholder attributes (from Mitchell et al. 1997)

Attribute	**Description**
Power (PW)	Power represents the likelihood that an actor in a social relationship will enforce their will despite resistance. It defines the dynamic between two social actors, where the first has the ability to compel the second to act in a way they otherwise would not. Therefore, in a relationship, an actor holds power to the extent that they have, or can gain, access to coercive, utilitarian, or normative means to impose their will within the relationship.
Legitimacy (LG)	Legitimacy is the widespread perception or assumption that an entity's actions are desirable, appropriate, or proper within a system of norms, values, beliefs, and definitions. It is a desirable social construct that can be defined and negotiated in various ways across different levels of social organization.
Urgency (UG)	Urgency is an actor's demand for immediate attention. Through this attribute, the model shifts from static to dynamic. Urgency exists when the nature of a relationship is time-sensitive and when that relationship is important or critical for stakeholders.

Value Co-creation. AI makes easier the interaction, generating collaborative co-creation environments. Companies can collaborate with their customers, developing products and services based on the direct audience involvement. These customer-centric co-creation processes offer companies competitive advantages (Sjödin et al., 2021). Through their contribution, customers get what they seek in the form of improved offerings, reinforcing dynamics of loyalty and trust. AI-enabled collaboration can extend to additional actors within the IE. Technologies like co-bots enhance VC processes, actively involving employees, directors, and managers (Sewpersadh, 2023). The case study shows that AI-based open virtual sharing spaces enhance collaboration with customers by enabling fluid, interactive exchanges of ideas and suggestions. These digital platforms analyze shared information, identify needs, and propose tailored solutions, promoting valuable customer input. Customers thus become an integral part of the VC, with a deeper engagement, directly shaping products and services, and getting the role of a strategic partner. AI also filters and organizes contributions, highlighting key proposals and speeding up implementation. The case study shows how AI-enabled collaboration also enhances coordination with suppliers, distribution channels, complementors, and research institutes, improving SC alignment.

Mass Customization. Machine learning algorithms enable personalized outcomes, resulting in the creation of products and services tailored to individual customers. This is referred to “mass” customization because such algorithms simultaneously customize offerings for different profiles, designing a more personalized value proposition through client-centric or “intelligent” VC (Burström et al., 2021). Customers are the main actors involved in this VC mechanisms, whose expectations are completely fulfilled through the processing of information regarding their preferences. From customers’ viewpoint, the impact of technology is most evident within hyper-personalized offerings (Cao, 2021), making the customer experience unique. The case study highlights the company's commitment to customizing its offerings based on different customer needs, balancing personalization with scalability by leveraging advanced technologies to provide solutions that meet individual preferences while serving a broad market. The integration of AI within a dedicated platform enables customers to monitor, analyse, and optimize their energy consumption in real time. The platform's algorithms provide tailored recommendations, enabling significant energy savings without compromising device performance. The development of these “innovative consumer” applications makes energy management more accessible, even for users with limited technical skills. Interactive dashboards, predictive analytics, and real-time feedback improve the overall customer experience by adapting to user demands.

Data exploitation. Data exploitation and analysis capabilities enable new opportunities for innovative VC offering optimization, automation, servitization, and personalization benefits (Burström et al., 2021). Smart tools primarily process customer-related data as first category of information, driving VC processes based on customers preferences and market trends. From a management perspective, the core organization can set up data-driven decision-making processes, which allow to mitigate risks, making more accurate decisions when there is uncertainty or ambiguity, and to aim for continuous improvement of results in management performance (Åström et al., 2022). AI is capable of extracting valuable and strategic information from large, vague and inconsistent datasets. As the case study shows, the company leverages AI in the analysis of data in various operational areas. The greatest results are in the form of data-supported resource optimization, particularly in the photovoltaic and wind power sectors. AI also discover important information from data, enabling preventive maintenance planning in production systems, increasing efficiency. In order to maximize the benefits gained from intelligent data analysis, the company has identified 70 resources of AI specialists. Data coming from customers are a major source of benefits, for building predictive models for failures and maintenance that are based on usage and consumption information. However, some critical issues related to the processing of personal data and customer privacy have emerged, which has led the company to work on new predictive analytics models that respect the principles of anonymization and security, minimizing the risk of exposure of sensitive information and ensuring compliance with privacy regulations. The identification of hidden patterns can also be an important opportunity for other actors such as standard and public bodies of identifying criticalities that prompt them to take action. The use of data by all the actors of the ecosystem can give them new business opportunities, as the use of data by universities and research entities that support the development of statistical investigations and academic studies. Data exploitation thus involves all the actors defined in the triple-layers ecosystem, improving operational efficiency at each layer, and accelerating innovation of VC multilaterally.

Automation. Within the new AI-based VC logics, automation is transforming business processes at every operational level. The effects result in simplifying the activities by optimizing costs, resources and time (Mishra and Tripathi, 2021). AI-driven automation permeates throughout all SC levels, allowing traditionally human and poorly digitized tasks execution while saving on labor costs (Cao, 2021). Automation accelerates intermediate processes, impacting actors throughout the entire SC, such as the core organization, distribution channels, suppliers, other suppliers, complementors, and customers. The case study highlights automation’s impacts on core organization, specifically in monitoring and maintenance phases of production systems, and in transaction management. The company exploits automation to optimize the logistical routes for the installation of wind turbines, and to manage and simplify coding activities in software developing, increasing productivity and reducing human error. In the distribution sector, AI plays a key role for computer vision technologies that automate controls identifying anomalies, improving operational efficiency and workplace safety. AI tools are also embedded in digital twin models, which create highly accurate virtual replicas of physical infrastructure, enabling simulations and advanced testing of complex scenarios. The result is the prediction and mitigation of risks on real infrastructure. Finally, AI automation also finds application in plant monitoring systems through sensors with real-time data collection, providing support for the planning of maintenance interventions. Thus, AI contribute to the advancement of the entire IE, involving core organization, distribution channels, suppliers, other suppliers, complementors and public bodies in carrying out automated and digitized services and processes, simplifying their accessibility.

Feedback loops and Network effects. Feedback loops are crucial input coming from users of digital platforms, which contribute to the progressive and continuous improvement of algorithm refinement. The increased use of AI tools provides significant benefits to technology performances, a concept known as network effects. When network effects are combined with feedback from core organization and customers, new VC mechanisms emerged within the network. Within a company or an IE, a AI-based digital platform can supports management by connecting business activities across multiple actors, including suppliers, other suppliers, core organization, complementors, and standard bodies. The interconnections within actors generates added value benefiting all involved parties (Katsamakas and Pavlov, 2022), including end customers. These loops make AI increasingly and iteratively "intelligent", creating more and more value and fostering an innovation process for all actors directly involved. Another benefit for the company is the information coming from feedback provided by platform users, which in the case study are mainly represented by core organization and customers, with a less regular but still significant contribution from other actors in the ecosystem. The collection and processing of this feedback increase the value generated, as it enables the company to refine its services and adapt them to different needs. As part of the VC that contributes to the company's offering, the category of feedback with the greatest potential to generate positive impacts comes directly from customers. These inputs correspond to written messages or pictures provided by customers, particularly useful in remote monitoring services. Customers can upload photos showing the status of energy meters or household devices, allowing AI systems to analyze images and identify possible problems or faults, providing detailed diagnostics. This process simplifies problem solving for clients, while simultaneously improving AI algorithms accuracy through the benefits of network effects. The effectiveness of the tool depends on the quantity and quality of feedback received. The more real data users provide, the better AI can make accurate assessments. Platform feedback includes customer services and internal processes that involve various actors along the SC, optimizing operational flows, improving collaboration, and making feedback crucial for fostering synergy and efficiency within the IE.

Integrated communication. AI enhances value generation in companies by improving internal communication through AI-powered digital systems and Enterprise Resource Planning (ERP) tools, enabling real-time exchange of information among different operational functions. This fosters VC and promotes co-creation, facilitating faster and more synergistic collaboration among actors. AI's role in business communication and coordination lies in its ability to efficiently transmit information, ensuring seamless connections (Mahr and Huh, 2022). AI-enabled exchanges extend beyond companies, involving all actors in the triple-layers ecosystem, and promoting a modern approach to communication that results in collaborative VC. The case study shows how customers are impacted by innovative communication methods such as chatbots, virtual assistants and smart devices, which make digital communications more accessible and interactive. The strategic use of AI tools in optimizing communication exchange with customers, a crucial element in improving user experience, was also highlighted. Advanced chatbots and virtual conversation assistants help in filtering and simplifying messages, through which customer requests are analyzed in real-time, categorized, and associated with recurring or easily solvable issues. In this way, only the most complex or specialized issues are addressed by human operators, allowing them to focus on higher-value tasks. This approach reduces response time and enhances quality, ensuring customers receive swift solutions for common issues and tailored support for more complex situations. At a broader level, AI-based virtual assistant optimizes information management between the company and other players in its ecosystem. This assistant can synthesize contents from various sources, including e-mails, business documents, video conferences, and messages. This functionality is crucial in managing the complexity of communications in dynamic, multi-actor environments, reducing the risk of critical information loss and improving coordination. Additionally, the virtual assistant supports the creation of automated reports, meeting summaries and activity follow-ups, ensuring stakeholders maintain a clear and up-to-date view of decisions and actions. By integrating these tools, the company fosters a fluid communication ecosystem where data and information are exchanged, analyzed, and intelligently used. Figure 2 summarizes these results.

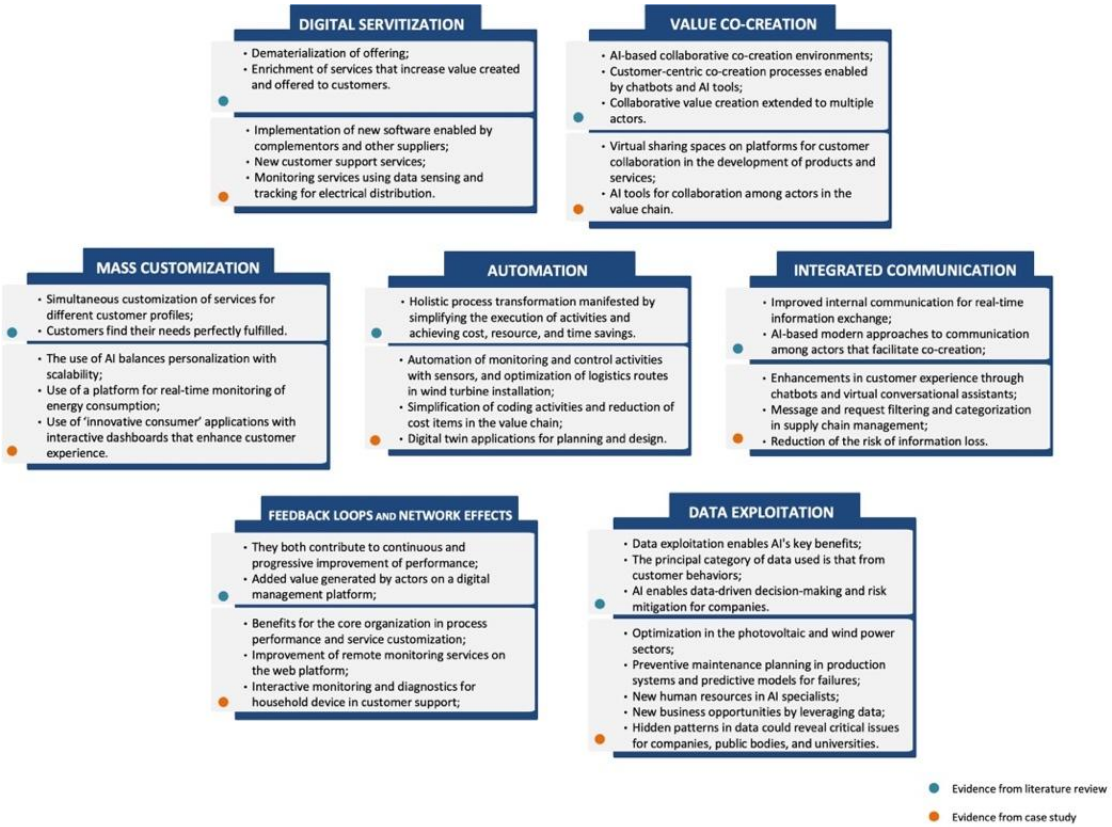


Figure 2 – AI-based VC innovations

3.2 The role of IE actors in AI-based VC innovations

Figure 3 summarizes the involvement of IE actors in the discovered AI-based VC innovation. These results are analyzed through the lens of ST, examining which salience attributes can be associated with each actor within the IE triple-layers structure.

The *Core Organization* possesses the attribute of *power* for several reasons: Digital Servitization, which introduces additional services such as data sensing and tracking that support customers even in the post-sale phase (Sjödin et al., 2021); Value Co-creation, demonstrated by the company's direct engagement with customers that generate power for core organization, fostering a sense of involvement and affiliation (Sewpersadh, 2023); Mass Customization, as evidenced by the company's ability to tailor its offerings to meet diverse customer needs, as highlighted in the case study; Automation, involving the execution of automated and digitized services and processes that simplify accessibility (Mishra and Tripathi, 2021); and Integrated Communication, which facilitates a fluid ecosystem for seamless information exchange. The effects resulting from the last three VC innovations show how the core organization acquires the attribute of power over customers thanks to their ability to improve products, services and processes which translates into their ability to improve market performance.

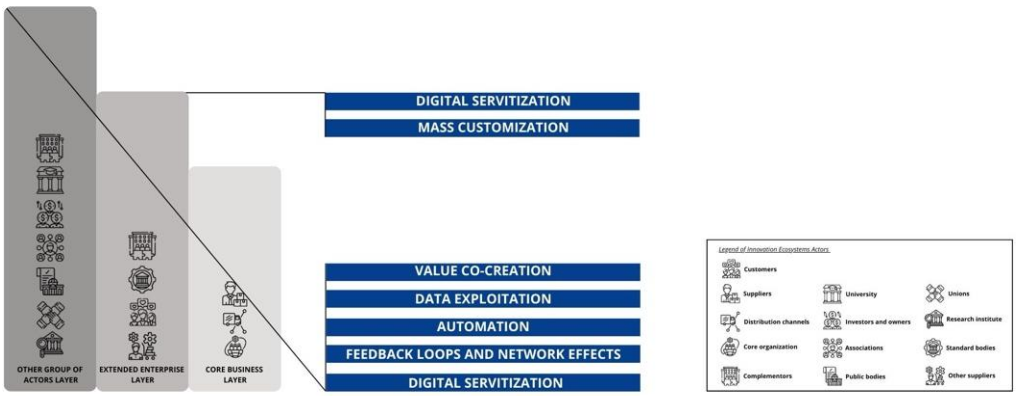


Figure 3 – The involvement of IE actors in AI-based VC innovations

Suppliers and *Complementors* also possess the attribute of *power*, driven by Digital Servitization, as these actors play a crucial role in supporting the company by implementing advanced AI-based software to integrate innovative services. Positioning in this role gives suppliers and complementors power over the company since them are capable of affecting the final result AI-based software impacting the company performance in providing the AI-based service.

Finally, *Customers* gain *power* attribute through Value Co-creation, which allows them to contribute to the development of improved offerings, thereby strengthening loyalty and trust. Additionally, feedback loops and network effects generate positive impacts, further enhancing the influence and power of customers within the IE. Indeed, thanks to these VC innovations, the role of the consumer evolves from being a mere user to becoming a co-creator who can assert their viewpoint and influence business decisions.

Customers gain *legitimacy* through the following VC innovations: Digital Servitization, which allows customers to send requests more quickly and efficiently, improving response times and overall satisfaction; Mass Customization, providing customers with access to hyper-personalized offers (Cao, 2021); Data Exploitation, enabling customers to leverage information derived from data to access current market trends; Feedback Loops and Network Effects, which streamline problem resolution, addressing customer issues promptly. Therefore, thanks to improvements in reducing response times and resolving customer issues, as well as the ability to offer personalized deals and provide direct access to market trends, desirable effects are generated, reinforcing the perception of legitimacy among customers.

The *Core Organization* possesses the attribute of *legitimacy*, enabled by the following VC innovations: Value Co-creation as supported by Sjödin et al., (2021), which involves the development of products and services based on involvement of the target audience; Automation as real-time data collection, providing crucial support for the planning and execution of maintenance interventions; Feedback Loops and Network Effects that enhance the company's performance by leveraging actors feedback to drive continuous improvement. By involving the target audience in product development, automating data collection to streamline maintenance processes, and incorporating feedback into improvements, the company takes appropriate actions toward IEs' actors, such as customers and suppliers, thereby enhancing its legitimacy. Thanks to Data Exploitation, the identification of hidden patterns enables the detection of problems or critical issues that enhance action efficiency.

Consequently, based on this evidence, *Public Bodies* acquire *legitimacy*, enabling them to operate in compliance with privacy regulations and within security boundaries during control operations.

The same attribute of *legitimacy* can be associated with *Complementors* and *Other Suppliers* and *Standard Bodies* enabled by the factor of Data Exploitation and Feedback Loops and Network Effects. These VC innovations generates value through a digital platform that supports the management of activities by connecting internal and external operations (Katsamakas and Pavlov, 2022), which provide legitimacy in taking appropriate intervention actions, such as consulting feedback provided by the company or processing data to enable predictive planning of interventions involving these actors in the SC.

Consumers gain *urgency* as an attribute through the following VC innovations: Digital Servitization, thanks to the accessibility and variety of services offered (Burström et al., 2021), customers can choose the company based on its competitiveness. This ability allows customers to assess the company's loyalty, and the significance of this action grants them the attribute of urgency; Value Co-creation that shared environments enable the collection of valuable customer inputs and encourage active participation in collaborative VC, in this way customers influence the timing of company's actions; Mass Customization that with interactive dashboards, predictive analytics, and real-time feedback enhance the customer experience by perfectly adapting to users' requests; Feedback Loops and Network Effects that emphasize the customer's role in driving value, fostering faster responses and continuous improvement; and Integrated Communication premising customers to play a crucial role as the main hub in optimizing communication and information exchange. Therefore, as beneficiaries of platform usage and central point of communication, customers possess the attribute of urgency for the company.

The *Core Organization* acquires the attribute of *urgency* through Automation factor, where its immediate attention is critical, especially during monitoring and maintenance phases of production systems, as well as in orders and transactions management (Mishra and Tripathi, 2021).

Suppliers, Other Suppliers, Distribution Channels, *Complementors*, and *Research Institutes* contribute to Value Co-creation aligning and coordinating activities across the entire SC. Due to their continuous and strategic support to the company in these previously non-outsourced activities, these actors acquire the attribute of *urgency*.

Summarizing, from an attribute-based observation, the salience of stakeholders highlights 5 of the 7 categories. There are Discretionary (LG) such as Standards Bodies and Public Bodies, Demanding (UG) are Distribution Channels and Research Institutes, Dangerous (PW, UG) are other suppliers, Dependent (LG, UG) are

Suppliers, Definitive (PW, LG, UG) are Core Organization, Customers and Complementors. There are no stakeholders that can be affiliated with the Dormant (PW) and Dominant (PW, LG) categories.

These results supports the definition of IE (Alka et al., 2024) as all actors have a "pro-active" role in relation to the phenomenon of the use of AI in VC strategies that excludes the dormant category. The absence of "preponderant" actors in relation to the same phenomenon underlines the result linked to the absence of the dominant category. Other evidence can be associated with the Data Exploitation factor which shows us how "the data speaks for itself" and gives attributes to the actors (Burström et al., 2021).

5 Implications

Theoretical and practical implications of the study were summarized in Table 2.

Table 2 - Implications

Theoretical Implications	This study enriches the academic scenario providing relevant insights in the business model innovation research area providing a list of seven AI-based VC innovations. Additionally, the interpretation of the results according to the theoretical lens of ST provide a contribution to the research stream of stakeholder management in IEs. Finally, the research stream focused to study the impacts of technologies in businesses was enriched by relevant insights about the impacts generated by AI in the VC. All results of this study represent a way to reflect about the overall impact generated by this emerging technology, opening the way to the identification of aspects worth investigating in the future both in the specific case of VC and in value capture and delivery.
Practical Implications	The study proposes the stakeholder identification in an IE focused on generating innovation using AI. These results are useful for those who want to innovate their business model through new AI-based VC strategies. The insights coming from ST describing the positioning of stakeholder in the analyzed IE and their salience attributes give interesting evidence about the possibility to involve several stakeholders in IE developing different innovative VC that led the company to serf the last industrial revolution according to the Innovation 5.0 paradigm.

6 Closing Remarks, Limits and Follow-ups

Thanks to the results obtained – particularly the identification of AI-based VC innovations - it was possible to answer the RQ1: "*How is AI transforming Value Creation (VC)?*". Furthermore, the discussion framed through the theoretical lens of ST enabled the identification of key actors within the IE and the assessment of their salience, thereby answering the RQ2: "How does this transformation affect the actors within the business ecosystem?". The added value of this study lies in the dual relevance of its findings: academically, by advancing the understanding of AI-based VC innovation within the framework of IEs; and practically, by emphasizing the importance of stakeholder management as a strategic level for fostering innovation.

Despite following a structured and rigorous methodology, certain limitations should be acknowledged. The qualitative bias stemming from the content analysis - conducted through a focus group to identify AI-based VC innovations - could be mitigated in future research by involving a broader panel of academic and industry experts. The robustness of the empirical evidence could also be strengthened through a multiple-case study design. Lastly, since the study identified *Data Exploitation, Feedback Loops, Network Effects,* and *Integrated Communication* as the most impactful AI-based VC innovation – due to their ability to engage all actors within the IE's triple-layer structure - future research could explore the relevance and influence of additional AI-based VC innovations.

Ethics and AI declaration

The interviews were conducted anonymously. Collected data were used in an aggregated form to ensure confidentiality and privacy. No AI tools were used in the creation of this paper.

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Can Artificial Intelligence Support Companies in Implementing Sustainable Innovation Strategies? Evidence from Agri-Food Companies

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Abstract

The agri-food industry is currently facing significant global challenges, including climate change, resource depletion, and growing demands for food security. In response to these challenges, sustainable innovation has become a critical focus for the industry. Sustainable innovation refers to the development and adoption of new technologies, practices, and business models that aim to improve environmental, social, and economic outcomes. One of the most promising technologies for supporting sustainable innovation is artificial intelligence (AI), which has the potential to enhance various aspects of sustainability within the agri-food sector. This study explores the role of AI in supporting sustainable innovation strategies and practices in the agri-food industry, with a focus on understanding how AI can help optimize processes, reduce waste, improve resource management, and foster more sustainable business models.

To achieve this, a comprehensive systematic literature review was conducted, analyzing seventy-three peer-reviewed articles related to AI applications in the agri-food industry. Through this analysis, the study identifies six main clusters of strategies that are currently being employed to drive sustainability in the sector. These strategies include optimizing production processes, improving supply chain efficiency, enhancing product traceability, and advancing precision agriculture practices. Additionally, the study highlights the role of AI in supporting twenty-four specific practices within these strategies, such as predictive analytics for crop yield forecasting, AI-driven waste reduction systems, and AI-based monitoring tools for environmental impacts.

However, the findings also reveal significant gaps in the application of AI, particularly the lack of support for circular economy approaches, which focus on reducing waste and reusing resources throughout the supply chain. This gap presents an opportunity for further research into how AI can be leveraged to support circular practices within the agri-food industry. The study provides a foundation for future exploration into the integration of AI and sustainable innovation, offering insights for both researchers and practitioners seeking to improve sustainability in the agri-food industry.

Keywords: AI, Business Strategy and Operation, Sustainability.

Paper type: Academic Research Paper

1 Introduction

Innovation is a crucial driver of economic progress, enabling competitiveness in global markets (Lopes et al., 2022). However, rapid climate change, resource scarcity, and a projected global population of 9.7 billion by 2050 compel businesses to adopt new approaches (Monteiro and Barata, 2021). The agri-food industry is particularly affected, being both essential globally and vulnerable to environmental crises. It significantly contributes to greenhouse gas emissions, water consumption, and biodiversity loss (Efremova et al., 2023). This reality underscores the urgent need for Sustainable Innovation Strategies (SISs), which integrate sustainability into strategic decisions, leveraging technologies and fostering business models that tackle resource inefficiencies and enhance food security (Voinea et al., 2021). Aligned with the Triple Bottom Line (TBL) framework, sustainability encompasses environmental, economic, and social dimensions (Elkington, 1998), addressing global challenges and aligning with the UN's Agenda 2030 and its 17 Sustainable Development Goals (SDGs) (Camelo and Nogueira, 2024). For Small and Medium-sized Enterprises (SMEs), transitioning to sustainable practices involves significant obstacles, such as balancing short-term profitability with long-term investments. Nevertheless, adopting Sustainable Innovation Practices (SIPs) is critical (Lopes et al., 2022). Digital technologies under the Industry 4.0 (I4.0) paradigm, specifically Artificial Intelligence (AI) and Big Data (BD), are vital enablers of sustainability (Sharma, 2022). These technologies can enhance productivity and reduce costs in the agri-food sector. AI's transformative capabilities, including learning and problem-solving, allow companies to optimize their sustainable innovation strategies (Taneja et al., 2023). However, AI adoption raises ethical and data security concerns, emphasizing the need for frameworks for its integration (Krishna et al., 2023). This research seeks to fill the gap in the literature regarding AI-based SISs and SIPs, exploring how AI can drive sustainable innovation in the agri-food industry and developing a framework to guide companies in their sustainable transition.

2 Background

2.1 The sustainable innovation in agri-food industry

Over time, innovation has evolved beyond the Schumpeterian concept of purely economic growth (Schumpeter, 2021), shifting towards Sustainable Innovation (SI), or eco-innovation, which aims to minimize environmental impacts and optimize resource use across production, consumption, and product life cycles (Lopes et al., 2022). SIs encompasses technological, organizational, and social forms, emphasizing resource efficiency and circularity (Slowak and Regenfelder, 2017). The agri-food sector is central to global economies, employing millions and generating significant revenue (Konfo et al., 2023). However, it is also responsible for one-third of global CO_2 emissions and faces numerous challenges. Extreme weather events, pests, and diseases disrupt agricultural practices and food security (Efremova et al., 2023). Additionally, deforestation, intensive land use, and habitat destruction endanger biodiversity at genetic, species, and landscape levels (Sharma et al., 2021). By 2050, the global population is projected to reach 9.7 billion, increasing food demand by 80% and stressing resources like arable land and freshwater, particularly in low-income regions (Monteiro and Barata, 2021).

Simultaneously, up to 50% of food is wasted, exacerbating resource inefficiencies. Rising food prices and reduced access to nutritious foods disproportionately impact vulnerable populations, especially in rural areas (Calicioglu et al., 2019). The 2030 Agenda underscores the need for systemic transformation in agri-food systems through the SDGs, including zero hunger, responsible consumption, and environmental preservation (Camelo and Nogueira, 2024). Companies face regulatory and social pressures to address these challenges, pursuing SIs through: i) technical innovations like improved farming systems and waste reduction; ii) organizational innovations such as supply chain collaboration; iii) systemic innovations involving new products, technologies, and markets (Perrin et al., 2023). Proactive strategies focusing on market differentiation often yield greater success than reactive, compliance-driven approaches (Lopes et al., 2022). However, economic barriers, including high initial investments and reduced yields during transitions (e.g., to organic farming), remain significant obstacles to SI in the agri-food industry.

2.2 The AI technologies in agri-food industry

The agri-food industry is still undergoing a digital transformation, driven by I4.0 technologies, which enhance sustainability and efficiency. Key technologies, for example, Internet of Things (IoT), BD, Advanced Automation (AA) and Robotics (AR), simulation, Additive Manufacturing (AM), allow companies: i) to perform real-time data collection on weather, energy use, and production; ii) to analyze large datasets for improved decision-making and process optimization; iii) to streamline tasks like planting and harvesting, reducing labor costs; iv) to model complex processes like crop growth and irrigation management; v) to customize food production while minimizing waste (Goldenits et al., 2024). AI revolutionizes the agri-food industry by optimizing processes and addressing specific challenges such as resource efficiency, food safety, and supply chain management (Taneja et al., 2023). Specifically, Machine Learning (ML), Deep Learning (DL), computer vision, Natural Language Processing (NLP), some of the main AI technologies, were applied in i) smart farming, for monitoring crop conditions, manages irrigation, and identifies pests, enhancing productivity; ii) in food safety and traceability, for detecting contaminants, improves hygiene, and ensures regulatory compliance and iii) in supply chain optimization, for supporting demand forecasting, risk management, and inventory control, enabling circular economy models (Nath et al., 2024). AI application in CE-based SIs within agri-food industry also emerged in the context natural landscape enhancement (Pathan and Db Sisodiya, 2023). Beyond the benefits, the adoption of AI technologies also involves risks and challenges that could impact sustainability. These include significant energy consumption, the production of electronic waste, market concentration in a few hands, potential job outsourcing, and even ethical issues related to the use of AI. Despite these challenges, AI continues to be a driving force in redefining the future of agri-food industry, as it helps address the sector's main challenges and promotes sustainability (Nath et al., 2024).

3 Methodology

The methodology of the study was built following a qualitative research approach (Figure 1). To address the RQs (see Figure 1), a SLR was chosen as research method, following the PRISMA guidelines in the data collection process for the definition of inclusion and exclusion criteria (Page et al., 2021). Two queries (see Figure 1) were designed to select two samples: the first focused on identifying the most emerging SISs and SIPs in a cross-industry context; the second specifically targeted AI-based SIPs applied within the agri-food industry. Data

analysis was conducted using qualitative content analysis, which enabled the identification of SISs and SIPs, as well as their AI-driven applications.

Additionally, a focus group with senior researchers contributed to defining the SISs and SIPs labels. Evidence was synthesized into the proposed framework (see Figure 4).

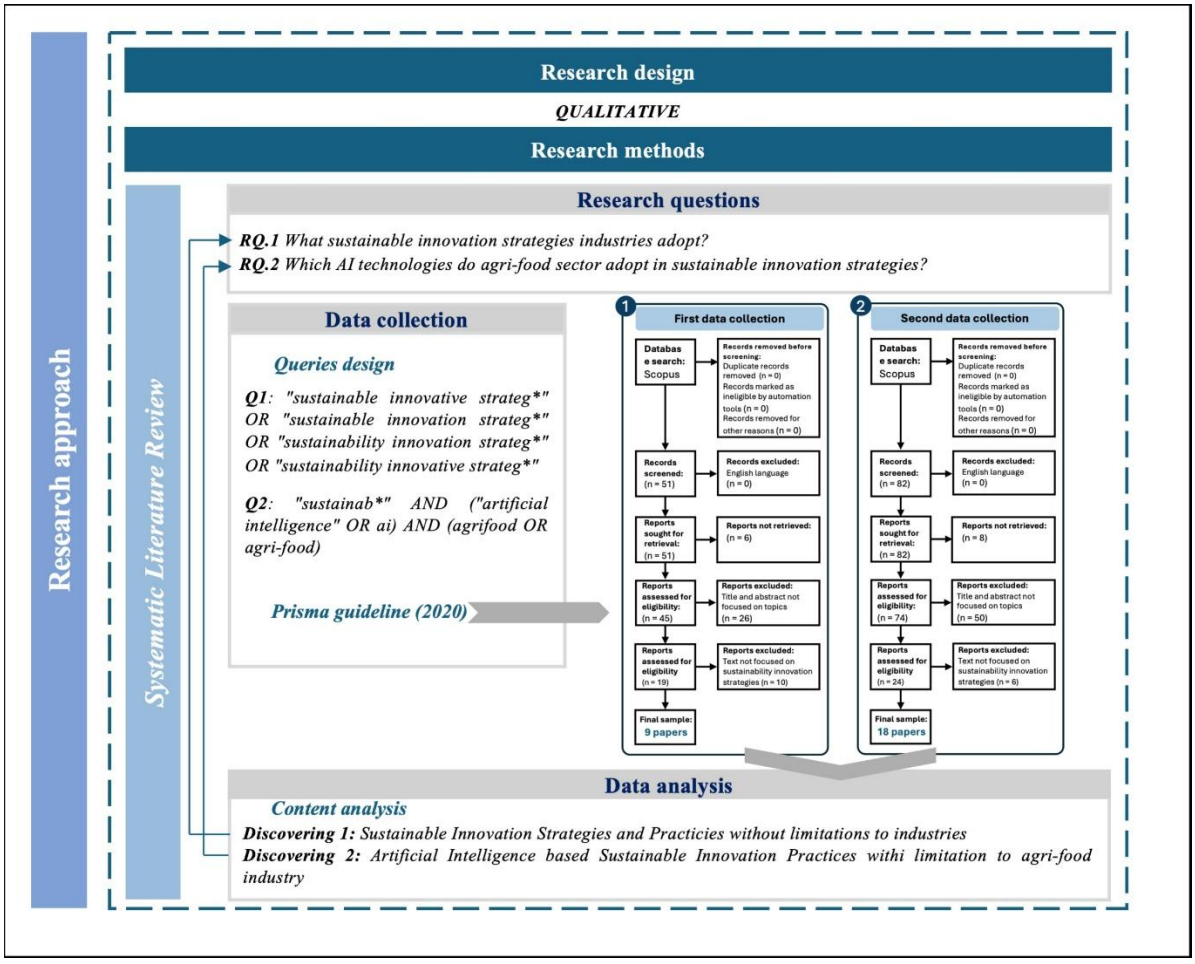


Figure 1: Research methodology overview

4 Findings

The analysis provided a comprehensive overview of the practices and strategies that companies implement to integrate sustainability into their business models. The identified practices span multiple industrial contexts, including the agri-food, oil and gas, healthcare, education, chemicals, technology, and service ones. The findings were presented as a classification of strategies, organized into clusters, where the 6 first-level SISs correspond to the main strategy categories, each further detailed into 16 second-level SISs (See Figure 2). For each practice within the clusters, the industry of application was identified, including details on whether AI is applied. The first cluster (in the gradation of blue color) encompasses SISs aimed at reducing the *production footprint* of industries.

The literature highlights SIPs that focus on reducing non-natural inputs in the agri-food industry (Krishna et al., 2023), and shows a cross-industry interest in minimizing water (Lopes et al., 2022), energy (Nath et al., 2024), and carbon (Kneipp et al., 2021) footprints. The second SISs cluster (in the gradation of green color) encompasses SIPs focused on waste reduction through *circularity approaches*, aiming to reintegrate waste materials into production cycles and extend their lifecycle (Lopes et al., 2022; Slowak and Regenfelder, 2017). No AI-based applications were identified within this cluster. The *Sustainable Enhancement of Territory* SISs cluster (in the gradation of yellow color) encompasses strategies aimed at valorizing local systems by preserving natural resources, and supporting local communities, integrating economic activities with environmental and social well-being (Efremova et al., 2023; Konfo et al., 2023). The *Sustainable Management* cluster (in the gradation of purple color) brings together SIPs focused on achieving social and governance sustainability goals. These include enhancing employee well-being, fostering proactive governance in sustainability initiatives, and promoting operational management driven by efficiency and sustainable performance (Kneipp et al., 2021).

The results reveal a group of SIPs classified under the *Improvement of Food Quality and Safety* cluster (in the gradation of orange color), primarily related to the agri-food sector. Key practices include actions aimed at food protection, covering aspects such as preservation, logistics, and hygiene (Nath et al., 2024). Other practices focus on the sustainability of packaging, with the goal of reducing material use and minimizing non-recyclable materials (Taneja et al., 2023). The last SISs cluster is related to the *Customer and Partner Relationship Care* (in the gradation of turquoise color), which encompass the social dimension of sustainability. The focus is on meeting the expectations of customers (Martinez et al., 2023) and other stakeholders (Cantino et al., 2019; Monteiro and Barata, 2021), while maintaining a strong emphasis on minimizing the environmental impact of the company's activities. By filtering the results from the content analysis of the two samples—focusing on the agri-food industry and AI-based applications—the set of SISs clusters was narrowed down to 9 second-level SISs (belonging to 5 out of 6 first-level SISs). These represent AI-driven practices designed to achieve sustainability goals within the agri-food industry (Figure 3). The identification and classification of SISs and SIPs allow the development of a framework (Figure 4) that highlights the connection between AI technologies and the clusters of SISs within the agri-food industry. Each practice is associated with a specific AI technology family (breafly introduced in background section), and where AI is not applied, the relevant I4.0 support technology is indicated. The framework offers an overview of practices and technological tools that a company could adopt based on the SISs it aims to achieve. Conversely, by examining the framework beginning with the company's existing technological resources, it becomes possible to identify applicable practices and broaden its sustainability scope within the various SISs.

5 Discussions

5.1 A strategic imperative for resilience in the agri-food industry

Our findings confirm and expand upon the theoretical foundations presented in the background section. SISs identified align with the TBL framework (Elkington, 1998), emphasizing the interconnected dimensions of environmental, economic, and social sustainability. Specifically, the environmental dimension resulted the most extensively addressed highlighting the strong connection between sustainability and climate-related issues. Nevertheless, SISs reflect a broader approach that also encompasses the governance dimension, particularly by emphasizing managerial engagement in sustainability goals, fostering more conscious governance policies and promotes self-assessment of performance. The social dimension also emerged as a key area of interest in agri-food SIPs, where environmental concerns are closely linked to the commitment to protecting natural resources, simultaneously benefiting local communities and enhancing society well-being and health. The classification of SISs into clusters, such as reducing production footprints, waste reduction through circularity, and sustainable enhancement of territories, reflects the systemic transformation required to address global challenges like climate change, biodiversity loss, and food insecurity (Efremova et al., 2023). The findings also highlight the importance of proactive strategies over reactive ones, as noted by Lopes et al. (2022). Proactive approaches, such as adopting circular economy principles and improving food quality and safety, are more likely to yield long-term benefits, aligning with the literature's emphasis on market differentiation and competitiveness. However, the findings reveal that economic barriers, such as high initial investments and reduced yields during transitions (e.g., to organic farming), remain significant obstacles, echoing the challenges discussed by Monteiro and Barata (2021).

		Sustainable innovation practice	Sector	References	Ai supported
PRODUCTION FOOTPRINT REDUCTION	Reduction of the use of non-natural inputs	Smart management of non-natural input quantities (such as seeds, fertilizers, insecticides)	Agri-food	Krishna et al. 2023, Taneja et al. 2023, Goldenits et al. 2024	Yes
		Precision weeding	Agri-food	Goldenits et al. 2024, Taneja et al. 2023	Yes
		Data-driven fertilizer composition	Agri-food	Krishna et al. 2023	Yes
	Water Footprint Reduction	Reuse of wasted water	Services	Lopes et al. 2022	No
		Reduction of water consumption with smart devices	Services (Construction and maintenance of	Lopes et al. 2022	No
		Wastewater treatment	Agri-food & Beverage	Lopes et al. 2022; Cantino, Giacosa, e	No
		Use of water from artesian wells and	Chemical	Marques Kneipp et al. 2021	No
		Use of a rainwater collection and storage system	Technology	Marques Kneipp et al. 2021	No
		Precision irrigation	Agri-food	Konfo et al. 2023, Monteiro e Barata 2021, Krishna et al. 2023, Taneja et al. 2023, Goldenits et al. 2024, Nath et al. 2024	Yes
	Energy Footprint Reduction	Use of white roofs to reflect sunlight	Technology	Marques Kneipp et al. 2021	No
		Use of a natural ventilation and lighting	Technology	Marques Kneipp et al. 2021	No
		Produce renewable energy	Agri-food & Beverage,	Lopes et al. 2022; Cantino, Giacosa, e	No
		Monitoring of artificial lighting in greenhouses	Agri-food	Goldenits et al. 2024	Yes
		Detection and control of online drying	Agri-food	Nath et al. 2024	Yes
	Carbon Footprint Reduction	Reduce packaging size to transport more	Health and education	Marques Kneipp et al. 2021	No
		Encourage the use of combined materials	Chemical	Marques Kneipp et al. 2021	No
		Monitoring of national and international	Chemical	Marques Kneipp et al. 2021	No
		Preventive maintenance of machinery and equipment	Chemical	Marques Kneipp et al. 2021	No
		Planting native trees	Health and education	Marques Kneipp et al. 2021	No
		Reduce the weight of packaging	Chemical	Marques Kneipp et al. 2021	No
		Reduce the weight of motor vehicles	Chemical	Marques Kneipp et al. 2021	No
		Replace oil boilers	Health and education	Marques Kneipp et al. 2021	No
		Reduction of air travel and the use of	Health and education	Marques Kneipp et al. 2021	No
ADOPTION OF CIRCULAR APPROACHES	Efficient end-of-life management	Recycling (wood, plastic, metal)	Agri-food, Services	Lopes et al. 2022	No
		Reuse of waste	Agri-food, IT, Services, Trade	Lopes et al. 2022; Marques Kneipp et al. 2021	No
		Implement a reverse logistics policy	Health and education	Marques Kneipp et al. 2021	No
		Reuse of car batteries for secondary purposes	Automotive	Slowak e Regenfelder 2017	No
	Remanufacturing	Remanufacturing of print components	Technology	Slowak e Regenfelder 2017	No
	Up-cycling	Production of soap from used oils	Trade (Provision of services and sales)	Lopes et al. 2022	No
SUSTAINABLE ENHANCEMENT OF TERRITORY	Social responsibility towards local communities	Promote events related to entrepreneurship and innovation to generate social and environmental benefits	Technology	Marques Kneipp et al. 2021	No
		Make donations to social institutions to generate social and environmental benefits	Technology	Marques Kneipp et al. 2021	No
		Participation in events in cities and supporting local initiatives	Health and education	Marques Kneipp et al. 2021	No
		Participation in events and organizing activities with restaurateurs to promote the culture of sustainable consumption and production	Agri-food & Beverage	Cantino, Giacosa, e Cortese 2019	No
		Purchase of local products	Health and education	Marques Kneipp et al. 2021	No
	Rural Landscape Care	Precision weeding	Agri-food	Taneja et al. 2023, Goldenits et al. 2024, Konfo et al. 2023	Yes
		Real-time monitoring of pastures	Agri-food	Efremova et al. 2023	Yes

SUSTAINABLE MANAGEMENT	Employee Well-being Improvement	Reduction of the weekly working hours	Health and education	Marques Kneipp et al. 2021	No
		Reduction of the gap between the highest and lowest salaries	Health and education	Marques Kneipp et al. 2021	No
	Proactive Sustainability Governance	Invest in certifications	Agri-food	Marques Kneipp et al. 2021	No
		Establish corporate policies that are more restrictive than legislation	Chemical	Marques Kneipp et al. 2021	No
		Periodic evaluation of sustainable strategies	Chemical	Marques Kneipp et al. 2021	No
		Purchase of carbon credits	Chemical	Marques Kneipp et al. 2021	No
		Analyze the environmental impacts of its products	Chemical	Marques Kneipp et al. 2021	No
		Product life cycle assessment	Chemical	Marques Kneipp et al. 2021	No
		Remove licensed products from the portfolio	Health and education	Marques Kneipp et al. 2021	No
		Specific programs aimed at raising employee awareness to reduce waste production	Chemical	Marques Kneipp et al. 2021	No
	Operational Management Efficiency	Reduction of paper-based processes in favor of digital processes	Services (communication, projects of investment)	Lopes et al. 2022	No
		Forecasting the optimal time for harvesting	Agri-food	Taneja et al. 2023	Yes
		Optimization of inventory levels	Agri-food	Taneja et al. 2023	Yes
IMPROVEMENT OF FOOD QUALITY AND SAFETY	Protection of Food Integrity	Replacement of pre-cooked meals with organic and more sustainable products	Agri-food	Lopes et al. 2022	No
		Detection of foreign objects	Agri-food	Taneja et al. 2023	Yes
		Avoid the use of polymer-based packaging	Agri-food	Taneja et al. 2023	Yes
		Avoid the use of preservatives	Agri-food	Taneja et al. 2023	Yes
		Analysis of operations data to make forecasts and improve production processes	Agri-food	Taneja et al. 2023	Yes
		Accurate shelf life prediction and maintenance of equipment	Agri-food	Taneja et al. 2023	Yes
		Sorting of food products	Agri-food	Taneja et al. 2023	Yes
		Cleaning and maintenance of equipment	Agri-food	Taneja et al. 2023	Yes
		Identification of materials and packaging design through data analysis (e.g., product and environmental data)	Agri-food	Taneja et al. 2023	Yes
		Detection of spoiled meat	Agri-food	Nath et al. 2024	Yes
	Eco-Design	Incremental innovation of products and services using more sustainable materials	Services, Agri-food, Technology	Lopes et al. 2022, Marques Kneipp et al. 2021	No
		Replacement of more polluting products with less polluting ones	Trade (Provision of services and sales)	Lopes et al. 2022	No
		Replacement or reduced use of plastic packaging	Agrifood; Health and education	Lopes et al. 2022, Marques Kneipp et al. 2021	No
		Replacement of non-renewable raw materials with renewable raw materials	Health and education	Marques Kneipp et al. 2021	No
		AI-assisted packaging design (in the design, production and functionality of packaging materials)	Agri-food	Taneja et al. 2023	Yes
CUSTOMER AND PARTNER RELATIONSHIP CARE	Customer Care	Active listening to customers to incorporate their 'green' knowledge	Textile industry	Martínez-Martínez et al. 2023	No
		Collaborations with customers who want to enhance environmental efficiency	Services (communication, projects of investment)	Lopes et al. 2022	No
		Promotion of environmental practices to customers	Agri-food	Lopes et al. 2022	No
		Investments in marketing sustainable products to increase demand	Agri-food	Lopes et al. 2022	No
		Personalized nutrition recommendations	Agri-food	Taneja et al. 2023	Yes
		Food customization	Agri-food	Taneja et al. 2023	Yes
		Understanding and strategic use of consumer preferences	Agrifood &Beverage	Taneja et al. 2023	Yes
	Stakeholder Care	Having mechanisms for interaction with stakeholders to understand their needs	Technology	Marques Kneipp et al. 2021	No
		Agreements with sustainable suppliers who have the same ecological point of view	Agrifood & Beverage; Oil, and gas , Trade (Provision of services and sales)	Lopes et al. 2022, Cantino, Giacosa, e Cortes 2019, Camelo e Nogueira 2024	Yes
		Collaborations with strategic partners to develop sustainable and environmentally friendly solutions	Oil and gas	Lopes et al. 2022	Yes

Figure 2: First-level and second-level SISs and related SIPs

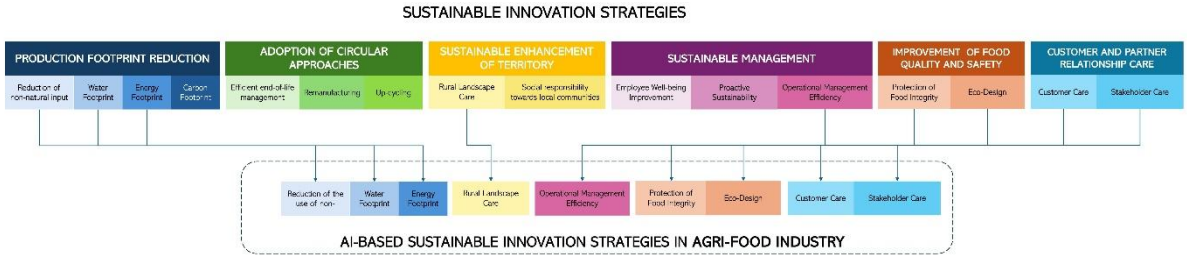


Figure 3: Representation of SISs with a focus on AI-based SISs in agri-food industry.

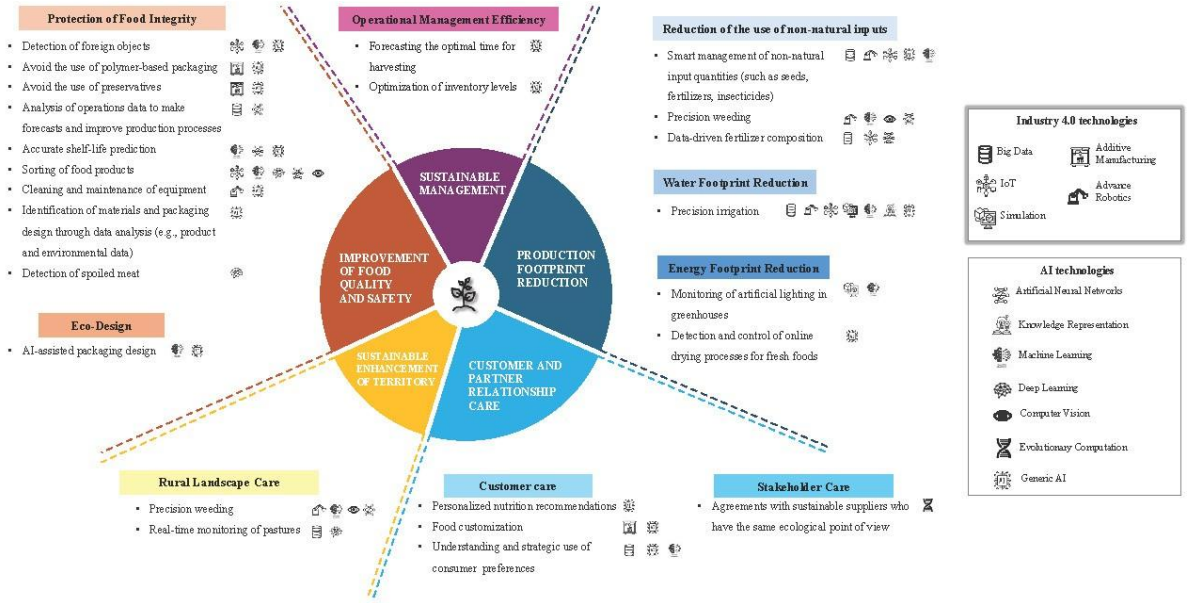


Figure 4: The proposed framework for discovering AI-based SIPs and related SISs in agri-food industry

5.2 The transformative power of AI technologies for sustainable practices

The findings revealed that the adoption of AI technologies in SISs is almost always accompanied by the integration of other I4.0 enabling technologies such as IoT, AR, Digital Twins (DT), AM, and BD. This means that to maximize the effectiveness of SISs, companies must rely on a process that is strongly centered around digitalization.

Therefore, the study underscores the transformative potential of AI and I4.0 technologies, in driving sustainability in the agri-food industry. The identified AI-driven SIPs, such as smart farming, food safety, and supply chain optimization, align with the literature's emphasis on AI's ability to enhance productivity, reduce waste, and enable circular economy models (Nath et al., 2024). For instance, the use of ML and DL for monitoring crop conditions and managing irrigation directly supports resource efficiency, as highlighted by (Sharma et al., 2021). However, the findings also reveal gaps in AI adoption, particularly in clusters like waste reduction through circularity, where no AI-based applications were identified. This result contrast the one that arose from a bottom-up research conducted by Pathan and Db Sisodiya (2023) in Irish landscape, where the authors identified four initiatives of Circular Economy-based sustainable innovation which encompass 3 AI technologies (Vision AI, ML, Computer Vision). However, this aligns with the literature's observation that AI adoption faces challenges such as high energy consumption, electronic waste, and ethical concerns (Krishna et al., 2023). These barriers highlight the need for systematic frameworks to guide the integration of AI into sustainability practices, as proposed in the findings.

5.3 Driving SI through Ecosystemic perspectives

From the *organizational perspective* - Sustainability must become a core component of a company's culture, governance, and strategic decision-making. Leadership is pivotal in embedding sustainability as a fundamental value, aligning it with the company's mission and long-term goals. This involves not only setting clear sustainability objectives but also ensuring that all employees and stakeholders embrace these values. Matching

the Perrin et al. (2023) and Konfo et al. (2023) conceptions of organizational innovation route, key clusters of SISs include: i) Sustainable Management, forecasting the optimal time for harvesting and optimizing inventory levels to reduce waste and improve resource efficiency; ii) Customer and Partner Relationship Care, personalized nutrition recommendations, leveraging consumer preferences strategically, and forming agreements with sustainable suppliers who share the company's ecological vision. For example, companies adopting circular economy principles aim to minimize waste and maximize resource reuse. By integrating sustainability into corporate strategy, leadership ensures that these practices are not treated as peripheral initiatives but as essential to the company's identity and competitive advantage.

From the *supply chain perspective* - Sustainability transcends internal company operations and involves collaboration with suppliers, partners, and logistical processes. This perspective emphasizes sustainable procurement, operational efficiencies, and minimizing the environmental and social risks associated with supply chain activities.

Key clusters of SIPs that reflect this perspective were: i)Production Footprint Reduction, focused on upstream agricultural practices, aiming to reduce the environmental impact of farming and sourcing raw materials; ii) Sustainable Enhancement of Territories, promoting agricultural practices that support local ecosystems and communities; iii) Food Quality and Safety Improvements, targeting production areas to ensure food standards and safety align with sustainability objectives; iv) Operational Management Efficiency, practices such as optimizing inventory levels and forming agreements with sustainable suppliers. v) Logistical Sustainability, reducing carbon emissions in transportation and ensuring responsible sourcing of raw materials. Collaboration is essential at this level, as companies work with suppliers and partners to drive innovation and ensure compliance with ethical labor practices and environmental standards. For example, multinational corporations increasingly prioritize suppliers committed to fair labor practices and sustainability. However, challenges persist in monitoring and ensuring compliance across all levels of the supply chain.

From a *compliance perspective* - AI-based SIPs play a key role in achieving sustainability objectives within the agri-food industry and beyond. AI and I4.0 technologies enable companies to embrace environmental, social, and economic sustainability dimensions, guiding them toward the accomplishment of the SDGs. In this regard, our framework reflects the possibility to address challenges global recognized by SDGs, as illustrated in Figure 5. All the SDGs are covered by the identified SISs and SIPs, making them a valuable guideline for implementing a holistic and multidimensional approach to corporate sustainability efforts. Focusing on the agri-food industry, AI's crucial role emerges through its contribution to various practices, enabling the achievement of 13 out of 17 goals. This allows companies to leverage AI and Industry 4.0 technologies to align with international sustainability ambitions, ensuring compliance with global sustainability performance standards while meeting regulatory requirements and common interests in the field.

6 Implications

The findings of this study offer significant theoretical and practical implications. These implications extend across various domains, from enhancing theoretical understanding of AI-based SIPs and SISs to providing actionable insights for companies, supply chains, and stakeholders in the pursuit of sustainability.

6.1 Theoretical Implications

The theoretical implications of this research align with and expand upon the existing literature on sustainability, innovation, and technology adoption. Firstly, the study supports and enhances the TBL framework, which emphasizes the environmental, social, and economic dimensions of sustainability (Elkington, 1998). The findings confirm that sustainability strategies in the agri-food industry must address all three dimensions, with a significant focus on the environmental dimension due to the sector's substantial contribution to greenhouse gas emissions, water consumption, and biodiversity loss as suggested by Efremova et al., (2023). By classifying the identified SISs into clusters such as reducing production footprints, waste reduction through circularity, and sustainable enhancement of territories, the research illustrates a comprehensive approach to addressing global challenges, such as climate change and food insecurity, in line with the United Nations SDGs (Camelo and Nogueira, 2024), as shown in Figure 5. Moreover, the study contributes to the theoretical understanding of AI-driven SISs, which, as noted by Nath et al. (2024) and Taneja et al. (2023), offer transformative potential for optimizing resource use and enhancing sustainability outcomes in the agri-food sector. The integration of AI with other I4.0 technologies, such as IoT, BD, and robotics, illustrates the multidimensional nature of technological adoption in achieving sustainability goals. The framework developed in this study provides a structured approach to understanding how companies can leverage these technologies

to drive sustainable practices, expanding on existing literature that has mostly focused on singular technological applications rather than holistic, integrated solutions (Nath et al., 2024; Sharma, 2022).

6.2 Practical Implications

From a practical standpoint, the results offer several key implications for the agri-food industry, that fall in the main fields of operational management, supply chain management, sustainability development, and the stakeholder ecosystem. Specifically, about operational management and supply chain optimization, the integration of AI and I4.0 technologies provides actionable insights for resource optimization, waste reduction, and food safety, as also recognized by Taneja et al., (2023). For instance, smart farming technologies that leverage ML and DL for monitoring crop conditions and optimizing irrigation directly address critical resource inefficiencies in the agri-food sector. Our insights reveal that these technologies not only enhance productivity but also contribute to the long-term sustainability of the supply chain by improving resource efficiency and minimizing waste, confirming the position of Sharma et al., (2021). The framework outlined in the study provides practical guidelines for organizations to adopt specific technologies based on their sustainability goals, enabling them to optimize inventory levels, reduce waste, and improve food safety standards.

About CE and waste management, one of the notable findings is the identification of SISs focused on waste reduction through CE models. While the study highlights gaps in AI-based applications in this area, it provides valuable insights for future research and industry practices. By embracing circularity, companies can reintegrate waste materials into production cycles, extending their lifecycle and reducing environmental impacts (Lopes et al., 2022). This is relevant for enhancing the resilience of the agri-food sector, especially as food waste continues to exacerbate resource inefficiencies. Supply chain partners can collaborate to develop closed-loop systems, which not only align with sustainability goals but also reduce costs associated with raw material procurement and waste disposal.

About sustainability development and stakeholder engagement, the study underscores the importance of engaging stakeholders in sustainability efforts, particularly in the context of customer and partner relationship care. Companies can differentiate themselves in the marketplace by aligning their sustainability strategies with customer values, particularly those who prioritize eco-friendly products and ethical sourcing. This alignment can be achieved through practices such as personalized nutrition recommendations, which leverage AI to optimize food production processes based on consumer preferences (Martinez et al., 2023). Moreover, fostering strong relationships with sustainable suppliers who share a commitment to environmental stewardship ensures that sustainability is embedded throughout the supply chain. As noted by Konfo et al. (2023), this collaboration across the stakeholder ecosystem is essential for driving systemic change toward more sustainable and resilient agri-food systems.

About regulatory compliance and global sustainability goals, from a compliance perspective, AI and I4.0 technologies offer significant support for companies striving to meet the sustainability targets outlined in the SDGs. By incorporating AI-driven SIPs, companies can align their operations with global sustainability frameworks, ensuring compliance with environmental and social standards. The study's findings demonstrate that AI has the potential to support the achievement of 13 out of the 17 SDGs, providing companies with the tools needed to track and optimize their sustainability performance. This is particularly important in a globalized economy where regulatory pressures and consumer expectations are increasingly focused on sustainability. The framework developed in this study serves as a valuable tool for companies seeking to navigate these challenges while ensuring long-term competitiveness and growth.

Summarizing, this study contributes to both the theoretical understanding of sustainable innovation in the agri-food industry and provides practical insights for companies, supply chains, and stakeholders to drive sustainability through the integration of AI and I4.0 technologies. By offering a structured framework, the research facilitates the adoption of sustainable practices, positioning businesses to meet the challenges of climate change, resource scarcity, and growing global food demand while simultaneously enhancing their competitiveness in the marketplace.

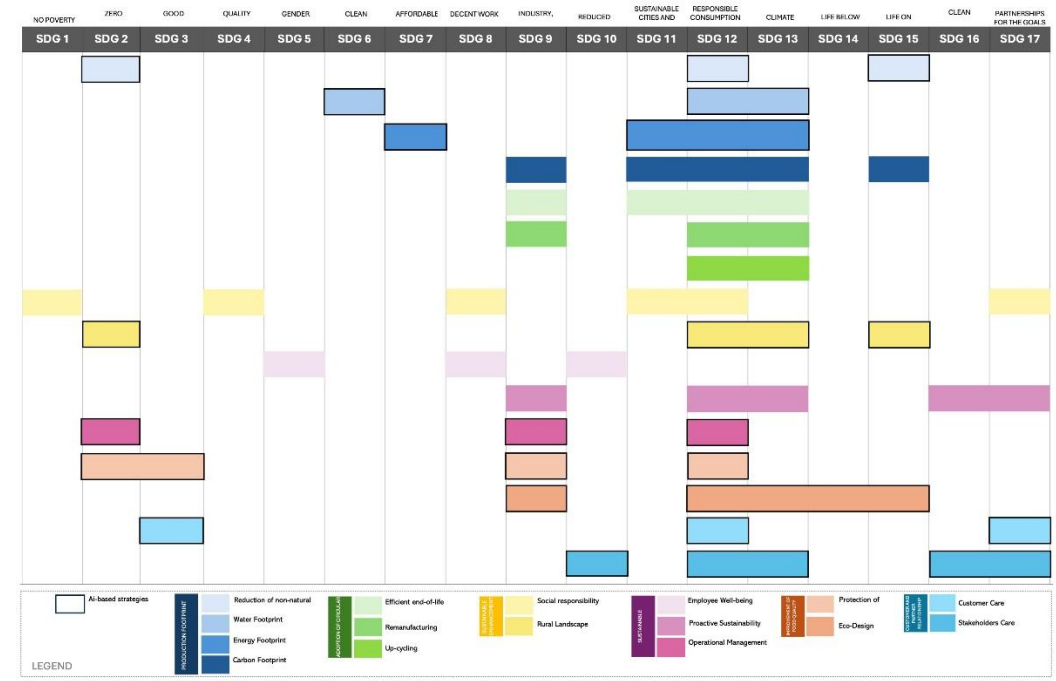


Figure 5: SISs, AI-based and not, contextualization within ONU SDGs

7 Conclusions

The study proposes a framework linking AI technologies to SIPs, addressing gaps in the literature regarding their integration. A detailed taxonomy of 6 first-level and 14 second-level clusters was developed, identifying 24 AI-supported SIPs. Despite its contributions, the study faces limitations, including a lack of AI technologies taxonomy, limited bibliographic scope, and sample size. Proposed follow-ups include developing a comprehensive AI taxonomy, refining methodologies, expanding research scope, and increasing the sample size for broader applicability. Moreover, it may be interesting to enrich the present qualitative research with a quantitative one, for example by investigating the key discriminating criteria for selecting one innovative strategy over another within a company. This could be carried out through a quantitative analysis, such as the multicriteria TOPSIS method applied to a case study, thereby enriching the research with a practical application. This approach would allow for a comparison between the theoretical findings and the feasibility of implementing SISs and SIPs in a real-world context.

Ethics declaration

This research did not involve human participants, animal studies, or any other procedures requiring ethical clearance. Therefore, no formal ethical approval was necessary for the research presented in this paper.

AI declaration

The authors declare that no artificial intelligence (AI) tools were used in the writing, editing, data analysis, or interpretation of this manuscript. All work was conducted and reviewed manually by the authors.

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Exploring the Preliminary Conditions for Blockchain Credibility in the Agri-food Industry

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Abstract

The traceability of product sourcing and production processes has become a crucial need for the Agri-food Industry, where stakeholders - particularly consumers - increasingly demand guarantees on product quality and authenticity. Blockchain technology, given its characteristics of immutability and transparency, can play a key role in solving issues related to traceability and information asymmetry, which undermine security and stakeholder trust in companies, as well as in promoting corporate social sustainability. The present study aims to fill a gap in literature by focusing on the operational application of this technology, with particular attention to the issue of credibility of the raw data entered into the system. To this end, a qualitative approach is adopted based on a multiple case study conducted through secondary data, integrated with primary data collected through a focus group. The work has a twofold objective: on the one hand, to explore the motives and goals that drive companies to implement Blockchain technology; on the other hand, to identify the preliminary conditions that ensure its operational effectiveness and credibility in the eyes of stakeholders. The results suggest that traceability is the main reason why companies decide to implement Blockchain technology, with the goal of ensuring product authenticity and transparency to the consumer. In addition, two sets of factors - operational and validation - were identified as key preconditions for effectively implementing a credible Blockchain information system. The study contributes to a deeper understanding of the operational application of Blockchain in the agri-food sector, providing relevant theoretical and practical implications.

Keywords: Blockchain Technology, Agri-Food Industry, Traceability, Credibility, Social Sustainability

Paper type: Academic Research Paper

1 Introduction

Critical issues such as food safety, contamination risks, and food counterfeiting are increasingly emerging in the agri-food industry (Salah et al., 2019; Duan et al., 2020; Shahid et al., 2020; Chaudhuri et al., 2021). Scholars identify information asymmetry as the cause of these problems, highlighting how it undermines supply chain ethics and trust relationships with stakeholders (Mao et al., 2018). From the demand side, consumers are becoming more concerned with the quality and authenticity of food products, demanding greater availability and transparency of information throughout the entire supply chain (Antonucci et al., 2019; Rana et al., 2021).

To address information asymmetry, the traceability of product sourcing and production processes has become a critical priority in the agri-food industry (Behnke and Janssen, 2020; Salah et al., 2019).

The need for traceability also stems from the need for agri-food companies to comply with increasingly stringent sustainable development requirements, especially regarding social sustainability (Saberi et al., 2018; Mastos and Gotzamani, 2022). Several studies identify product traceability and information sharing as key elements closely related to social sustainability (Golini et al., 2017; Mastos and Gotzamani, 2022). Toussaint et al. (2021) argue that only collective efforts and effective traceability systems - that cover from seed collection to final distribution - can achieve social sustainability.

Consequently, the clear and detailed collection, management and communication of information presents a significant challenge for the agri-food industry. Pre-existing traceability systems are typically centralised and third parties dependent, making them vulnerable to fraud, and lacking in transparency and verifiability (Salah et al., 2019; Shahid et al., 2020).

In this context, Blockchain technology can be seen as a promising tool to enhance food traceability and sustainable supply chain management, with positive benefits for both producers and consumers (Tian, 2017; Duan et al., 2020).

Blockchain technology is defined as a distributed, shared, and immutable ledger capable of documenting the production, processing, and distribution of agri-food products (Kramer et al., 2021). As such, it serves as a tool for tracking and communicating data and information.

However, the mere recording and sharing of data do not fully guarantee its accuracy or credibility, due to the significant risk of manipulation of the collected information (Behnke and Janssen, 2020), as well as the threat of inaccurate data entry into the system (Böhmecke-Schwafert et al., 2022). Therefore, it is critical that agri-food

companies implement Blockchain systems that are not only operationally effective but also perceived as credible and reliable by stakeholders. Although the academic debate has extensively explored Blockchain's potential in agri-food supply chain, few studies have addressed its inability to ensure the reliability of the raw data entered into the system. Indeed, the effectiveness and validity of a Blockchain-based traceability process ultimately depend on the quality and truthfulness of the raw data entered - an aspect over which technology itself has no control.

In light of this, the study aims to fill this gap by adopting a managerial perspective to provide theoretical, managerial and institutional implications related to Blockchain implementation. Specifically, it aims to examine, first, the motivations and objectives that drive agri-food firms to adopt Blockchain technology; and second, the necessary preconditions required for Blockchain to be considered not only operationally effective, but also credible and valid in the eyes of stakeholders.

Accordingly, this paper addresses the following research questions:

- *Why, and with what objectives, do agri-food companies choose to implement Blockchain technology?*
- *What tangible and intangible resources do agri-food companies consider necessary prior to the introduction of Blockchain in order for it to be operationally effective and credible in data management?*

The paper has the following structure. Section 2 presents the literature review on the Blockchain technology and Blockchain technology in agri-food industry and agri-food supply chain; section 3 illustrates the methods; section 4 describes the results emerging from the empirical analysis; section 5 illustrates discussions, implications and conclusions.

2 Literature review

2.1 Blockchain technology

The Blockchain can be defined as a distributed ledger, structured as a chain of blocks, which stores related transactions in chronological order and whose integrity is guaranteed by cryptographic algorithms and consensus rules (Tapscott and Tapscott, 2016; Treiblmaier, 2019). In the Blockchain, each participating node can propose the creation of a new data block. This block is added to the chain only after being validated by the network, without the need for a central authority, and can no longer be modified. This process, based on a peer-to-peer consensus mechanism, makes Blockchain a decentralised, secure, transparent and immutable system (Zheng et al., 2017). Its core characteristics include traceability, reliability and auditability (Casino et al., 2019). Blockchain systems can be distinguished into three generations (Swan, 2015) and three main types: public, private and consortium. These variants offer similar functionalities, differing primarily in their levels of efficiency and governance structure (Zheng et al., 2018).

Blockchain first emerged in the financial sector with Bitcoin 5hlprd(Nakamoto, 2008) and later expanded its application to various non-financial sectors. Theoretical discussions have extensively explored Blockchain technology from a technical standpoint, defining its areas of application based on its core functionalities (Crosby et al., 2016; Zheng et al., 2018; Zhao et al., 2016; Casino et al. 2019; Pal et al. 2021; Gad et al., 2022). In this context, several authors highlight the potential of Blockchain technology to successfully integrate into both business process management (Di Ciccio et al., 2018; Medling et al., 2018), by improving operational efficiency (Li and Xu, 2025), and supply chain management (Gad et al, 2022), by significantly reducing information asymmetry (Nuttah et al., 2023) and fostering collaboration and trust among stakeholders (Nofer et al., 2017; Shin, 2019), through the use of Smart Contracts. Given these technical functionalities, scholars consider Blockchain as a particularly promising technology for addressing critical issues of transparency, traceability and trust in the agri-food industry and, more generally, throughout the entire agri-food supply chain (e.g. Kamilaris et al., 2019).

2.2 Blockchain technology in agri-food industry and agri-food supply chain

The influence of Blockchain technology on the performance of the agri-food industry and its supply chain has been the focus of extensive academic debate, which has revealed its positive and beneficial impact on traceability and transparency (Vern et al., 2024).

Blockchain is considered potentially revolutionary for its ability to track, in real time, who performs specific actions, when and where these are performed, as well as the quality and quantity of the product (Saberi et al., 2018), thereby contributing to the establishment of its digital identity. Many scholars agree that Blockchain improves traceability efficiency by providing a transparent and reliable system to validate the quality, safety and sustainability of the agri-food supply chain (Salah et al., 2019; Duan et al., 2020; Ji & Xu, 2025). Other scholars

emphasize Blockchain's potential in reducing food fraud and protecting the authenticity of agri-food products (Tian, 2016; Galvez et al., 2018; Antonucci et al., 2019), as well as in improving the efficiency of product recalls, thereby reducing food waste, lowering costs, and mitigating risks (Kshetri, 2018; Duan et al., 2020; Feng et al., 2020; Hao Fu et al., 2020). To test the effectiveness of Blockchain-based traceability systems, several pilot studies have been conducted (e.g. Yiannas, 2018; Bumblauskasa et al., 2020).

Furthermore, the positive impact of this technology on the sustainability of agri-food enterprises is widely recognised (Rana et al., 2021; Giganti et al., 2024). According to Chaudhuri et al. (2021), Blockchain supports sustainability integration into business strategies, by making information immutable and ensuring traceability and transparency, especially in the social dimension. Indeed, Blockchain is an effective tool for addressing key challenges in social sustainability, including food safety, product quality, fostering trust and collaboration among stakeholders, and monitoring both social conditions of workers and supplier performance. This promotes greater accountability among producers and consumers, empowering them to make more ethical and responsible choices and thus contributing concretely to the advancement of social sustainability (Saberi et al., 2018; Mastos and Gotzamani, 2022; Giganti et al., 2024).

The academic debate, therefore, emphasises the ability of Blockchain to reduce information asymmetry (Vern et al., 2024) by configuring it as a strategic communication tool. Some studies emphasise its value as an enabler of "secure communications", capable of improving the flow and exchange of information (Bovenzi et al., 2023). This has a significant impact on consumers: direct access to data via product labels fosters the development of new, more direct and transparent forms of communication, addressing growing demands for authenticity and safety (Martinelli and De Canio, 2023). Furthermore, Sepe (2023) shows that data accessibility has a significant impact in influencing consumers in their purchase of food products.

However, to gain a more comprehensive understanding of Blockchain technology, further in-depth study is required, one that moves beyond the purely technical focus typically limited to its potential and barriers across different application domains, including the agri-food industry. It is crucial to focus on the critical issues that may hinder its effectiveness and efficiency. Among these, the question of the reliability of raw data entered into Blockchain systems is particularly interesting, as the technology itself has no direct control over the accuracy of the input data. To the best of our knowledge, while academic literature has extensively explored the functionalities of Blockchain in business process and supply chain management within the agri-food sector, few studies have addressed its inability to verify the reliability of raw data, which may be tampered with or altered before being recorded in the system (Galvez et al., 2018; Duan et al., 2020). In this context, the certification of the authenticity of the data remains dependent on the certifying body, and cannot be ensured by the Blockchain system alone (Böhmecke-Schwafert et al., 2022).

Therefore, this study seeks to fill the gap emerging from the academic debate by exploring, in the first phase, the motivations and objectives driving companies to Blockchain and, in a second phase, the tangible and intangible resources they consider preliminary for its implementation in business management, from both operational and strategic perspectives.

3 Methodology and research process

To achieve this goal, our research design, based on a qualitative research approach, follows a two-step process. Firstly, we conduct a multiple case study based on secondary data (Eisenhardt, 1989; Miles & Huberman, 1984). This method enables a more comprehensive exploration of the research questions, thereby improving the reliability of the research findings (Eisenhardt & Graebner, 2007). Secondly, to enhance the robustness of our multiple case study, in line with prior literature (Eisenhardt, 1989), we incorporate secondary data with primary data. As a part of this approach, we choose to utilize focus groups (Morgan, 1996; Bloor et al., 2001) because, as Stewart and Shamdasani stated, "*the most common purpose of a focus group interview is for an in-depth exploration of a topic about which little is known*" (p.102, 1990).

Our research process comprises several stages: (1) the identification of case studies. The analysis was specifically targeted in Italy, with a particular emphasis on Agri-food Industry in Campania. We contextualized the research in Campania because it is the Italian region with the highest number of traditional food products (GU Serie Generale n. n. 61, 2024). We selected 5 companies (see Table 1) based on the following criteria: Campania companies that have pioneered the adoption of Blockchain Technology in different agri-food sectors; the greatest availability of data; and willingness to participate; (2) secondary data collection. We used the main company platforms (websites and social media) and third-party sources that reported relevant information; (3) focus group establishment. Being a focus group "an interview style designed for small groups" (Berg, 1998, p. 100), typically involving from six to 10 people (Blackburn and Stokes, 2012), we selected 9 participants. Participants in the focus group include representatives from the selected companies, two experts, an academic

representative and an institutional representative (see Table 2). The two-hour focus group discussion dealt with the implementation of Blockchain within inter-organizational business processes, focusing on 3 key elements: the reasons why they decided to implement Blockchain; the goals they aim to achieve by implementing Blockchain; tangible and intangible resources supporting the implementation of Blockchain.

The use of multiple methods and diverse data types enabled the application of a Methodological Triangulation Approach, which aimed to reduce bias and enhance both reliability and validity (Jick, 1979; Eisenhardt, 1989; Yin, 1994).

Table 1: Selected companies

Companies
Azienda Agricola San Salvatore
Bioitalia
Pastificio Liguori
Solania
Spinosa

Table 2: Participants

Focus Group Participants	**Number of Participants**	**Range of Title**
Corporate Representative	5	CEO, Communications Manager, Export Manager
Blockchain Expert	2	Provider
Academic Community	1	Full Professor
Institution	1	Agency ICE

4 Findings

The analysis of the results for the three research questions is presented below.

- *RQ1: The reasons why they decided to implement Blockchain.*

The analysis of secondary data reveals that the primary reason companies choose to implement a Blockchain-based data recording system is to enhance the traceability of the individual product or the entire supply chain (See Table 3).

This is also confirmed by the focus group discussion. Participants recognised traceability and transparency as essential features of Blockchain, as they enable the verifiable recording of every production stage and the full traceability of a product's lifecycle.

- *RQ2: The goals they aim to achieve by implementing Blockchain*

The analysis of secondary data highlights two main objectives that explain the behaviour of companies in adopting Blockchain technology: a. ensuring authenticity and combating counterfeiting; b. enhancing transparency for consumers (see Table 3).

The fight against the counterfeiting of Made in Italy products has led the companies investigated to adopt Blockchain to safeguard the authenticity of their products. The technology allows them to provide information about the origin and processing of the raw materials, the manufacturing production processes up to the issuance of the Blockchain traceability certificate.

Similarly, the objective of transparency towards the consumer - particularly evident in the cases BioItalia, Pastificio Liguori and Spinosa - is considered a milestone. This objective is pursued through Blockchain adoption, which facilitates not only direct access to supply chain information, but also greater corporate responsibility, capable of strengthening consumer trust, a key element for the smooth functioning of markets and B2C relationships. These objectives also emerged prominently during the focus group.

Table 3: Secondary data results

	Azienda agricola San Salvatore	**BioItalia**	**Pastificio Liguori**	**Spinosa**	**Solania**
Sector	Agri-food	Agri-food	Agri-food	Agri-food	Agri-food
Company Size	PMI	PMI	PMI	PMI	PMI
Blockchain Application	Yogurt and creamy buffalo milk products	The entire range of products	The entire range of products	Mozzarella di Bufala Campana PDO	San Marzano Tomato PDO

	Azienda agricola San Salvatore	BioItalia	Pastificio Liguori	Spinosa	Solania
Blockchain Information	Product description; Origin and processing of raw materials; Production process; Locations of processing stages; Certification	Product description; Origin and processing of raw materials; Production process; Locations of processing stages; Certification	Origin of the cultivated field; harvest period; processing dates and locations for semolina; production date and location for the pasta	Origin verification; Milk Monitoring; Milk Processing Stages; Packaging and distribution details	Sowing process; Harvesting phase; Processing stages; Storage of the finished product
Reason	Traceability of selected products	Traceability of the entire product range	Traceability of the entire product range	Traceability of selected products	Traceability of selected products
Objective	To prevent counterfeiting and safeguard product authenticity.	To make the entire supply chain transparent to the final consumer	To make the entire supply chain transparent to the final consumer and to safeguard product authenticity.	To make the entire supply chain transparent to the final consume	To prevent counterfeiting and safeguard product authenticity.

Authors' elaboration

- *RQ3: Tangible and intangible resources supporting the implementation of Blockchain*

This research question was primarily explored through the focus group. The discussion highlighted the importance of certain resources, which we classified as *operational factors*, and of further resources that emerge in a later stage, referred to as *validation factors*. Together, these represent fundamental preconditions for the effective use of Blockchain technology. In the category of operational factors, we included the following factors, which were deemed necessary by the stakeholders participating in the debate:

The role of the supplier. The need to identify suppliers who are willing to collaborate actively, sharing data and information about their activities, was emphasized. This is essential for entering accurate information into the Blockchain system, thereby making every stage of the procurement and production process traceable and transparent.

Trust in B2B relationships. Trust in the relationship with suppliers allows the integrity of the data entry process within the blockchain system to be guaranteed.

Management. The focus group identified two key managerial competencies related to this factor: supply chain management and business innovation: supply chain management and business innovation.

Supply chain management is considered a strategic activity and a key operational factor. Having a well-structured supply chain monitoring and managing system in place prior to the implementation of the Blockchain, participants expressed that this is a considerable advantage for the introduction of the Blockchain, as the company already possesses a very thorough knowledge of its supply chain.

Regarding business innovation, during the discussion, all participants identified this as a crucial factor for Blockchain implementation. In particular, the need to initiate a profound cultural-organizational renewal within enterprises was highlighted, so that they would be inclined to embrace a process of full-scale technological innovation. Such transformation, to be effective, must take on a systemic and structural character. For this reason, a fundamental role is attributed to institutions, which are believed to have to assume a leading and coordinating function in promoting collaboration among the various actors involved (businesses, stakeholders, certifying bodies, consumers).

Internal and/or external digital expertise. The need to develop digital expertise, both within organisations and among external stakeholders, is crucial for the implementation of blockchain technology. During the discussion, Indeed, it emerged that one of the main obstacles to the success of Blockchain is the lack of adequate human and structural resources to manage such systems.

Finally, the participants also dwelt on the consumer's digital knowledge and skills, which are often scarce and not adapted to technological developments. As a result, the need to focus on consumer education in order to inform them about the utility and advantages of such technology was stressed by several parties.

The Validation Factors category considered the resources and factors identified as crucial for the validity of the raw data entered into the Blockchain and, consequently, to the trustworthiness of the information within the Blockchain system. One key factor identified was Data Credibility and Corporate Reputation.

The issue of data credibility was represented as a strategic element of paramount importance. In fact, the interlocutors raised several critical issues associated with entering raw data into Blockchain, agreeing on the difficulty of verifying its accuracy. Blockchain technology allows the freezing of data, making them immutable, but this aspect does not guarantee their truthfulness and credibility. As emphasised by the participants, the truthfulness and credibility of the data entered by companies largely depend on professional ethics and their willingness to consolidate their corporate reputation.

Similarly, the inclusion of inaccurate data can undermine the company's credibility for the information reported in Blockchain producing negative fallout in terms of trust and image.

Although not quoted verbatim here, these findings are supported and corroborated by several statements from focus group participants.

5 Discussions and conclusions

Based on the results of the companies surveyed, the adoption of Blockchain in the agri-food sector is mainly driven by the possibility of guaranteeing product traceability. In this context, the aim is not so much to implement a control mechanism on data and information, but rather to adopt a strategic tool to enhance the authenticity and transparency of products for the consumer, thus combating the counterfeiting phenomenon. The empirical results are consistent with what has emerged from the existing academic debate, which configures Blockchain as a communication tool (Bovenzi et al., 2023) capable of conveying the traceability of the entire product lifecycle with the aim of promoting its transparency and authenticity (Banerjee, 2018; Saberi et al, 2018; Kshetri, 2018).

Furthermore, the results obtained confirm the positive impact of Blockchain technology on social sustainability. The motivations and objectives identified for its implementation, as well as the factors that emerged from empirical analysis, reflect the key elements that the literature has identified as determinants of social sustainability. These include transparency, accessibility and verifiability of all relevant information to ensure food safety and quality, the promotion of collaboration and trust among stakeholders, and the monitoring of the supply chain, including supplier behaviour and the social conditions of workers. In this context, Blockchain emerges as an enabling tool for the integration of social sustainability into business strategies in the agri-food sector, consistent with the arguments of Giganti et al. (2024), Saberi et al. (2019) and Mastos & Gotzamani (2022).

In parallel, the analysis of the resources that the investigated companies consider to be preliminary in order to guarantee the operational effectiveness and credibility of the Blockchain, led to the identification of a set of crucial factors, divided into two main categories - operational and validation - from which derive important insights for the identification of the following theoretical and practical implications.

Regarding the theoretical implications, this research provides insights into the theoretical debate on the operational application of Blockchain in the context of business management, an area still little explored in existing literature. Regarding managerial implications, this study provides valuable insights useful to entrepreneurs, managers and business leaders on the organisational and managerial level in order to guide strategic choices and promote greater awareness in the adoption of Blockchain technology. Finally, with reference to the institutional implications, there emerges the need for a more proactive role on the part of institutions, especially in the function of guiding and coordinating innovative processes, in order to guarantee a technology that is inclusive, sustainable and regulated among the various actors involved (businesses, stakeholders, certification bodies, consumers).

Limitations: This research is an initial approach and thus has some limitations that open the way for further research. Future studies could replicate and expand the analysis to a larger set of companies belonging to different industrial sectors and located in different geographical areas.

6 Ethics declaration

Ethical approval was not required for this study.

7 AI declaration

AI was used to assist with language editing. All intellectual content was created and validated by the authors.

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Multi-Criteria Decision-Making to Evaluate Sustainability and Performance in the Agri-Food Supply Chain

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Abstract

Mathematical modeling of complex problems, with particular attention to multi-criteria and optimization models, is particularly effective for analyzing critical issues in the agri-food supply chain. These tools allow analyzing problems of different nature through the use of qualitative and quantitative criteria, often conflicting with each other, and decision alternatives. Their versatility allows adapting solid theoretical constructs to different contexts and application areas, ensuring a modeling that takes into account the peculiarities of the problem under examination. In fact, multi-criteria analysis tools and optimization models allow supporting decision makers in the different phases that characterize the agri-food supply chain. This work addresses in particular the decision problem related to the transition of agri-food products from the storage to the marketing phase, using the Analytic Hierarchy Process (AHP) method. Once the products have undergone transformation processes, they are stored in one or more warehouses for distribution to commercial activities. There are several choices to be made in this phase, including the choice of the commercial establishments in which to distribute the products. In particular, the use of the AHP method is proposed for the analysis of a decision problem relating to the choice of the warehouse distribution with respect to four different commercial establishments (alternatives) that sell directly to the final consumer. A sensitivity analysis is conducted to test the robustness of the method. Through the analysis of a practical case, it is highlighted how the agri-food supply chain is a very complex context, in which the competitiveness of organizations is based on the ability of the decision maker to identify problems, imagine alternatives and adopt solutions. It is also highlighted that these tools, if correctly implemented in organizations, allow the start of an organizational learning process, reducing the costs associated with decision-making errors.

Keywords: Multi-criteria Decision Making, Decision Support Systems, Decision Analysis, Agri-food Supply Chain.

Paper type: Academic Research Paper

1 Introduction

Large-scale retail trade is now the main component of the Italian agri-food system, intercepting over 50% of the value generated by the entire system. This sector therefore represents one of the strengths of the agri-food economy, but still has ample room for development linked to the wide possibilities of innovation and diversification of services. If on the one hand it is necessary to adopt strategies that allow the valorization of the processes in progress, on the other hand it appears necessary to experiment with new processes that meet the needs of consumers and that are capable of carving out new spaces on the markets (e.g. Carbon Neutral products).

Moreover, there is the phenomenon of food waste which, due to its economic, environmental and social implications, represents a particularly relevant issue for the transition towards sustainable development. Nowadays, initiatives to reduce food waste and losses and to recover food products that are no longer saleable but still edible have multiplied throughout the world, contributing to placing ever greater attention on this issue.

In such a context, the agri-food supply chain appears to be crucial and the competitiveness of organizations is based on the ability of the decision maker to identify problems, imagine alternatives and adopt solutions. This is directly influenced by the ability of organizations to acquire knowledge and start decision-making learning processes to recognize the problem (Fattoruso & Squillante, 2023).

In this field, in order to guarantee the overall sustainability, the processes to be evaluated are by definition multidimensional and characterized by a plurality of actors, complex contexts, a high degree of uncertainty and ambiguity, plurality of objectives, criteria and decision alternatives. In such contexts, several studies suggest the use of multi-criteria and optimization approaches. In fact, there are many advantages that the adoption of such approaches can bring. Among these, of great relevance for the purposes of strategic evaluation is the possibility of articulating the decision-making process on the basis of a rational quantitative model that takes into account the plurality of interests of the different actors, and guarantees the decision-maker the ability to modify the

decision-making process at any time based on the robustness of the results of the new alternatives/solutions that may arise.

Theoretical elaboration and field experiences have shown how Multi-criteria Decision Making (MCDM) methods are particularly suitable for representing the evaluation and decision-making processes in the context of complex problems (Proto et al., 2013; Ishizaka & Nemery, 2013; Greco et al., 2016).

The Agri-food Supply Chain certainly represents a field in which MCDM can face important conceptual and operational challenges, contributing to effective problem solutions (Ammirato et al., 2021).

The use of MCDM methods is particularly suitable for solving problems in the Agri-food Supply Chain. In fact, they can support the resolution of problems at every level of the Agri-food Supply Chain such as the storage, distribution and trade phases.

Moreover, also the definition of optimization models, designed in order to effectively manage the uncertainty that characterizes this application field, can be a useful support for decision makers (Violi et al. 2020; 2023).

This work proposes the use of multi-criteria analysis and optimization models and methods to support decision makers in the different production processes of the Agri-food Supply Chain by proposing the analysis of real problems. The work highlights that the implementation of multi-criteria methods, if correctly implemented, allows to start an organizational learning process, reducing the costs associated with decision-making errors.

2 Main Literature

In the literature analysis of particular importance is the understanding of the scientific landscape in which the object of study is placed. In this sense, the database composed of the final articles was analyzed using the VOSviewer software (Van Eck et al. 2010). The focus of our investigation was to verify if and which multi-criteria and optimization models are used to improve competitiveness and sustainability in the agri-food sector. The analysis provides the mapping of the relationships between the different keywords of the scientific articles highlighting all the connections existing between the articles considered. The bibliometric analysis conducted with VOSviewer allowed to identify the main research areas and the connections between key concepts related to the agri-food supply chain. Three visualizations were produced: co-occurrence network, temporal analysis and density map. Fig. 1 shows the co-occurrence network, or the scientific landscape, composed of the keywords of the selected articles. In particular, the scientific landscape is made up of 1015 keywords. The filter for the minimum number of relations that each keyword must have was set to 5. By applying this filter, 29 nodes that make up the network are identified.

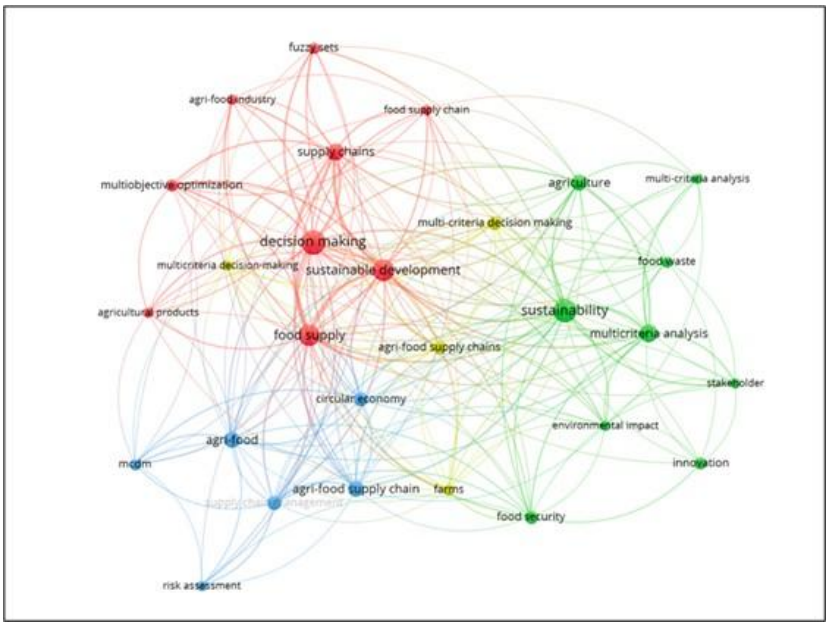


Figure 1: Scientific Landscape
Source: elaboration with VOSviewer software

The *Scientific Landscape* shown in Fig. 1 highlights thematic clusters that represent closely related research areas. From the analysis of the results obtained, we can in particular refer to 4 main Clusters:

- Red Cluster - It includes topics such as decision making, supply chains, multiobjective optimization, food supply, and sustainable development. This cluster highlights the importance of decision analysis and optimization models to manage food supply chains in a sustainable way.
- Green Cluster - It concerns topics related to sustainability, agriculture, environmental impact, food waste and innovation. It focuses on environmental impact and sustainable practices in agri-food production.
- Blue Cluster - It includes topics such as agri-food, supply chain management, risk assessment, MCDM and circular economy. This cluster analyzes risk management and circular economy in the agri-food sector.
- Yellow Cluster - It concerns topics related to agri-food supply chain and multi-criteria decision making. This cluster analyses the use of the main modelling tools for decision support relating to multi-criteria decision making in the agri-food sector.

The analysis of the main literature highlights how multi-criteria methods and multi-objective optimization models are crucial tools to improve the competitiveness and sustainability of agri-food supply chains. In particular, multi-criteria models are useful tools to make decisions balanced between economic efficiency and sustainability. In fact, from the analysis of the main literature it emerges that the joint use of multi-criteria analysis tools and integer linear programming allows to address issues such as the design of sustainable agri-food supply chain networks (Fathi et al., 2024)

The use of multi-criteria approaches allows to analyze problems of different nature in the agri-food supply chain among these we refer for example to the evaluation of circularity in agri-food industries using the AHP model (Coluccia et al., 2024); the study by Silvestri et al., (2024) proposes a multi-criteria model useful for the reduction and reuse of agri-food waste and again Das et al., (2023) identify the main risks in the cereal supply chain and propose mitigation strategies using FAHP and FTOPSIS.

The adoption of multi-criteria and multi-objective optimization methodologies allows to address complex problems, taking into account multiple dimensions (economic, social, etc.). The use of these methodologies is supported by the literature (Ishizaka & Siraj, 2018; Figueira et al., 2005), which highlights their versatility and effectiveness in real contexts. These models offer advantages such as: Rational structuring of the decision-making process (Wątróbski et al., 2019); Management of qualitative and quantitative criteria (Ishizaka & Nemery, 2013); Analysis under uncertainty (Aissi & Roy, 2010); Interaction with stakeholders to reflect on preferences (Klamroth & Miettinen, 2008). The Analytic Hierarchy Process (AHP) method is confirmed as the most widespread for its ability to address problems of choice, sorting and classification (Ishizaka & Siraj, 2018). Advanced models such as Analytic Network Process (ANP), AHP Sort I and II expand decision-making capabilities, managing interdependencies between criteria and decision alternatives (Saaty & Vargas, 2013; Ishizaka et al., 2020). The combined use of quantitative and qualitative models allows for more effective management of supply chains.

3 Method

The method under study is the well-known AHP method, introduced in the 70s by Thomas Saaty (Saaty, 1988). The structuring of a decision problem with the AHP method is defined through the construction of an analytical process aimed at determining a multi-level hierarchical structure (Fig. 2) consisting of all the elements that come into play in the decision-making process: the objectives (O_1 at Level 1), the criteria (g_m with $m = 1, \dots, M$, at Level 2) and the alternatives (A_n with $n = 1, \dots, N$ at Level t) (Ishizaka & Labib, 2009). The number of levels will depend on the complexity and the degree of detail of the decision problem; in any case, the number of levels cannot be less than $t = 3$.

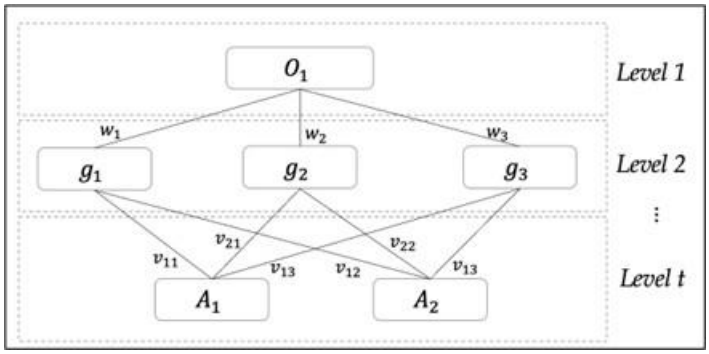


Figure 2: multi-level hierarchical structure
Source: own elaboration

The evaluation of alternatives is derived through the use of pairwise comparison matrices (PCMs) (Cavallo et al., 2012; Cavallo et al., 2019) aimed at obtaining the *local priority* of the criteria and alternatives evaluated with respect to each criterion (Fig. 2); the determination of the weights of the criteria and alternatives can be derived through the use of several techniques, among which the most used are the eigenvector method, the geometric mean and the arithmetic mean (Cavallo et al., 2018). In Fig. 3 we report an example of PCM of the criteria with respect to the objective with the relative priority vector w_m.

$$\begin{array}{c|cccc} O_i & g_1 & g_2 & \cdots & g_m \\ g_1 & 1 & g_{12} & \cdots & g_{1m} \\ g_2 & g_{21} & 1 & \cdots & g_{2m} \\ \vdots & \vdots & \vdots & 1 & \vdots \\ g_m & g_{m1} & g_{m2} & \cdots & 1 \end{array} \rightarrow \begin{pmatrix} w_1 \\ w_2 \\ \vdots \\ w_m \end{pmatrix}$$

Figure 3: PCM of the criteria
Source: own elaboration

The evaluations expressed by decision makers are defined through the use of specific evaluation scales; the most used is the Saaty semantic scale (Saaty, 2001), a scale that represents the intensity of importance of an alternative compared to another using values from 1 to 9. Note that the pairwise comparison matrix is a reciprocal matrix (for example: if $a_{12} = 3$ then $a_{21} = \frac{1}{3}$) and therefore the elements present on the main diagonal are all unitary since the alternative is compared with itself; this reciprocal relationship arises from the need to guarantee the symmetry of the importance judgments.

The final evaluation (*global priority*) of the alternatives with respect to each criterion characterizing the decision problem is obtained through the principle of hierarchical recomposition: the local priorities of each element are multiplied by the priorities of the superordinate elements and the products thus obtained are added.

The best alternative will have the greatest global weight. The use of the AHP method is suggested when the criteria are quantitative, qualitative and mixed; to obtain the ordering or classification of the alternatives as well as choose the best alternative; allocate resources; evaluate the sensitivity of the alternatives to changes in judgments.

4 Decision Problem

The use of AHP can be of support in solving problems at every decision-making level of the Agri-Food Supply Chain. The decision-making problems that can occur in the various phases are complex, structured and unstructured problems, generally characterized by variables affected by uncertainty. Particularly delicate are the decision-making processes that characterize the storage, distribution and trade phases. If we want to try to represent the phases that generally characterize the Agri-Food Supply Chain, we can refer to Fig. 4.

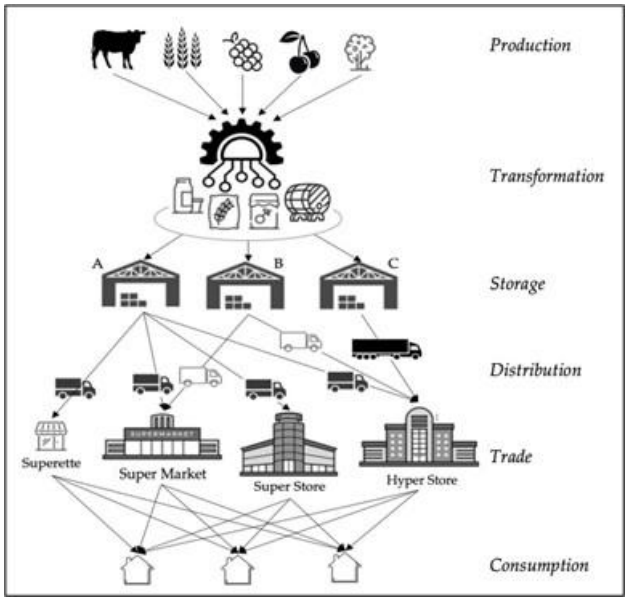


Figure 4: Phases of the Agri-Food Supply Chain
Source: own elaboration

For each phase that characterizes the Agri-Food Supply Chain, different modeling approaches can be used based on the problem being analyzed.

For example, in the Storage phase, logistics and warehouse management problems that influence the product transportation phase can be considered. For example, in the literature for this last model, an age-based model has been proposed for the problem of routing perishable goods stocks with stochastic demands (Violi et al., 2023). The decision-making problems that characterize the distribution and trade phases are also particularly delicate. This work deals in particular with the decision-making problem regarding the transition from the storage and trade phase using the AHP method. Once the products have undergone transformation processes, they are placed in one or more warehouses in order to distribute them to commercial activities. There are several choices to be made in this phase, including the choice of commercial establishments in which to distribute the products. The case study (Fattoruso & Squillante, 2023) concerns, in particular, the choice of distribution of warehouse A with respect to four different commercial establishments (alternatives) that sell directly to the final consumer:

- Superette (A_1) – establishments with a small retail sales area (200 – 400 m²), normally located in city centers with a number of inhabitants lower than (<) 10,000;
- Super Market (A_2) – establishments with a medium retail sales area (500 – 800 m²) that serve municipalities with a number of inhabitants higher than (<) 10,000;
- Super Store (A_3) – establishments with a medium-large retail sales area (1500 – 3500 m²) normally located in the peripheral areas of inhabited centers with a number of inhabitants higher than (<) 10,000;
- Hyper Store (A_4) – stores with a large retail area (2500 – 4000 m²) normally located in shopping centres or in peripheral areas of towns with a population greater than (>) 10,000.

The choice of stores to which to deliver the products depends on 4 criteria:

- Distance (g_1) or the distance that the means of transport must travel from the warehouse to the store. This criterion is important for the decision maker as it determines the costs of maintaining the means of transport that will deliver the products.
- Size of the store (g_2). The selection of this criterion is linked to the quantities of product that the decision maker can deliver to the stores. The larger the size of the store, the greater the quantity of product to be delivered.
- Reputation of the store (g_3). The reputation of the business is a qualitative criterion that cannot be ignored in the choice of businesses to supply, as it can increase or decrease the number of customers served and therefore the increase in demand for products.
- Position (g_4). The position of the business attracts a different number of potential consumers and therefore the consequent increase (or decrease) in product demand.

4.1 Results

The AHP method was applied using Software Expert Choice (Ishizaka & Labib, 2009). The main results obtained are reported below. In Table 1, the local priorities of the criteria can be observed, while in Table 2 the local priorities of the alternatives with respect to each criterion considered are reported.

Table 1: Local Priority of criteria

	Local Priority
g_1	0,418
g_2	0,120
g_3	0,271
g_4	0,191

Table 1: Local Priority of alternative

	g_1	g_2	g_3	g_4
A_1	0,302	0,180	0,243	0,270
A_2	0,283	0,219	0,263	0,123
A_3	0,165	0,489	0,189	0,100
A_4	0,250	0,112	0,305	0,507

By adopting the principle of hierarchical recomposition, the global priorities of the alternatives are obtained and, therefore, their final ranking (Fig. 5).



Figure 5: Ranking of the alternatives
Source: elaboration with Expert Choice

As can be seen, by adopting a Multi-criteria approach that takes into account the evaluations of each alternative with respect to multiple decision criteria, the alternative that best satisfies the needs of the DM is the Hyper Store and to follow in order of importance: Superette, Super Market and Super Store.

Based on the ordering of the alternatives, it is clear that the DM prefers to supply larger commercial establishments with a higher customer potential despite this meaning having higher transport costs.

In order to evaluate the robustness of the method and the results obtained, a sensitivity analysis is conducted (Fig. 6).

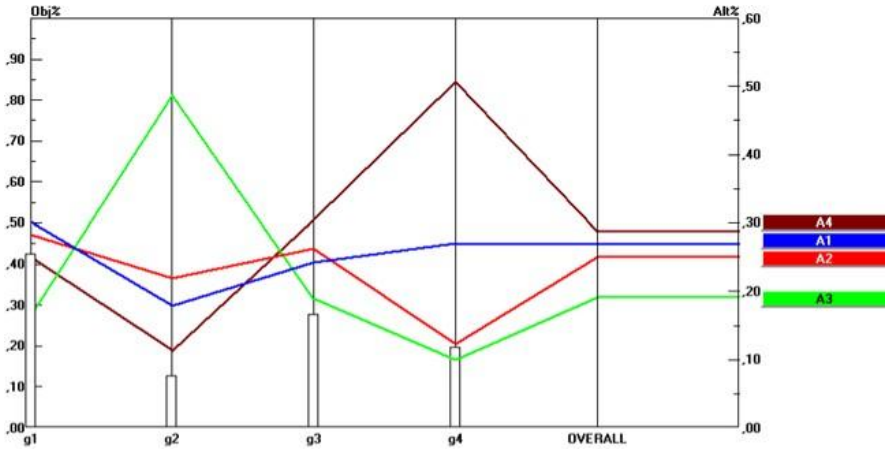


Figure 5: Sensitivity analysis
Source: elaboration with Expert Choice

In particular, Fig. 6 shows how the position of the alternatives varies as the importance attributed to the criteria varies. It can be observed that alternative A_4 is predominant with respect to criterion g_4 and maintains its position in the final ranking; Alternative A_3 shows oscillations; it performs well with respect to criterion g_2, but is weak with respect to g_1 and g_4. This indicates high sensitivity to changes in the weights of

the criteria. Alternatives A_1 and A_3 have a stable trend which suggests that they are less sensitive to changes in the weights than A_3.

5 Conclusion

The agri-food supply chain appears to be a very complex and varied context, in which the competitiveness of organizations is based on the ability of the decision maker to identify problems, imagine alternatives and adopt solutions. This ability is directly influenced by the ability of organizations to acquire knowledge and initiate decision-making learning processes to recognize the problem. In the context of agri-food supply chain, the role of knowledge is particularly relevant as decision-making problems appear to be structured at multiple levels. In fact, the decision taken by an agri-food organization can be considered as the final product of the data collected, the processing of information and the knowledge present within the organization (Daft, 2021, p. 502). For this reason, the tools supporting the decision-making process must take into account a plurality of criteria, capable of helping the decision makers of agri-food organizations in the generation and selection of alternatives. These tools, in fact, if correctly implemented, allow for the initiation of an organizational learning process, reducing the costs associated with decision-making errors.

Furthermore, it should be highlighted that the implementation of Multi-Criteria models appears to be strongly influenced by the nature of interorganizational relationships that links agri-food organizations with other types of organizations (especially universities and research centers). In fact, the prerequisite for the creation of these models is the simultaneous presence of two different domains of knowledge. A first domain of knowledge, highly specific to the processes and activities connected to the agri-food supply chain (or to the business system in general), and a second domain of "technical" type knowledge, fundamental for building the model (Canonico, et al. 2022).

The interaction and contamination, through a dynamic communication process, between the two domains of knowledge, becomes crucial to correctly create a Multi-Criteria model (Ishizaka and Siraj, 2018).

6 Declarations

- Funding: This research received no external funding.
- Conflict of interest/Competing interests: None of the authors have a conflict of interest to disclose.
- Ethics declaration: Not applicable.
- Consent to participate: Not applicable.
- Consent for publication: Yes.
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- Code availability: Not applicable.
- AI declaration: No AI tools were used for creation and/or revision of the manuscript
- Authors' contributions: The authors contributed equally to this work.

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The Role of Intelligent Packaging in Reducing Food Waste: A Consumer Behaviour Analysis

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Abstract

This study explores how consumers perceive and respond to smart packaging technologies as a practical solution to the growing issue of food waste. While traditional food packaging plays a role in preservation, it often lacks the ability to communicate real-time information about freshness or quality.
Smart packaging, which includes technologies such as sensors, freshness indicators and traceability systems, allows for real-time monitoring of product quality, providing consumers with essential information to make more informed decisions and extend the shelf life of food products.
To understand the factors influencing consumers' intention to adopt these technologies, the research adopts an extended version of the Technology Acceptance Model (TAM). In addition to the classic variables: Perceived Usefulness (PU), Perceived Ease of Use (PEU) and Attitude toward Smart Packaging (ATT), the study introduces a novel variable such as Willingness to Pay (WP).
Data were collected through a structured online survey using realistic, scenario-based situations, and analyzed using Partial Least Squares Structural Equation Modelling (PLS-SEM).
The preliminary findings show that Perceived Usefulness (PU), Perceived Ease of Use (PEU) and Attitude toward Smart Packaging (ATT) significantly influence consumers' intentions to adopt such innovative solutions. Conversely, Willingness to Pay (WTP) does not show a statistically significant relationship with consumer intention.
This research contributes to the academic and practical discourse on sustainable innovation in food systems, offering insights for policymakers, businesses and technology developers aiming to promote smart packaging solutions. The study emphasizes the importance of consumer engagement and targeted strategies to support sustainable consumption patterns and reduce food loss across the supply chain.

Keywords: Food waste; Smart packaging; Consumer behaviour**;** Technology Acceptance Model**;** PLS-SEM

Paper type: Academic Research Paper

1 Introduction

Food waste (FW) is one of the most pressing challenges of our time, with significant implications for the economy, environment, and global food security.

Each year, vast quantities of food are wasted across the agri-food supply chain, resulting in major resource loss and serious environmental and social impacts (Roka, 2022). The Food Waste Index Report 2024 indicates that 1.05 billion tons of food were wasted globally in 2022 (United Nations Environment Programme, 2024). This is in addition to the 13% of food lost from post-harvest to retail, as estimated by the FAO (FAO, 2023). The environmental consequences of FW are alarming. As food decomposes in landfills, it emits substantial greenhouse gases, exacerbating climate change (Scherhaufer et al., 2018). Packaging was developed to slow food deterioration and serves several purposes: storage, safety, transportation and delaying decay. However, traditional packaging lacks the ability to provide real-time data on food quality and shelf life. Smart packaging offers the potential to address these limitations and reduce FW. Innovative solutions like smart packaging can inform consumers about food quality and shelf life in real time (Dodero et al., 2021). It goes beyond basic containment to represent a technological evolution of traditional packaging (Drago, 2020). With smart technologies, consumers can monitor internal and external conditions, assess product quality and extend durability (Robertson, 2005). These innovations increase perceived value by offering useful data and support both European policies and the Sustainable Development Goals (SDGs). Intelligent packaging contributes to SDG 2 (zero hunger) by promoting FW reduction, and SDG 12 (sustainable consumption and production) through improved supply chain management (SDG, 2020).

This study aims to explore consumers' intentions to adopt smart packaging to enhance sustainability in the food supply chain and reduce FW. The research uses Partial Least Square Structural Equation Modelling (PLS-SEM) and builds on Davis' (1989) Technology Acceptance Model (TAM). The model incorporates a new variable, Willingness to Pay (WP), alongside Perceived Utility (PU), Perceived Ease of Use (PEU), and Attitude toward Smart Packaging (ATT).

A scenario-based approach (Weber, 1992) is applied, presenting participants with hypothetical yet realistic use cases of smart packaging. The study provides insights into consumer behaviour, helping policymakers, businesses, and stakeholders encourage the adoption of intelligent packaging. The article proceeds as follows: first, a literature review and theoretical framework; second, an explanation of the methodology and survey results; and finally, a discussion on the research's implications, limitations, and directions for future studies.

2 Literature review and theoretical framework

Food waste (FW) remains a global crisis, with one-third of all produced food going to waste. Food packaging contributes twofold: through material waste, plastic, glass, rubber, cartons, aluminium and FW due to contamination or poor packaging. However, packaging can play a key role in minimizing FW and empowering informed consumers. User-friendly packaging designs that reduce leftovers or spoilage have transformed the sector.

Current technologies support the development of various smart packaging types, classified by materials, data capabilities and user interaction (Fernandez et al., 2023). These fall into three main categories: interactive packaging, sensor-based packaging, and indicator-based packaging (Biji et al., 2015). Interactive packaging, such as barcodes, RFID and NFC, enables food traceability and monitors storage conditions throughout the supply chain, enhancing transparency and safety (Ruiz-Garcia et al., 2011). Sensor-equipped packaging monitors parameters like temperature, humidity and impact, providing real-time data and alerts about potential safety or quality issues (Nilsson et al., 2012).

Indicators, though not data-transmitting, visually signal problems, for instance, via colour changes indicating spoilage or contamination (Hogan and Kerry, 2008). Common types include time-temperature, freshness and gas indicators (Bhardwaj et al., 2022). These innovations improve food chain sustainability by reducing waste and optimizing resources (Poyatos-Racionero et al., 2018). However, wider adoption requires better understanding of consumer perceptions and intentions.

Few studies have addressed consumer concerns, acceptance and awareness of smart packaging or motivations behind its adoption (Incpen and Wrap, 2019). Cammarelle et al. (2019) noted that consumers often purchase smart-packaged food due to social pressure rather than a desire to reduce waste.

Additionally, literature shows that those who view FW reduction as a moral duty behave differently from those indifferent to environmental issues. Misiak et al. (2018) found that communities facing food insecurity prioritize product value over waste concerns. Thus, visual elements like colour-changing indicators can influence consumer behaviour positively or negatively.

Some studies warn that smart packaging may paradoxically increase FW (Young et al., 2020). Higher packaging costs and misinterpreted indicators can lead consumers to discard still-edible food (Pennanen et al., 2015). This highlights the need for clear communication and regulation to avoid unnecessary waste.

Research suggests consumers often prioritise personal benefits, with price being a major barrier to green purchases (Kulshreshtha et al., 2017). A key issue in green consumption is the gap between attitudes, intentions, and actual behaviours. For example, in the U.S., 82% of consumers report strong environmental intentions, but only 16% act on them (Bennett & Williams, 2011). In the U.K., although 30% express concern, ethical food products hold just 5% market share (Wheale & Hinton, 2007).

The central question is whether consumers will embrace advancements in food-packaging technology.

To explore this, the study uses the Technology Acceptance Model (TAM) to examine how perceived usefulness (PU), perceived ease of use (PEU) and attitude (ATT) affect the intention to purchase smart-packaged food (INT). It extends TAM by introducing willingness to pay (WP) as a new variable.

Developed by Davis (1989) as a refinement of the Theory of Reasoned Action (TRA) (Ajzen & Fishbein, 1980), TAM links behavioural intention to technology adoption (Davis & Granić, 2024). In its original form, Davis identified PU and PEU as key cognitive factors shaping attitudes and behavioural intentions (Davis, 1985). Later, Davis and Bagozzi (1989) proposed including external variables to enhance the model's adaptability. Since then, many researchers have expanded TAM with additional factors. In this study, WP reflects consumers' willingness to invest in smart packaging.

Within our research on smart packaging and FW reduction, the extended TAM framework enables a comprehensive evaluation of purchase intentions by integrating cognitive (PU, PEU), emotional (ATT) and economic dimension (WP).

Accordingly, we developed a research model (Figure 1) based on TAM variables extended with WP.

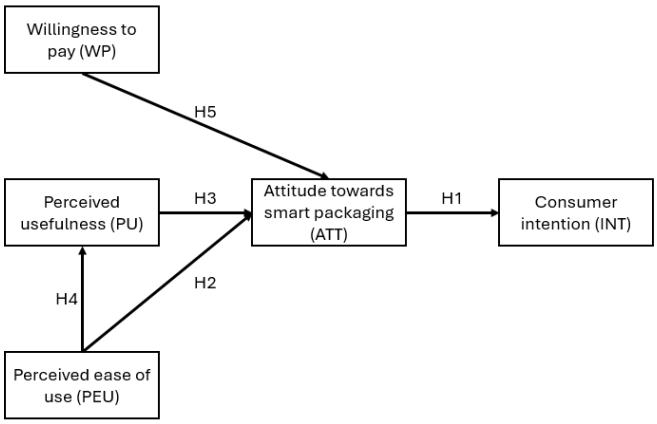


Figure 1: The proposed model

2.1 Attitude

Attitude is an individual's comprehensive assessment of a particular future behaviour (Luongo et al., 2023). Consumption intention results from hedonic and utilitarian motivations. Hedonic motivation is derived from emotions, fun and enjoyment whereas utilitarian motivations are the product of rational evaluation of future outcomes. Attitudes are predictors of intentions and if food packaging technologies should encourage hedonic (product real-time information) or utilitarian motivation (food waste) in consumers. Accordingly, we propose the following hypothesis:

- *H1: Attitude towards smart packaging influences consumer intention.*

2.2 Perceived Ease of Use and Perceived Usefulness

Perceived ease of use is a critical determinant in shaping consumer attitudes toward technological innovations, including smart and intelligent food packaging. Drawing from TAM, Davis (1989) emphasised that when users perceive a system as easy to use, their overall attitude and intention to adopt it improve. This idea extends smart food packaging. The latter, which is simple to understand and easy to interact with consumers, e.g., QR codes, freshness indicators, time and temperature and traceability enhance consumers' overall user experience.

Research suggests that when consumers have to make little or no adjustments, they adopt the technology faster (Silayoi et al., 2007). Correspondingly, a few studies also concluded that user friendly interface and information availability and clarity on food packaging influence positive intentions and attitudes in consumers (Young et al., 2020). Hence, the ability of consumers to utilize the functions of smart packaging influence consumers' intentions to adopt technology, which translates into an effort to reduce FW and improve food safety. Previous studies revealed that PEU is also considered as a relevant factor in driving technology usage. Accordingly, PEU influences PU because technologies requiring fewer efforts can be perceived as more useful. PU refers to the belief that a consumer has regarding using a technology, which makes the usage of the particular product effortless and beneficial. Studies conducted by Incpen and Wrap (2019) found that consumers recognize the benefits of innovative packaging, but the intention to purchase it to reduce food waste is under-researched. Indeed, fewer studies have been conducted to address consumers' angst, acceptability and awareness of PU of innovative packaging and underline reasons to choose innovative packaging (Incpen and Wrap, 2019). Hence, we propose the following hypothesis:

- *H2: Perceived ease of use influences attitude towards smart packaging.*
- *H3: Perceived usefulness influences attitudes towards smart packaging.*
- *H4: Perceived ease of use influences perceived usefulness.*

2.3 Willingness to pay

Price is a crucial and multifaceted factor in consumer decision-making for environmentally friendly products. Consumer purchasing decisions are often influenced by the perception that sustainable packaging is more expensive. Higher price tags for eco-friendly packaging often influence consumers positively (environment conscious) as well as negatively (price conscious). A Vietnamese consumer-based study concluded that people are willing to pay higher prices for biodegradable or eco-friendly packaging (Kulshreshtha et al., 2017). In contrast, studies based in European countries highlighted the difference in intention of consumers towards high-

priced packaging. The studies pointed out that the higher-income economies do not correlate with environmental consciousness (Liobikienė et al., 2025). Willingness to pay premiums for eco-friendly options correlates with environmental concern, though price remains a barrier for low-income households. Hence, consumers' positive perception of smart packaging will enhance the technological advancement and success of the technology also depends on consumer acceptance (Michaud et al., 2017). Therefore, we propose the following hypothesis:

- *H5: Willingness to pay influences attitude towards smart packaging.*

3 Methodology

To collect data, a survey was conducted among consumers in Naples (Italy) between October 2024 and December 2024. The questionnaire, developed using Microsoft Forms, was administered in areas with high consumer traffic relevant to food purchasing behaviour, specifically near grocery stores, supermarkets and shopping centres. The survey link was shared via QR code.

Following the scenario-based approach proposed by Weber (1992), the survey began with a brief explanatory scenario outlining the concept and benefits of smart packaging in the food sector. This helped provide context and guided participants in evaluating how certain features of smart packaging may influence their purchase decisions.

The study utilized a structured questionnaire with a seven-point Likert scale to gather quantitative data. The first part of the survey collected demographic and personal information, such as gender, age, income and education level. The second one consisted of 15 items measuring consumer perceptions and behavioural intentions related to food products with smart packaging, rated from 1 (Strongly disagree) to 7 (Strongly agree) (Podsakoff et al., 2003).

All measurement items were adapted from validated sources in the literature. Intention to use smart packaged products was assessed with three items from An et al. (2017), attitude toward smart packaging (ATT), perceived ease of use (PEU) and perceived usefulness (PU) were each measured with three items from Kim and Woo (2016) and willingness to pay (WP) using three items from Prakash and Pathak (2017).

The face validity of the instrument was confirmed through a pilot test involving 30 respondents from the sample group and revisions were made accordingly. Data analysis was conducted using Smart-PLS software. The sample size was determined in accordance with the statistical power threshold of 80% (Green, 1991), resulting in 154 valid responses.

The dependent variable in this research is consumers' intention to purchase food products using smart packaging (INT), while the influencing factors are latent variables (LVs), which are measured indirectly through observable indicators (manifest variables, MVs). Due to the complexity and the nature of the relationships among variables, Structural Equation Modeling (SEM) was selected as the most suitable statistical method.

4 Results and discussion

The adoption of PLS-SEM using the Smart-PLS software was motivated by its robustness in handling a wide range of assumptions related to the distribution of variables and error terms (Hair et al., 2019). The structural model delineates the interrelationships among latent variables (LVs), whereas the measurement model specifies the associations between a LV and its observed indicators (MVs). The application and interpretation of PLS-SEM encompass two fundamental stages: the evaluation of the measurement model and the assessment of the structural model (Hair et al., 2019).

4.1 Descriptive results

The final sample consists of 154 valid responses. In terms of gender, 45,5% of participants identified as female (n = 70), 44,8% as male (n = 69) and 9,7% (n = 15) preferred not to disclose their gender. The age distribution shows a concentration in the younger age groups. 20,1% of participants are aged 18–24 years (n = 31), 21,4% are aged 25–34 years (n = 33), and 19,5% are aged 35–44 years (n = 30). Additionally, 19,5% of participants are aged 45–54 years (n = 30) and 19,5% are aged 55 years and above (n = 30). Regarding annual income, most respondents are in income brackets below 30.000 euros. Specifically, 16,2% reported having an income of less than 12.000 euros (n = 25), 19,5 percent have an income between 12.000 and 19.999 euros (n = 30) and 21,4% percent have an income between 20.000 and 29.999 euros (n = 33).

4.2 Measurement model evaluation

The overall adequacy of the model was evaluated through a set of indices recommended by Hair et al. (2019), focusing on the reliability of the measurement model as well as its convergent and discriminant validity.

4.2.1 Reliability

To evaluate reliability, Dillon-Goldstein's rho, was examined for each construct to ensure it exceeded the accepted threshold of 0.7 (Dillon & Goldstein, 1984). It is regarded as a more appropriate reliability metric for SEM compared to Cronbach's alpha (Sanchez, 2013). This preference stems from its basis in factor loadings rather than correlations among observed variables, as noted by Chin (2009). As shown in Table 1, all CR values surpassed the minimum threshold, ranging from 0.781 to 0.9.

4.2.2 Convergent and discriminant validity

Convergent validity was assessed through the examination of normalized weights and the Average Variance Extracted (AVE). According to Henseler et al. (2015), outer loadings should exceed 0.6, while AVE should be greater than 0.5 (Hair et al., 2019). As presented in Table 1, all item loadings were above or exceeded the 0.7 threshold, and AVE values for each construct were above 0.5. These results confirm the adequacy of convergent validity.

Discriminant validity was assessed using the Fornell-Larcker criterion (Fornell & Larcker, 1981). According to this method, discriminant validity is confirmed when the square root of each construct's AVE (displayed on the diagonal) is greater than the correlations between that construct and all other constructs (off-diagonal elements) in the corresponding rows and columns.

As shown in Table 2, the square root of the AVE for each construct exceeds its highest correlation with any other construct, thereby confirming that the Fornell-Larcker criterion has been met. Several items were examined to determine those with strong loadings on their respective constructs and minimal loadings on others. The cross-loadings for all constructs were consistently low, supporting the presence of strong discriminant validity across the measurement model.

Table 1: Outer loadings, composite reliability and convergent validity

Construct	**Outer loading**	**Cronbach's alpha**	**Dillon-Goldstein's rho**	**Average variance extracted (AVE)**
ATT1	0,835	0,739	0,850	0,654
ATT2	0,826			
ATT3	0,764			
INT1	0,861	0,833	0,900	0,750
INT2	0,862			
INT3	0,875			
PEU1	0,869	0,782	0,872	0,695
PEU2	0,769			
PEU3	0,860			
PU1	0,761	0,572	0,781	0,546
PU2	0,614			
PU3	0,826			
WP1	0,798	0,747	0,854	0,661
WP2	0,823			
WP3	0,817			

Table 2: Fornell-Larcker criterion

	ATT	**INT**	**PEU**	**PU**	**WP**
ATT	0,809				
INT	0,458	0,866			
PEU	0,644	0,627	0,834		
PU	0,697	0,418	0,497	0,739	
WP	0,533	0,662	0,540	0,488	0,813

4.3 Structural model evaluation

4.3.1 Multicollinearity

To evaluate potential multicollinearity among the constructs in the model, the inner Variance Inflation Factor (VIF) was calculated. According to Hair et al. (2019), an inner VIF value below 3.3 is generally considered acceptable, indicating that multicollinearity is not a concern. As shown in Table 3, all VIF values fall within the acceptable range, suggesting that multicollinearity does not affect the research model.

Table 3: VIF coefficients

	ATT	INT	PEU	PU	WP
ATT		1,000			
INT					
PEU	1,570			1,000	
PU	1,460				
WP	1,552				

4.3.2 R-square coefficient.

The R-squared (R^2) coefficient is used to evaluate how well the model explains variance in each dependent variable (Hair et al., 2019). In this study, the model accounts for 60% of the variance in the primary dependent variable (INT), while explaining 26% and 24% of the variance in two additional constructs (ATT; PU). Although these values are close to the lower threshold, they still approach or meet the minimum benchmark of 0.26 proposed by Cohen (1988), indicating that the model possesses an acceptable level of explanatory and predictive power for the variables considered.

4.4 Testing the research hypotheses

As shown in Table 4, all hypothesized relationships were supported by the data, apart from WP to INT, which was not statistically significant.

Table 4: Final results

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics	P values	Support
ATT -> INT	0,458	0,462	0,070	6,543	0,000	Yes
PEU -> ATT	0,349	0,347	0,069	5,043	0,000	Yes
PEU -> PU	0,497	0,506	0,078	6,409	0,000	Yes
PU -> ATT	0,466	0,470	0,079	5,898	0,000	Yes
WP -> ATT	0,116	0,117	0,090	1,296	0,195	No

5 Discussion

This study explores how consumers perceive the use of smart packaging technologies to reduce FW. Based on TAM, the research shows that PU, PEU and ATT play an important role in influencing consumers' decisions to adopt these innovative technologies. It is interesting to note that WP does not seem to correlate significantly with behavioural intentions. These findings are in line with previous research that has highlighted the "attitude-behavior gap" associated with sustainable consumption. According to Ares et al. (2020), a systematic review discovered that many customers have embraced smart packaging, but this doesn't necessarily translate into monetary rewards for such technologies.

Consumers' motivation to purchase smart packaged products is influenced by their perceptions and behavioural control, as demonstrated by Cammerelle et al. (2021), rather than their WP. The gap between positive attitudes and behaviors may result from several factors. Consumers may perceive smart packaging as a standard solution rather than a premium option.

Furthermore, the specific benefits of smart packaging, such as freshness and reduced FW, may not be immediately recognized. This scenario highlights how important it is to clearly communicate the benefits of smart packaging to bridge the gap between positive perceptions and actual purchasing behaviour. This finding contradicted several earlier studies that had identified WP as a significant factor in the adoption of innovative and sustainable packaging.

Fennell et al. (2023) discovered that nearly 50% of US consumers are open to paying more for packaging options, which can influence their purchase decision in terms of sustainable packaging. In contrast, the present study shows that there is no significant correlation between WP and ATT.

These insights highlight the urgent need for focused educational initiatives and clear communication strategies to enhance consumer understanding and trust in smart packaging technologies.

By increasing familiarity and highlighting concrete advantages, stakeholders can effectively link positive attitudes to actual purchasing actions.

6 Conclusion, implications and limits

In conclusion, this paper contributes to academic debate on food waste reduction, proposing an extended version of TAM. However, it highlights some limitations that future researchers may address to gain deeper insights. The sample was sourced from Italy, making it difficult to generalize the findings to other contexts or populations in different geographic areas or economies. The sampling method, although effective for quick data collection, may hinder the broader applicability of the results to larger populations. Future researchers may leverage this study's findings to refine the research model and assess it using various methodological approaches. They should also consider demographic and sociographic factors to unravel the complex interplay of intentions and attitudes, ultimately aiding in predicting behaviours. While our study examined the relationships among WP, PU, PEU and ATT, incorporating demographic variables could yield richer insights into the intentions behind purchasing smart packaging aimed at reducing food waste. Further research should investigate the moderating roles of consumer knowledge, perceived risk and technological trust on the link between WP and adoption intentions. Additionally, examining demographic and cultural influences could enhance understanding of consumer behaviour in this area.

Furthermore, the study provides important implications for companies, policy makers and stakeholders in the agri-food supply chain. Smart packaging is not only a technological tool, but also a strategic instrument to improve the sustainability and transparency of the food chain, contributing to the achievement of sustainable development goals. For this reason, collaboration between different actors in the agri-food supply chain is essential to promote the benefits of smart packaging and foster its adoption.

7 Ethics declaration

Ethical approval was not required for this study, as it did not involve sensitive personal data, vulnerable populations or procedures posing risks to participants.

8 AI declaration

The AI-based tool Grammarly was used solely to assist with grammar and spelling correction throughout the manuscript. All content was written by the authors, and the tool did not contribute to the generation of original ideas or substantive content.

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Organizing the Agri-Food Supply Chain to Reduce Food Waste: An Exploratory Study

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Abstract

The agrifood business system, in terms of sector turnover and employment, assumes significant weight for creating economic value within local socio-economic systems, with a direct impact on population health. Furthermore, the agri-food business system is a sector that has direct repercussions in terms of public health and well-being of people. In recent years, the agrifood sector has undergone numerous changes, both regulatory and technological view. These recent changes along with growing societal awareness, have shifted the focus towards combating food waste in the agrifood supply chain. As an effect, the agrifood business system has garnered increasing attention from policymakers and scholars. Consolidated studies on agri-food business systems have focused their attention on historical and evolutionary aspects, leaving out managerial aspects such as those linked to inter-organizational relationships and the supply chain.

This preliminary study aims to offer a first analysis of the main regulatory and organizational elements within the agri-food supply chain business system. This study, through a qualitative approach, analyzes organizational actors, interorganizational relationships and sustainability-oriented strategies along the entire supply chain. The theoretical approach used is based on knowledge management studies. Adopting an exploratory research design, this study employs qualitative methods to gather in-depth insights into the dynamics of the agrifood supply chain. Given the complexity and diversity of organizational actors within the agri-food business system, this exploratory study aims to identify the main evolutionary trends—both regulatory and managerial—of the agri-food supply chain. The research adopts a qualitative methodology, drawing on secondary data sources such as industry reports, regulatory documents, and academic literature.

This study contributes to the academic and practical discourse on agri-food business system by focusing on the organizational dimensions of the issue. Unlike existing literature, it integrates these additional drivers for change, beginning with the regulatory context. The findings provide initial observations and reflections for practitioners seeking to reduce inefficiency through organizational innovation and for scholars in organizational theory. Furthermore, the proposed regulatory framework emphasizes the importance of integrating data-driven technologies and predictive analytics into decision-making processes, enabling more precise inventory management, better coordination among supply chain actors, and the development of reactive strategies to mitigate waste. These practical implications also extend to policymakers, offering pathways for creating supportive regulatory environments and incentivizing sustainable practices in the agrifood sector.

Keywords: Agri-food supply chain, food waste reduction, organizational models, digital regulation, sustainability

Paper type: Academic Research Paper

1 Introduction

The development of the agri-food sector plays a key role in the growth of an economic system, both in terms of turnover and employment rate. This assumption has attracted the attention of scholars and policy makers in recent decades. In fact, the agri-food sector represents the economic sector that can most increase youth entrepreneurship and, at the same time, reduce socio-economic imbalances. In fact, in low- and medium-income countries, the agri-food sector can offer opportunities to combat youth unemployment, urban migration, as well as poverty and social unrest (Maïga, et al., 2020). Suffice it to say that, in 2020, according to Eurostat data, the agri-food sector contributed to the formation of the Gross Domestic Product (GDP) of the EU27, with a share of 1.3%, with a Gross Added Value (GVA) of 178.4 billion euros. To this we must add that the European Union, through three funds (Common Agricultural Policy, CAP; European Agricultural Guarantee Fund, EAGF; European Agricultural Fund for Rural Development, EAFRD) has supported the agri-food sector with over 50 billion euros. According to EU estimates, each euro spent in the agri-food sector can reinject approximately 0.76 euros into the economy.

For this reason, the agri-food sector is the subject of analysis in many disciplinary sectors, determining a broad and varied scientific panorama (James, et al., 2011; Grandori, 2015). Consequently, the study of the agri-food sector is not simple but characterized by various analytical perspectives with overlapping concepts and terms. The first complexity, which scholars face in the analysis of the agri-food sector, lies in the lack of a univocal definition of the boundaries of the sector itself, or in the use of a shared terminology. Historically, the agri-food

sector has been associated and overlapped with the agricultural sector. A clear example of the conceptual nebula that revolves around the agri-food sector lies in the abundance of terms, often overlapping with each other. Furthermore, in common language, the terms “agri-food industry”, “food” or “agri-food system” (Baregheh et al., 2014; Dasgupta et al., 2015; Grandori, 2015; de Souza Filho & Miranda, 2019; El Bilali, 2019) are used as synonyms, contributing to confusion. It is therefore necessary to begin to overcome this first conceptual obstacle, trying to provide a definition of the boundaries of the agri-food sector.

In recent years, with the emergence of new consumer needs and technological progress, it has become necessary to include in the agri-food sector also services related to control and certification and agri-food safety, as an essential aspect for the design and reorganization of the agri-food supply chain. The agri-food sector therefore includes all organizations and actors that are directly and indirectly involved in satisfying the food needs of a country or territory. A further complexity in the study of the agri-food sector is linked to the intrinsic characteristics of the sector itself. The deterioration of fresh products in a short time, heterogeneity of products, control of diseases or parasites, dependence on weather conditions is just some of the intrinsic complexities of the sector and challenges that agri-food organizations must face daily. All this determines, along the entire food supply chain from the producer to the final consumer, the coexistence of organizations, often small or medium-sized, that adopt different organizational models, strategies and procedures. Unlike other mature sectors, the organizations that populate the agri-food sector have remained largely family-run (European Commission, Eurostat 2022).

2 Theoretical framework

2.1 Regulatory framework in the agri-food business system

Over the past three decades, the agri-food sector has undergone a significant paradigmatic transformation, catalyzed by the introduction of the European Green Deal and, more specifically, by the “Farm to Fork” Strategy [N. Lucifero; S. Carmignani]. This initiative, embedded within the broader framework of the European Union’s sustainability policies, has entailed a substantial reconfiguration of the entire agri-food supply chain (Albisinni; E. Rook Basile]. The Strategy, through its multidimensional approach to environmental, social, and economic sustainability, has impacted each stage of the chain—from the production phase, such as the selection of methods and inputs, to commercialization, including, for instance, the application of green claims, and finally to the management of surplus, by-products, and waste[P. Borghi, I. Canfora, A. Di Lauro, L. Russo]. Such end-of-chain management is increasingly influenced by the principles of the circular economy, which promote the reuse of materials—within the agri-food sector or in other industries—through the support of technological innovation.

The emerging regulatory framework arising from this green strategy is characterized by a holistic and systemic approach that seeks to reconfigure sectoral practices in alignment with the overarching objectives of climate neutrality, biodiversity preservation, and the promotion of fair, healthy, and environmentally respectful food systems [L. Costato, F. Albisinni; N. Ferrucci]. In this context, the EU legislator has adopted a number of legal instruments impacting the entire value chain. From primary production to marketing, from processing to final consumption, each phase is increasingly regulated in accordance with sustainability and efficiency criteria. Regulation (EU) 848/2018 on organic production and labelling of organic products [N. Lucifero], and Directive (EU) 2022/2464 on corporate sustainability reporting (CSRD), exemplify how EU law integrates sustainability into both input selection and strategic communication processes [S. Bolognini].

This evolution of the regulatory framework in a “green” direction has stimulated the adoption of sustainability certifications, non-financial disclosure obligations, and environmental labelling, which are reshaping organizational conduct beyond the mere logic of compliance [A. Jannarelli]. For example, environmental claims and labelling mechanisms—soon to be further regulated by the Green Claims Directive (COM/2023/166)—are gradually redefining consumer engagement and inter-firm communication within the supply chain. Regulatory design thus acts as a catalyst for both institutional isomorphism and innovation.

At the same time, public procurement rules incorporating environmental criteria (so-called CAM – Minimum Environmental Criteria), incentives for sustainable investment, and funding mechanisms under the Common Agricultural Policy (CAP) reinforce the legitimacy and diffusion of sustainability-oriented models. Law, in this sense, operates not only as a constraint, but as an enabler and disseminator of new organizational logics [A. Germanò; L. Russo].

Among the most transformative dimensions of this legal-institutional evolution is the codification of circular economy principles in the governance of agri-food waste. Through the EU Circular Economy Action Plan and

amendments to Directive 2008/98/EC on waste, the Union has introduced a new legal hierarchy in food waste management, prioritizing prevention, reuse, and valorization over disposal [F. De Lenonardis].

This framework has been implemented at national level through legislation such as Italy's Law No. 166/2016 (the "Gadda Law"), which facilitates the redistribution of unsold food and the valorization of by-products. These legal instruments operationalize circularity by defining "by-product" and "waste" categories, thereby enabling their reuse within or across industrial sectors (e.g., as feedstock, bioplastics, or energy). Simultaneously, the legal articulation of circularity entails significant interdependencies with food safety law, which delineates the conditions under which reuse is legally permissible. These constraints reflect a broader regulatory tension between risk governance and resource efficiency, which supply chain actors must manage strategically [S. Manservisi].

In this regard, digital technologies such as blockchain, the Internet of Things (IoT), and artificial intelligence (AI) are assuming an increasingly central role in the implementation and traceability of sustainable practices. On one hand, such technologies enable compliance by facilitating traceability, predictive inventory management, and loss prevention [M. Ferrari]. On the other hand, they require new regulatory standards on data governance, liability, and interoperability across digital platforms. Thus, regulatory innovation must keep pace with digital innovation to ensure that legal frameworks remain fit for purpose.

The integration of predictive analytics and real-time monitoring into legal risk management systems is also transforming how companies operationalize compliance. For instance, smart contracts may automate regulatory obligations, while AI-based systems can generate compliance reports aligned with CSRD and ESG metrics. These developments suggest an increasingly techno-mediated form of regulation and open new pathways for organizational adaptation and legal design.

Despite substantial progress, the evolution of sustainable law in the agri-food sector remains marked by institutional fragmentation and heterogeneous enforcement across Member States. Variability in administrative capacity, divergent national implementations, and overlapping sectoral regulations may generate legal uncertainty and compliance asymmetries along transnational supply chains.

To mitigate such frictions, recent EU efforts aim to promote regulatory harmonization and coherence, including through initiatives such as the Digital Product Passport and the food waste monitoring and reporting. From an institutional theory perspective, these harmonization efforts reflect a transition from soft law to hard law instruments, intended to stabilize expectations and reduce institutional ambiguity in the agri-food domain.

The legal transformation of the agri-food chain—understood as a process of institutionalizing sustainability norms—constitutes a cornerstone of the systemic transition toward food systems that are just, inclusive, and regenerative. Law does not merely reflect societal change, but actively constructs the frameworks within which new practices become legitimate, widespread, and routinized [I. Canfora; L. Paoloni].

The agri-food supply chain thus becomes a locus of legal experimentation, where the design of rules, incentives, and sanctions interacts dynamically with organizational innovation and digital technologies. From this perspective, sustainability in the agri-food sector cannot be achieved solely through technical optimization or moral persuasion: it requires a coherent, enforceable, and adaptive legal architecture that acknowledges the complexity and pluralism of the food system.

2.2 Knowledge management in agri-food business system

The affirmation of the principles of the knowledge economy inevitably requires a rethinking of traditional management and organizational models, in favor of new models based on the valorisation of knowledge. The competitiveness and survival of companies, therefore, is based on the organizational capacity to valorise existing knowledge, introduce new knowledge and trigger it in production processes. In traditional sectors, such as the agri-food sector, characterized by managerial practices with a low rate of innovation and knowledge, the introduction of new knowledge management practices can represent the real new challenge of the sector, capable of determining the survival or otherwise of organizations. Several studies (Gaziulusoy et al., 2013; Vesperi and Coppolino, 2022) have highlighted that the sector is not able to generate new knowledge and innovation alone. Knowledge can be acquired through, or together with, partners thanks to complementary relationships (Chesbrough, 2006), generating new sustainable value. This determines that agri-food organizations must base their competitive advantage on knowledge obtained from third-party and shared organizations. It is important to highlight that from a KM perspective, the mere existence of knowledge within an organization is not a sufficient condition to generate a competitive advantage. For knowledge to be transformed into a lever for competitive advantage, it must be managed in a systemic manner. In fact, in agri-food organizations, knowledge is present in different forms (tacit/explicit; technical, relational, etc.); but the real obstacle lies in the difficulty in introducing knowledge and innovation into production processes, starting a

virtuous circle of increase in knowledge possessed. On the other hand, organizations belonging to the agri-food sector are slower in absorbing new knowledge and adopting new technological solutions compared to other sectors.

As evidence that the agri-food sector is not a static sector but a dynamic sector and highly vulnerable to socio-economic dynamics, it is possible to identify some future development paths of the food system. The growing attention of consumers and policy makers on factors such as food safety and food waste is imposing the spread of sustainable food systems (Esposito, et al., 2020); circular (Aznar-Sánchez, et al., 2020) and sustainable (Garnett, et al., 2013; El Bilali, et al., 2019).

3 Methodology

The main objective of this study is to define and explore the main elements of the agri-food business system. To achieve this goal and considering the intrinsic complexity of the agri-food business system, it has determined the use of an exploratory approach based on a qualitative methodology. A qualitative approach, in fact, allows to explore the richness and variability of phenomena without limiting oneself to numerical or standardized measurements, offering a more detailed view of the processes, relationships and practices that define the agri-food system. This approach allows to collect preliminary data and information useful for the formulation of future theories and for the identification of emerging themes within the agri-food system. This approach allows to deepen the meaning attributed by the participants to complex phenomena such as sustainability, innovation, and organizational challenges in a constantly evolving global context.

The secondary sources used in this study include a variety of documents, such as industry reports, academic articles, official publications of government bodies and reports of trade associations. These documents were analyzed to identify trends, challenges and opportunities within the agri-food business system, as well as to gain an in-depth understanding of the main actors involved, such as producers, distributors, consumers and regulatory authorities. Furthermore, the analysis of secondary sources allowed to reconstruct the history and evolution of the agri-food system, in relation to economic, social and environmental dynamics. Another central aspect of the data collection was the analysis of the legislation on agriculture, food and sustainability. This analysis involved the review of national and international laws and regulations governing the agri-food sector.

4 First results and discussion

The agri-food business system takes on a strategic importance in terms of economic impact, and also on the system of health and collective well-being. In fact, the agri-food business system, comprising a multitude of organizations, from micro-enterprises in the primary sector to large and maxi-enterprises in the secondary sector, from those that deal with direct cultivation to those that deal with fourth-range production and physical distribution of products, highlights the extreme heterogeneity of the organizations present, of different sizes, where the use of technologies ends up making the difference, completely changing the added value produced. With respect to this heterogeneity, the dynamics of change end up having very different repercussions in the agri-food business system, forcing the organizations that are part of it to continuously review the structures and organizational models adopted, in search of ever new paths of growth and development.

The results of this study highlight the importance that “knowledge” plays within organizations. By focusing on the agri-food business system, and on the organizations that are part of it, knowledge takes on an even more relevant role. In fact, the heterogeneity and plurality of organizational models, and their hybrid forms (Touzard, et al., 2015; Ménard, 2018), imposes the need to rethink knowledge based on the specificities of the agri-food business system. For this reason, to analyze the connotation that knowledge takes on, it is necessary to enrich the analysis perspective. From the perspective of knowledge management theory, individual knowledge of organizations that make up the agri-food business system can be considered as a set of knowledge and skills that derive from experience and learning in the field, generally indicated with the term know-how (Nonaka, 1994), which helps the individual to carry out their tasks. Individual knowledge recalls the widely discussed concept of explicit knowledge and tacit knowledge but, at the same time, highlights that individual knowledge within the organization is not present in a uniform manner. The asymmetric distribution of knowledge manifests itself with a concentration of knowledge in a few individuals, making it difficult to transfer (Davenport & Prusak, 1998; Adam & Lamont, 2003), identify and exploit existing knowledge sources within the organization. This aspect justifies the constant interest of management and organizational theory scholars in analyzing the ways in which it is possible to facilitate the processes of knowledge creation and transfer. The agri-food organization, therefore, can be considered as an aggregate of individual knowledge, distributed in a non-uniform manner within itself, and on which its survival and competitiveness in the business system depends. Consequently, this

condition helps to explain the differences, in terms of performance and behavior, that are found between different units of the same organization.

Following this perspective, the agri-food business system can be understood as a set of actors, which by integrating upstream and downstream, through interorganizational relationships generate an environment of open innovation (so-called open innovation) in the agri-food business system (Solarte-Montufar, et al., 2021; Oltra-Mestre, et al., 2021). In recent times, open innovation has also become increasingly important in the agri-food business system. In fact, the study by Sarkar and Costa (2008), demonstrates a rapid growth in the number of open innovation projects that occur within the agri-food business system (Ferreira & Teixeira, 2019).

This configuration can explain the existence of a concentration of organizations, which within the agri-food business system, have the primary objective of providing new knowledge and support networks for R&D activities (Touzard, et al., 2018). Agri-food organizations, therefore, thanks to inter-organizational relationships with research centers, consulting firms, universities and researchers are able to respond to new competitive paradigms. However, for agri-food organizations to benefit from them, they must be able to collect, systematize, categorize, disseminate and exploit the knowledge that can be generated from external sources (O'Connor & Kelly, 2017; Agostini, et al., 2020). Agri-food organizations must, therefore, explore and exploit the available knowledge (Ciampi, 2017; Rialti, et al., 2018; Condor, 2020), implementing an adequate innovation management system to get the most out of collaborative relationships with external partners.

The regulatory evolution outlined above is expected to generate systemic outcomes that go beyond mere compliance, contributing to a structural reconfiguration of agri-food supply chains in terms of sustainability, resilience, and innovation capacity

In the medium to long term, the consolidation of sustainability principles within EU law is likely to produce various positive externalities: environmental (reduction of greenhouse gas emissions, resource efficiency, biodiversity conservation), economic (value creation through circular processes and short supply chains), and organizational (enhanced coordination, data-driven decision-making, and vertical integration of sustainability standards). In particular, the institutionalization of food waste prevention as a legal objective redefines the contours of responsibility across the supply chain, fostering co-responsibility, transparency, and efficiency.

From a regulatory perspective, two major developments can be foreseen. First, the shift from voluntary commitments to binding obligations will transform sustainability from a reputational asset into a legal requirement, thereby raising the stakes for organizational adaptation. Second, the integration of digital technologies into compliance systems will likely become standard practice, requiring clearer legal standards on interoperability, liability, and data ownership in multi-actor platforms.

In light of this, several policy recommendations can be formulated. At the EU level, it is crucial to promote regulatory convergence and reduce interpretative uncertainty, particularly in areas such as waste/by-product classification, data governance, and ESG reporting frameworks.

At the national level, legislators should support SMEs in the sustainability transition by providing legal and technical assistance, fiscal incentives, and capacity-building programs. Dedicated support mechanisms—alongside those provided within the framework of the Common Agricultural Policy—are essential to prevent regulatory asymmetries and to ensure equitable access to innovation across the supply chain.

For supply chain actors, a proactive approach is strongly recommended. Legal compliance should be perceived not as a constraint but as a lever for innovation and inter-organizational alignment. The establishment of compliance-by-design mechanisms, the use of digital compliance tools, and participation in public-private governance platforms can enhance adaptive capacity and strategic positioning.

Ultimately, a resilient and sustainable agri-food system requires a legal ecosystem that is not only prescriptive but also enabling—capable of evolving in step with technological change and organizational complexity, while remaining anchored in the normative goals of justice, inclusion, and ecological responsibility..

5 Ethics declaration

Ethical clearance was not required for the research.

6 AI declaration

No AI tools were used for creation and/or revision of the manuscript

7 Other declarations

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The Kilowatt Project: An Overview about Aims, Tools, and Key Activities

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Abstract

The distribution of fresh products presents unique challenges. Kilowatt specifically aims to: optimize and improve the logistics management of the fresh product supply chain; support processes that ensure the quality and organoleptic and nutritional properties of food; reduce food waste; maximize the energy recovery of waste.
The key points of the project can be summarized as follows: business model innovation, enhanced environmental and social sustainability, optimization of the distribution chain, Smart Packaging design, and waste recycling.
The development of the new business model will focus on offering high-quality products certified for safety, authenticity, environmental impact, and strong market orientation. These products will be strategically placed in various outlets based on real-time demand analysis. A sustainable and ethical approach to food marketing will be promoted, with an emphasis on recovering waste materials to produce alternative energy, as well as redistributing unsold products to the third sector to benefit vulnerable groups in society. Logistical activities for goods distribution will be optimized to reduce travel distances, enabling the planning of deliveries over a longer time horizon, minimizing store visits, and reducing the risk of unsold goods. Finally, smart packaging systems, composed of active wrappers designed to extend product shelf life and integrated with IoT sensors for monitoring, will be developed. Additionally, digestion matrices will be defined to maximize the energy produced from food waste.

Keywords: Sustainability, Optimization, smart packaging, sensor data, waste minimization

Paper type: Practical Paper

1 Introduction

The Kilowatt project (smart pacKagIng and Logistics for food waste reduction) is focuses on redefining the processes involved in the storage, preservation, sale, and disposal of perishable agri-food products within large-scale distribution networks. By leveraging Internet of Things (IoT) technologies and real-time data transmission, the project aims to reduce food waste, minimize environmental impacts, and enhance energy recovery from food scraps.

The project (started in 2024 and running until 2026) has been funded by the “Ministero delle Imprese e del Made in Italy” under the "Accordi per l'innovazione" initiative. It was selected as part of a call for proposals aimed at funding industrial research and experimental development activities, designed to create new products, processes, or services, or significantly improve existing ones, through the development of key enabling technologies (KETs).

Through its innovative solutions, Kilowatt aims to contribute to advancements in sustainable agri-food logistics, smart packaging, and waste reduction, fostering technological progress in the areas of environmental sustainability, energy efficiency, and circular economy practices.

In Italy, sustainability in large-scale distribution is addressed by only 16% of operators, and their efforts tend to focus more on the use of eco-friendly packaging rather than energy consumption, especially related to transportation. The fresh produce supply chain, in particular, is a high-energy impact sector due to the perishable nature of its products, which require daily deliveries in large volumes. The environmental impact of transport, along with the waste generated from product deterioration at the point of sale, represents a significant issue that needs to be addressed. Kilowatt aims to solve these challenges by incorporating “smart” systems that manage stock, packaging, and sales processes. These smart solutions will allow for prolonged product integrity, improved logistical efficiency, and the integration of advanced technologies within the supply chain to enhance delivery processes.

The project involves strong collaboration among the co-proposing partners, including two universities (UNICAL e Università del Sannio) and two IT companies (Itaca and Consoft Informatica). Each partner will contribute specialized knowledge and experience not only in their areas of expertise but also in close cooperation with others.

The project’s broader goal is to integrate enabling technologies and innovative approaches into the logistics of agri-food products, aligned with new, sustainable business models and optimized logistics chains. Ultimately,

the expected long-term result is the improvement of competitiveness and sustainability within national agri-food production, which will be achieved by reducing product loss and waste. This will be pursued through a comprehensive approach involving innovative interventions in various areas. Key objectives of the Kilowatt project include:

- Innovation in business models: A new business model will be developed, characterized by offering high-quality certified products. These products will be certified for safety, authenticity, and environmental impact, meeting the growing consumer demand for sustainable and ethical products.
- Optimization of distribution logistics: By optimizing distribution, the project aims to reduce fuel consumption, lower carbon emissions, and minimize the environmental footprint associated with transporting perishable goods.
- Improvement of sales forecasting models: The Kilowatt project aims to develop new, more accurate sales forecasting techniques that surpass the limitations of existing models. By improving the precision of demand forecasts, it will be possible to better align supply with real market needs, reducing the risk of product spoilage and waste.
- Enhanced product positioning through sensor data: Using IoT sensors, the project will monitor the conditions of products throughout the supply chain.
- Sustainable packaging solutions: The project places significant emphasis on improving packaging solutions to reduce waste and environmental impact. New biocompatible packaging materials will be developed and tested, which will help extend the shelf life of perishable products.
- Reduction of food waste and optimization of by-product reuse: The project aims to minimize food waste by ensuring that products are consumed before reaching their expiration date, reducing waste generated by spoilage.
- Social and environmental sustainability: The Kilowatt project places a strong emphasis on ethical and sustainable food commercialization. Beyond reducing food waste, the project aims to recover food scraps and by-products for the production of alternative energies, creating a circular economy that promotes the sustainable use of resources.

2 An overview: the context, the tools, the aims.

One of the major challenges in the food market is related to shelf life, a factor that becomes critical for fresh foods, especially when considering the need to supply distant markets (e.g., typical regional products), which require significant transportation time. The deterioration of food products slows down when the product remains intact and is transported and/or stored in controlled atmospheric and climate conditions (temperature and humidity). The goal of this initiative is to preserve the integrity of food products through the implementation of smart systems for inventory management, packaging, and certain sales processes, aimed at reducing food waste.

Companies in the food and beverage sector, as well as large-scale retail (GDO), are increasingly committed to delivering fresh and high-quality products. Ensuring uninterrupted supply is therefore essential, which means the supply chain—internal or external—must leverage the most advanced technologies to support delivery operations. The entire logistics process for food products must integrate enabling technologies and smart systems with new sustainable business models and logistics chain optimization strategies.

In Italy, only 16% of businesses address sustainability through a dedicated internal governance model, focusing more on eco-friendly packaging than on energy consumption associated with product transportation. The fresh food supply chain is now consistently categorized as high-energy impact due to the perishability of products and the requirement for daily deliveries of large volumes. The environmental impact of transportation and waste due to product deterioration at points of sale are highly critical factors.

The use of solutions for fleet management, inventory control, and product distribution—both downstream and upstream in the supply chain—developed within the project, will enable the implementation of best practices and green supply chain initiatives. These practices can foster systemic growth by increasing the perceived value of purchased goods or services for the end user. This means increasing transport efficiency by avoiding empty returns, optimizing routes, and strategically locating warehouses and suppliers; as well as optimizing product and waste logistics (reverse logistics). Furthermore, optimized delivery systems—from distribution centers (Cedi) to points of sale (PDV), and from PDVs to end customers (e.g., home grocery delivery)—will reduce emissions and the environmental impact of the logistics chain.

All actors in the logistics chain must pursue a logistics model based on integration and collaborative networks involving companies, customers, and suppliers. The development of such solutions requires the definition of innovative optimization models that account for the specific characteristics mentioned above. Alongside these

models, heuristic and metaheuristic algorithms will be developed to efficiently solve the formulated optimization problems. The types of heuristics to be developed, implemented, and tested will be defined in the project's research activities.

The models will be based on data predicted using artificial intelligence techniques, so as to minimize the probability of unsold goods. For this purpose, forecasting paradigms based on both classical and modern AI methods will be used—particularly deep learning techniques. The project will explore innovative approaches that combine domain expert knowledge (e.g., rules) with historical sales and inventory data. These paradigms will be integrated with explainable AI techniques, such as abstract argumentation, to provide analysts with explanations of the forecasting results. This approach aims to improve the interpretability of forecasts and build trust in the models, ultimately enhancing decision-making effectiveness.

In terms of shelf life monitoring, IoT (Internet of Things) devices will be developed to track the remaining useful life of food products within at least one selected supply chain. These devices will enable Last Minute Market policies to be implemented under favorable conditions, thereby reducing the likelihood of unsold and wasted goods. Among the options considered is the donation of unsold products to third-sector organizations, which would serve a dual purpose: supporting disadvantaged individuals—especially during this socially critical time—and significantly reducing disposal-related costs for companies. These policies, to be implemented through appropriate sales channels, will be thoroughly studied and validated during the project.

The devices will be designed and integrated into biocompatible packaging, made from high-performance materials comparable to low-cost bio-polymer films with controlled gas permeability, enabled by a precisely regulated microstructure during the manufacturing process. These materials will ensure proper food preservation, equal to or better than traditional packaging, while being entirely biocompatible and aligned with 100% green environmental policies. Additionally, the materials will be designed to facilitate the integration of smart devices into packaging without altering it during application or post-sale recovery.

As for unsold products, they may be converted to energy through anaerobic digestion, following specific regulations and matrices that will be studied throughout the project. This approach seeks to maximize the energy recovery of unsold goods and thereby reduce the environmental impact caused by unsold inventory.

3 Methodology

The activities of the project are structured in 13 work packages, for each work package, the release of deliverables is defined in order to ensure communication between working groups and the conduct of cross-cutting activities. In this section we propose an overview of each work package.

1. The main goal of the first work package (*Definition of qualitative-quantitative models for sustainability and assessment socio-economic-environmental*) is to develop business and organizational models that allow for a systematic and integrated assessment of the sustainability and applicability of proposed innovations. This involves measuring and analyzing potential socio-economic and environmental impacts using both quantitative and qualitative methods. To achieve this goal, WP1 is organized into the following activities: - Analysis of the regulatory framework; - Development of Life Cycle Management models; - Definition of a scalable business and organizational model for process optimization aimed at reducing food waste; - Representation of the organizational and business model of the “market” for products nearing their expiration date; - Development of MCDA (Multi-Criteria Decision Analysis) models and optimization techniques to evaluate sustainability and performance; - Definition of sales policies from a Last Minute Market perspective; - Design and analysis of data collection through focus groups; - Identification and analysis of evolving scenarios in real-world contexts.
2. The aim of the second work package (*Design of a management and monitoring system for the shelf life of food products, with the valorization of food items no longer suitable for consumption for energy purposes*) is to tailor packaging performance to the specific needs of each food product, creating an interaction between the packaging and the food. Innovations include developing new materials that enable controlled release of antimicrobials, which extend shelf life by preventing bacterial growth. For example, the BioSwitch system releases antimicrobials on demand when external conditions (pH, temperature, UV) trigger it, increasing preservation stability while reducing chemical use. These antimicrobials are encapsulated in polysaccharide particles that break down in the presence of bacteria, releasing the antimicrobials precisely when needed. Regarding intelligent packaging, a focus will be on monitoring product shelf life through devices called Time Temperature Integrators (TTIs). These are adhesive labels that change color proportionally to the product’s exposure to temperature over time, indicating the product’s thermal history. Once programmed based on mathematical models, these labels provide non-reversible color changes, helping consumers identify safer, higher-quality products. The

ultimate aim of functional packaging (combining active and intelligent features) is to preserve food quality over time and increase consumer appreciation. These solutions respond to higher standards of hygiene, sensory quality, and usability by interacting with the product and its environment, often by modifying the "headspace" inside the package. To achieve this goal, WP2 is organized into the following activities: - Identification of kinetic degradation models; - Definition of development models for phytopathogenic microorganisms; - Comparative analysis of usable smart systems (labels, sensors); - Design of a system based on real data, focused on shelf life analysis; -Identification of mixtures of products no longer suitable for food consumption and characterization of the physical-chemical parameters of the matrices and mixtures used; -Batch evaluation of methane production from different matrices

3. The third Work Package (*Models and Algorithms for Inventory Management and Distribution Logistics of Perishable Products*), addresses the issue of food waste along the supply chain, emphasizing how the complexity and slowness of logistics processes negatively affect efficient stock management. The main cause of waste is the premature expiry of products in warehouses (about 70%), but inefficient distribution and delays also contribute significantly. To tackle these problems, the use of collaborative digital models is proposed, such as VMI (Vendor Managed Inventory), in which the supplier directly manages inventory at retail locations, optimizing replenishment and reducing both stockouts and unnecessary overstock. The goal is to create an efficient and sustainable logistics ecosystem between distributors (GDI) and points of sale (PDV), supported by demand forecasting models, transport optimization, and a strong focus on environmental impact. The importance of managing demand uncertainty is highlighted through the development of optimization models under distributional ambiguity, representing a new frontier in stochastic programming. Additionally, the integration of machine learning is proposed to accelerate the resolution of logistical problems and to identify useful patterns. Lastly, the development of a Last Minute Market logistics system is envisioned to enable the rapid sale of soon-to-expire products both in-store and online, using fast and environmentally friendly delivery models. The entire system aims to maximize both sustainability and operational efficiency. The activities planned for the completion of the WP are: -analysis of the state of the art on the inventory routing problem, VMI, and routing of perishable products; - definition of models and algorithms for product demand forecasting at Points of Sale; - definition of models and algorithms for the distribution logistics of perishable products.
4. The fourth Work Package (*Design of Biocompatible Smart Packaging Systems)* addresses advanced technologies in food packaging, including innovative extraction techniques, active nanoparticles, and sensors. These technologies aim to extend food shelf life and improve logistics. While petrochemical-based polymers have been widely used due to their cost-effectiveness and versatility, concerns over their environmental impact and poor biodegradability have led to a shift toward bio-based, low-impact materials, often sourced from agri-food waste (e.g., cellulose, starches, chitin, alginates, and proteins). The bioplastics market is growing and represents a sustainable opportunity.

Active packaging offers antioxidant and antimicrobial properties, while smart packaging can interact with the environment, such as changing color to indicate food spoilage. Smart packaging technologies are divided into data carriers, indicators, and sensors.

The design phase focuses on eco-friendly, food-compatible materials in line with EU regulations. Tested polymers include cellulose, PLA, lignin, starches, and proteins. There's also a push for digital integration between packaging and control devices (wireless/bluetooth) to optimize the supply chain and reduce waste and energy consumption.

The WP consists of the following activities: research on biocompatible materials and design of packaging for pluggable active devices.

5. The fifth Work Package (*Design of IoT Devices for Smart Packaging)*, is aimed at a comparative analysis of the available technology in terms of sensors, in order to identify the best starting solutions for the subsequent design of IoT devices. Based on the identified scenarios, it will be possible to define one or more IoT boards capable of measuring different parameters and/or managing different configurations depending on the type of product to be monitored. It will be necessary to specifically study the usage methods and develop biocompatible enclosures that can isolate the devices without contaminating the food, while still functioning correctly in humid environments and/or at low temperatures. To this end, research will be conducted on biocompatible materials suitable for 3D printing and their potential for creating enclosures compatible with the application scenarios outlined in the KILOWATT project, providing adequate protection and/or insulation. In this regard, the regulatory aspects studied in OR1 may offer useful guidance during the design phase. The WP includes the following activities: - Analysis

and research of devices, - Communication protocols in the IoT domain, - Design of an IoT board to support smart packaging.

6. The sixth WP is titled *Architecture Design and Requirements Definition* and involves analyzing the literature in the field of enterprise architectures and enterprise integration patterns, namely the most effective approaches for developing complex software systems and integrating heterogeneous subsystems in terms of data and functionality. It is structured into the following activities: - analysis of the state of the art in enterprise architectures and enterprise integration patterns; -definition of the high-level architecture and functional requirements; - study of the architectural components.
7. The objective of OR 7 (*IoT Device Prototyping*) is to prototype the IoT devices that will be designed in OR 6, and to implement the sensor network and all the tools for reading/accessing information. The following activities are planned: -prototyping of the boards; -firmware and protocol development; -development of libraries for data access and device registration; -definition of the integrated circuit.
8. WP 8 (*"Development of Algorithms for Inventory Management and Distribution Logistics – Inventory Managed"*) will implement an optimization system in the field of distribution logistics, based on the studies outlined in OR3, covering both application areas (from the distribution center to the point of sale, and from the point of sale to the end customer). The planned activities are: development of the routing subsystem and development of the optimization system for distribution logistics.
9. The objectives of WP9 ("Development of Decision Support Systems and Prototyping of Biocompatible Packaging") are the creation of prototypes that provide decision support functionalities for residual shelf life prediction and demand analysis, based on the techniques developed within OR2 and OR3, as well as the development of a biocompatible packaging prototype capable of integrating smart devices that supply data to the decision support systems. The activities planned are: - development of a software system for calculating residual shelf life based on data collected from smart devices; - development of a Decision Support System (DSS) for product demand analysis at points of sale (POS); -creation of a biocompatible package that can be integrated with a smart device.
10. WP 10 (*"Comparative Analysis and Design of User Experience and Sales Systems"*) aims at designing the User Experience for user interaction with the system and access to content and functionalities, both through web apps and mobile devices. This is based on the specific services already designed and defined in the earlier phases of the project, and is intended to support the product sales process.The OR is divided into three activities: -a comparative analysis of apps and sales systems in the food sector, as well as the technological solutions used to enable the sales process; -an analysis of the state of the art in UX methodologies, processes, and tools; -the design of the user experience and the definition of the graphical interfaces for the Kilowatt platform.
11. The objective of OR 11 (*"Development of IoT Sales and Monitoring Systems"*) is to create client systems that will effectively utilize the software solution in all its aspects. The activities will be carried out based on the architectural strategies defined in OR7 and the requirements, which are partly derived from the business models that have been appropriately implemented. The systems to be developed are as follows: - IoT monitoring platform; -device programming/configuration system; - e-commerce platform; -mobile app; -software module for VMI (Vendor Managed Inventory) distribution logistics.
12. The goal of WP 12 (*"Integration and Testing"*) is to define, design, and implement the integration infrastructure, using and applying the methodologies and technologies that represent the state of the art and best practices in architectural patterns, as defined in WP 6. The planned activities are: - analysis and design of the integration platform; -integration plan; -commissioning.
13. The last WP (*"Testing and Validation of Qualitative-Quantitative Models for Sustainability and Socio-Economic-Environmental Assessment"*) involves testing, validation, and verification of the qualitative-quantitative models for sustainability defined in OR 1, with the aim of measuring the potential benefits that can be achieved. The activities it is divided into are: -integrated sustainability assessment and definition of a communication plan for sustainability performance; -validation of the organizational and business model; - implementation and validation of Multi-Criteria and optimization models for sustainability and performance evaluation; -testing and validation of sales policies from a Last Minute Market perspective; - preparation of sustainability plans and porting strategies.

4 Conclusions

The expected result of the project is to improve the competitiveness and sustainability of national agri-food production linked to the reduction of the amount of product lost and/or wasted and pursued through a coherent set of innovative interventions:

- the optimization of logistical activities of fleet handling, both upstream and downstream, through the implementation of appropriate models and algorithms designed to reduce emissions dueto transport activities;
- the definition of models and techniques for forecasting sales at the different points of the network that,by combining the characteristics of qualitative and quantitative approaches, overcome the limits of applicability of existing techniques and their accuracy;
- definition of models and techniques for calculating explanations of sales forecasts provided;
- the enhancement of the suitability of territories propaedeutic to the creation of added value linked to the origin of products, as well as the improvement of their sustainability thanks to more efficient interrelationships between agroecosystem and production process;
- the optimization of the positioning of the product in the different sales channels in terms of time/quality/price ratio, through a process of iterative refinement of the offer according to the information derived from the sensoristics that constantly monitor the products; The optimization of product positioning in different sales channels in terms of time/quality/price ratio, through a process of iterative refinement of the offer according to the information derived from the sensors that monitor products constantly;
- the improvement of the efficiency of the logistics and distribution system in terms of time, economic and environmental;
- the improvement of the packaging management process, thanks to new biocompatible packaging properly researched and designed;
- the reduction of costs in all segments of the supply chain resulting from the reduction of “waste” and to their reintroduction within the production and consumption cycle, through uses innovative uses for energy purposes.
- the achievement of biocompatible active and intelligent packaging from raw materials with high added-value from agrifood chain waste.
- the extension of the shelf-life of products in the supply chain thanks to the functionalisations operated on biocompatible packaging with direct decrease of waste in the supply chain starting from the end line to transportation, on-shelf and home-storage.

The new business model developed will feature:

- an offer of high-quality products certified for safety, typicality and environmental impact and accompanied by a range of additional information that will also be enhanced by new information and communication technologies;
- a strong market orientation, in terms of demand analysis and addressing consequential supply, through vendor managed inventory routing algorithms,that is, capable of placing products on different outlets based on the analysis of actual demand;
- a sustainable, eco-friendly orientation aimed at reducing the environmental impact of the logistics distribution, but also to the recovery of waste materials for the purpose of producing alternative energies;
- an ethical and socially inclusive orientation, aimed at recovering unsold products and products nearing close to expiration, to be allocated to third sector organizations that work in defense the weaker sections of society;
- an impact on consumer food culture, through the promotion of high-quality eservices and information related to the handling, storage and consumption of food products;
- an incisive impact on the relationship between raw materials and products actually consumed through the reduction of supply chain waste;
- an impact on the nutraceutical qualities of products through the active-packagings used.

5 Ethics declaration

For the research reported in this paper, ethical clearance was not required.

6 AI declaration

AI was used for a general review of the text.

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SME Performance through Modern Technology and Sustainable Business Strategies

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Abstract

This research aims to analyze how operational sustainable business strategies and modern technologies, including employee training influence performance. The methodology is a quantitative approach with a cross-sectional design. Data was collected from 207 SMEs in Aguascalientes, central region of Mexico, through a survey administered to managers or those responsible for operations (INEGI, 2024). The data will be analyzed using EQS software to assess the relationships between the variables. This research aims to provide valuable insights into the factors contributing to firms' operational performance success. The research model will be assessed by the reliability and validity of the measurement instruments using Cronbach's Alpha, Dijkstra-Henseler's rho, Composite Reliability Index, and Average Variance Extracted (AVE). So, the analysis will ensure that the constructs are distinct and not overlapping. The good fit for the proposed theoretical model will be evaluated to suggest that the relationships between the variables were adequately represented (Henseler et al., 2015). The study focuses on the crucial role of sustainable business strategies in enhancing the operational performance of SME (Buttle & Maklan, 2019; Marr, 2016; Marston et al., 2011; Sutherland, 2019). The results obtained in this study indicate that, on the one hand, the factor loading of the variables is within the norm and, on the other hand, sustainable business strategies do have a significant impact on the performance of operational activities in this type of company. This means that for manufacturing SMEs, it is very important to have a sustainable environment that allows all of their operations to be focused on the performance of their internal operating systems. The data collection period was between March and May 2024, considering a stratified random sample of companies within the state of Aguascalientes.

Keywords: SME Performance, Sustainable Business Strategies, Modern Technology, Operations Management, EQS.

Paper type: Academic Research Paper

1 Introduction

This study investigates how factors like **sustainable business strategies and modern technology that include employee training** impact the performance of Small and Medium Enterprises (SMEs). The management and control of resources, especially human resources, are crucial for companies, as they ensure the fulfillment of business commitments and customer satisfaction while prioritizing employee safety (Gavilanes-Lagla Marco A. et al., 2021; Herrera-González & Quesada, 2013). Firms must ensure reliable processes, sustainable business strategies, adequate capacity to meet market demand, and the integration of appropriate technological advancements to remain competitive (Baker, 2006; Chams & García-Blandón, 2019; Ringvold et al., 2023; Vollenbroek, 2002). Managers need to focus on process control, capacity analysis, and staff training to meet customer needs without compromising quality (Argote & Ingram, 2000; Jones & Craven, 2001; Vidal-Salazar et al., 2012).

Increasingly, firms are concerned with sustainability in their operations and environmental impact (Banerjee, 2002; Lawrence & Lorsch, 1967; Porter & van der Linde, 1995). Studies show that sustainable business practices, like energy conservation and waste reduction, help achieve environmental goals while also enhancing operational efficiency and cutting costs (Li et al., 2020). Process flexibility and production capacity improvement are crucial for adapting to market demands and maintaining competitiveness (Ibero-American General Secretariat, 2023). It **highlights the importance of sustainability in business operations and emphasizes the need for continuous improvement and adaptation to thrive in a dynamic and competitive environment.**

Technological improvements are essential for productivity, product design, equipment upgrades, and process reliability (Boudreau & Robey, 2005; Mikalef & Pateli, 2017). Higher corporate sustainability performance has been linked to innovation and technology within firms (Wang et al., 2020). Managers must assess whether their staff is adequately trained and aware of the importance of sustainability and proper material handling (Guzman et al., 2016; Kiseľáková et al., 2018). Technology has several benefits from various perspectives, from information management to collaborative experiences between company workers and

customers. Among these benefits is the automation of repetitive tasks, which increases efficiency and reduces operating costs. Similarly, processes can be made more efficient through emerging technologies, such as the Internet of Things, (Laudon & Laudon, 2012) *blockchain*, among others, by providing greater real-time visibility and traceability of products or services in companies (Christopher, 2011).

2 Theoretical framework

- Nowadays, every organization is committed, not to mention that it is obliged to meet the objectives proposed in a community and environment so that benefits are achieved not only within the organization but also with its environment, in economic, operational, logistical terms and of course in the aspect of sustainable development, (Hahn & Figge, 2011). After the pandemic, these elements have been key to sustainable improvements in companies committed to continuous improvement in general terms, since the environment in particular requires it due to its importance and because organizations must offer products as well as services not only of good quality but free of processes that affect the environmental environment that affect the health status of their workers. the natural environment, the environment and of course that this impacts on its low financial and operational performance, (Munro, 2020; Gatto, 2020; Saavedra, 2022).
- Worldwide, if there is the demand for competitiveness on the part of companies outside of their work activities since performance is considered implicit and this performance of course applies to all their functional areas both on the operational and administrative side, and as companies in this case manufacturing we think about the aspects focused on the management of operations highlighting supplies, operations, quality and maintenance, activities that in their nature of work, have a special relationship with the environment and potential waste due to the auxiliary materials that are used, which leads to think about an improvement where sustainable business strategies that are significant in the performance of the organization and therefore, in business competitiveness, (Freshness, 2007; Maffini, Kruglianskas, Scherer, Da Luz Neto, & Marques, 2013).
- In this sense, for manufacturing SMEs, it is important that within their business strategies they take into account the development of sustainable businesses, since it is not enough only to have organized and reliable processes but that these are organized in such a way that each part of the operational process is with the care required by the nature of the process where either for aspects of quality or certifications, it is guaranteed that at each stage there is no damage to the environment or to sustainable aspects since it is natural for companies to integrate technological and innovation improvements but that they do not affect the environment and that they are reliable, competitive companies with a performance in accordance with their business guidelines and objectives, (Saavedra, 2022). It is important to highlight that sustainability improvements in companies should not only focus on operational processes but also on all activities of the organization so that there is a better role in the sustainable development of the company, (Bercovich & López, 2005; Lawrence, Collins, Pavlovich & Arunachalam, 2006; Samier & Qian, 2010).

It is important to point out that companies such as manufacturing SMEs in particular, in their management of operations not only operational but also financial, for their permanence in business they need performance and competitiveness and this performance is of course operational where adequate strategies are involved in supplies, control of materials, successful use of technologies, an adequate quality system, good control of operational indicators that have an impact on the needs of the customer as well as an efficient system of sending products to the customer, but it is also important to reflect all this operational activity in a solid financial performance without neglecting the good results that have been obtained by having a good sustainable performance as long as it is considered in the companies, (Mohammend, 2019; Amedu, Llemena, & Umaigba, 2019; Buchholz, 2020; Keskin, Dincer & Dincer, 2020; Mahmood, Qadeer, Saleem, Han & Ariza-Montes, 2021; Wong & Ngai, 2021; Chakroun & Ben Amar, 2022).

The growth of companies certainly depends on the internal strategies generated by the managers of these organizations, on the preferences of the market as well as their direct customers but also on the effort and commitment of their workers, and if they are integrated into the policies and needs of the company considering their job stability as well as support for the initiatives that are generated internally. the effect on the outside will be reflected by projecting a sustainable environment that does not affect the environment, (Saavedra, 2022). Having companies with sustainability strategies is not only that it is a clean and pollutant-free company, they must be strategies that have an impact on future generations where the needs of each company are not neglected, considering that sustainability must focus on the environmental but also on the social and economic, (Saavedra, 2022).

The purpose of this study is to analyze the impact of sustainable business strategy on the performance of the activities of companies such as the manufacturing SME in the state of Aguascalientes in Mexico (Quinn and Rohrbaugh, 1983; Pereira, Claver, Molina, & Tari, 2012; Saavedra, 2022), and in this sense the following hypothesis is raised:

- *H_1: The sustainable business strategy has a positive impact on the performance of the manufacturing SME in Aguascalientes.*

3 Methodology

For this study, a theoretical model was designed that has the purpose of analyzing the impact that sustainable business strategies have on the performance of the Manufacturing SME in the state of Aguascalientes, where a measurement instrument sent to the managers of this type of companies in the period between March - May 2024 was also designed and applied. period in which the data collection was carried out. For this analysis, the database offered by the Business Directory of Aguascalientes (Inegi, 2024) was taken as a reference, which mentions the following:

- Population of 445 SMEs in the Manufacturing sector.
- Application of the study with 207 in a stratified sample.
- 95% confidence level.
- 5% error.
- The study has a quantitative approach.
- Deductive, descriptive and correlational methodological design.
- Data collection was cross-sectional.

For the measurement of the variables in this research, the survey was divided into 2 blocks of which are mentioned below:

1. Block I: ***Sustainable Business Strategies***, measured with 12 variables (Pereira, Claver, Molina, & Tari, 2012).
2. Block II: ***Performance***, made up of 12 variables (Quinn and Rohrbaugh, 1983). The variables were measured with the Likert scale 1-5.

Likewise, for this research work, a theoretical model was designed which contains the two main blocks of Sustainable Business Strategy and performance, which is shown in Figure 1

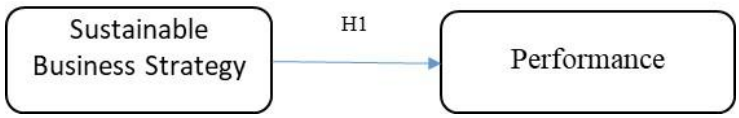


Figure 1: Theoretical Model of Research Work

Source: Adaptation of Hernández from Pereira, Claver, Molina y Tari, 2012 and Quinn y Rohrbaugh, (1983).

4 Analysis and Results

With the data obtained from the fieldwork and subjected to statistical treatment, a Confirmatory Factor Analysis (CFA) was performed in order to analyze and evaluate the reliability as well as validity of the measurement scales used in the theoretical model in Figure 1. Likewise, the statistical analysis of Structural Equations was also carried out, to check if the structure of the Model is correctly designed considering the support of the EQS version 6.1 software. Within the analysis to evaluate the reliability of the model, Cronbach's Alpha coefficient (Frías, 2014), and the composite reliability index (IFC) were used; (Bagozzi and Yi, 1988; Hatcher, 1994; Escobar, Cárdenas, & Aguilar, 2016). Table 1 shows the values of Cronbach's alpha and the Composite Reliability Index (CFI) of each construct, which meet the recommended level of 0.7 of reliability (Nunnally, 1967; Fornell & Larcker, 1981; Nunnally & Bernstein, 1994; Hair *et al.*, 1995) and the analysis suggests that the model provides an acceptable fit, which is shown below:

S-BX2 (df = 103) = 222.9972; p < 0.0000; NFI = 0.891; NNFI = 0.928; CFI = 0.938; RMSEA = 0.075

The variables of the two blocks that represent the theoretical model are significant ($p < 0.05$), the size of all the factor loads as can be seen in Table 1, in each indicator are greater than 0.6 (Bagozzi and Yi, 1988) and the index of variance extracted (IVE) of each pair of constructs is greater than 0.5 recommended by Fornell and Larcker (1981). The complete result of the analysis can be seen in the following table 1:

Table 1 Internal Consistency and Convergent Validity of the Theoretical Model

Construct	indicator	t robust	CF > 0.6 factor loading	Squared factor loading	Mean factor loading	error	aver error	Alpha Cronbach > a 0.7	IFC > a 0.7 Composite Reliability Index	IVE > a 0.5, Variance Extracted Index
Sustainable Business Strategies (F1)	GA01	1,000	0,810	0,656	**0,837**	0,344	**0,710**	0.966	0,966	0,704
	GA02	16,861	0,850	0,723		0,278				
	GA03	13,140	0,809	0,654		0,346				
	GA04	12,835	0,769	0,591		0,409				
	GA05	16,009	0,896	0,803		0,197				
	GA06	14,879	0,865	0,748		0,252				
	GA07	15,893	0,878	0,771		0,229				
	GA08	14,857	0,864	0,746		0,254				
	GA09	14,791	0,839	0,704		0,296				
	GA10	14,948	0,897	0,805		0,195				
	GA11	15,115	0,879	0,773		0,227				
	GA12	10,772	0,689	0,475		0,525				
	Σ		***10,045***	***8,449***		***3,551***				
Performance (F2)	RE01	1,000	0,860	0,740	**3,335**	0,260	**1,201**	0.961	0,965	0,700
	RE02	17,322	0,819	0,671		0,329				
	RE03	15,606	0,836	0,699		0,301				
	RE04	20,536	0,878	0,771		0,229				
	RE05	14,800	0,851	0,724		0,276				
	RE06	17,705	0,850	0,723		0,278				
	RE07	21,765	0,896	0,803		0,197				
	RE08	22,885	0,914	0,835		0,165				
	RE09	16,471	0,859	0,738		0,262				
	RE10	17,185	0,805	0,648		0,352				
	RE11	19,669	0,801	0,642		0,358				
	RE12	9,039	0,637	0,406		0,594				
	Σ		***10,006***	***8,398***		***3,602***				

* = Parameters bound to that value in the identification process, , *** = p < 0.001

Source: Own Elaboration

Respect the discriminant validity analysis, Table 2 indicates through two tests. On the one hand, with a 95% reliability interval, none of the individual elements of the factors contains a value of at least 1.0 (Anderson and Gerbing, 1988) and secondly, the test clearly shows that the variance extracted between each pair of constructs in the model is greater than its corresponding Variance Extracted Index (Fornell and Larcker, 1981). Therefore, it can be concluded that this research work shows sufficient evidence of reliability and convergent validity, as well as discriminant validity in the construction of the theoretical model

Table 2 Discriminant Validity of the Theorical Model

Factores	**F1** ***Sustainable Business Strategies***		**F2** ***Performance***
F1 *Sustainable Business Strategies*	**0,672**		(0.648)2
			0,420
F2 *Performance*	0,648	0,098	**0,690**
	0,452	**0,844**	

Source: Own Elaboration

The diagonal represents the Extracted Variance Index (IVE), while above the diagonal is shown the part of the variance (The correlation to the table). Below the diagonal, the estimate of the correlation of the factors with a 95% confidence interval is presented. Within the analysis carried out to evaluate the Structural Equations model, it is intended to test and contrast the hypothesis raised, using the main blocks of: Sustainable Business Strategy and Performance. The nomological validity of the model was analyzed through the performance of the Chi-square test, in which the theoretical model was compared with the model's measurement (Anderson & Gerbing, 1988; Hatcher, 1994), see table 3.

Table 3 Results of the Hypothesis Test of the Theoretical Model

Hypothesis	Structural Relationship		Standardized Coefficient	Robust t-value	FIT measurement
H1. The sustainable business strategy has a positive impact on the performance of the manufacturing SME in Aguascalientes.	Sustainable Business Strategies	Performance	0.543***	17.514	S-BX2 (df = 100) = 216.5021; p < 0.0000; NFI = 0.894; NNFI = 0.928; CFI = 0.940; RMSEA = 0.075

Source: Own Elaboration

The hypothesis raised in this research work shows the following results: Hypothesis $\mathbf{H_1}$ refers to the result obtained presented in Table 3 ($\beta = 0.543$, $p < 0.000$), and this refers to the fact that Sustainable Business Strategies have a positive impact on the Performance of the manufacturing SME in the state of Aguascalientes, which indicates that approximately 54.3% of companies perceive the owners or managers responsible for operations in this type of companies that it is important to consider sustainable business strategies within their organizations to favor performance and further guarantee the fulfillment of the objectives that are organized so that these companies are increasingly competitive

5 Conclusions

Current times present dizzying changes in various directions that aim to have improvements of all kinds within organizations outside of their business activity. It is here where those responsible for this type of companies must have good control of the direction of their operations and in the particular case foresee significant improvements in what is of impact so that their effect on the customer and market is important since as leaders it is thought that everything is focused on supplies, productive operations and efficient quality systems since the customer certainly demands it at all times. Of course, everything is important because in order to have reliable operational processes that meet the needs of the customer, you must have excellent logistics and supply control where what is understood as TIME and FORM, is that the raw materials arrive on time but at the same time are received without defects.

Likewise, as what has already been mentioned is relevant for the competitiveness of this type of company, it is necessary and demanding that all internal activities are also evaluated in the sustainable aspect as a diagnosis where those areas of opportunity that require urgent and significant improvement can be appreciated since these improvements in sustainability have a positive impact on the economic and environmental aspects. The results obtained in this study indicate that for entrepreneurs responsible for operations in their organizations it is important to integrate as well as improve sustainable business strategies because they visualize a substantial performance that will have general benefits, which should be analyzed in detail in subsequent research to maximize in order to prospect these good foresight results that convince managers and all personnel regardless of their level within the organizational chart.

This means that we must work hard, first, as already mentioned, in making a diagnosis to detect areas of opportunity for improvement in sustainable matters, training all personnel where we work on the awareness of how necessary the environment is as well as the sustainable aspects and of course in implementing strategies that have performance effects as also commented both in the environment and in the economic. The important thing is that you have confidence in having consistency in frequent training with the internal staff of the company since you must have convinced each member of the work areas about the importance of having sustainable companies and of course having processes that are not polluting and this includes waste, so you must be very careful in the management of these during your operational activity. Managers undoubtedly have a challenge in their improvement and implementation of sustainable strategies to have reliable companies with high business performance.

6 Ethics Declaration

For the preparation of this manuscript, no special permission was required from the sources of information used in the statistical analysis. The sample data held by INEGI constitutes public information.

7 AI Declaration

It was not necessary to use AI in the preparation of this manuscript, neither for the consultation of the theoretical framework nor for its preparation, nor to prepare the statistical analyses or conclusions.

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Proposal for an Inclusive and Sustainable Telemedicine Ecosystem in Mexico

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Abstract

The healthcare system in Mexico faces persistent and multifaceted challenges, such as the exclusion of vulnerable populations, limited access to medical services in rural and marginalized areas, and increasing pressure due to an aging population. The COVID-19 pandemic exacerbated these structural weaknesses, highlighting the urgent need to integrate innovative technological solutions that not only optimize available resources but also expand and improve access to healthcare services.

In response to these needs, a sustainable and inclusive telemedicine ecosystem was proposed, grounded in methodologies from Exponential Organizations (ExO), to ensure long-term scalability, adaptability, and effectiveness.

A diagnostic assessment using the Pan American Health Organization (PAHO) tool revealed a low level of technological maturity at the Centro Médico Puentecillas. To address these gaps, the CANVAS model was applied to redesign the center's business structure, incorporating ExO SCALE principles: staff autonomy, active community participation, and continuous user engagement.

Additionally, the proposal included the development of a digital platform for managing teleconsultations, telemonitoring, and teleassistance, integrating real-time clinical data collection to support evidence-based medical decision-making and preventive health monitoring.

The methodology focused on identifying key technological and organizational deficiencies, prioritizing intervention strategies such as digital literacy training for medical personnel and infrastructure enhancement to improve system performance and reliability.

Keywords: Telemedicine, inclusion, sustainability, Exponential Organizations, digital health, innovation, public health, technology.

Paper type: Academic Research Paper

1 Introduction

The COVID-19 pandemic exposed global weaknesses in public health systems, revealing structural deficiencies and a lack of resources (Gómez Vaca, 2020; Hernández-Aguado, 2021). This underscored the urgent need for technological innovation to improve healthcare coordination and effectively respond to health and economic crises (García Barbero, 2021; Nogueira et al., 2021).

In Mexico, approximately 41% of the population, especially in rural and indigenous areas, lacks effective access to public healthcare services, evidencing significant social exclusion (INEGI, 2016; Martínez et al., 2018). Low public investment (2.8% of GDP) and high out-of-pocket spending (45%) worsen this situation, resulting in deficient public care and high rates of home mortality (Hernández-Bringas, 2020; Chertorivski-Woldenberg et al., 2020). Non-communicable diseases now account for the majority of national mortality, reflecting a critical epidemiological transition (Hernández Lara, 2020).

Since the 1990s, Mexico has promoted telemedicine to address social exclusion and improve access to public healthcare (Martínez, 2018). However, the system now faces challenges arising from demographic transition and projected population aging between 2030 and 2050 (Murillo, 2022).

The state of Guanajuato possesses a robust health system with 631 public units distributed across 46 municipalities, including hospitals and specialty medical centers (Cano et al., 2023). It also stands out for its potential in applying technological innovation to health, which is essential for its socio-economic development.

During the pandemic, the relevance of telemedicine was further highlighted, especially in Latin America, where mortality rates were particularly high (Romero, 2021). During this period, several barriers were eliminated to facilitate its implementation, such as reimbursement issues and licensing restrictions (HIPAA, 2020).

International telemedicine models have proven effective in enhancing access and quality of healthcare. In the United States, the Mercy Virtual Care Center uses remote monitoring and big data to reduce hospitalizations (Mercy, n.d.; American Hospital Association, 2016). China connects thousands of rural and urban hospitals via teleradiology (China Daily, 2020), while Norway integrates teleconsultation and monitoring into its public system

(WHO Europe, 2024). In Latin America, TeleSaúde Brazil enhances primary care through teleconsultations (Pfeil et al., 2017). These examples underscore the importance of adapting technology, training personnel, and maintaining strong regulatory frameworks.

In light of the above, this paper proposes the integration of a telemedicine system in the Centro Médico Puentecillas (CMP), located in Guanajuato capital, Mexico, to address current challenges in access and healthcare efficiency. Drawing on an analysis of successful international models, a strategy is proposed to expand CMP's medical coverage using digital tools, with a focus on strengthening primary care. The proposal includes not only technological implementation but also an educational component aimed at training patients in the proper use of digital services, fostering self-care, and enhancing responsiveness to their health needs. This aims to move towards a more accessible, efficient, and sustainable healthcare system.

2 Telemedicine Components and Services

Components of e-Health Scott and Mars (2010) identified four main components within the field of e-Health. The first is health informatics, encompassing the use of electronic records for managing clinical information. The second component is telehealth and telemedicine, which enable remote consultations. The third component is e-learning, focused on continuous education for healthcare professionals. Finally, the fourth component is e-commerce, which relates to administrative systems in the healthcare sector (PAHO, 2016).

Main Telemedicine Services Key telemedicine services include remote assistance, such as teleconsultation, telemonitoring, and electronic communication between professionals, which contributes to reducing hospital stays and empowering patients (PAHO, 2016). Additionally, telemedicine covers administrative management, such as testing and billing, as well as ongoing professional training. It also facilitates network-based evaluation and collaborative research. In the United States context, it is estimated that implementing electronic health records could generate annual savings of up to USD 77 billion and reduce adverse drug-related events (PAHO, 2016).

2.1. Innovation Models

The Low Touch Economy is an economic model defined by limited physical interactions, strict health measures, and significant changes in behaviors and industries due to COVID-19 (De Ridder and De Mey, 2020). This model forces companies to rapidly adapt in order to continue operating under new health and social norms, incorporating digital and remote solutions.

2.2. Exponential Organizations

Remote healthcare, home wellness, and e-commerce represent key opportunities within this economy, favoring innovative approaches such as Exponential Organizations (ExO) to adapt and expand health services in low-touch contexts (De Ridder and De Mey, 2020).

Exponential Organizations apply emerging technologies and disruptive models to grow exponentially, contrasting with traditional linear growth. These organizations use advanced digital technologies (AI, Big Data, robotics), promoting agile and decentralized structures that quickly adapt to technological changes and market demands (De Ridder and De Mey, 2020). A Massive Transformative Purpose (MTP) is essential, guiding ambitious goals beyond linear limitations (Mana and De Giovanni, 2018).

2.3. Characteristics of Exponential Organizations

The characteristics of Exponential Organizations (ExO) are divided into two main categories: logical and creative.

The logical characteristics (I.D.E.A.S.) include:

- Interfaces: automation of processes through artificial intelligence;
- Dashboards: enabling continuous measurement and performance management;
- Experimentation: promoting agile development based on hypotheses and rapid feedback;
- Autonomy: encouraging self-managed teams;
- Social: fostering connection, trust, and transparency with clients.

The creative characteristics (S.C.A.L.E.) include:

- Staff on demand: temporary hiring of external experts;
- Community and Crowd: using community-based marketing to strengthen organizational visibility and participation;

- Algorithms: leveraging Big Data to optimize processes and decision-making;
- Leveraged Assets: temporary use of external assets without the need for ownership;
- Engagement: pursuing deep client commitment through Mobile Technology Platforms (MTP) (Ismail, Malone, and Gueest, 2014).

These features enable organizations to take advantage of disruptive technologies identified by the McKinsey Global Institute (Manyika et al., 2013).

3 Methods

This study presents a methodological proposal for designing an inclusive and sustainable telemedicine model at the Centro Médico Puentecillas (CMP), in Guanajuato, Mexico. A qualitative-applied and exploratory approach was adopted, focused on organizational analysis, strategic planning, and conceptual development of a digital health ecosystem. The methodology was divided into four sequential and interdependent phases: preliminary institutional analysis, maturity assessment, strategic model design, and technological integration.

Phase 1. Preliminary organizational assessment as a business unit Prior to model development, a general diagnosis of CMP was conducted as a health service provider and organizational system. This assessment explored key aspects such as:

- Current care model (in-person, hybrid),
- User profile and unmet needs,
- Available human resources (physicians, technicians, support staff),
- Operational and technological infrastructure,
- Current communication and service channels,
- Relationships with external institutions and potential partnerships.

This analysis helped identify innovation opportunities, internal strengths (such as community focus), and structural weaknesses requiring attention. A customized CANVAS model was used as a preliminary diagnostic tool to visualize CMP's positioning as a potentially sustainable digital service provider with a social mission (Osterwalder and Pigneur, 2017).

Phase 2. Institutional maturity assessment Subsequently, the Pan American Health Organization's (PAHO, 2020) tool was applied to measure CMP's maturity level regarding telemedicine service implementation. This tool evaluates six core dimensions: leadership, organization, human resources, technological infrastructure, care processes, and information management.

Results placed CMP at levels 1 and 2, indicating an incipient technological foundation, absence of formal digital protocols, and lack of interoperability—but also institutional readiness for progressive adoption of the model. This assessment guided the strategic design and allowed prioritization of critical organizational needs (PAHO, 2020).

Phase 3. Strategic design of the telemedicine model Based on the technical-organizational diagnosis, an operational telemedicine model was developed using two methodological frameworks:

The CANVAS model defined the digital service value proposition, key users (patients with chronic diseases, family physicians), digital channels (web platform and app), revenue streams, and key operational activities (Osterwalder and Pigneur, 2017).

The Exponential Organizations (ExO) approach contributed elements of adaptability and scalability by incorporating attributes such as staff on demand, community & crowd, algorithms, leveraged assets, and engagement (Ismail et al., 2014). This approach enabled the construction of a model capable of dynamically responding to complex environments with limited resources.

Phase 4. Technological integration and operational planning In the final stage, a reference technological architecture and phased implementation plan were designed. The proposed solution features a modular, secure, and interoperable platform supporting remote medical care through video calls, clinical messaging, and remote monitoring devices. Minimum technical requirements, accessibility criteria, and cybersecurity best practices were established.

Operational workflows, evaluation indicators, and an activity timeline (Gantt chart) were also defined, including software development, equipment acquisition, staff training, clinical validation of protocols, and pilot testing. Legal and regulatory considerations in force in Mexico were included to ensure the model's regulatory viability (CENETEC, 2020; DOF, 2022).

4 Discussion

The proposed integration of telemedicine services at the Centro Médico Puentecillas (CMP) represents a concrete and context-specific response to the challenges faced by Mexico's healthcare system, particularly those related to access inequality, population aging, and lack of infrastructure in non-urban areas. Based on the institutional assessment, CMP was identified as being at an early stage of technological maturity, limiting its immediate implementation capacity. However, this evaluation also enabled the establishment of a clear roadmap toward digital transformation, aligned with innovative business models such as CANVAS and the principles of Exponential Organizations.

The discussion of results suggests that telemedicine, beyond being technically feasible under appropriate conditions, can generate significant impacts on service quality, operational efficiency, and economic sustainability at CMP. The low-touch approach and the SCALE logic from ExO facilitate the model's adaptation to a changing environment, enabling rapid scalability and more flexible management. Moreover, the combination of teleconsultation, teleassistance, and telemonitoring services supports continuous care, which is particularly valuable for monitoring chronic diseases prevalent in an aging population.

Another key finding is the potential for community engagement through digital platforms that allow direct interaction, educational campaigns, continuous feedback, and active participation in health management. This transforms patients into active, empowered users who share responsibility for their well-being—a cultural shift critical to the model's success. The phased implementation approach, supported by technical assistance, can help reduce resistance to change and facilitate technological adoption by medical and administrative staff.

Finally, CMP's proposal may serve as a reference for other health institutions with similar characteristics in Mexico. Its value lies not only in the application of technological tools but also in its strategic vision integrating innovation, education, patient-centered care, and financial sustainability. CMP's experience provides relevant elements for building a more equitable and resilient healthcare system capable of responding to both current demands and future crises, as evidenced by the global COVID-19 pandemic experience.

5 Conclusion

The healthcare system in Mexico—and specifically in Guanajuato—faces significant challenges and an urgent need to improve the quality and accessibility of services. Adapting existing processes, infrastructures, and available resources is essential to meet these emerging demands. Today, access to technology is driving a much deeper development within the healthcare sector; the incorporation of smart devices and artificial intelligence opens a vast range of possibilities to enhance medical care.

However, such technological advancement also demands the establishment of a new ethical framework to regulate emerging processes during its use. Moreover, while technology represents a powerful engine for transformation, its effectiveness will depend on the population's level of understanding and education, always taking into account the socioeconomic and cultural context in which it is applied.

To address these challenges, it is necessary to promote collaboration among government, health institutions, academia, and civil society, strategically integrating innovation. Business models based on emerging technologies and appropriate tools must be adopted. Effective technological implementation—mindful of user experience and social inclusion—will be key to achieving a sustainable, equitable, and future-ready healthcare system.

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7 Ethical declaration

No direct interventions with individuals were conducted, and no sensitive data were used; therefore, institutional ethical approval was not required.

8 AI declaration

ChatGPT was used to support technical writing, academic structuring, and grammar review. The conceptual content was entirely developed by the author.

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The Role of Human Expertise in Digital Transformation and Innovation of SMEs

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Abstract

Small and Medium Enterprises (SMEs) are fundamental to Mexico's economy, representing over 70% of formal employment. Despite their importance, many SMEs, particularly in traditional industries such as leather-footwear, struggle to adopt digital technologies due to outdated infrastructure, limited resources, and cultural resistance to change. The COVID-19 pandemic intensified these challenges, underscoring the need for digital transformation to ensure competitiveness and sustainability.
This study explores how SMEs in Guanajuato's leather-footwear sector can leverage digital innovation and human capital to overcome transformation barriers, enhance competitiveness, and align with sustainability goals. It examines the intersection between technology, knowledge management, and organizational culture in the context of the Fourth Industrial Revolution.
A qualitative, multi-case methodology was employed, using semi-structured interviews with managers from 13 SMEs. These interviews explored four key dimensions: technological infrastructure, digital culture, challenges to adoption, and future strategies. Triangulation with academic literature ensured analytical rigor and contextual relevance.
Findings reveal that only 15% of the companies have sufficient technological infrastructure to support comprehensive digital transformation, while 70% possess only basic tools such as computers and internet access—often underutilized. A significant 85% of managers cited lack of employee training as a major obstacle. Nonetheless, companies with a strong culture of learning and openness to collaboration showed higher adaptability and up to 20% increases in operational efficiency. The pandemic also acted as a catalyst, pushing many firms toward digitalization, although often reactively.
A conceptual model was developed integrating the four dimensions of transformation, offering a framework for SMEs to navigate digital change. The study further proposes knowledge management strategies including training programs, the integration of digital tools, and collaboration with startups and government agencies. These were identified by 60% of interviewees as key enablers of sustainable innovation.
This research contributes to academic understanding of digital transformation in traditional sectors and provides actionable insights for entrepreneurs and policymakers. It aligns with IFKAD's vision of integrating human expertise and digital innovation to foster socially responsible businesses. By focusing on knowledge as a strategic asset, the study highlights the importance of human capital in driving innovation, sustainability, and long-term resilience in SMEs.

Keywords: Digital Innovation, SMEs, Human Capital, Sustainability, Industry 4.0

Paper type: Practical Paper

1 Introduction

In the context of the fourth industrial revolution, digital transformation has become a strategic necessity for small and medium-sized enterprises, especially in traditional sectors such as leather-footwear. The digital transformation process involves the incorporation of technological and digital tools to optimize processes, improve competitiveness and adapt to new market requirements. In Mexico, SMEs play a fundamental role in the country's economy, representing most of the business fabric and contributing significantly to both employment generation and Gross Domestic Product (GDP).

The ownership dynamics of SMEs reflect a diversity of profiles, where both men and women play key roles in EU leadership. Business decisions, access to resources and growth strategies may vary depending on the demographic and socio-economic characteristics of owners. Where, about 97.5% of EU owner establishments are micro-retailers, while small businesses account for just 2% of the total.

Regarding economic activity, there is a clear preponderance of the private non-financial trade and services sectors in the economic structure. In contrast, the manufacturing sector, although significant, is considerably smaller, suggesting an economy with a strong focus on services and trade. With respect to the low participation

of other economic activities, this suggests a lower diversification in these areas, which is consistent with trends observed in countries with tertiary oriented economic structures.

The high activity in private non-financial services and trade sector in the economic structure indicates the need to consider information technology (IT) tools to improve their competitiveness and efficiency in these sectors. Technological tools and digitalisation can transform the way in which the EU operates, even facilitating its processes. Information technologies (IT) have come to transform technological and economic processes, restructuring the way in which the EU operates, communicates and competes on the market. As IT becomes a core part of business operations, it improves efficiency and reduces costs and drives innovation and the creation of new business models. These technological advances have enabled the EU to optimise its supply chains, improve its customer relations and generate data-driven decision making, thus facilitating a faster and more accurate response to market demands (Chan, 2000).

2 Justification for the Research

The digital transformation has been consolidated as a strategic imperative for SMEs, especially in contexts of high competitiveness and global uncertainty. In Mexico, SMEs account for more than 99% of all economic units and generate more than 70% of formal employment, so their digitization is not only a business need but also an essential component for the country's economic development. Despite this, many SMEs still face structural and operational challenges that hinder their transition to digitised business models (INEGI, 2020).

The leather-footwear sector in Guanajuato, one of the industrial pillars of the state, has shown an uneven evolution against digitalization. While some companies have adopted technological tools in a partial way, many others continue to operate with traditional models, limiting their competitiveness, responsiveness to market changes and the possibility of innovation. This situation is compounded by the lack of strategies focused on human capital development as a transformative agent.

Most digital transformation efforts have focused on the acquisition of digital technologies or platforms, without considering the role of knowledge, experience and human capabilities in their implementation and use. This techno-centric vision omits an essential component: organizational transformation depends largely on the culture, skills and willingness of staff to lead change.

From this perspective, the study is justified by its holistic approach that links digital transformation with knowledge management and human capacity development. Based on the recognition that technologies alone do not transform businesses; people do, through their learning, innovation, collaboration and adaptation to change. Analysing this process in a traditional and vulnerable sector such as leather-footwear enables the identification of viable routes, practical strategies and more effective public policies.

3 Research Problem Statement

In an increasingly competitive global environment, SMEs face the challenge of implementing digital transformation processes to ensure their survival and growth. However, the reality in traditional sectors, such as leather-footwear in Guanajuato, shows a considerable gap between the need for digitalization and the effective ability to carry it out. This gap is not only manifested in the lack of technological infrastructure or investment, but mainly in the lack of human skills, leadership and an organizational culture oriented to innovation (Del Do et al., 2023).

Numerous public and private programmes have promoted the incorporation of technological tools in SMEs. However, its impacts have been limited due to a reductionist view of digital transformation focused exclusively on the technical. This has led to initiatives that fail or stagnate because human factors such as resistance to change, staff training, lack of strategic vision and weak digital leadership within organizations are not considered.

In the case of the leather-footwear sector in Guanajuato, these limitations are even more marked. Despite being a nationally recognized industrial cluster, many enterprises have traditional hierarchical structures, low investment in continuing training and little articulation with educational or technological institutions. This hampers the integration of disruptive technologies, hinders the generation of innovation and reduces competitiveness in international markets.

Therefore, the problem of research lies in understanding how knowledge, that is, the set of skills, experience, organizational learning and digital leadership, affects the success or failure of digital transformation processes in this type of companies.

This problem becomes more relevant in a post-pandemic context, where many SMEs were forced to adopt technologies without a clear strategy, highlighting the need for a more holistic approach that combines technology, processes and people. In this context, it is essential to investigate:

What is the role of knowledge in the digital transformation and innovation of SMEs in the leather-footwear sector in Guanajuato?

4 Research Objectives

4.1. General Objectives

Analyse the role of knowledge in the *digital transformation and innovation processes* of SMEs in the leather-footwear sector in the state of Guanajuato, identifying the key factors that affect the success or failure of these initiatives.

5 Theoretical framework

The digital transformation in small and medium-sized enterprises (SMEs) has taken on special importance in recent years, driven by the Fourth Industrial Revolution, changes in consumption patterns, and the need to adapt to highly competitive and technological environments. This process not only involves the incorporation of disruptive technologies, but a profound transformation in processes, business models and human capital of organizations.

5.1. Digital Transformation: Beyond the Technological

Digital transformation has generated significant interest in recent years, especially in organizational dynamics that are exposed to disruptive technologies. This transformation is understood as a horizontal technology, which means that it affects all sectors and actors of the economy and society. His main area of study is nature as a "technology of general utility", which refers to the technology capable of transforming various economic, social and cultural activities, even modifying its own reality (Luis Curbelo, 2017). However, it is not only limited to the implementation of tools, but involves an organizational reconfiguration that requires leadership, change management and human capacity development.

The digital transformation comes to consider three key elements: technology, processes and people. These relate to each other to facilitate the adoption of new technologies in operational processes, optimizing business models and ensuring the participation of human capital. The integration of these factors allows companies to face various challenges such as resistance to change and lack of digital skills, while taking advantage of opportunities to generate value and develop new products and services (Verina, Titko, 2019).

5.2. SMEs in the digital age

SMEs represent 99.8% of the economic units in Mexico and generate more than 70% of formal employment (INEGI, 2020). Despite their importance, they face major constraints to innovation: limited resources, low formalization, lack of technological infrastructure and low professionalization. These structural barriers are accentuated in traditional sectors such as leather-footwear, characterized by a strong craft tradition, hierarchical structures, and low access to technology.

In 2001, Schwartz refers to the adaptability of enterprises, those who can respond to new technological trends are those who will be able to maintain the competitiveness of organizations and their future development, and those who are not able to adapt may be victims of "digital Darwinism". Therefore, the ability of organizations to assimilate digital transformation by adding additional value to technology should be considered.

To contemplate digital transformation, it is necessary to develop digital capabilities in which activities, people, culture and organization are aligned with organizational goals. Hence the development of more efficient and productive models as one of the main challenges for managers of SMEs (Antonorsi M. & Vidal R., 2019). Incorporating industry 4.0, which is a concept promoted by academia, industry and governments that seeks the transformation of companies to generate new opportunities through digitization and digital transformation processes.

5.3. Human capital and knowledge as a transformational axis

Over the past four decades, technological development has profoundly and structurally transformed the economic and social environment. This development has promoted the transition towards a knowledge-based economy, positioning it as the main factor of production and generating a series of implications in the theoretical and practical approach to production processes (CONAHCYT, 2023).

In 2006, Luis Mateo refers to the knowledge society as two parameters (knowing and knowing) that govern and restrict the structure and composition of today's society, integrating commodities as determining tools of well-being, integration and progress of society. Where the commodity is presented as a reference to knowledge, since both are objects of purchase and sale, in which, new knowledge is bought or sold in two forms:

1. Direct form such as patents, licenses, shares, etc., allowing the buyer to produce goods and services making use of acquired knowledge.
2. Indirect form forming part of the price of the product, good or service to which knowledge gives rise. (Luis Mateo, 2006).

In addition, transformational leadership, organizational culture oriented to learning, and continuing education are elements that allow human capital to become an active enabler of digital transformation (García & Malagón, 2020).

In this sense, the role of human capital in SMEs transcends the operational to become an engine of organizational change. This includes from the effective adoption of digital tools to the ability to rethink processes and redesign business models focused on innovation.

5.4. Towards a sustainable and people-centred digitisation

The digital transformation must be approached with a vision of sustainability and social responsibility. In this sense, people-centred digitalization seeks not only operational efficiency, but also organizational well-being, equity in access to technology, and the generation of shared value.

The incorporation of knowledge management strategies, collaboration networks and links with the innovation ecosystem (academia, government, startups) becomes essential for SMEs to scale their digitalization in a sustainable way and with social impact.

6 Methodology

A qualitative multi-case methodology was used, where semi-structured interviews were conducted with managers and leaders of 13 SMEs in the leather-footwear sector of the state of Guanajuato. The data collection was carried out through an interview guide focused on four dimensions: technological infrastructure, digital culture, barriers to adoption and strategic vision. The analysis was carried out with the support of the software Atlas.ti, using open coding and triangulation with scientific literature.

6.1. Analysis Procedure

The results reveal a deep heterogeneity in terms of the degree of digitalization and technological maturity of the companies interviewed. Only 15% of SMEs have the appropriate technological infrastructure for comprehensive digitization processes. However, 70% have basic tools such as computers, e-mail or social networks, although their use is not systematic or aligned with an organizational strategy.

One of the most relevant findings is that the main obstacle identified by 85% of participants was lack of staff training. This lack not only hinders the adoption of new tools but also creates resistance to change and external dependence for operating basic systems.

On the other hand, companies were identified that have advanced significantly in their digitalization thanks to three key factors:

1. Innovative-minded leadership
2. Organizational culture opens to learning
3. Links with academic or technological institutions

These companies reported up to 20% improvement in operational efficiency, reduction of delivery times and greater adaptability during the pandemic. Another significant finding is that the most successful digital transitions were those that were approached as strategic processes, not just as technological decisions.

It was shown that the digital transformation has been more effective when accompanied by knowledge management, continuous training and internal feedback mechanisms. Without these components, initiatives tend to fail or remain in the middle, generating organizational frustration and wasted resources.

The analysis of the case studies and their codification in atlas.ti made it possible to structure a conceptual model for digital transformation specific to SMEs in the leather-footwear sector. This model integrates four dimensions:

1. Technology infrastructure and connectivity
2. Organizational culture
3. Organizational barriers

4. Opportunities, strategies and vision

The interconnection between these dimensions (see Figure 1) demonstrates that knowledge acts as a central axis of the digital transformation process, influencing the perception of obstacles and the ability of companies to design and implement innovation strategies.

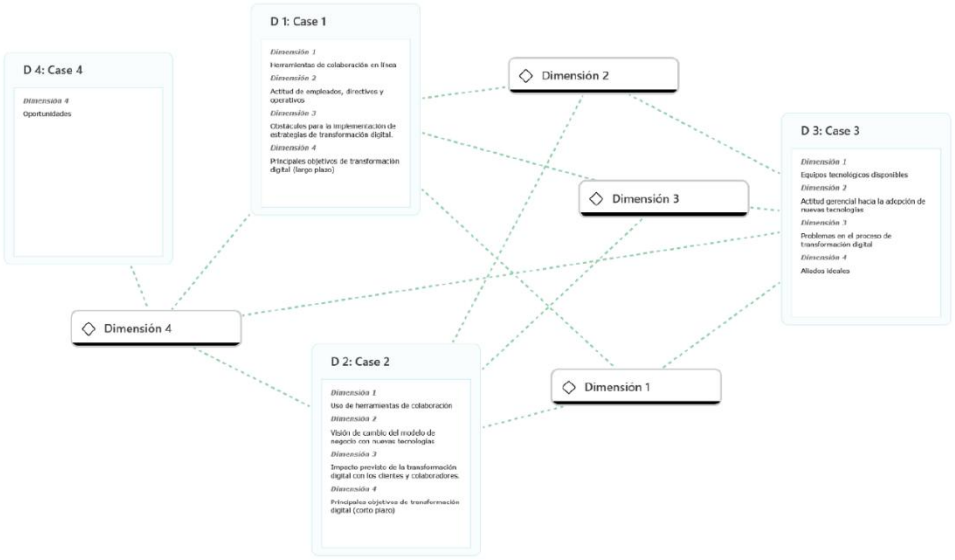


Figure 1: Network of interaction between the dimensions and their analysis codes.
Source: Adapted from Scientific Software Development GmbH (ATLAS.ti, 2023)

The general organization of the diagram is based on two main points:

1. By dimension: Represents the dimensions set out in the case study, each of the dimensions addresses specific themes and is linked to one or more cases.
2. By case: The cases are the result of individual studies of each dimension, where the main codes were identified by dimension.

Each dimension addresses a key point in the digital transformation process:

- Dimension 1 examines collaboration tools and their use in a digital environment, the main linked cases are case 1, 2 and 3, as these explore the adoption of collaboration tools highlighting the importance of technologies that facilitate communication and remote working.
- Dimension 2 explores attitudes towards technology and its view of change in models' business, this is linked to cases 1, 2 and 3 because these come to reflect the attitudes of employees, managers and digital transformation, which can influence the success of implementation of digital strategies.
- Dimension 3 covers the problems and obstacles in adopting transformation digital, the main linked cases are case 1, 2 and 3, in which the main challenges such as lack of infrastructure, resistance to change or failures in strategic processes.
- Dimension 4 reflects the opportunities of the digital transformation process as well as its strategic allies, in this dimension all cases are linked (case 1, 2, 3 and 4) because it focuses on identifying the main areas for improvement, potential collaborations and future strategies.

Dimensions 2 and 3 are considered as central axes, since they are linked to the first three cases. These dimensions cover transversal and strategic aspects that generate a greater impact on the digital transformation process. Regarding dimension 1, although it is connected to cases 1, 2 and 3, it is not considered as a central dimension, since its role is more specific and functional, focused mainly on the implementation of digital tools.

The centrality of dimensions depends not only on the connections between them, but also on the conceptual weight of the dimension in its global analysis. Although organizational attitudes and barriers are key elements influencing technology adoption and the challenges inherent in digital transformation, while the use of tools Although relevant, it is more operational and depends on factors determined by other dimensions.

Regarding dimension 4, this is limited to the presence of opportunities where in some cases indicates that this aspect is transversal and relevant considering this dimension as an area of opportunity.

7 Conclusions

The digitization of SMEs is more than just the introduction of innovative technologies in their operation. It is a multidimensional process involving radical restructuring and fundamental redefinition of organizational and cultural priorities. To be specific, these barriers do not lie primarily in infrastructure but rather in human perception and how organizations manage development. In the example of the leather and footwear sector in Guanajuato, their entrepreneurs lack the digital atmosphere, as well as tending to intentionally oppose changes and decrease their expenditure on continuing education in their domain. Thanks to qualitative analysis provided by semi-structured interviews and thematic coding with the help of Atlas.ti, the features revealed make it possible to identify from which companies were able to explore further.

Finally, this research contributes to the academic debate on digital transformation from a people-centered perspective. It reaffirms that the success of digitization in SMEs depends not only on technology, but on its people, their ability to learn, adapt, collaborate and lead changes. To achieve a sustainable and inclusive digital transformation, continued investment in human skills development will be crucial, Strengthening the link with the innovation ecosystem and designing public policies that recognize human capital as a strategic axis of business development.

8 Ethics declaration

This research did not require direct intervention in the health or physical integrity of participants; however, semi-structured interviews were conducted with people working in SMEs in the manufacturing sector. For this reason, fundamental ethical principles such as informed consent, confidentiality and anonymity of participants were followed. All interviewees were informed of the purpose of the study and gave their consent to participate. The information collected was treated confidentially, without mentioning names or data that could identify specific individuals or companies. Due to the nature of the study and in accordance with institutional ethics policies, it was not necessary to submit the project to a formal ethics committee. However, the ethical principles established in social and human science research were observed.

9 AI declaration

The qualitative analysis of this study was carried out using the software Atlas.ti, a specialized tool for qualitative data analysis. This platform facilitated the coding of interviews, the organization of thematic categories and the mapping of relationships between analytical dimensions. It should be clarified that Atlas.ti is not a generative artificial intelligence tool, but a methodological support software. The analysis, interpretation and writing of the results were carried out entirely by the author.

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How Does AI impact Human Capital and Capability (HCC) in MBMI Processes?

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Abstract

The impact of Artificial Intelligence (AI) on Human Capital (HC) responsible for designing, reengineering, and developing Business Models (BM) has not been extensively investigated. Latest research seems to diverge on whether AI has a negative or positive impact on HC competences, HC capabilities, and Business Model Innovation (BMI) processes. Studies indicate that HC is at risk of being wasted or underutilized due to AI, as research verifies that if the human brain is not utilized as much as AI enables today, where AI takes over HC tasks and HC will be wasted, spilled or lost. Other research shows that AI can release unused HC and potential when AI designs and reengineers Business Models (BMs) and Business Model Ecosystems (BMES). In some cases, AI is even shown to be able to release unused HC when downloading, analyzing BMs, and sensing disruptive, radical, and/or incremental BMs.

The paper investigates AI´s impact on HC and HC´s capabilities (HCC) in 7 different Multi Business Model Innovation (MBMI) processes, seeking to determine whether AI can enhance the use and potential of HC, or, conversely, hinder and reduce HCC in MBMI.

The impact of AI and MBMI was studied in seven MBMI projects in different BMESs that are influenced by AI. The effect of AI on HCC was analyzed as a key finding and output to the research question: Does AI lead to HCC Waste, spill, loos or does it increase the grow, increase and release HCC potential?

Keywords: Human Capital Waste, Human Capital Potential, AI, Knowledge Management, Multi Business Model Innovation (MBMI)

Paper type: Academic Research Paper

1 Introduction

Literature (Kaplan et al., 2018; Desolda et al., 2024) suggest that AI can lead to less creativity and BMI, thereby wasting, spilling or loosing Human Capital (HC). However, other findings (Ghosh, 2025) point to the opposite: that AI can unleash HC potential and accelerate the faster and higher quality of BM design, reengineering, and development. AI is claimed to be able to lead to HC growth with increased use of HC potential, growth of HC, and increased HCC. These results correspond to the hypothesis that AI is a predictor of potential for success and advantage for Human beings, leading to the growth of HC. However, what is the truth?

The research is conducted in the context of a discussion on the impact of AI, HCC, Knowledge Management and MBMI. The research has a particular focus on a new concept, “Human Capital and Capability Waste and Potential,” as shown in Figure 1 inspired by Garland (2010), focusing on the process of broadening and building positive emotions (upper right part) and the process of narrowing tunnel vision through negative visions (lower right part). The model propose that the physical aspect of humans is considered, regarding the individual as possessing physically valuable competencies – a physical Human Capital (HC), which can be “grown”, “increased”, “found” as well as “wasted”, “spilled” and “lost”.

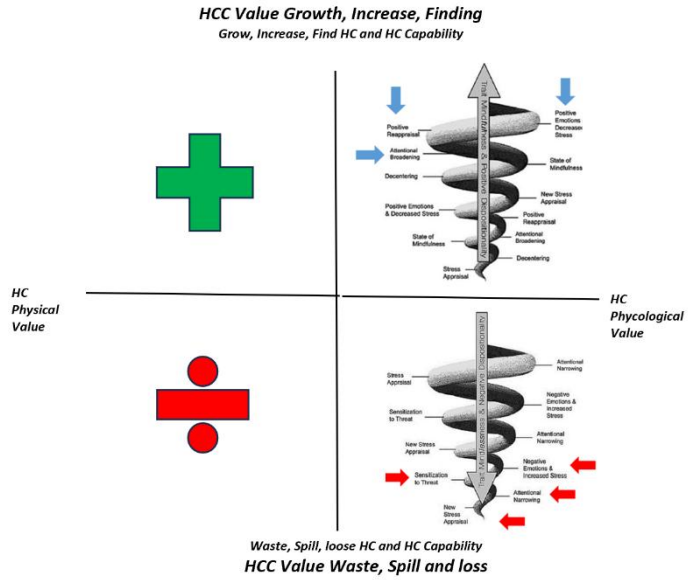


Figure 1: Human Capital Waste and Potential – Grow, Increase, Find - Waste, Spill, Lose -- HC Value/Capability

HCC refers to the **physical part** – physical fitness – physical health and wellbeing –and the **psychological/intellectual part** - psychological health, skills, knowledge, education - of humans that are valuable in a MBMI contexts. Humans HCC physical and phycological parts in this concept are essential in MBMI design, reengineering and development (Golding, 2014). It is included in the – The Competence dimension - more Specific for HC, The HR component of the BM framework (Lindgren 2018) has a substantial impact on MBMI and the human being's motivation, earnings and perceived earnings (Demings, 2022) of MBMI. Research shows that HCC investments yield high economic returns for businesses. Poor investment or neglect can result in wasted, spilled and lost HCC. This can increase or decrease HCC to create, capture, deliver, receive, and consume values, and the design, reengineer, and develop BMs. Businesses can enhance HCC through training and education, which can improve the quality, production and output of MBMI. However, HCC can also be wasted, spilled and even lost impacting both the physical and psychological value of HCC, as indicated in Figure 1.

HCC, in a broader definition, is "the pool of competence and Capabilities" together with the potential of these that the business and its users, customers, and network possess together or waste, spill, or loos.

HCC is "a core raw material" to any BMI. No society or business (UIE 2025) can afford to waste and spill HCC – or simply let HCC "Shrink" – and not been used at its full potential and availability – because there is a lack of HCC today (Draghi 2024). The demand for HCC, especially in Europe is exceptionally high and 4 causes are mentioned to create the lack - **The Retirement Generation - Skill Shortage - Employee Burn Out - Pandemic** (Premier 2025). Waste and spill of HCC can lead to fewer resources of HCC for MBMI and thereby fewer new and reengineered BMs, less developed or poorer innovated BMs. When HCC is wasted or spilled, the hypothesis is that less learning, knowledge creation and creativity will happen. Opposite – hypothetical - increased creation and use of HCC potential will lead to increased MBMI. However, literature shows that an increase in HCC via knowledge creation requires learning (Krogh 2000, Lindgren 2018) or HC needs to learn, or to be learned in the moment, in short and long-term perspectives. However, can HC learn and evolve its HCC with AI, be impacted by AI, or when AI takes over basic and, in the future, more complex HCC´s tasks?

A paradox according to research (Shors et al, 2011) showed that if HC – "the brain" of one human or many humans together are not used then the HCC - the business HCC - is in risk of wasting, spilling and loosing HC and HC capability to do MBMI. Research shows that even children between 6 – 12 years, who are usually eager to learn and are curious to learn new skills when using computers, mobile phones, and social media embedded or "supported" by AI, are at risk of losing their ability, capability, and interest in creativity and innovation. Increased use of AI via these devices has shown some tendencies and trends (Zhai 2005) of the children losing the ability to learn. At some point, "The human brain" is constructed to do things easily, and the easy tasks first – or even for some "to do nothing" (Haidt Ferguson 2009, Haidt 2014).

As the world becomes more Volatile, Uncertain, Complex, and Ambiguous (VUCA) (Lindgren, 2023), it is of utmost importance for humans, business and Societies (Draghi 2024) to be creative, innovative, curious, and to learn continuously. Our research hypothesis is that individuals embedded in networks with a general MBMI

capability can value and increase the output of MBMI via the use of AI. Conversely, our hypothesis is also that the opposite can be the outcome if AI and HCC are not led and managed.

2 AI in business model innovation

The history of AI dates back to antiquity, with myths, stories, and rumours of artificial beings endowed with intelligence or consciousness by master craftsmen. The study of logic and formal reasoning, from antiquity to the present, has led directly to the invention of the programmable digital computer. This device and the ideas behind it inspired scientists to begin building an “electronic brain”.

The field of AI research was founded in 1956 (Kaplan A, Haenlein M 2018) as a prediction that machines as intelligent as humans would exist within a generation. Heavy funds were provided to AI research to make the “electronic brain” vision come true (Newquist, HP, 1994). We are now at the beginning of this AI generation, as it has become apparent that researchers and businesses have underestimated the challenge of innovating and developing AI. A visionary initiative by the Japanese Government and the success of expert systems reinvigorated investment in AI. By the late 1980s, the AI BMES that had grown into a billion-dollar BMES. However, investors' enthusiasm waned in the 1990s, and the field was criticized in the press and avoided by industry (a period known as an "AI winter"). Nevertheless, research and funding continued to grow under other names.

In the early 2000s, machine learning was applied to a wide range of challenges in academia and BMES. The success was due to the availability of powerful computer hardware, the collection of immense data sets, and the application of solid mathematical methods. Deep learning (DL) proved to be a breakthrough technology, eclipsing all other techniques. The transformer architecture debuted in 2017 and was used to produce generative AI applications and robotics was at this time attached to the umbrella of AI.

Investment in AI skyrocketed in the 2020s alongside quantum computing. The boom, driven by transformer architecture, led to the rapid development and release of large language models (LLMs) like ChatGPT, which showcase human-like knowledge and creativity across various sectors. However, concerns about the risks and ethical implications of AI have sparked debate about its future impact on society and HC. Figure 2 illustrates the historical timeline and key inventions in the AI field.



Figure 2: The Story of AI

AI is today transforming the core dynamics of BMES by redefining the way businesses operate, design, reengineer, and develop BMs and HC in BMI. In the context of BMI, the MBMI approach and “the MBMI brain” (Lindgren, 2020) are now possible to realize. AI and DL in a world of persuasive BM could propose all possible archetypes of BMs. MBMI Processes and corresponding interaction archetypes patterns of any BM interactions can be carried out with,

• *Human Intermediary - Machine Intermediary or a Mix of Human and Machine Intermediary BM Interaction*

MBMI patterns analysis, MBMI Library combined with AI and DL are already supporting MBMI Brains in businesses leadership and management.

Businesses are challenged by a world that is increasingly adapting AI – and AI in MBMI as the world becomes more Volatile, Uncertain, Complex and influenced by Ambiguity – (VUCA) Lindgren 2022). In these situations, it is a big option, opportunity, and drive to use AI to become faster in MBMI – and “jump” the gates of the MBMI challenge easily.

AI in MBMI adds one more layer to the businesses' challenge to innovate and develop BM faster. This trend and the desire to do this has been addressed for many years (Fine 1999, Chesbrough 2008, Vercanti 2009) – as an exponential pressure and request on businesses and humans responsible of MBIM - to change BM´s faster – “high-speed BMI”. Survival of a business - until today – has been equal to HC to innovate, develop, and change

BMs faster. However, innovation and development of HCC seems no longer a “competition” and a “game” of “human to human” MBMI, but now a “game” of human to humans and machines MBMI. Further, this includes fewer single BM BMIs but innovation of multitudes of BMs simultaneously – the new era of designing and reengineering of BMs. A paradigm shift in BMI - to be capable to practice MBMI in business’s BM design, reconfiguration, and development processes. Participants in AI-supported MBMI processes risk marginalization, waste of HCC, and a loss of innovation capability when AI takes over many tasks and HC may not be fully utilized or trained, as AI is easier, faster, and cheaper to implement.

3 Research questions, design, and research methodology

These reflections led us to the following research questions:

- *How does AI influence HCC and potential in MBMI and MBMI processes in different BMES?*
- *Are the HCC and its potential wasted, spilled and lost when AI is implemented?*
- *What is AI´s impact on HCC´s output and MBMI success in short and long-term perspectives?*

This study combined literature review, case research, participatory action research, interviews and secondary sources.

4 AI in MBMI: state of the art

AI has emerged as a key facilitator that improves decision-making, promotes interconnectivity among BMs, and optimizes operations across different BMES (Mishra & Tripathi, 2021). AI is transforming how businesses approach MBMI, impacting HC utilization in MBMI. While AI enhances effectiveness, efficiency, and analytical capabilities, it raises concerns about HC displacement and underutilization. Although the role of HC in MBMI is changing research the AI impact on MBMI processes have not been the primary focus. AI-based technologies, including classical machine learning, deep learning, natural language processing, and robotics, enabling the transformation of MBMI processes in various BMES (Jorzik et al., 2024). AI enables intelligent automation, predictive analytics, and data-driven decision-making in MBMI. The important changes brought about by AI in MBMI are:

Improved Decision-Making: AI can scan massive datasets to detect patterns, forecast patterns important for MBMI and maximize MBMI investment (Haleem et al., 2024). Businesses can build improved MBMI forecasting models, predict consumer, supplier, and network wants, demands, and needs, and avoid possible risks by using AI. This ability enables MBMI decision-makers to adopt proactive MBMI strategies, allowing flexibility during changing BMES conditions (Stefia et al., 2024).

Operational Effectiveness and Efficiency in MBMI*:* Automating MBMI processes reduces manual tasks, cuts errors, and lowers expenses. AI-driven tools, such as robotic process automation (RPA), streamline repetitive tasks, allowing staff to focus on higher-value HC MBMI work. This enhances productivity, improves resource allocation and efficiency, and reduces costs (Gong et al., 2024).

Data-Driven Insights*:* AI-driven analytics provide real-time insights enabling businesses to adapt to changing market conditions. These insights facilitate data-driven MBMI decisions supported by empirical evidence. AI-based data visualization tools provide dashboards that enable executives to monitor performance metrics and identify areas for improvement in MBMI projects. (Matheus et al., 2020). (Matheus et al., 2020) (Matheus et al., 2020)

BMES Crossflow: AI enhances integration among businesses in vertical and horizontal BMEs by connecting various BMs. For instance, AI platforms in finance are merging with those in healthcare and retail to create personalized financial packages based on consumer behavior tracking. This horizontal BMES collaboration fosters innovation by using AI to bridge gaps between typically non-overlapping BMEs. (Carmona-Lavado et al., 2023)

AI-Augmented HCC: Although there are concerns about HCC loss related to MBMI, AI provides opportunities for reskilling and upskilling HCC. Businesses are investing in AI literacy training to equip HC with the skills necessary to work with AI-powered systems. This shift can enable a harmonious relationship between HC and AI, resulting in the development of more hybrid jobs that will be able to blend analytical, technological, business, and HCC.

As AI continues to evolve, the role of MBMI in harnessing AI-driven MBMI changes becomes increasingly critical. Therefore, businesses need to create ethical guidelines and governance policies to address the socio-economic effects of AI adoption. By embracing AI responsibly, organizations can tap into new growth opportunities while promoting sustainable BMI.

Today, many businesses do not really systematically download, see, sense, and use their full HCC potential regularly. Thereby they waste, spill and loos much of their HCC – HR competences and HR Capabilities either by not using the HRC, using the HRC in a wrong position, for a wrong task or more radically speaking "wasting" these by physically or psychologically "killing" – destroying HC – e.g. by having AI influencing the HC to not continuously be curious, learn, pushing their "HC brains" to valuable MBMI. Figure 3 illustrates different HCC waste, spill, loos - sources on a physical and psychological scale and relate these to our cases.

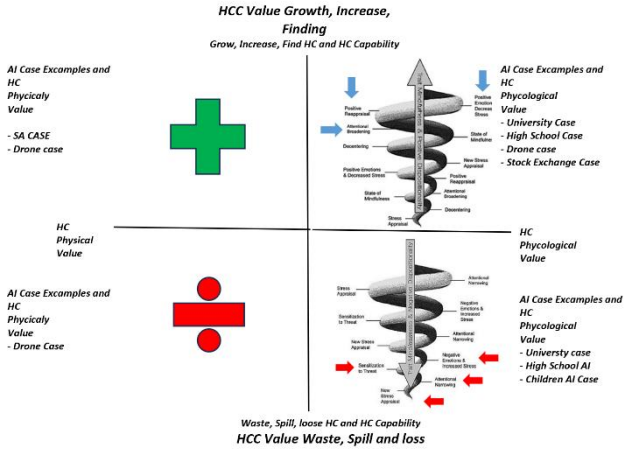


Figure 3: HC Value Growth, Increase and Finding – HC Value Waste, Spill and Loss

The cases are also related to HCC Value Growth, Increase and Finding scale.

5 The role of HC and HRC capability in AI-augmented MBMI

As AI improves operational effectiveness, efficiency and learning in MBMI Processes, it can potentially remove the requirement for HCC. However, some research suggests that it redirects the work of stakeholders in the MBMI process towards more strategic thinking, creativity, and challenge-based solving of complexities that AI cannot overcome. AI into MBMI operations can affect HCC in following manner:

- ***Augmentation of HC Capability***: AI is a tool that enhances human capabilities in MBMI, boosting effectiveness, efficiency, and productivity. It aids managers in optimizing AS IS and TO BE BMs by providing actionable insights and utilizing predictive analytics. AI-driven decision-making helps reduce uncertainties in experimentation and innovation within MBMI.
- ***The Transition to Higher-Skill MBMI Jobs****:* AI is a tool that enhances HCC in MBMI, boosting effectiveness, efficiency, and productivity. It aids managers in optimizing AS IS and TO BE BMs by providing actionable insights and utilizing predictive analytics. AI-driven decision-making helps reduce uncertainties in experimentation and innovation within MBMI.
- ***Human-AI Collaboration in MBMI***: Automation through AI streamline routine tasks, enabling HC to focus on strategic planning, creative problem-solving, and relationship management with key stakeholders. This shift necessitates continuous learning and skill upgrades, prompting businesses to invest in reskilling and upskilling initiatives for employees and the broader network to prepare for AI-enabled MBMI roles.

6 The role of HCC waste and/or potential – decreasing/enhancing HCC via AI

While it has its benefits with the growing involvement of AI in MBMI, it also raises concerns about job replacement and HC underutilization. Various issues arise as Businesses adopt AI-based MBMI processes:

- ***Redundancy of Jobs in Repetitive Tasks***: Robots and AI replace operational and administrative MBMI jobs, resulting in workforce layoffs in certain MBMI areas.
- ***Digital Divide and Skill Gaps***: The rapid development of AI creates a gap between the skills available in the MBMI workforce and the AI-integrated competencies and capabilities required for MBMI.
- ***Social and Ethical Implications****:* Businesses must address the ethical implications of AI deployment in MBMI, including providing equitable employment opportunities in MBMI and mitigating the potential dislocation of the MBMI workforce.

7 AI's impact on MBMI success and output

AI plays a crucial role in achieving MBMI initiatives by maximizing BM flexibility, expandability, and profitability. Major areas in which AI contributes to MBMI success are:

- *BM Flexibility:* AI-powered systems enable businesses to modify their BMs in real-time, adjusting to BMES patterns and customer needs dynamically. Adaptive AI-based MBMI keeps businesses strong in rapidly evolving environments.
- *Data-Driven Decision Making for MBMI Output*: AI supports real-time decision-making through the analysis of BMES data, competitor actions, and consumer behavior patterns. This enhances BM design, minimizing trial-and-error iterations and expediting MBMI success.
- *MBMI Acceleration*: AI enables quick MBMI, including prototyping, allowing businesses to test new value propositions, revenue, cost, and earnings models in a quick, effective, and efficient manner. By automating MBMI activities, AI minimizes costs and optimizes the feasibility of multi-business model integration.

8 AI and HC retention strategies in MBMI

To counter the effect of AI on HC, businesses can adopt MBMI strategies that guarantee balanced AI-human interaction in MBMI processes. Some approaches are:

- *MBMI Workforce Reskilling Investments*: Businesses must develop ongoing learning initiatives aligned with BMES demands, driven by AI and other emerging technologies.
- *Human-AI Synergy:* AI should be utilized as an enhancement tool, rather than a substitute for human intelligence.
- *Redefining Professional Jobs:* New professional types, such as AI-ethics MBMI consultants, MBMI digital strategists, and AI-supported MBMI decision-makers, need to be developed.
- *Ethical AI Deployment:* Businesses need to undertake responsible AI deployment, avoiding job displacement and labor marginalization. AI plays a crucial role in achieving MBMI initiatives by maximizing BM flexibility, expandability, and profitability. Major areas in which AI contributes to MBMI success are:

9 AI and HCC retention strategies in MBMI

Seven different cases in different BMES influenced by AI were studied from February 2022 to April 2025. 4 cases were selected for this article. The participatory action research method (Chevalier, 2013; Bryman and Bell, 2011) forms the general research methodology framework and approach for the cases. Observation and secondary data analysis was also used.

9.1 AI and SA case – AI advancing HCC

SA in the Auto recycling BMES of scrapping, dismantling cars and other vehicles. One of the most challenging MBMI tasks for SA is to assess a car for the BM values it includes quickly. By using AI SA - employee can faster judge which BMs are included in the car and thereby value the SA Business. Hereby, the AI enables the SA Employee to utilize their HCC better resulting in higher Quality, greater precision and better earning.

9.2 AI and drone technology - AI advancing HCC

DR constructs Drones for Defence and Security BMES. The customers of the drones demand drones equipped with devices that can capture images and videos of equipment on the ground. The interest of the users and customers was initially to obtain photos and videos quickly. However, the DR MBMI employees discovered that the pictures and videos were not of core interest and would not lead to new BMs, as the photos and videos were often outdated - old "data". However, with AI embedded, it was possible to "see" between the "pixels," which enables the customers together with DR to forecast the future actions of "the businesses on the ground". This turned was extremely valuable, especially in the defence and security BMES. This BM was unable to innovate and develop with existing HCC, as the HC was not able to do so.

9.3 AI and MBMI at Universities - positive and negative HCC effects of AI

Universities are struggling with AI-related issues due to students' increasing use of AI. Some Universities have forbidden the use of AI, while others have encouraged its use under specific leadership and management

regulations. Many university students are engaged in MBMI projects for businesses, where they utilize AI to find valuable BM in their MBMI process. They also use AI to write the draft proposal for their MBMI report to businesses. For those students who use AI as a supporting tool and carefully review the AI-generated proposal, this approach has proven to be highly valuable. However, for those who are more uncritical and less rigorous in their quality checks, some have experienced adverse outcomes and results.

9.4 AI and healthcare – fast diagnosis, cost savings, and improved healthcare quality

Healthcare sectors now utilizing AI to rapidly scan for various conditions, such as cancer and other diseases that require prompt attention to meet business standards, reduce treatment time, and facilitate fast patient diagnosis. AI is employed to alleviate the workload of employees, who often face a severe shortage of resources and expertise, and can be redirected to other, more value-added areas of the business. The quality of screening and diagnosis is increasing. As diagnosis involves multiple types of data and various forms of analysis, this results in employees transitioning to jobs that require different competencies and capabilities at higher levels.

10 Discussion and reflection

There is a great difference in how and why MBMI participants utilize AI in the cases studied – and how AI impacts on HC and HC Capability to perform MBMI. The general observation is that the quality of the BM value proposition is increased, costs are saved, and HC is released to often more self-realization job areas, that are on a higher intellectual level than the HC typically would deal with and solve. AI can play a role in pushing HC to become better, develop, and grow its HCC. AI can also play a role in increasing HC´s capability to do MBMI and more advanced MBMI – radical and even disruptive levels. This support other research that AI leads to job changes often to higher-level jobs and HCC use on a higher level than usual.

11 Conclusion, relevance, and contribution

AI and its use among MBMI participants and MBMI teams is expected to be beneficial for organizing, designing, reengineering, developing, and managing MBMI. Our research seems to deviate on whether AI has a negative or positive impact on HC competences and HC capabilities, MBMI processes and output. In the cases studied we found both positive and negative results. AI in MBMI processes on individual and team levels seem to show that AI influences much the actors in MBMI projects. It was in some cases possible to verify the participants' output of their MBMI solutions, which showed higher quality in most cases. It was not possible to measure if the output were ambitious enough or if HC really produced better MBMI solutions. It was possible to find that the HC involved could meet, overcome and solve more advanced MBMI Challenges – equal to higher HCC.

The research indicates that HCC are in some case at risk in being wasted, spilled and lost due to AI. As the research verified, if HC is not utilized as AI enables, and AI takes over specific HC tasks, HCC will be wasted, spilled and even lost. In some cases, AI has been verified to release unused HCC and unlock HC potential when used to design and reengineer BMs and BMES.

The research finds that learning and knowledge innovation with AI can occur and are beneficial in many cases for organizing, optimizing, and supporting MBMI processes. However, it can also result in the opposite - HC waste and spill, as well as reduced MBMI, if AI is misused. AI can strengthen MBMI, but it needs to be treated with utmost care, new leadership and management methods.

12 Further research

A future interdisciplinary experiment is needed to measure AI´s impact on MBMI processes and HC, to distinguish between the positive and negative effects of knowledge and practice in MBMI processes. Additionally, a profile test of the involved persons (Big Five) will reveal their personal human capital status, preferences, and actions related to knowledge innovation and development. In future research, we intend to investigate how businesses influenced by and using AI can achieve high-quality MBMI and HCC Value innovation, enabling HC to perform better MBMI.

13 Ethics declaration

Ethic clearance was not required for this research as only publicly accessible data were used an no personal data collected.

14 AI declaration

No AI tools were used for creation or revision of this paper

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Exploring Technology Diffusion for Enhanced Energy Efficiency: An Empirical Approach

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Abstract

The present study examines the impact of technology diffusion on energy consumption and efficiency in small and medium enterprises (SMEs) in Montenegro. The focus of this study is a project proposal submitted by a specific SME. The project entails the procurement of the machine for heating and waste collection, as well as the implementation of a digital key for purpose of productivity and energy monitoring. The objective of the project is threefold: firstly, to reduce electricity consumption; secondly, to increase revenue; and thirdly, to promote sustainable practices. This is an empirical study, and as such the results obtained from the real-life consumption of a company can be representative. It was demonstrated that undertaking of project activities would result in the company accruing benefits in both the short and long term. It has been indicated that a reduction in both energy consumption and CO_2 emissions will be observed. However, it is anticipated that the project activities will, over time, lead to the adoption of even more sustainable practices within the company. The paper provides a comprehensive exposition of the demonstration of the Rogers model (TOE and IDP framework) using empirical evidence. Project of this nature are of great benefit to SMEs in Montenegro and the wider region. The provision of financial assistance is but one of the functions of this calls, another is the raising of awareness of various issues. The concept of energy efficiency should not be perceived as disadvantageous, rather, it should be regarded as a concept that is universally accessible and demonstrably manageable in a variety of ways.

Keywords: technology diffusion, energy efficiency, SMEs, transition, innovation.

Paper type: Academic Research paper.

1 Introduction

The global market has confronted considerable challenges in recent years. It has been demonstrated that the known and familiar is not adequate for market survival. It is imperative to adapt to changes in a timely and efficient manner, demonstrating the necessary agility to respond swiftly to evolving circumstances. Technology has been regarded as both a potential catalyst and solution to a paradigm shift regarding not only modes of thought but also modes of business.

The implementation of a multidisciplinary approach is imperative for the survival of the business. Regardless of the technology's necessity, its presence is indispensable for the continuity of a business. The primary focus of this paper is the relationship between technology diffusion and energy efficiency.

The relationship will be explained through the empirical results, conducted for the Innovation Fund's call within the Energy Efficiency Program for Small and Medium Enterprises.

The theoretical framework for technology diffusion will be established to demonstrate the efficacy of energy-efficient practices through an empirical approach and collected data of the chosen company. The research question to be addressed in this research is: What is the impact of technology diffusion on reducing energy consumption and enhancing energy efficiency? The main focus of this research is that technology can help create a better environment and reduce waste, which can also help save energy.

A significant number of researchers have identified a solution within the technological domain. The proliferation of technological innovations has engendered a variety of methods for the generation of energy within corporate entities. Such methods assist companies in becoming more sustainable and in diminishing their environmental impact.

The first part of a paper will mainly focus on a literature review, with special attention on most relevant papers and journals in field of technology diffusion and innovation. This part of a paper will give a solid background for the more detailed analysis. The third part will demonstrate the methodology of the research, how the data were conducted and the sample selection, and so.

The most important part of the paper will be demonstration and elaboration of the results. The results represent a forecast of the energy efficiency usage, based on the reference period. The discussion of the paper will provide a more detailed and comprehensive understanding of the relationship between technology diffusion and energy efficiency, as evidenced by a real-life example.

2 Literature review and Theoretical frameworks

According to the theory of technological diffusion, innovations – defined as new products, processes, or technological advancements – gradually evolve within society and industry (Palm, 2022). This theory posits that innovation does not occur in a single, abrupt action but rather progresses over time in a gradual and steady manner. The imperative for companies to digitize their processes has had a significant impact on technology diffusion practices, as evidenced by nowadays empirical evidences in world's society.

Therefore, despite their apparent need and importance, small-to-medium enterprises (SMEs) continue to grapple with the implementation of energy efficiency solutions. The research network is exerting its utmost efforts to ascertain the potential underlying causes of the phenomenon under study. The aforementioned factors serve as the primary rationale for the increasing prevalence of scientific works within the domain of research concerning technology diffusion and energy efficiency.

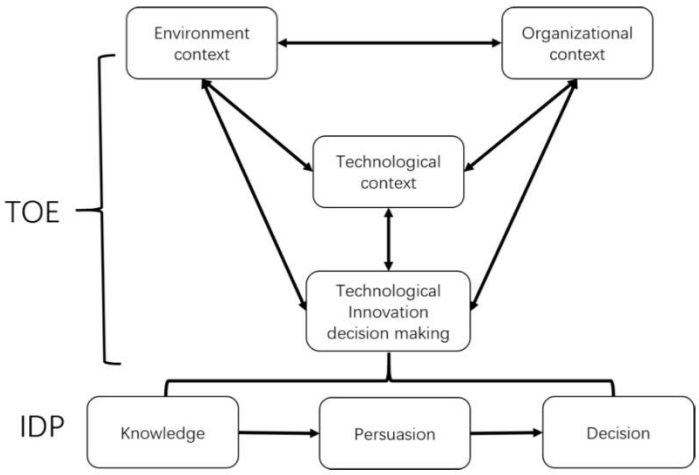
In the realm of entrepreneurship, a prevalent issue that has garnered significant attention is that of financial constraints in the context of technological innovation and implementation. This concern has been repeatedly emphasized by numerous entrepreneurs, underscoring the need for comprehensive solutions to address this critical challenge. In contrast, the governance entity has initiated a series of measures designed to provide support, including allocation of potential subventions and the formulation of diverse project calls.

For purpose of this paper, the literature review will serve as the foundation for synthesizing empirical results and theoretical frameworks. In such circumstances, the authors of the paper have implemented specific measures in bibliometric tools to guarantee the relevance and quality of the database of publications.

The Web of Science database was the primary source for this literature review. A comprehensive search strategy was employed, encompassing keywords such as "energy efficiency", "technology diffusion", "SMEs", "transition", and various filters, which yielded a foundation of literature amounting to 581 papers. Given the database's prevalence in recent years, it is notable that from 2014 to 2024, the number of publications pertaining to these subjects exhibited a marked increase. This finding underscores the database's significance and relevance in contemporary academic discourse.

The OSLO Manual (2018) provides a comprehensive overview of the measurement of innovation, encompassing the innovation itself, the methodology of data collection, and the identification of firm's capabilities. Subsequently, Allcott and Greenstone (2012) conducted a discussion on the absence of energy efficiency investments, despite the existence of evidence indicating otherwise. The emphasis is on the provision of empirical evidence to ensure the profitability and sustainability of investments. As all prior researchers, their goal was to make this "energy gap" less noticeable and apparent. In contrast, Wang and Sun (2021) have addressed the mathematical formulation of the Bass model and sought to articulate the merits of new energy industries. It is notable that the other literature also focus on the cohesion of culture, institutions and politics in regard to the same goal of changing paradigms towards energy utilization and transitions to energy efficiency. A considerable number of authors concur that the diffusion of technology innovation is a pivotal asset in the effort to combat climate change.

The work of Shi, Zeng, Engo, and others (2020) examines the factors influencing the adoption of technology for energy efficiency among small and medium-sized enterprises (SMEs). They identify a significant barrier in this area, which is the lack of resources and information. The model presented in the paper serves as a theoretical framework for this research. The model is primarily based on Rogers' model. It is essential to recognize the significance of the Technological, Organizational and Environmental (TOE) and Innovation decision process (IDP) framework, as it serves as a foundational model for the subsequent analysis discussed within this paper. The Rogers's model has been delineated to explicate the interplay of components over time.



Graph 1: The Rogers model
Source: E. M. Rogers, Diffusion of Innovations, The Free Press, New York, 1962.

This model is indicative of the convergence of two elements that are synergistically aligned with the objective of facilitating technological dissemination at the level of corporate entities. Two independent models are characterized by lapping feature – technological innovation decision making.

The TOE employs an analytical framework to assess the adoption of information technology within corporate entities, considering a range of contextual factors. As previously indicated, technological integration has become imperative for contemporary business enterprises. In this regard, the technological context of frameworks is examined to determine a firm's capacity to incorporate technological innovation. Defined characteristics, such as relative advantage, technical and information context, have been shown to influence diffusion processes in different ways. It is important to consider all three aspects of the TOE when contemplating the risks that may arise. One such risk is the potential for the dissemination of false information, which has the capacity to divert attention from the dissemination of information itself. The model is employed to facilitate an investigation into the processes involved in the change, with consideration given to both static and dynamic aspects.

The IDP process is predicated upon three fundamental stages: knowledge (awareness), persuasion, and decision. The IDP process constitutes the preliminary stage in the transition and decision-making process. When combined with the TOE, they aligned with the technological innovation decision and changes are implemented into the company.

3 Methodology of research

In response to the Innovation Fund's call within the Energy Efficiency Program for Small and Medium Enterprises, the company LAMEX DOO, based in Podgorica, has been selected as the subject of this research.

The primary data collected serve as the basis for the technical justification study aimed at improving energy efficiency and incorporating renewable energy sources. The research methodology included several key activities: an on-site visit by company's technical consultant, analysis of the current energy situation, definition of baseline energy consumption and reference period, evaluation of proposed energy efficiency measures, and assessment of energy usage by end consumers.

The goal of the technical justification study was to conduct detailed analysis and interpretation of the energy consumption data.

Lamex DOO specializes in the design and manufacture of furniture made from wood-based panel materials, interior doors, ventilated facades, and sanitary cabins. Due to the nature of its operations, the company experiences high energy usage and generates significant waste. Being environmentally conscious, Lamex seeks to implement practices that contribute to environmental preservation. As part of their project proposal, the company planned to undertake several activities aimed at enhancing energy management:

- Replacing the existing mobile dust collectors used during panel processing with a centralized ventilation system featuring radial fans, a prismatic silo, and a parts separator;
- Purchasing a crusher for processing wood and panel material waste;
- Acquiring four digital licences for the specialized design software Corpus;
- Procuring a system for monitoring and managing energy consumption;

- Hiring and training a team member responsible for overseeing energy management, optimizing consumption, and tracking energy savings in the production facility.

One of the key challenges faced by the company is the usage of large-scale machinery that generates excessive dust, compromising the working conditions for operators. The implementation of a centralized ventilation system is expected to significantly improve the work environment and enhance dust and waste management. This study places special emphasis on the acquisition of the energy monitoring and management system, evaluating both the current state of energy usage and the projected improvements following implementation.

4 Results

The findings of the technical study indicate that the company is prepared to implement sustainable energy solutions on a daily basis. The technical consultant was tasked with conducting an analysis of the current state of affairs and identifying potential avenues for enhancement subsequent to the execution of project activities. The primary focus of the paper is on digital solutions, with a discussion on the potential implementation of digital/smart solutions. The focus will be on the acquisition of four digital licences for specialized design to software Corpus and the procurement of a system for monitoring and managing energy consumption.

4.1. Implementing digital/smart solutions

The implementation of digital keys for upgrading the software system of production will benefit with more precise and optimized consumption of raw material. The Corpus digital key is a program solution that facilitates the process of projecting, drawing, and executing the entire production process. The company's current version affords them the opportunity for intuitive modelling of furniture. The impact of this function is twofold: first, it leads to a decrease in errors, and second, it enables more efficient management of the production process.

The implementation of the Corpus 5 Pro system will afford the company range of functional advantages and facilitate a substantial enhancement in the efficiency of its production processes. The software itself will provide a functionality that enables the generation of barcodes for CNC machines utilized in the production processes. Consequently, the software will automatically retrieve information from the database of a specific machine, including the elements and their respective dimensions. The utilization of barcodes facilities the automation of operations, thereby streamlining the workflow and reducing the time allocated for production. This is facilitated by the implementation of software version 5 PRO, which enables the machines to operate with enhanced efficiency and precision. The advantages of this software are manifold. Chief among them are increased productivity and decreased operator workload. The software also facilitates more efficient and precise processes in production.

Table 1: The overview of calculation of delivered energy consumption reduction through software version upgrade

Estimated savings in delivered energy for the operation of production machines (%)	100%
Delivered energy for the operation of production machines before replacement (existing state) (kWh/year)	146.007
Delivered energy for the operation of production machines after replacement (new state) (kWh/year)	144.547
Delivered energy savings (kWh/year)	1.460
Annual CO_2 emissions before replacement (existing state) (tCO_2/year)	71,54
Annual CO_2 emissions after replacement (new state) (tCO_2/year)	70,83
Reduction in CO_2 emissions (tCO_2/year)	0,72

Source: The technical justification study of company LAMEX DOO.

4.2. The improvement of energy management processes and optimization of energy consumption

The second solution is the implementation of a monitoring system and real-time electric energy consumption monitoring. This will provide precise tracking and analysis of consumption. The system is to be entirely dependent on smart sensors, which facilitate meticulous measurement and documentation of energy consumption on an individual device basis. This affords the company a comprehensive understanding of energy utilization and the identification of opportunities for optimization. The implementation of this system will empower the applicant to make decision regarding consumption management, loss reduction, and the optimization of machine and equipment operation. The overarching objective of this system is to achieve greater energy efficiency and cost reduction.

The implementation of this solution will require equipment of:

- Smappee Power Box – central unit for measuring electricity consumption that enables connection with current sensors and transmits data;
- Smappee Connect – communication module that allows data transmission to the Smappee Cloud via Wi-Fi or Ethernet connection.
- Current sensors (CT sensors, Rogowski coils) – devices that enable electrical current measurement with various ranges (50A, 100A, 250A, 500A), depending on the load.

The strategic placement of sensors at pivotal locations within each sector is instrumental for the precise measurement of electricity consumption and peak power. The implementation of the aforementioned solution would facilitate the company's adoption of standard energy efficiency, as defined by the ISO 50001 standard.

Table 2: The overview of calculation of delivered energy consumption reduction through the improvement of energy management and optimization of energy consumption

Estimated savings in delivered energy for the operation of production machines (%)	100%
Delivered energy for the operation of production machines before replacement (existing state) (kWh/year)	252.846
Delivered energy for the operation of production machines after replacement (new state) (kWh/year)	250.292
Delivered energy savings (kWh/year)	2.554
Annual CO_2 emissions before replacement (existing state) (tCO_2/year)	123,89
Annual CO_2 emissions after replacement (new state) (tCO_2/year)	122,64
Reduction in CO_2 emissions (tCO_2/year)	1,25

Source: The technical justification study of company LAMEX DOO.

The project activities, as outlined, necessitate the incorporation of a new employee whose primary responsibility will be to meticulously monitor and track the daily operations of individual elements, namely the machines. This individual will be tasked with synchronizing the machines' activities, formulating utilization plans, conducting analysis of energy consumption, and documenting the outcomes. The overarching objective of this initiative is to achieve the highest attainable level of energy efficiency.

5 Discussion

The company's application to the Innovation Fund's call, signifies its commitment to integrating more sustainable practices into its daily operations. In consideration of the empirical results and the established framework (TOE and IDP), a range of analysis can be conducted.

As previously mentioned, the company has encountered issues with its work environment and significant electrical energy consumption. Consequently, there is a necessity for implementing changes in these areas. The utilization of substantial machinery in manufacturing facilities is a crucial component of business operations. However, these machines also present significant hazard to the well-being of the company's workforce. Achieving successful project implementation is conductive to enhancing job satisfaction, yet most significantly, it contributes to fostering a more favourable occupational environment. It is evident that the implementation of the dust collector and crusher for processing wood, in addition to the acquisition of digital licences and a system for monitoring and managing energy consumption, will engender a novel business context within the company. In relation to the findings of the research, it is evident that the implementation of the aforementioned activities would result in a decrease in delivered energy and a reduction in CO_2 emissions.

This further refines the innovation making process and the IDP part of a theoretical framework. It is evident that the requisite knowledge was present in the applicant at the time project application, thus enabling the correct choice to be made and the project activities to be defined in a suitable manner. As illustrated, this demonstrates a clear commitment to employing an individual who will assume responsibility for the management and monitoring of energy consumption. A preliminary evaluation of results suggests that the implementation of digital/smart solutions is advantageous in the short term. It is evident that the company has demonstrated a commitment to the continuous enhancement of its sustainability and efficiency, which is a commendable initiative in the transition towards a green business model.

It is imperative that the government and institutions adopt a shift towards a green and digital economy in the coming years, embracing the evident and present changes that are already in evidence. It is only through the continuation of the project that the results of the project can be sustained.

6 Conclusion

The application has been demonstrated to encompass the majority of the most significant domains with regard to energy efficiency, thus providing opportunities that have the potential to influence a reduction in energy utilization.

Montenegrin society is currently facing a number of challenges. Project of this nature are instrumental in prompting companies to develop and adapt novel sustainable solutions that are relevant to their business activities and market presence. It is asserted that the financial assistance provided by the governance body is desirable. This will assist the individuals seeking to instigate change by providing them the opportunity to do so.

The process of technology diffusion is often protracted and frequently necessitates considerable alterations to established systems. It is important to note, however, that this will have a beneficial impact on the business, rendering it a valuable investment. Transition is characterised by uncertainty and unpredictably, yet it is a process that invariably yields substantial and significant outcomes. It is evident that SMEs possess a high degree of agility and have the capacity to act as catalysts for change. Consequently, it is imperative that they adopt a proactive approach and demonstrate a willingness to embrace the challenges that confront them.

Digitalization, understood as a new paradigm of conducting business, necessitates the dissemination of technological processes. The provision of an enhanced and more sustainable environment for all members of society is thereby facilitated. In consideration of the aforementioned, it is evident that digital solutions facilitate the effective utilisation of energy resources, thereby enabling society to prioritise the exploration and adoption of renewable energy sources. It is precisely such mechanisms that facilitate the creation and innovation of new ideas.

7 Ethics declaration

This work includes the use of research data obtained from a project application submitted by Lamex DOO. The data were used with proper acknowledgment and in accordance with ethical standards of research integrity. No confidential or proprietary information has been disclosed, and all data have been handled responsibly and transparently. The authors confirm that the use of these materials does not violate any agreements or intellectual property rights.

8 AI declaration

Parts of this document were created with the assistance of artificial intelligence tools. These tools were used for language editing, grammar correction and idea refinement. All content has been reviewed and approved by the authors, who take full responsibility for the final version.

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What Regenerative Approaches Drive Resilience? A Knowledge Frame for Social-Ecological Systems

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Abstract

As environmental and social challenges intensify, regenerative practices in supply chain management (SCM) are emerging as a transformative approach, shifting focus from sustainability to the active restoration of socio-ecological systems. The present study analyses how regenerative principles, including poly-rhythmicity, proportionality, and reciprocity, enhance supply chain resilience through systemic renewal. A comprehensive review of 33 high-impact articles (2010–2024) has identified six key regenerative practices: supply chain plasticity, ecological restoration, circular measures, sustainable resource management (SRM), reshoring, and restorative topophilia. These practices address ecological degradation, economic volatility, and social inequities, all while promoting adaptability. Whilst circularity and SRM predominate in industry applications, there is considerable potential in niche practices such as restorative topophilia, which combines place attachment with ecological restoration. The combination of reshoring and circular principles has the potential to reduce emissions by 30% and stimulate local economies. However, it is important to note that 40% of reshoring initiatives are unsuccessful, resulting in the relocation of production activities that are associated with increased environmental impact. Supply chain plasticity has been demonstrated to exhibit operational resilience; however, it frequently neglects ecological reciprocity, thereby highlighting an evident implementation gap. It is imperative to emphasise the pivotal role that stakeholder engagement, notably from communities and non-governmental organisations (NGOs), plays in transcending the divide between sectors. The present study proposes a framework for "regenerative intelligence" that integrates ecological, social, and supply chain objectives. The study validates institutional redundancy (policy-market synergy) and emphasises poly-rhythmicity as an unexplored lever for resilience. The study provides practical insights for transitioning from protective to proactive regeneration, and it notes two limitations: potential interpretive biases and a focus on academic literature. The study suggests that future research should explore metrics, cultural contexts, and decision-support tools. This work reframes supply chains as catalysts for systemic renewal, advocating for strategies that restore rather than merely sustain.

Graphic abstract



Figure 1: Word Map of Most Frequent Keywords

Keywords: Regeneration, Resilience, Social-Ecological System, Supply Chain Management.

Paper type: Academic Research Paper

1 Introduction

As environmental challenges escalate and the urgent need for sustainable development becomes increasingly evident, the concept of regeneration has surfaced as a compelling and transformative approach that has captured significant attention in both academic literature and practical applications (Buckton et al., 2023). Regeneration, distinct from conventional sustainability-related models, represents a paradigm shift that not only aims to mitigate environmental harm but actively seeks to restore and enhance the well-being of ecosystems

and social structures. This shift towards regeneration is particularly pertinent in supply chain management (SCM), where traditional models have often focused primarily on minimizing damage, rather than fostering positive ecological and social outcomes (Gualandris et al., 2024). Unlike traditional sustainability frameworks that emphasize reducing negative impacts, regenerative practices offer a holistic, forward-thinking approach aimed at healing and improving the systems they interact with. These practices do not merely seek to maintain equilibrium but focus on revitalizing and nurturing the interconnected elements of the environment and society, aiming for a net positive impact. This means transforming supply chains from linear, resource-depleting models to regenerative, circular systems that continuously replenish the social-ecological ecosystems they depend on (Gualandris et al., 2024). Through the implementation of these practices, supply chains can evolve into systems that are not only stable and adaptable but also capable of driving positive change and transformation even in the face of disruption (Wieland and Durach, 2021). This evolving perspective introduces a new lens for examining supply chain resilience. Historically, resilience has been understood primarily in terms of the ability to withstand and recover from disturbances. However, under a regenerative framework, resilience extends beyond simple recovery; it emphasizes the active enhancement of both ecological and social well-being through adaptive learning, resource regeneration, and long-term systems thinking. This interpretation opens up new avenues for advancing resilience in supply chains, with a focus on fostering greater adaptability without compromising ecological and social health (Ali, 2024). The current shift toward regenerative supply chains calls for a deeper understanding of the principles that underpin these practices and their potential to shape the resilience of social-ecological systems. A critical area of exploration is the interplay between regenerative principles—such as poly-rhythmicity, proportionality, and reciprocity—and the resilience of supply chains, particularly in the context of unsustainable global challenges, including climate change, resource depletion, and growing social inequalities. These principles are foundational to regenerative practices, as they offer a framework for rethinking how supply chains can operate within broader socio-environmental systems. Poly-rhythmicity, for example, refers to the synchronization of different rhythms in social-ecological systems to enhance adaptability; proportionality speaks to the need for actions that are aligned with the scale of the challenges faced; and reciprocity emphasizes mutual benefit and the interconnectedness of systems, fostering long-term collaborative relationships (Gualandris et al., 2024). This study positions itself within the growing body of research aimed at understanding the implications of regenerative practices on supply chain resilience. It seeks to uncover the ways in which regenerative principles can support the transition from unsustainable practices to more resilient, restorative systems. Specifically, it explores how these principles can enhance resilience in supply chains and the broader social-ecological systems, enabling them to navigate uncertainty and external disruptions, such as climate crises and resource scarcity. In doing so, this research aims to advance both theoretical and practical insights in the SCM domain, offering new perspectives on how organizations can build resilience through regenerative practices. By investigating the intersection of regenerative principles and supply chain resilience, this study contributes to the theoretical development of sustainability in SCM. It also provides actionable insights for practitioners seeking to transition toward more regenerative, resilient, and sustainable supply chains, ultimately supporting the achievement of broader sustainability goals at both the organizational and global levels. As such, it represents a crucial step in advancing the discourse on sustainable supply chains, highlighting the need for transformative practices that restore, rather than simply preserve, the systems upon which they depend.

2 Methodology

A comprehensive literature review, through which articles are systematically selected based on predefined inclusion and exclusion criteria through a qualitative research approach, is deployed to understand how regenerative practices can be effectively deployed to improve social-ecological resilience, offering both theoretical insights and practical guidance in setting strategies within the context of SCM by considering the interconnectedness, scale, and mutual benefits inherent in social-ecological systems. The methodology is grounded in a critical review of existing literature, following the path proposed by Xiao and Watson, (2019), and adopts a deductive approach to systematically collect and analyze relevant articles. As this domain is still at his infant phase, a deductive approach allows the study to test predefined concepts of social-ecological systems—such as the principles of regeneration and resilience—against the data gathered from the selected articles. In doing so, the research draws upon regenerative principles proposed by Gualandris et al. (2024), in conjunction with the resilience principles and manifestations proposed by Wieland et al. (2023), allowing for the development of a robust knowledge framework that present the multitude implications of adopting regenerative practices. This ensures that the review remains focused on the theoretical constructs as it evaluates how regenerative practices contribute to strengthening resilience within supply chains and in the overall system. By structuring the analysis based on established theoretical frameworks, the study provides a clear and

systematic pathway for synthesizing the literature and drawing meaningful conclusions. To ensure the trasparency and reliability of the review process, each step of the methodology was rigorously documented, including the inclusion and exclusion criteria, the selection of databases, and the search terms used. The decision to utilise Scopus for this literature search was made on the basis of its comprehensive coverage of high-quality, peer-reviewed journals in the domains of management, sustainability, and operations. The academic community has acknowledged this as a pivotal resource for systematic literature reviews, thus ensuring the incorporation of pertinent, peer-reviewed, and academically rigorous articles (Sauer & Seuring, 2023). Keywords related to regenerative practices, including terms such as "regeneration," "restore," "revitalize," and "renew.", associated with those related to supply chains (see Sauer and Seuring, 2017), were included in the search. To reflect the evolving conceptualization of supply chains as socio-ecological systems, the term "social-ecological system" was incorporated into the synonymous of supply chain keywords. Finally, “resilience” was included as a core single keyword to filter results in line with the research objectives, in line with Sauer & Seuring (2023). Starting from a pool of 718 documents found, the selection targeted peer-reviewed journal articles (472) and reviews (60) written in English (689), published in journals listed in the latest 2024 ABS list (157), ensuring that the analysis is directed towards high-quality, management-focused research. Focusing exclusively on papers published in journals with ABS rankings of 3, 4, or 4*, a total of 33 papers were selected for the analysis to capture the latest developments in research driving the domain forward. For data analysis, RStudio and Biblioshiny were firstly employed for bibliometric analysis, allowing for the extraction and visualization of key trends and patterns in the literature. These tools facilitate a structured analysis of the data, ensuring a systematic approach to the content analysis and synthesis. The content analysis was thus performed using a qualitative approach, where researchers took notes and provided comments on each full-paper. These notes were cataloged into Excel files for further analysis. This process ensures that the data is systematically organized and analyzed, with clear coding of key themes in light of the aforementioned constructs. Access to supplementary materials, detailing the data anaylisi, is available upon request to the authors.

3 Research Findings

3.1. Bibliometric Analysis

This bibliometric analysis examines 33 academic articles and reviews published between 2010 and 2024. While only one article was published in 2010, output remained sporadic until 2023, when a significant surge occurred with 10 articles, followed by 8 in 2024. This recent acceleration suggests a growing recognition of the importance of resilience and disruption in global supply chains. The average document age is 4.58 years, with an impressive mean citation count of 57.52 per document, underscoring the field's impact. Early works, such as those from 2010 and 2014, garnered substantial citations (85 and 130.5 per article, respectively), indicating their foundational role. In contrast, more recent publications (2023–2024) exhibit lower citation counts due to their shorter time in circulation, yet their rapid production signals an active research frontier. To conclude, the 2872 references cited across these works highlight a robust engagement with existing literature. The dataset, drawn from 19 diverse sources, reveals an annual growth rate of 16.01%, reflecting increasing academic interest in these emerging topics. The International Journal of Production Economics and the International Journal of Production Research emerge as leading sources, each contributing 4 articles. Close behind are Annals of Operations Research, Environmental Science and Policy, and Journal of Business Logistics, with 3 articles each. These journals serve as primary platforms for disseminating research on SCM. Over time, their contributions have grown steadily, with notable increases post-2020, reflecting heightened interest following global disruptions such as the COVID-19 pandemic. The bibliometric analysis reveals significant geographical and institutional patterns in the study of supply chain resilience and disruption. The United States leads in scientific production, contributing 26 articles, followed by China (21) and the United Kingdom (10). These three nations dominate the field, collectively accounting for over 70% of the publications. The USA’s research output has grown steadily since 2010, with a notable acceleration post-2020. Similarly, China's contributions, initially limited, surged after 2022, reflecting a growing focus on supply chain resilience amid global disruptions, while the UK's output, though smaller, remained consistent low with a notable increase in 2023–2024. Institutional analysis highlights the University of Tehran as the most prolific, with 6 articles, closely followed by the University of Birmingham (5) and Peking University (4). These institutions, along with Stellenbosch University and The Hong Kong Polytechnic University (3 articles each), serve as key hubs alike contributing to the growing literature on regenerative supply chains. A close examination of terms that occur with high frequency within the context of regenerative practices in supply chains reveals a marked emphasis on concepts resilience and SCM, as provided by keyword setting. The temporal analysis confirmed a marked increase in research activities

concerning resilience and SCM post-2020, largely in response to global disruptions such as the COVD-19 pandemic. Notably, regenerative-related keywords emerges as a key secondary theme, reflecting growing recognition of interest on sustainabity. The emergence of terms related to "climate change," "uncertainty analysis," and "disasters" reflects an increasing recognition of the environmental and social challenges that significantly influence social-ecological resilience. Moreover, concepts associated with restoration, risk assessment, and rural areas highlights the pressing need for regenerative practices that can effectively address disruptions within the social-ecological systems. This evolution suggests the field is expanding from its technical-operational roots to address broader societal and environmental challenges. However, the relatively low density of the climate change cluster indicates this expansion remains in early stages, with opportunities for more systematic integration of environmental and social dimensions into core resilience frameworks.

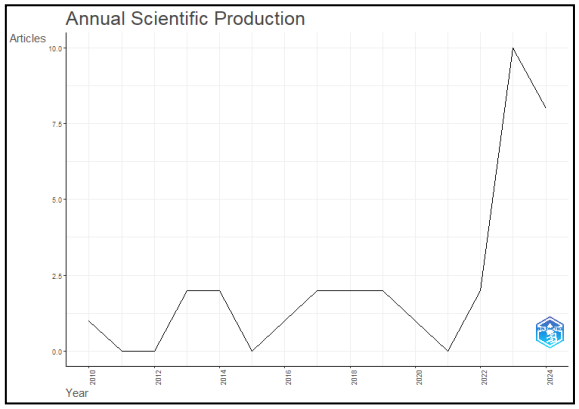


Figure 2a – Annual Scientific Production

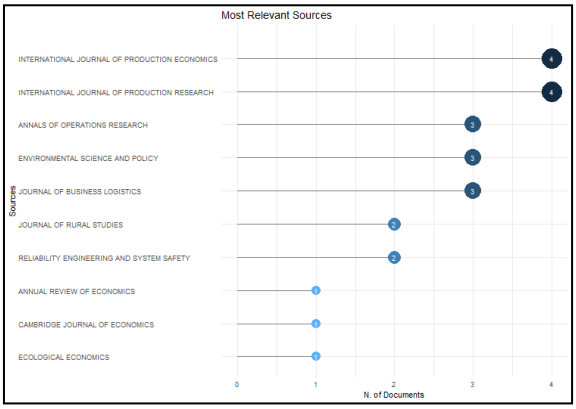


Figure 2b – Most Relevant Sources

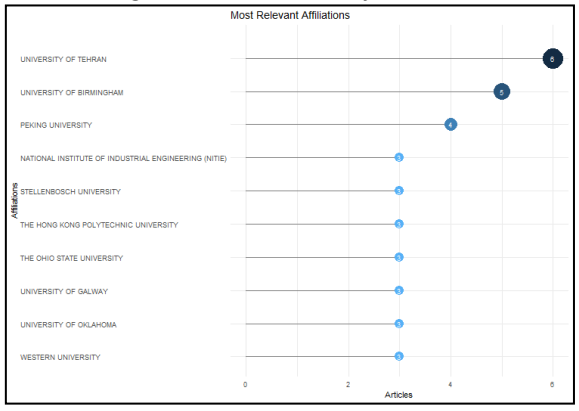


Figure 2c– Most Relevant Affiliations

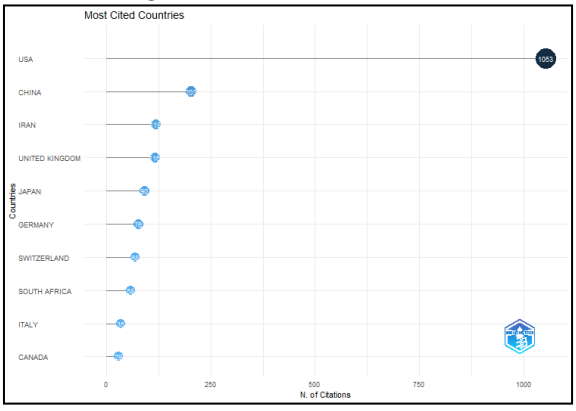


Figure 2d – Country Scientific Producion

3.2. Content Analysis

The global pandemic has been identified as a pivotal case study in numerous academic papers (see, for instance, Gaudenzi et al., 2023), functioning as an impetus for new research initiatives while providing a validation of existing resilience frameworks. This event has been identified as a contributing factor to the acceleration of the integration of socio-environmental factors into a discipline that was previously characterised by operational focus. In this context, a pronounced industry-specific orientation becomes evident, with applications in the energy, manufacturing, and healthcare sectors illustrating the heterogeneity of resilience strategies across operational contexts. Secondly, quantitative studies, particularly those employing network analysis and optimisation modelling, dominate operational research, while qualitative methods prevail in studies of social-ecological systems and policy impacts. It is evident from the content analysis that there are six key regenerative practices which collectively enhance the resilience of social-ecological systems. These are: *supply chain plasticity, restoration, circular measures, sustainable resource management (SRM), reshoring, and restorative topophilia.* The synergy of these practices is such that they are able to tackle issues such as environmental degradation, economic volatility, and social inequities, while also fostering systemic adaptability. The effectiveness of these practices is evaluated through the lenses of Wieland's resilience principles and Gualandris' regenerative criteria (see Figure 3), with stakeholder engagement emerging as the critical enabling factor across all these practices. The most comprehensive practice pattern that has emerged is that of **ecological**

restoration, which has been demonstrated to enhance biodiversity, addressing diversity and redundancy, while simultaneously fostering community well-being. Projects such as Bui et al.'s (2020) mangrove rehabilitation initiative have been shown to generate a multitude of benefits, including the recovery of biodiversity (+37% in studied sites), coastal protection, and the creation of livelihoods. However, technological solutions such as those proposed by Chen et al. (2023) for the purpose of drone-assisted reforestation have been shown to fall short of the principles of proportionality. This is due to the high cost of the technology, which renders it ill-suited to the more modest budgetary constraints typically associated with grassroots initiatives, as documented by Shackleton et al. (2018) in South African townships. The analysis demonstrates that restoration projects consistently exhibit the strongest reciprocity scores, as evidenced by urban greening initiatives that concomitantly enhance environmental benefits and mental health (Tidball & Stedman, 2013). However, the partial absence of slow variable management in 40% of cases indicates a requirement for longer-term monitoring frameworks to track cumulative impacts within the entire social-ecological system. The **circular measures-SRM dyad** pairing is indicative of the operational core of regenerative systems. However, it also exhibits an interesting divergence. While both emphasise resource efficiency, circular practices demonstrate stronger private-sector adoption, whereas SRM more frequently involves policy actors (85% of cases). This complementarity engenders resilience through what can be termed "institutional redundancy", whereby market-driven circularity and regulatory SRM mechanisms are employed in tandem. Conversely, Mahmood et al. (2024) demonstrated that AI-driven circular systems attained 92% material efficiency in controlled settings. However, Rajabzadeh and Wiens (2024) found that only 18% of EU cities effectively scaled these systems through policy (e.g., Jiang et al.'s, 2023). The observed discrepancy between policy and practice is analogous to the findings in Gualandris' ratings, where circular measures exhibited robust reciprocity yet exhibited inconsistent poly-rhythmicity. The concept of **reshoring**, otherwise referred to as the relocation of production facilities to the home country, has evolved from a cost-saving strategy to a multifaceted regenerative practice. A thorough investigation by Xu et al. (2023) of the textile industry emphasises reshoring's triple dividend: a 30% decrease in transport emissions due to the reduction of supply chains, the revitalisation of local craft economies, and the strengthening of community-business relationships. The relocation of textile factories resulted in the generation of skilled employment at a rate that was 2.3 times higher than that of offshore facilities, whilst concurrently supporting traditional craftsmanship. Such spatial reorganization has been shown to encourage more SRM through several mechanisms: reduced transportation needs, leading to a decrease in fossil fuel consumption; proximity, enabling more effective monitoring of environmental standards; and shorter loops, facilitating the integration of circular economy principles (Xu et al., 2023). However, research undertaken by Bailey et al. (2018) indicates that 40% of US reshoring initiatives merely relocated resource exploitation, rather than transforming production paradigms. The environmental advantages of reshoring extend beyond emissions reduction, as it also generates environmental benefits in line with operational changes while simultaneously generating reciprocal socioeconomic value. From an economic perspective, the process of reshoring has been shown to have a catalyst effect on regional regeneration (Smith, 2023). In addition, local production has been demonstrated to enhance transparency across value chains, strengthen place-based knowledge exchange, foster equitable stakeholder relationships, and build community resilience through the diversification of local economies. **Supply chain plasticity** demonstrates particularly strong alignment with resilience principles by enabling rapid adaptation to disruptions through supplier diversification and localized production. Particularly, Guntuka et al. (2024) demonstrate how adaptive reconfiguration helped businesses navigate disrutpions mostly related pandemic shocks. This practice enables to manage connectivity and to adaptive systems thinking, as the frequent involvement of firms and supply chain actors (70% of studies) underscores their pivotal role in operationalizing this plasticity, though greater inclusion of workers and local communities could strengthen its social-ecological resilience through reciprocity. However, its weaker performance on poly-rhythmicity suggests opportunities to better synchronize production cycles with ecological rhythms. In this light, Ivanov and Sokolov (2019) caution that without meaningful community engagement, such plasticity risks becoming merely a technical fix rather than a transformative approach. Yet as Ivanov and Sokolov (2019) caution in their logistics research, such plasticity often prioritizes economic continuity over ecological reciprocity—only 40% of cases studied (e.g., Hughes et al., 2023) integrated circular principles like closed-loop material flows. The concept of **restorative topophilia**—the fusion of place attachment with ecological restoration—has emerged as a critical yet often overlooked dimension of regenerative practice. Conversely, restorative topophilia eschews conventional environmental interventions that prioritise technical solutions, instead leveraging the profound emotional bonds between people and their environments to drive sustained ecological and social transformation. This phenomenon is vividly illustrated in Tidball and Stedman's (2013) longitudinal study of post-Katrina New Orleans, where community-led tree-planting initiatives rooted in place attachment demonstrated three times higher survival rates and significantly greater long-term engagement compared to technocratic

reforestation programs. The success of these efforts underscores a fundamental insight: when environmental restoration is intertwined with cultural meaning and personal identity, it ceases to be merely an ecological intervention and becomes instead a collective act of place-making and healing. The implications of restorative topophilia extend far beyond the sphere of urban greening. The distinguishing characteristic of restorative topophilia is its ability to fulfil all three of Gualandris' regenerative principles. These principles are as follows: proportionality, which is achieved by scaling interventions to local cultural and ecological contexts; reciprocity, which is achieved through mutually reinforcing benefits for ecosystems and communities; and poly-rhythmicity, which is achieved by aligning restoration activities with the natural and social cycles of place. In particular, the work of Hill, Clarvis et al. (2014) is noteworthy in demonstrating how community gardens, which are often established in neglected urban spaces, can serve as effective agents for simultaneously enhancing local biodiversity and fostering mental well-being. This observation highlights the potential for such initiatives to establish feedback loops between ecological health and social cohesion, underscoring the multifaceted benefits of urban gardening. In this regard, restorative topophilia has emerged as a concept that fosters a comprehensive understanding of resilience, wherein the emotional and psychological benefits derived from engagement with nature are recognised as indispensable components of recovery and regeneration of the system. This approach not only enhances the well-being of the inhabitants but also fosters a sense of interconnectedness with their environment. It is imperative that stakeholders at various levels collaborate in adopting regenerative practices that enhance socio-ecological resilience. The shift from traditional risk management to proactive and regenerative strategies indicating a maturing perspective in the field that blends technological innovation, collaborative models, and socio-environmental responsibility. At the micro level, the roles played by firms, employees and top managers are pivotal to the advancement of sustainability. Firms function as agents of change, leveraging their resources and influence to implement sustainable business models and corporate social responsibility (CSR) initiatives. This engagement has been demonstrated to engender value creation that extends beyond the pursuit of profit, thereby contributing to the regeneration of both natural and social systems. Moreover, the involvement of workers and their alignment with sustainability goals are of critical importance for achieving systemic resilience, by strengthening innovation and collaboration. The integration of effective leadership with stakeholder engagement is instrumental in ensuring that regenerative practices are both inclusive and impactful. At the macro level, the promotion of sustainability and regeneration relies on the vital contributions of broader societal stakeholders, including academia, environmental organisations, the media, governments, and local communities. Academia provides essential knowledge and evidence for effective policy formulation, while environmental organisations advocate for ecosystem protection and restoration.

Reference	Gualandris principles for regenerative practices		
	Proportionality	Reciprocity	Poly-rhythmicity
(Mahmood et al., 2024)	⚠	✅	⚠
(Guntuka et al., 2024)	⚠	⚠	❌
(Durugbo and Al-Balushi, 2024)	⚠	✓	⚠
(Bown, 2024)	⚠	✓	❌
(Gualandris et al., 2024)	✓	✓	✓
(Rajabzadeh and Wiens, 2024)	✓	✓	⚠
(Abushaega et al., 2024)	✅	⚠	❌
(Huang et al., 2024)	✅	✓	✅
(Mishra et al., 2023)	✓	✓	✓
(Chen et al., 2023)	⚠	✓	✓
(Xu et al., 2023)	✅	✓	✓
(Bailey et al., 2023)	⚠	✓	⚠
(Tafakkori et al., 2023)	⚠	✓	⚠
(Caputo et al., 2023)	✓	✓	✓
(Hughes et al., 2023)	⚠	✓	⚠
(Jiang et al., 2023)	⚠	✓	✓
Legend	✅ Clearly present	✓ Present	⚠ Partially present ❌ Not-present

Reference	Gualandris principles for regenerative practices		
	Proportionality	Reciprocity	Poly-rhythmicity
(Gaudenzi et al., 2023)	✓	✓	✓
(Cheng et al., 2023)	✓	✓	⚠
(Zhang et al., 2022)	✓	✓	✓
(Flood et al., 2022)	✓	✓	✓
(Bui et al., 2020)	✓	✓	✓
(Ivanov and Sokolov, 2019)	⚠	⚠	✓
(Hosseini et al., 2019)	✓	✓	⚠
(Shackleton et al., 2018)	✓	✅	⚠
(Bailey et al., 2018)	✓	✓	❌
(Khalili et al., 2017)	✓	⚠	❌
(Gabler et al., 2017)	⚠	✅	⚠
(Hosseini and Barker, 2016)	⚠	✓	⚠
(Hill Clarvis et al., 2014)	✓	✓	✅
(Day, 2014)	✅	✓	⚠
(Tidball and Stedman, 2013)	✓	✅	⚠
(Richter et al., 2013)	✅	✅	⚠
(Dowty and Wallace, 2010)	✅	⚠	⚠
Legend	✅ Clearly present	✓ Present	⚠ Partially present ❌ Not-present

Figure 3a - Qualitative Assessment of study discussing regenerative practices, according to Gualandris principles

Reference	Wieland principles for resilience						
	1. Maintain Diversity and Redundancy	2. Manage Connectivity	3. Manage Slow Variables and Feedbacks	4. Foster Complex Adaptive Systems Thinking	5. Encourage Learning	6. Broaden Participation	7. Promote Polycentric Governance
(Mahmood et al., 2024)	⚠	✅	❌	✓	✓	✅	❌
(Guntuka et al., 2024)	✓	✓	❌	✓	✓	❌	❌
(Durugbo and Al-Balushi, 2024)	⚠	✓	❌	✓	✓	❌	❌
(Bown, 2024)	⚠	✓	❌	✓	✓	❌	❌
(Gualandris et al., 2024)	✓	✓	✓	✓	✓	✓	❌
(Rajabzadeh and Wiens, 2024)	✓	✓	⚠	⚠	❌	❌	❌
(Abushaega et al., 2024)	✓	✓	❌	✓	❌	❌	❌
(Huang et al., 2024)	✅	✅	✅	✅	✅	❌	❌
(Mishra et al., 2023)	✅	✅	⚠	✓	✅	✓	✓
(Chen et al., 2023)	⚠	✓	✓	✓	✅	✓	❌
(Xu et al., 2023)	✅	✅	✓	✓	✓	✓	✓
(Bailey et al., 2023)	✓	⚠	❌	⚠	❌	❌	⚠
(Tafakkori et al., 2023)	✓	⚠	❌	⚠	❌	❌	⚠
(Caputo et al., 2023)	✅	✓	❌	✅	❌	❌	❌
(Hughes et al., 2023)	⚠	✓	❌	✓	✅	⚠	❌
(Jiang et al., 2023)	❌	✅	❌	✅	✅	⚠	❌
(Gaudenzi et al., 2023)	✓	✓	⚠	✓	✓	✓	✓
(Cheng et al., 2023)	✓	✓	✓	✓	✓	✓	❌
(Zhang et al., 2022)	✓	✓	✓	✓	✓	✓	✓
(Flood et al., 2022)	✓	✓	✓	✓	✓	✓	✓
(Bui et al., 2020)	✓	✓	✓	✓	✓	✓	❌
(Ivanov and Sokolov, 2019)	✓	⚠	❌	✓	⚠	❌	❌
(Hosseini et al., 2019)	✓	⚠	❌	✓	⚠	❌	❌
(Shackleton et al., 2018)	✅	✅	✅	✅	✅	✅	✅
(Bailey et al., 2018)	✓	✓	❌	✓	✓	❌	❌
(Khalili et al., 2017)	✅	✓	❌	✓	❌	❌	❌
(Gabler et al., 2017)	✓	✅	❌	⚠	❌	⚠	⚠
(Hosseini and Barker, 2016)	✓	✓	❌	✓	⚠	❌	❌
(Hill Clarvis et al., 2014)	✓	✓	✓	✅	✓	✓	✓
(Day, 2014)	✓	✅	❌	✅	✓	✓	✓
(Tidball and Stedman, 2013)	✓	✓	❌	✓	✓	✓	❌
(Richter et al., 2013)	❌	✅	✅	✅	⚠	❌	⚠
(Dowty and Wallace, 2010)	✓	⚠	✓	✅	✅	⚠	✅
Legend	✅ Clearly present		✓ Present	⚠ Partially present		❌ Not-present	

Figure 3b - Qualitative Assessment of study discussing the manifestation resilience, according to Wieland principles, have emerged from the adoption of regenerative practices.

4 Discussions

The findings present a compelling paradox within the realm of regenerative systems research: despite being in its early stages, characterised by the identification of merely six core practices, the field encompasses an exceptionally diverse ecosystem of stakeholders. This dichotomy suggests that the regenerative approaches are not limited by the availability of actors; rather, they are limited by the imperative for more sophisticated integration across social, ecological, and supply chain dimensions. The pre-eminence of conventional stakeholders – comprising firms, policymakers and supply chain participants – demonstrates the deeply entrenched status of regeneration within current systems. However, the critical involvement of unconventional actors, such as environmental non-governmental organisations (NGOs) and community organisations – as evidenced by Hosseini et al. (2019) in their studies on wetland restoration – highlights the significance of boundary-spanning partnerships that transcend traditional sectoral divisions. These findings are in alignment with the work of Pagell and Wilhelm (2025), who emphasise the fundamental inclusivity of all actors interacting within systems as a prerequisite for transitioning towards sustainable SCM. The principle-based assessment of regenerative practices yields nuanced insights regarding their maturity and implementation. For instance, circular measures and sustainable resource management (SRM) demonstrate robust performance across both regenerative and resilience dimensions, likely attributable to their longer research history and the clarity of their metrics, as evidenced by the quantifiable material efficiency gains reported by Mahmood et al. (2024). Conversely, the resilience-oriented profile of supply chain plasticity reveals a critical tension: while it is essential for operational adaptability, its weaker alignment with regenerative principles suggests that current implementations often prioritise economic continuity over systemic restoration. This observation is in alignment with the critique proposed by Ivanov and Sokolov (2019) concerning solutions that are exclusively technical and devoid of transformative intent. This underscores the pressing necessity for plasticity models that explicitly incorporate the reciprocity principle. It is noteworthy that only the aspect of supply chain plasticity directly addresses logistical systems, thus revealing an "implementation gap" within regeneration theory. Whilst supply chains are increasingly conceptualised as social-ecological systems, there is a tendency for practical applications to disproportionately prioritise environmental outcomes, frequently at the expense of systemic integration. Significantly, the exceptional regenerative capacity of less prevalent practices, including reshoring and restorative topophilia, underscores valuable pathways for systemic transformation. Xu et al. (2023) elucidate reshoring's triple-value proposition, which simultaneously addresses environmental, economic, and social dimensions. However, the realization of such potential necessitates the implementation of reshoring initiatives that are designed to integrate the principles of the circular economy, as opposed to the mere relocation of environmental impacts. In a similar vein, restorative topophilia accentuates the socio-cultural dimensions, as evidenced by Tidball and Stedman's (2013) community-led urban regeneration studies. These studies demonstrate the potential of place-based connections to function as foundational enablers of more extensive systemic transformations. This finding opens critical avenues for theoretical exploration, particularly concerning social readiness—the cultivation of shared values and stewardship mindsets—as a pivotal precursor to effective

ecological and supply chain interventions. Notwithstanding its underrepresentation in extant literature, this practice exemplifies the latent potential inherent in the cultural and psychological dimensions of regeneration.

The novel conceptualisation of social-ecological resilience within regenerative frameworks represents a substantial theoretical advancement, advocating for the simultaneous optimisation of ecological restoration, social equity, and supply chain resilience. This integrated approach is at odds with conventional resilience models, which are predicated on a reactive response to perturbations. Instead, this approach promotes proactive rejuvenation as a strategy to address perturbations. Moreover, a pivotal theoretical implication of the study is the imperative for regenerative practices to engage more profoundly with broader socio-cultural contexts. This engagement fosters a cohesive integration of human and ecological dimensions. Despite the study presents significant theoretical advancements, it underscores the emergent importance of poly-rhythmicity—the synchronization of ecological, social, and economic rhythms. This concept represents a frontier in regenerative research, highlighting the urgent need for dynamic frameworks that can align diverse stakeholders across varying temporal and spatial scales. The objective of such frameworks is to address the implementation gaps that have been identified in contemporary practices. From a managerial perspective, the study provides actionable insights by emphasising core regenerative practices – particularly reshoring and restorative topophilia – that hold significant potential for fostering systemic renewal but remain underutilised. Supply chain managers can strategically employ reshoring to not only mitigate transportation emissions but also to revitalize local economies, strengthen community ties, and facilitate the renewal of socio-ecological systems. It is imperative for managers to recognise the identified implementation gap, acknowledging that achieving meaningful regenerative outcomes necessitates transcending operational efficiency to embed environmental reciprocity and stakeholder collaboration within supply chain strategies. It is important to note that stakeholder engagement, particularly with unconventional actors such as NGOs and community groups, becomes pivotal in bridging ecological and social dimensions. This, in turn, enables organisations to integrate regeneration more effectively into their strategic and operational frameworks. The study emphasises the significance of policy-market synergy for policymakers, advocating institutional redundancy as a strategic mechanism to support regenerative SCM. The facilitation of regenerative transitions at both micro and macro levels is contingent upon the coordination of policy interventions. Specifically, policies that incentivise reshoring initiatives in accordance with circular economy principles have the potential to yield substantial environmental, economic, and social benefits. Nevertheless, policymakers must remain cognizant of the limitations of reshoring, as geographic relocation may inadvertently shift rather than alleviate environmental impacts. Addressing gaps in poly-rhythmicity will require the development of governance structures capable of dynamically adapting to evolving ecological, economic, and societal rhythms, thus enabling sustained regenerative transitions.

Whilst this study has advanced theoretical and practical understandings of regenerative SCM, it has also identified significant methodological limitations. The decision to confine the literature review to ABS-ranked journals (ranked 3, 4, or 4*) ensures a level of academic rigour and a management-oriented research focus. However, this approach may inadvertently result in the exclusion of innovative practices emerging from practitioner-led or grey literature, which could provide valuable and diverse insights. It is recommended that future research extend its scope to encompass industry reports, practitioner-driven studies, and non-academic publications. This approach will facilitate a more comprehensive capture of developments in regenerative SCM. The study posits that the subsequent phase in regenerative research should not be the identification of additional discrete practices, but rather the construction of connective frameworks that integrate isolated innovations into coherent systemic transitions. In this context, the ability to optimise ecological restoration, social equity, and supply chain resilience across multiple scales represents a critical challenge and an opportunity. The proposed framework (see Figure 4) illustrates how multi-level stakeholder collaboration can facilitate systemic coherence and adaptability, emphasising collective action and reciprocity as foundational principles of socio-ecological regeneration. This integrated perspective has the potential to transform the conventional understanding of supply chains, reconceptualising them as catalysts for comprehensive socio-ecological renewal.

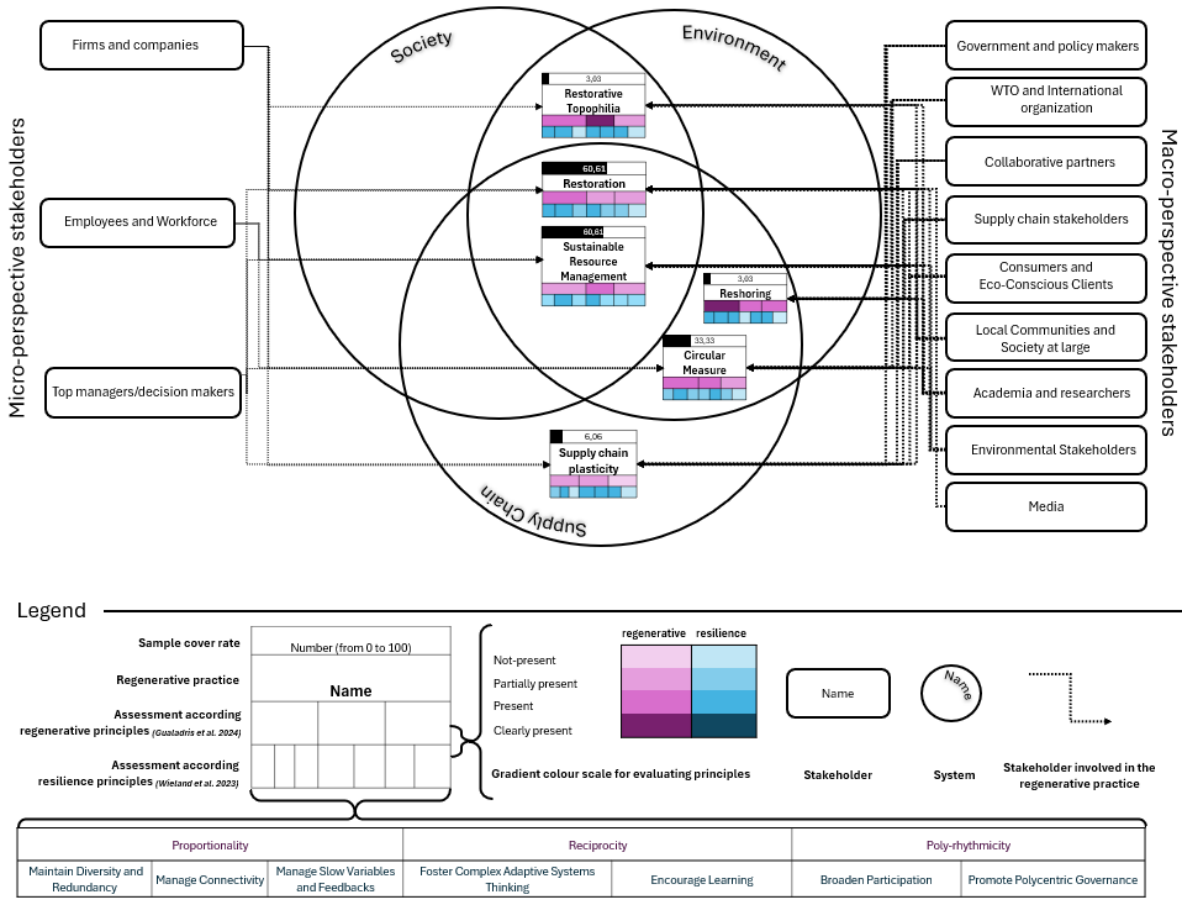


Figure 4 - A comprehensive framework for bridging regenerative practices and social-ecological resilience.

5 Conclusions

This study offers significant contributions to the emergent field of regenerative SCM by methodically analyzing the intricate interconnections among six core practices and socio-ecological resilience. Our findings contest traditional paradigms by illustrating that genuine regeneration does not arise from isolated interventions; instead, it emerges from the intentional integration of complementary practices across social, ecological, and supply chain dimensions. The theoretical framework developed herein (illustrated in Figure 4) marks a notable progress, conceptualizing regenerative intelligence as a systemic characteristic that results from thoughtfully coordinated stakeholder interactions and alignment across various domains. Three principal theoretical contributions arise from this investigation. Firstly, we provide empirical validation for restorative topophilia as an essential yet previously overlooked aspect of regeneration, thereby addressing a significant gap within the supply chain literature. Secondly, we introduce and operationalize the concept of "institutional redundancy" as an innovative mechanism that fortifies resilience through the strategic alignment of market forces and policy interventions within circular systems. Thirdly, our analysis identifies poly-rhythmicity as both a conceptually sophisticated and practically underexplored principle in contemporary regenerative practices, highlighting it as a crucial area for future scholarly inquiry. From a practical perspective, this research yields valuable insights for a variety of stakeholders. Supply chain managers are equipped with a structured methodology for evaluating and aligning their operations with objectives related to resilience and regeneration. Policymakers benefit from empirical evidence that supports the development of governance frameworks designed to facilitate cross-sector collaboration while addressing the temporal complexities inherent in socio-ecological systems. The framework's emphasis on reciprocal relationships offers concrete guidance for organizations transitioning from protective sustainability measures toward proactive regeneration strategies. Nevertheless, several limitations warrant recognition. The qualitative methodology employed, while fitting for this exploratory study, introduces potential interpretive biases, particularly concerning the nuanced principle of poly-rhythmicity. Furthermore, our focus on ABS-ranked journals, although ensuring academic rigor, may have inadvertently excluded valuable innovations arising from practitioner insights. The limited sample size, while

robust for this nascent field, indicates opportunities for further exploration as the literature evolves. Future research should prioritize three critical domains: (1) the development of robust metrics to quantify regenerative impacts across multiple system dimensions; (2) cross-cultural examinations of place-based regeneration approaches to accommodate contextual variations; and (3) the creation of practical decision-support tools for the implementation of poly-rhythmic supply chain strategies in diverse operational contexts. This study represents a significant conceptual advancement by reconceptualizing supply chains not merely as logistical networks but as potential catalysts for systemic renewal. The proposed framework provides scholars and practitioners alike with both a theoretical foundation and practical toolkit essential for navigating the complex transition from sustainability-as-mitigation to regeneration-as-renewal. By stressing the fundamental significance of reciprocal relationships and system-level thinking, this research delineates a pathway towards more resilient, equitable, and regenerative systems.

6 Ethics declaration

This research did not involve human participants, animal studies, or any other procedures requiring ethical clearance. Therefore, no formal ethical approval was necessary for the research presented in this paper.

7 AI declaration

The authors declare that no artificial intelligence (AI) tools were used in the writing, editing, data analysis, or interpretation of this manuscript. All work was conducted and reviewed manually by the authors.

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An Analysis of Fintech Patents in the Lights of Green Technologies

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Abstract

This article analyses the green aspects of technologies embedded within the Fintech sector, providing insights into the intersection of financial innovation and environmental sustainability. The technological advancements introduced in the financial sector over the past decades hold considerable potential to facilitate the ecological transition and promote environmental sustainability – a potential that has been widely acknowledge in the literature. However, there is still little research on the green attributes of the technologies underlying the Fintech sector, particularly through the lens of patents, which serve as concrete indicators of technological innovation.
Our findings contribute to the understanding of technology, finance, and sustainability, emphasising the value of patent data in tracking progress and guiding future developments.
Through the use of statistical analyses and the Social Network Analysis techniques, we define a multi-step methodology and a set of new measures that allow us to analyse Fintech technologies, as described by the underlying patents, in the light of the environmental and eco-friendly perspective, as proposed by the WIPO IPC Green Inventory classification. The statistical analysis of the green Fintech patents reveals several notable trends. The relative frequency of patents containing a number of green technology classifications within the complete dataset exhibits an increasing trends, although this has stabilised in recent years.
Furthermore, the data indicate a modest deceleration in the overall growth of this segment, suggesting a potential plateau in the expansion of green-oriented innovations in the Fintech domain.
Our results offer an original perspective on the idea of green, expanding the analysis to encompass the collective behaviour of the Fintech ecosystem of technologies and, eventually, any other industrial sector.

Keywords: Fintech, Green Patents, Green Technologies, IPC, Social Network Analysis

Paper type: Academic Research Paper

1 Introduction

The term financial technology ("Fintech") refers to a wide range of innovative approaches that use advances in software, mobile applications, blockchain, artificial intelligence, big data analytics, and other emerging technologies to transform the way financial services and transactions are rendered. In order to understand the technological landscape of Fintech, the analysis of patents pertaining is extremely relevant. In fact, patents are a reliable source of information since they include accurate technical, legal, and economic data. Patent observation plays an important role in the evaluation of technological innovations and the understanding of the landscape of intellectual property (Liu et al., 2023).

The analysis of patents in the Fintech sector has produced several scientific papers (Lee et al., 2009; Kabulova and Stankevičiené, 2020); Cojoianu et al., 2021; Lee and Sohn, 2017; Wang et al., 2022; Zhao et al. 2022).

The increasing integration of environmental, social, and governance (ESG) criteria into corporate strategies underscores the need to evaluate Fintech technologies' environmental characteristics, especially in light of growing pressures on businesses to adopt sustainable practices. For these reasons, the environmental impacts of Fintech are increasingly gaining attention, especially as the financial technology industry grows and intersects with sustainability goals. However, the "greenness" of the technologies underlying the Fintech sector remains largely underexplored, especially from the patent perspective.

This research aims to fill this gap by extending the analysis of Fintech patents conducted by Ferraro et al. (2024a) and Ferraro et al. (2024b) and analyses Fintech patents that involve the use of technologies defined as "green". We adopt the classification of green technologies based on the International Patent Classification (IPC) codes of the World Intellectual Property Organization (WIPO), over the period from 2010 to 2023. In particular, we refer to the WIPO IPC Green Inventory, developed by an IPC Committee of Experts with the aim to facilitate searches for patents information relating to Environmentally Sound Technologies, as listed by the United Nations Framework Convention on Climate Change.

We will try to answer the following research questions:

- RQ 1: How green are the technologies inherent in Fintech patents?

- RQ 2: How can we measure how well the Fintech sector complements green technologies? Can the rate at which green technologies are linked to a patent be measured?

2 Research design: data and methodology

This section shows the four main phases of our research: definition of keywords, construction of the database, processing of the database, and analysis of the results.

2.1 Definition of the keywords and patent database construction

Scopus database is used to analyse the relevant literature to define the keywords. We chose Scopus because it provides a comprehensive suite of scientific, technological, and social measures and content related to the scientific literature (Thelwall, M., 2018; Waltman L., 2016). The keywords of the title and abstract served as the basis for the analysis carried out on Scopus. The terms "Fintech" and/or "financial technology" were examined, resulting in a total of 4,836 scientific articles. The time period examined goes from 1980 to 2023. We chose the list of terms to search in the WIPO patent database based on the keywords we found through the analysis of academic publications and with the guidance of a panel of five experts.

We pay particular attention to IPC codes, which offer a hierarchical system of language-independent symbolism for classifying patents according to the technical domains to which they belong. We considered classification symbols, based on the WIPO repository.

The IPC Green Inventory was developed by an IPC Expert Committee in 2010 with the aim of facilitating the obtaining of patent information regarding "ambient sound technologies" defined by the United Nations Framework Convention on Climate Change. These technologies are recognized in numerous industries and are currently widely distributed in IPC codes. Although relatively new, the green technology sector has attracted a lot of attention from investors due to increasing awareness of the effects of climate change and the depletion of natural resources. The database of Fintech patents related to green technologies was analyzed and various statistics and analyses were carried out to understand the characteristics of these patents and the underlying technologies. In this research focused on green technologies applied to Fintech patents over a period of time from 2010 to 2023, we considered the date of publication of the patent application, i.e. the date on which the document is made available to the public, thereby making it part of the state-of-the-art.

2.2 Database analysis

The data set under investigation consists predominantly of textual data, including text bodies, names, and categorical labels. To gain an initial understanding of its structure and properties, we employ descriptive statistical techniques to summarize the structural and quantitative properties of the dataset.

2.2.1 Descriptive statistical analysis

The descriptive statistical analysis proceeds with several key steps aimed at understanding the distribution and dynamics of the data set. First, we analyse *the time evolution of applications* by examining the number of patent submissions per year. This time series analysis highlights the temporal dynamics of patent activity, revealing trends, growth patterns, or potential periods of stagnation in the application process.

Then, we construct rankings for the feature *applicants* by calculating the frequency of each applicant in the dataset, thus identifying the most active entities in terms of patent submissions. Hence, a similar ranking is created for the *IPC codes*. By counting the frequency of each IPC code, we identify the most prevalent technological sectors within the dataset, providing insight into innovation trends and technological focus areas.

To enhance the depth of our analysis, we introduced a measure of *the degree of prevalence* of green IPC codes. Each patent is associated with a set of IPC codes, of which only a subset belongs to the Green IPC inventory. The degree of prevalence of green codes within each patent is then quantified using the following statistic, for any patent *i*:

$$\pi_i^{(g)} = \frac{Number\ of\ green\ IPC\ codes}{Total\ number\ of\ IPC\ codes} \qquad (1)$$

It is immediately seen that $0 \leq \pi_i^{(g)} \leq 1$.

This measure quantifies the widespread presence of green technologies compared to other technologies in a patent. This enables an assessment of which Fintech patents incorporate a higher degree of environmentally friendly technologies, thereby establishing a form of green-technology footprint.

2.3 Network analysis

We perform a network analysis because this analysis enables the calculation of several metrics that disclose different properties as explained, for example, in Barabási (2016). We initially focus on the entire set of IPC codes as they are present in the collection of patents in order to analyze the mix of green technologies that appear in the Fintech patents. We begin by extracting all of the IPCs for every patent from our dataset. Next, we take into account a node for every single IPC and a link between two of them if they were included in the same patent. For every patent in the dataset, this process is repeated, producing a final network that we refer to as G_{IPC}.

From the construction of the graph we have eliminated the IPC codes that are not related to other codes. Since these codes exist as a code that is never coupled with another code in each patent, they are actually represented as a single node in the network and are therefore irrelevant to our analysis.

2.3.1 New measures to evaluate the patent greenness

Among the many methods used in network analysis, social network analysis (SNA) is one of the most popular tools. In this paper, we introduce three new measures that are derived from well-known centrality measures, and we use them to quantify how green a patent is and to better understand how a green IPC tends to appear alongside other green IPCs. It is important to note for the sake of this paper that nodes in our network representation stand in for IPC, and links exist between two nodes when the respective IPCs are simultaneously included in a patent.

2.3.2 IPC greenness

Let's consider a variable δ_i to associate to each node i, where $\delta_i = 1$ if the node refers to a green IPC code, 0 otherwise. The first measure indicates the percentage of green nodes with respect to the degree, in formula:

$$g_i = \frac{\sum_{j \in N(i)} \delta_j}{d_i} \qquad (2)$$

where g_i ranges from 0 to 1 and indicates the percentage of green nodes with respect to the degree d_i of node i with neighbourhood $N(i)$. Equation 2 gives the fraction of links to green IPCs for every IPC and quantifies how a technology is related to green technologies and when $g_i = 1$ all nodes in the relative neighbourhood are green; conversely, when $g_i = 0$, none of the linked nodes are green. In other words, if $g_i = 1$, then it means that this specific IPC i is a complementary technology to green technologies and is developed to work with them to improve or improve their overall performance or functionality. On the other hand, if $g_i = 0$, the technology is never considered together with a green technology.

2.3.3 IPC nearest neighbour average greenness

The second measure is based on the average degree of nearest neighbour introduced in Pastor-Satorras et al. (2001). This measure allows us to examine the neighbourhood $N(i)$ to check for possible hierarchical structures in the network topology and non-trivial correlations between the connectedness of nodes. In formula:

$$g_{nn,i} = \frac{1}{d_i} \sum_{j \in N(i)} g_j \qquad (3)$$

where d_i is the degree and g_j is the greenness score for the nodes j adjacent to i. This measure takes into account the average proportion of green nodes in a node's neighbourhood; in other words, it allows one to examine the structural organization surrounding a node by combining topological data about its neighbourhood with the greenness score of the nodes that make up that neighbourhood. This feature takes into account the identification of local network clusters where connected technologies can merge and, in cases where nodes have a high nearest-neighbour average greenness score, combine to produce greener patents. Figure 1 displays two distinct local configurations of green nodes for a node i in the same neighbourhood.

Equation 3 also gives weight to the average greenness score of its neighbouring IPCs and quantitatively accounts for each IPC's role, regardless of its degree. Since high-degree nodes are regarded as more significant than low-degree nodes, it is actually common practice to create a hierarchy of nodes. In our scenario, high-degree nodes could be connected to low greenness nodes, resulting in a low nearest-neighbour average greenness value, whereas low-degree nodes could be surrounded by nodes with high levels of greenness, resulting in a high value of neighbour average greenness value. In the former case, we saw a core technology that was less associated with other green technologies, and in the latter case, we have a less central technology that is closely associated with green technologies.

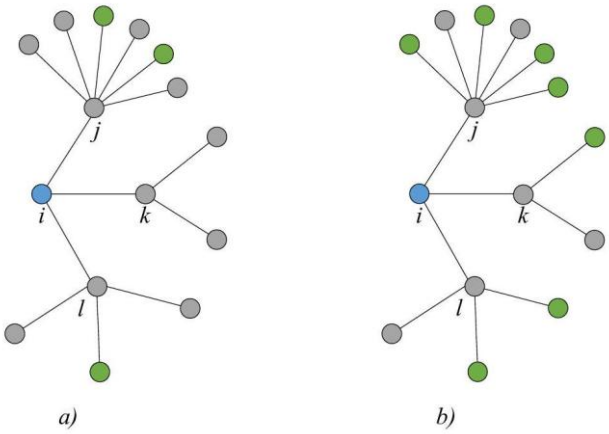


Figure 1: Two examples of a local neighbourhood for node i (green IPC are represented with green coloured nodes). In the a) panel, nodes score $g_j = 0.33, g_k = 0, g_l = 0.33$, thus $g_{nn,i} = 0.22$; in the b) panel nodes score $g_j = 0.66, g_k = 0.5, g_l = 0.66$, thus $g_{nn,i} = 0.60$.

2.3.4 Patent greenness

The third measure considers the connectivity between IPCs. Indeed, suppose that a given patent j is related to a given number of IPCs, says k; then it has a technological profile resulting in a set that we can call $p_j = \{IPC_1, IPC_2, \dots, IPC_k\}$. Since each IPC is a node in our network, it has associated a greenness g_i, thus we can average such values to obtain the patent greenness as:

$$p_j^g = \frac{1}{k}\sum_{l=1}^{k} g_l \qquad (4)$$

it quantifies the degree to which a technology is related to green technologies.

When $p_j^g = 1$, it indicates that the patent is fully composed of IPC codes related to green nodes, while $p_j^g = 0$ indicates a patent with all IPCs not related to other green IPCs. Equation 4 determines the greenness of a patent by averaging the greenness scores of all the technologies used. Thus, we move the emphasis from evaluating the greenness of individual IPCs to evaluating the greenness of a single patent. Therefore, differently from (1) which calculates the percentage of green IPCs in its technological profile, the measure (4) quantifies the general extent to which a patent is associated with green technologies.

It should be noted that Equations 2 and 3 do not take into account whether a node i is green or not. We adopt this formulation because we are interested in the degree to which IPCs are connected to green nodes, regardless of whether they are green or not.

3 Results

3.1 Fintech Green database

According to the database construction step, the string used as input in the advanced search engine of Patentscope for the Title or Abstract field, (with the "Single Family Member" set to True), is based on the keywords extracted from Scopus preliminary search. The complete Fintech database contains 7,107 patents, from 2010 to 2023. By intersecting IPC codes from our database with those in the WIPO IPC Green Inventory, we extracted the green Fintech database, containing 5,168 patents.

3.2 Database analysis

We focus our analysis of the green Fintech database relying in the "Publication date", "Applicants", "IPC code", and "Abstract" fields.

3.2.1 Descriptive statistical analysis

Time evolution of patent publication. Figure 2 shows the frequency and the cumulative frequency of the number of patents with and without green technologies from 2010 to 2023. A peak in the number of patents can be observed in 2019. With regard to the cumulative frequency, an increasing number of patents with sustainable technologies is evident, which demonstrates a growing attention on the part of companies filing

Fintech patents towards the use of technologies considered green. However, a slight decline was observed in 2023, and the data seem to indicate a modest deceleration in the overall growth of this segment.

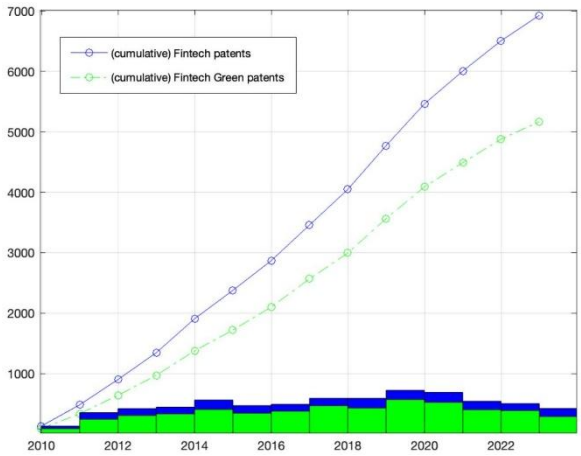


Figure 2: Frequency and cumulative frequency of patents.

Applicants. By determining the number of patents associated with each applicant, we can establish their classification, which reflects their level of involvement in research and development activities. It becomes apparent that the most active applicants are globally recognized institutions and banks that serve a global clientele. (Figure 3). We note the presence of: (i) MasterCard International Inc., which provides payment processing products including credit, debit, prepaid, personal, commercial, chip, and contactless cards; (ii) Ping An Technology Ltd, which uses artificial intelligence, cloud and other cutting-edge technologies to develop and operate platforms that support financial services; (iii) Shenzhen Cifpay network bank technology co. Ltd, which is active in data processing systems, digital information transmission, and electric digital data processing; (iv) Visa International, which offers an operational structure to support consumer payment services globally by providing telecommunications worldwide, manages data payment processing and, settles payments.

The analysis performed shows that only large technology companies with a consolidated position in the digital services sector are a prominent feature of the application landscape.

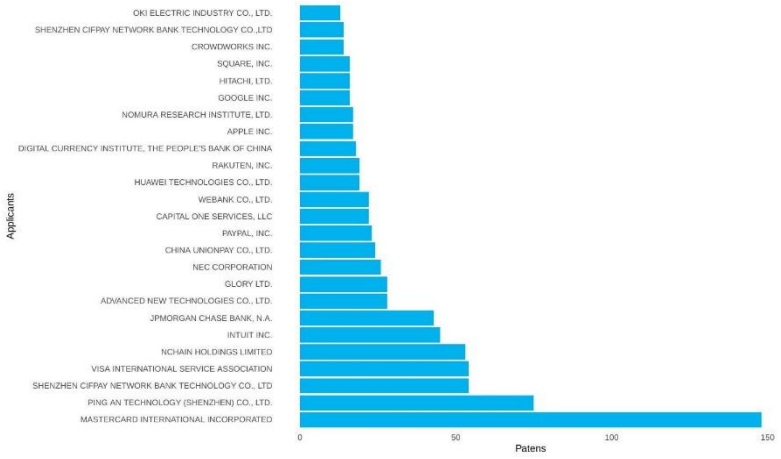


Figure 3: Patents of the Top 25 applicants.

IPC patent codes. The frequency of IPC codes may serve as an indicator of the technological distribution and focus areas within the patent dataset. The observed frequencies in our green Fintech database are shown in Figure 4.

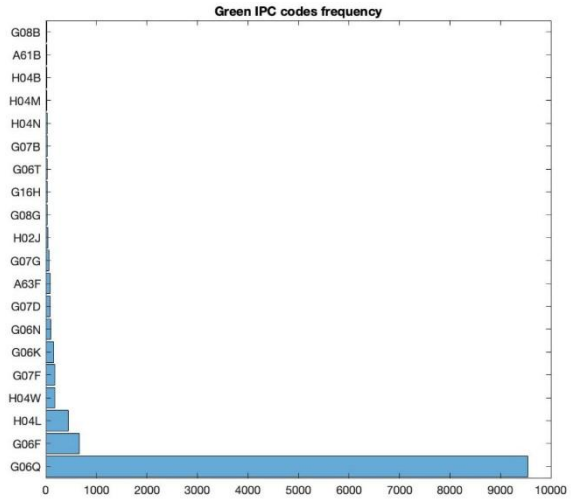


Figure 4: Frequency of the IPC green codes, considering only Section, Class and Subclass of the hierarchical classification scheme.

The *green IPC codes* most commonly used are described in Figure 5. The most frequent codes are G06Q 40/00 related to "Finance Insurance, Tax strategies, Processing of corporate or income taxes", G06Q 20/38 "Payment protocols", G06Q 20/40 "Authorization", G06Q 40/02 "Banking", and G06Q 20/06 "Private payment circuits". The code G06Q is unquestionably important in the dataset. It relates to data processing systems or methods, specifically for business or administrative purposes, and is included in the category of green technology for several reasons. G06Q covers systems optimising resource and energy use including supply chain tools, demand side management, and smart grids.

We also analyse *the degree of prevalence* of green IPC codes. We calculated the values of $\pi_i^{(g)}$ (see (1)) for all patents in the entire dataset of 7,107 documents. The distribution of the statistic is depicted in Figure 6. We can observe that in the set of 5,168 green patents, 3,858 contain only codes belonging to the WIPO IPC Green inventory, corresponding to 75%. Moreover, more than 93% of the patents exhibit a degree of green prevalence greater than 0.5. In contrast, 1,939 patents of the entire Fintech dataset are characterized by technologies that are considered non-green.

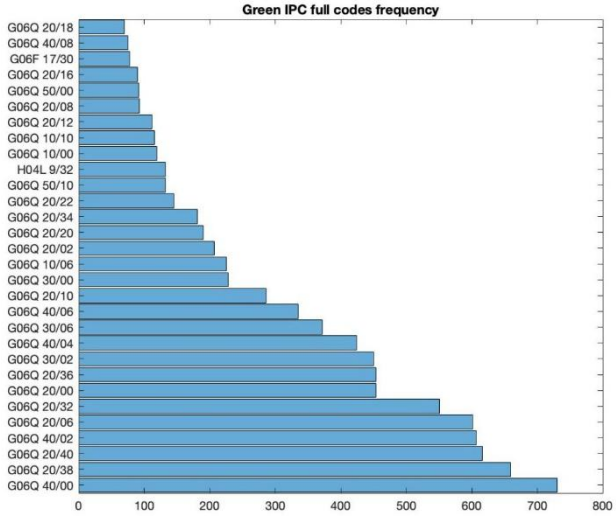


Figure 5: Frequency of the IPC green full codes.

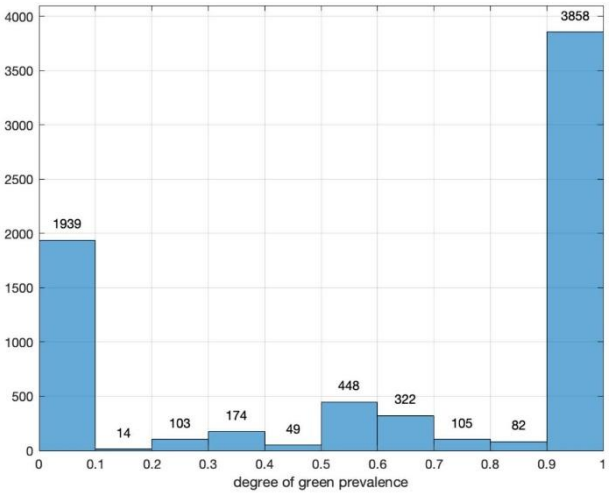


Figure 6: Observed frequencies of prevalence $\pi_i^{(g)}$.

3.3 Network analysis

Using our dataset, we constructed the weighted and undirected network G_{IPC} composed of 707 nodes and 5,048 links. The nodes with higher degree d_i, that is, the nodes with the largest number of other nodes related to them, are G06Q 20/38 ($d_i = 203$), G06Q 30/02 ($d_i = 193$), G06Q 40/02 ($d_i = 189$) and G06Q 20/06 ($d_i = 186$); G07F $19/00$[1], with $d_i = 59$, is the first IPC not in the G06Q class as well as the first not green IPC with the highest degree; finally, H04L $9/32$[2], with $d_i = 98$, is the first not in section G.

Figure 7 reports the density values when Equation 2 (left panel) and Equation 3 (right panel) are applied to network G_{IPC}. The right panel illustrates that the majority of nodes are located between 0.25 and 0.75 , while the peak values for g_i are centred around 0.5 . We can infer that the majority of IPC codes, or nodes, have around 50% of their neighbourhood made up of green nodes since g_i measures IPC's greenness, defined as the percentage of its linkage to other green IPC. While g_i indicates a good distribution of IPC codes associated with green IPC codes - that is, most patents do include the current presence of green IPC codes - a consistent peak began to emerge around the value of one, indicating that several IPC codes are linked with only green IPC codes.

When looking closely at IPC greenness, only 18 green IPCs receive a score of 1 , compared to 85 non-green IPCs with the same score. The highest score for both sets is obtained when the degree is $d_i = 7$, which is related to H02J 7/02 and H04L 65/40, respectively. Just one green IPC (G08G 1/123, with degree $d_i = 1$) and ten non-green IPCs (G01R $33/02$, the one with the higher degree, $d_i = 4$) have a score of zero. Whether the IPC was green or not was not specifically included in the calculations.

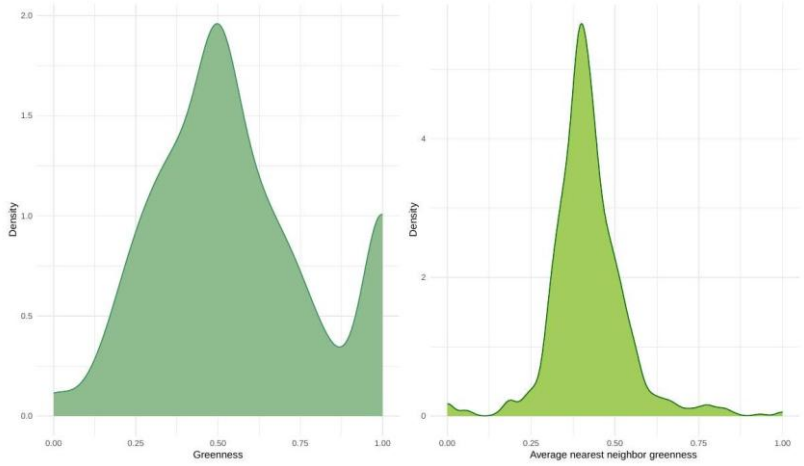


Figure 7: Density of g_i and $g_{nn,i}$.

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Table 1 shows the four distinct classes in which IPC can fall, according to the WIPO specification and the greenness score.

Table 1: A classification of various technology classes based on the green WIPO definition and the greenness findings from the network study.

		Network results	
		Low greenness	High greenness
WIPO specification	Non-green	Non-green technology (i.e. IPC) that complements a small number of green technologies.	Non-green technology (i.e. IPC) that complements a large number of green technologies.
	Green	Green technology (i.e. IPC) that complements a small number of green technologies.	Green technology (i.e. IPC) that complements a large number of green technologies.

The density of $g_{nn,1}$ offers a similar perspective. In fact, the values between 0.25 and 0.75 still have a concentration, but their significance has changed because $g_{nn,1}$ measures for an IPC the average value of the greenness of its adjacent. Taking this into account, the results indicate that nearly every node is connected to other nodes that have a certain level of greenness. Consequently, the network is filled with green nodes that are not confined to particular regions within the network.

When it comes to patents, we can calculate their overall greenness using Equation 4, which is the total of the single greenness g_i of the considered IPC averaged by the number of them in the considered patent. The density of p_i^g is reported in Figure 8, which indicates that the range of 0.25 to 0.50 is where the concurrent presence of green IPC is concentrated. As a result, a significant amount of patents contain elements of greener IPC, or green technology.

The production of green patents by applicants can be examined through the study of patent greenness. The top 14 applicants are ranked in Table 2 according to the number of patents they have presented, as well as their minimum average, and maximum patent greenness scores.

With 148 patents, MasterCard International Incorporated has the highest production, with greenness scores ranging from 0.26 to 0.57 and an average of 0.35. Despite having much fewer patents, numerous other applicants in the table likewise attained comparable averaged values. With a few exceptions, most maximum values fall between 0.55 and 0.70 , and no one achieves a maximum score of one.

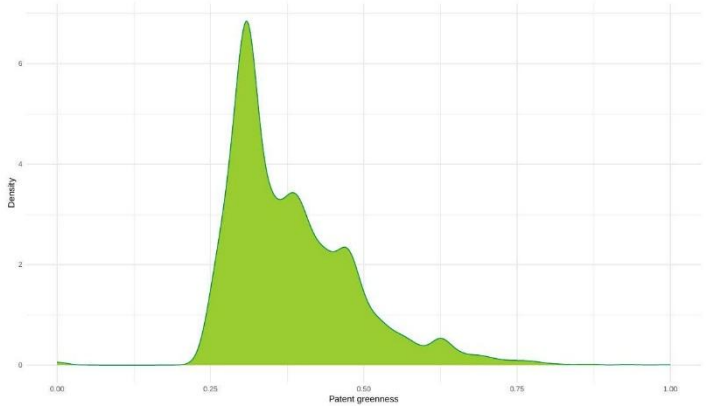


Figure 8: Density of p_i^g.

Table 2: Minimum, averaged and maximum values of patent greenness p_j^g for the top 14 applicants sorted in order of number of patents.

Applicant	**Nr. of patents**	**Min**	**Ave**	**Max**
MASTERCARD INTERNATIONAL INCORPORATED	148	0.26	0.35	0.57
PING AN TECHNOLOGY (SHENZHEN) CO., LTD.	75	0.27	0.40	0.70
SHENZHEN CIFPAY NETWORK BANK TECHNOLOGY CO., LTD	54	0.25	0.39	0.49
VISA INTERNATIONAL SERVICE ASSOCIATION	54	0.26	0.33	0.54
NCHAIN HOLDINGS LIMITED	53	0.26	0.36	0.52
INTUIT INC.	45	0.26	0.38	0.58

JPMORGAN CHASE BANK, N.A.	43	0.25	0.36	0.63
ADVANCED NEW TECHNOLOGIES CO., LTD.	28	0.25	0.33	0.56
GLORY LTD.	28	0.25	0.37	0.51
NEC CORPORATION	26	0.26	0.37	0.62
CHINA UNIONPAY CO., LTD.	24	0.25	0.34	0.65
PAYPAL, INC.	23	0.26	0.37	0.66
CAPITAL ONE SERVICES, LLC	22	0.26	0.33	0.62
WEBANK CO., LTD.	22	0.26	0.37	0.67

4 Discussion and conclusions

This paper examines the green aspects of Fintech. The relative frequency of patents containing a number of green technology classifications within the complete dataset exhibits an increasing trend, which has, however, stabilised in recent years. Despite this stabilization, a slight decline was observed in 2023. Furthermore, the data indicate a modest deceleration in the overall growth of this segment, suggesting a potential plateau in the expansion of green-oriented innovations in the Fintech domain.

These findings lead to several important conclusions. The stabilization in the relative frequency of green patents suggests that the integration of green technologies into the Fintech landscape may have reached a more mature stage, with companies consolidating efforts rather than pursuing rapid expansion. The slight decline observed in 2023 may indicate signs of market saturation or changes in industry priorities. The decline could also reflect the impact of external factors, such as economic uncertainty, regulatory shifts, or reduced funding.

The prevalence index analysis of the Fintech patent dataset gives a picture of the use of green technologies, providing an answer to our research question RQ1. In particular, the prevalence index shows that most patents (93%) rely more than 50% on technologies classified as green and that almost 75% use green technologies completely. This, of course, depends on the fact that the IPC code most involved in Fintech patents (G06Q) is included in the WIPO Green Inventory. We used network analysis in order to answer RQ2, and we propose three new measures that capture different aspects: (i) the degree of complementarity with green IPCs as measured by the greenness index; (ii) the degree of complementarity with green IPCs extended to the neighbourhood as measured by the nearest neighbourhood average greenness; (iii); the patent greenness, measured as the averaged greenness of the IPCs taken under consideration in the patent.

In particular, the second measure, which takes into account both the neighbors of a node and the neighbours of neighbours, is referred to as a measure of the second order since it takes into account the local organization surrounding a node. In particular, it finds local clusters of high-scoring nodes that may eventually combine to form a greener patent; second, it clarifies the distinction between an IPC's greenness in terms of quantity and quality, emphasizing that the degree - that is, the number of complementary technologies - is insufficient to distinguish between local clusters where green technologies are concentrated.

Regarding the third measure, it makes it possible to determine each patent's greenness based on its IPCs. With this measure, the greenness of a patent may be measured not only by the quantity of green IPCs that include it but also by their overall green behaviour within the Fintech ecosystem of technologies.

The analysis of the network results show that green codes represent technologies defined hubs, so even if they are relatively few, they are extremely relevant in terms of their influence on other technologies. Moreover, the distribution of the greenness values is peaked around 50%, with a less prominent spike at 100%, while the average greenness, which takes into account the degree of the node, is less dispersed around the mode value.

However, as green nodes are less than others, they result in being very pervasive, Regarding the top Fintech patent applicants, we observe the presence of a significant player in terms of the number of Fintech patents. However, it should be noted that the player itself has a relatively small number of patents that contain green codes. Nevertheless, for some applicants with a small number of Fintech patents, maximum greenness values are found to be even higher than 0.50. The distribution of greenness for individual applicants exhibits a concentration of values below 50%, with instances of multimodality (Shenzen Cifpay Network Bank Technology Co., Ltd and NChain Holdings Limited), indicating the presence of different types of patents, from the perspective of patent greenness, within the same company.

4.1. Limitations and future research

This study exclusively used the WIPO database, relying on the definition of green technologies by the organization based on the classification provided by IPCs. Future research should incorporate additional classification systems, such as the ENVTECH database developed by the OECD to categorize green technologies, as well as the Y02/Y04S labelling scheme introduced by the European Patent Office (EPO) in 2013.

5 Ethics Declaration

An ethics statement is not applicable because this study is based exclusively on published literature.

6 AI Declaration

The authors of this research declare that they did not use any AI tools.

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Understanding Socio-Economic Perceptions Complexity in Romania and Moldova: Implications for the Business Environment

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Abstract

This paper investigates how people's perceptions of socio-economic indicators in Romania and the Republic of Moldova influence the development of the business environment at local and regional level, in the context of growing challenges to economic and social resilience. Based on a questionnaire applied to a sample of 3228 respondents, the study analyzes eight key indicators, grouped into two composite indices: "Economic and social policies" (I_1) and " Access to basic services/resources (critical infrastructures) services" (I_2). These two indices were then combined into a third, entitled " Overall socio-economic perceptions" (I_3), to provide an integrated picture of the well-being of the population. During the course of the work the K-means clustering algorithm and the Silhouette indicator were applied to validate the optimal number of clusters, using the RStudio software the research identified different relevant county-level clusters. In the case of the I_1 index, Romanian counties clustered in a distinct cluster from those in the Republic of Moldova, suggesting significant differences in income satisfaction, job security and access to public services. In contrast, for I_2, the analysis revealed five clusters, reflecting greater variation in perceptions of access to utilities, energy, education and health. Thus, even though the majority of counties in Romania received high scores, there were also a few counties that scored lower, for which some improvements should be made. The results provide a useful tool for policy makers and business actors, suggesting areas with different needs and varying investment potential. The study highlights the importance of understanding local perceptions in formulating development and intervention policies.

Keywords: Socio-Economic Analysis; Clustering; K-means; Complexity; Business Environment

Paper type: Academic Research Paper

1 Introduction

Starting from the idea that the population's perceptions of socio-economic conditions can have a direct influence on economic behavior, the level of trust in institutions and, implicitly, on the dynamics of business environment development, it was deemed necessary to conduct this analysis. With the help of understanding these perceptions, a much clearer picture of the investment potential and the real needs of communities can be created. In this context, this paper aims to explore the complexity of the socio-economic perceptions of the inhabitants of Romania and the Republic of Moldova and to determine how this thinking influences the business environment by grouping counties in both countries into clusters based on their socio-economic characteristics. Based on a questionnaire administered to respondents from these countries, the research aims to investigate eight socio-economic indicators, which are then aggregated into two variables that address socio-economic aspects ("Economic and social policies" and "Access to basic services/resources (critical infrastructures) services").

Over time, a series of researchers have considered the socio-economic indicators for analyzing economic resilience, both at local and regional level. Observing the increasing number of extreme natural disasters, Borre et al. (2025) developed a composite index (Recovery Gap Index) that has the ability to assess and quantify the capacity to respond and recover from such an event. Aligica and Ciobanu (2025) explore the trade-offs between the economic benefits of global economic integration and the risks that this interdependence entails, particularly in the context of geo-economics and security. The two authors advocate a balanced approach that combines economic efficiency with security and resilience to reduce geopolitical risks.

Ma and He (2024) have demonstrated that the business environment is able to significantly simulate the quality of economic development, observing that total labor force is considered as a mediating variable. Moreover, the relationship between business climate and the level of economic progress has been intensively investigated by Djankov et al. (2006) who showed that if a country moves from the worst to the best economic regulations, this can lead to an increase in the economy by 2.3 percentage points per year. Furthermore, Li et al. (2023) showed that the upgrading of high-tech areas has a stronger impact on urban economic development in well-connected eastern cities with developed economies or close to provincial capitals, thus highlighting the crucial role of tailored regional policies.

In the present work, clustering was chosen as it allows to identify and understand the similarity between patterns, helping to group those data that prove to have characteristics that are similar (Abediniangerabi *et al.*, 2020; Qiao *et al.*, 2021). Moreover, the K-means method has been used over time in different fields of activity such as: renewable energies and optimization of integrated energy systems (Tan *et al.*, 2025), medicine (Win *et al.*, 2025), urban resilience planning (Moradpour *et al.*, 2024) or even petroleum engineering (Wang *et al.*, 2023).

2 Methodology

Three indexes have been used in the analysis, as described below. Also, a discussion related to the process of choosing the optimal number of clusters for each indicator is provided. In terms of software used, RStudio has been selected, due to its powerful capability of analyzing and manipulating data (Aria and Cuccurullo, 2017).

2.1 Data Collection

In order to collect the data used in this analysis, a survey was created and administered in turn to respondents in Romania (between December 2021 and January 2022) and in the Republic of Moldova (between February and March 2022). In Romania, all 41 counties were targeted, plus the capital, Bucharest, with a total of 2216 respondents. In the Republic of Moldova, 35 administrative units were included, with a total number of 1012 respondents. The survey asked about economic factors, social policies and access to basic services. The answers were recorded on a scale from 0 to 1 and the values analyzed are averages of the perceptions expressed by the respondents.

2.2 Economic and social policies Index (I_1)

The first indicator created is the one on economic factors and social policies. It has been formed on the basis of four key variables, each of which provides a detailed picture of the level of satisfaction of citizens at county level with: the level of personal income, job security, sense of belonging to their community and ease of access to local services (Table 1).

Table 1: Variables included in I_1 metric

Metric	Variables	Brief description
I_1	High personal income	The average value of the responses offered by the individuals through which they are evaluating whether they have a high personal income
	Job security	The average value of the responses offered by the individuals through which they are evaluating whether they have a high job security
	Community belonging sentiment	The average value of the responses offered by the individuals through which they are evaluating whether they have a high community belonging sentiment
	Easy access to local public services	The average value of the responses offered by the individuals through which they are evaluating whether they have an easy access to local public services

2.3 Access to basic services/resources (critical infrastructures) services Index (I_2)

The second indicator, the access that citizens have to the different basic services, representing crucial aspects for the well-being and development of communities. This indicator was created to measure the perceptions of the population at county level on the availability and ease with which they can access basic services such as utilities, energy, healthcare or even education (Table 2).

Table 2: Variables included in I_2 metric

Metric	Variables	Brief description
I_2	Access to utilities	The average value of the responses offered by individuals regarding their evaluation of how easily they have access to basic utilities
	Access to energy	The average value of the responses offered by individuals regarding their evaluation of how easily they have access to reliable energy sources
	Access to healthcare	The average value of the responses offered by individuals regarding their evaluation of how easily they have access to healthcare services
	Access to education	The average value of the responses offered by individuals regarding their evaluation of how easily they have access to education services

2.4 Overall socio-economic perceptions (I_3)

This index was created by calculating the average of the scores recorded at county level for I_1 and I_2, in order to provide a global and integrated assessment of the economic and social status of the population. By combining the two indexes, it was intended to achieve a more comprehensive analysis of the well-being of citizens, reflecting both the standard of living and accessibility to utilities, energy, health and education. In addition, it provides an effective tool for assessing the performance of regions and identifying those with shortcomings in both areas, allowing the identification of regions in need of integrated policy interventions, simultaneously addressing both economic factors and access to services .

2.5 Silhouette Index

The Silhouette Coefficient is an indicator that measures the classification quality of an object in a cluster by comparing how close it is to the items in its own cluster to those in other clusters (Chattopadhyay and Chattopadhyay, 2025). The formula for this indicator is:

$$S_i = \frac{b_i - a_i}{\max\{a_i; b_i\}} \quad (1)$$

In the formula, a_i is the average distance from point i to all other points in the same cluster, thus measuring the internal cohesion of the cluster: a smaller a_i indicates that the point is well integrated in its cluster. On the other hand, b_i is the average distance from point i to all points in the nearest neighbour cluster, expressing how well separated i is from other clusters. The larger b_i is, the better the point is delimited from the other clusters (Yang et al., 2025). By using the maximum between a_i and b_i in the denominator, the score Si is normalized and will have values between -1 and 1. As an interpretation, a score close to 1 indicates a correct assignment of the point, one close to 0 suggests that the point is on the border between two clusters, and a negative score shows that the point might be misassigned and would rather belong to another cluster (Rousseeuw, 1987).

2.6 K-means Clustering

The K-means clustering algorithm is an unsupervised machine learning technique used to divide a dataset into k distinct clusters. It requires prior determination of the number of clusters and works without a training process. Initially, k centroids are randomly chosen, and each data point is assigned to the cluster whose centroid is the closest, based on distance (usually Euclidean distance). Afterwards, the centroids are recalculated as the average of the assigned points, and the process is repeated until convergence, meaning that the data points no longer change clusters and the loss function is minimized. The algorithm reduces the internal variation of each cluster by efficiently delineating the divisions within the data (Ahmed et al., 2020; Chattopadhyay and Chattopadhyay, 2025; Faber, 1994).

3 Results Interpretation

The first part of this section covers the process of selecting the optimal number of clusters, using the Silhouette indicator, which ensures the validity and relevance of the clusters obtained. The second part provides a clear picture of each cluster formed, highlighting the main characteristics and particularities of the components of each cluster. The third and last part of this sub-chapter includes a discussion section, in which the results obtained are interpreted and recommendations are formulated to provide directions for action for policy makers and other stakeholders.

3.1 Choosing the Optimal Number of Clusters

To make sure that the chosen number of clusters for each indicator is the optimal one, the Silhouette index was used. Silhouette score values were generated for different clustering scenarios (from 2 to 6 clusters) and the number of clusters corresponding to the maximum value of this index was then chosen.

Table 3: Silhoutte index for I_1, I_2 and I_3

Number of clusters	Silhoutte index for I_1	Silhoutte index for I_2	Silhoutte index for I_3
2	0.93	0.84	0.95
3	0.79	0.88	0.83
4	0.57	0.94	0.62
5	0.61	0.99	0.65
6	0.65	0.89	0.65

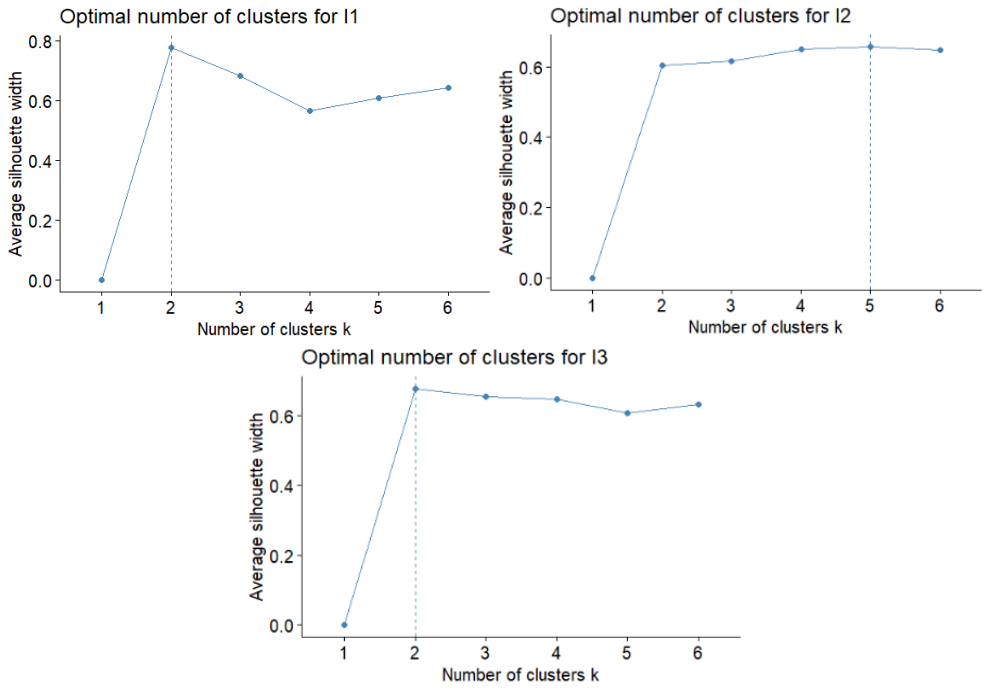


Figure 1: Optimal number of clusters for I_1, I_2 and I_3

Table 3 contains the scenario-specific values for the Silhoutte indicator, while Figure 1 helps to visually observe the optimal number. Thus, as mentioned in the previous paragraph, for each index, the highest value of the Silhoutte indicator will be chosen as the optimal number of clusters. For I_1, 2 clusters will be formed, for I_2, 5 clusters will be generated, and for I_3, similar to the situation of I_1, 2 clusters will be wanted.

3.2 Building Clusters

Knowing the optimal number of clusters for each indicator, one can proceed to the actual construction of each cluster. For this step, the K-means method was chosen, due to its efficiency and popularity in identifying homogeneous clusters in complex datasets. The construction of the clusters was realized using the average of the answers that the respondents provided when answering the questions related to each variable included in the creation of a particular indicator. Thus, for each county, a representative mean score was calculated for each indicator, and these mean values formed the basis on which the K-means algorithm was applied. This approach allowed the grouping of respondents according to the similarities in their perceptions and experiences of economic and social policies and level of access to basic services. Depending on the number of clusters chosen for each indicator, each time, the first cluster represents the average of the highest scores given by the respondents. As the number obtained by each cluster increases, the average of the answers it contains will be lower (e.g. the last cluster will always contain the averages of the lowest answers recorded).

Table 4: Counties clusters for I_1

Cluster	Components
1	Alba, Arad, Arges, Bacau, Bihor, Bistrita-Nasaud, Botosani, Braila, Brasov, Bucuresti, Buzau, Calarasi, Caras-Severin, Cluj, Constanta, Covasna, Dambovita, Dolj, Galati, Giurgiu, Gorj, Harghita, Hunedoara, Ialomita, Iasi, Ilfov, Maramures, Mehedinti, Mures, Neamt, Olt, Prahova, Salaj, Satu Mare, Sibiu, Suceava, Teleorman, Timis, Tulcea, Valcea, Vaslui, Vrancea.
2	Anenii Noi, Balti, Basarabeasca, Briceni, Cahul, Calarasi, Cantemir, Causeni, Chisinau, Cimislia, Criuleni, Donduseni, Drochia, Dubasari, Edinet, Falesti, Floresti, Glodeni, Hincesti, Ialoveni, Leova, Nisporeni, Ocnita, Orhei, Rezina, Riscani, Singerei, Soldanesti, Soroca, Stefan Voda, Straseni, Taraclia, Telenesti, Ungheni, UTA Gagauzia.

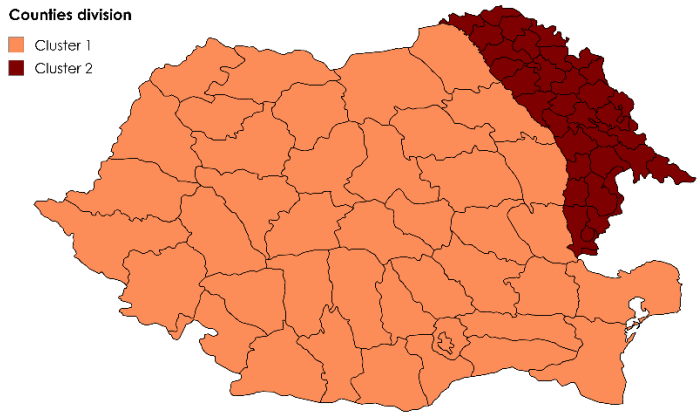


Figure 2: Counties clusters - I_1

Table 4 and Figure 2 give a very clear picture in terms of comparing the perceptions of respondents from Romania and the Republic of Moldova regarding the economic and social policies index. Cluster 1 is composed only of counties from Romania, with mean scores between 0.70 and 0.97, while Cluster 2 is composed only of counties from the Republic of Moldova, with mean scores between 0.32 and 0.60. From this can be deduced the difference in the perceptions of the citizens of the two counties analyzed regarding their own income, job security, sense of belonging to the community, as well as the ease they perceive in terms of local public services.

If for the previous index only 2 groups were formed, this time for the index on access to basic services, a total of 5 clusters were identified. Cluster 1 contains mean responses between 0.92 and 0.97, Cluster 2 between 0.88 and 0.91, Cluster 3 between 0.84 and 0.87, Cluster 4 between 0.8 and 0.83, and Cluster 5 between 0.77 and 0.78. In terms of the number of counties, the most populated clusters as can be seen in the Table 5 and Figure 3 are Cluster 2 and Cluster 3, which shows that the majority of respondents have positive perceptions regarding the ease of access to utilities, energy, healthcare or education.

Table 5: Counties clusters for I_2

Cluster	**Components**
1	Cluj, Dolj, Galati, Hunedoara, Iasi, Maramures, Mures, Valcea, Taraclia, UTA Gagauzia.
2	Alba, Arges, Bacau, Bistrita-Nasaud, Braila, Brasov, Bucuresti, Buzau, Calarasi, Caras-Severin, Giurgiu, Mehedinti, Neamt, Olt, Sibiu, Vaslui, Anenii Noi, Basarabeasca, Causeni, Chisinau, Cimislia, Criuleni, Dubasari, Hincesti, Ialoveni, Leova, Stefan Voda, Straseni.
3	Arad, Botosani, Dambovita, Gorj, Harghita, Ilfov, Prahova, Satu Mare, Teleorman, Timis, Tulcea, Balti, Briceni, Cahul, Cantemir, Donduseni, Drochia, Edinet, Falesti, Floresti, Glodeni, Ocnita, Orhei, Rezina, Riscani, Singerei, Soldanesti, Soroca, Telenesti.
4	Bihor, Constanta, Covasna, Salaj, Suceava, Calarasi, Nisporeni, Ungheni.
5	Ialomita, Vrancea

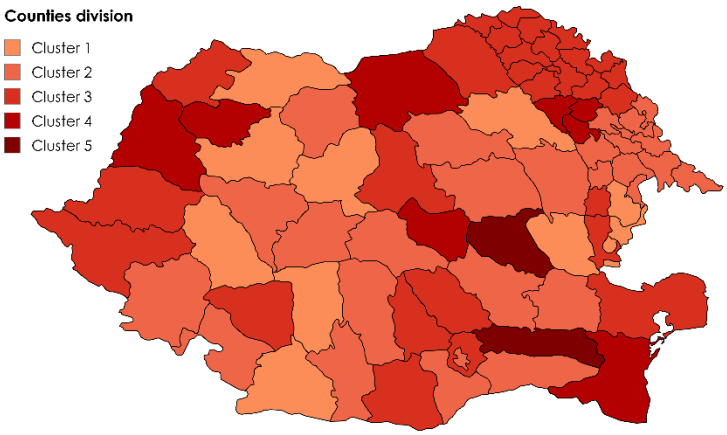


Figure 3: Counties clusters - I_2

In the case of the third index, which refers to overall socio-economic perceptions, Table 6 and Figure 4 show a situation similar to the one encountered for I_1, with two Clusters. Cluster 1 contains response averages between 0.78 and 0.94 and Cluster 2 has averages between 0.59 and 0.75. Considering that this index was created from I_2 and I_3 it is interesting to note that only one county in Romania migrated from Cluster 1 to Cluster 2 (Ialomita). This change is explained by the fact that, although in the case of the first indicator (I_1) the score of Ialomita county (0.70) was located at the lower limit of the range for Cluster 1, when averaging I_1 and I_2 to form the new index (I_3), the aggregate score (0.73) fell better within the range specific to Cluster 2. Thus, the average between the two dimensions caused its migration to a different cluster.

Table 6: Counties clusters for I_3

Cluster	Components
1	Alba, Arad, Arges, Bacau, Bihor, Bistrita-Nasaud, Botosani, Braila, Brasov, Bucuresti, Buzau, Calarasi, Caras-Severin, Cluj, Constanta, Covasna, Dambovita, Dolj, Galati, Giurgiu, Gorj, Harghita, Hunedoara, Iasi, Ilfov, Maramures, Mehedinti, Mures, Neamt, Olt, Prahova, Salaj, Satu Mare, Sibiu, Suceava, Teleorman, Timis, Tulcea, Valcea, Vaslui, Vrancea.
2	Ialomita, Anenii Noi, Balti, Basarabeasca, Briceni, Cahul, Calarasi, Cantemir, Causeni, Chisinau, Cimislia, Criuleni, Donduseni, Drochia, Dubasari, Edinet, Falesti, Floresti, Glodeni, Hincesti, Ialoveni, Leova, Nisporeni, Ocnita, Orhei, Rezina, Riscani, Singerei, Soldanesti, Soroca, Stefan Voda, Straseni, Taraclia, Telenesti, Ungheni, UTA Gagauzia.

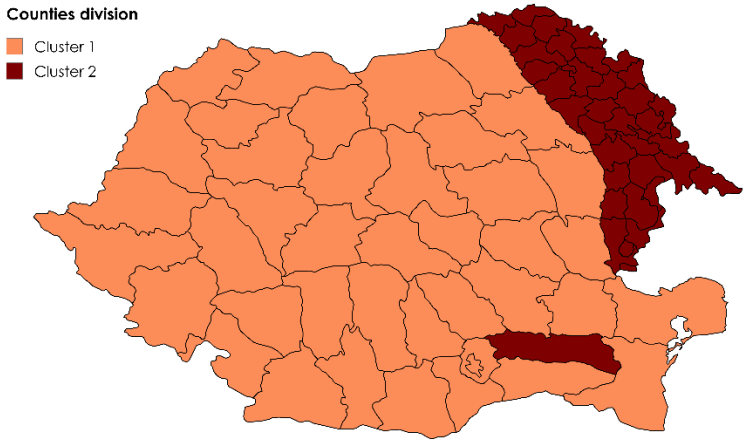


Figure 4: Counties clusters - I_3

3.3 Discussion and Recommendations on the Obtained Clusterizations

The largest number of respondents (102 respondents) came from the capital (Bucharest), the rest of the counties participating in the research having between 50 and 54 respondents. In the analysis, the age of respondents was between 18 and 65 years. The most common age category among Romanian respondents was between 36 and 45 years old, followed by 46 and 55 years old; while in the Republic of Moldova the age range was 26 and 35 years old, followed by 36 and 45 years old.

As previously mentioned, there were four variables in the "Economic and social policies index" component. According to the clustering results, it is very easy to deduce that the perceptions of the inhabitants of the analyzed counties, in relation to: personal income, security felt at work, sense of belonging to the community, and the perceived level of ease of access to public services, are very different. Respondents from Romania gave much more favorable answers, which denotes a higher level of security and satisfaction, compared to the answers collected from the Republic of Moldova, where the level of satisfaction is lower, which can be easily observed in Figure 2, where the division is very clear, with Romanian counties forming Cluster 1 and those from the Republic of Moldova Cluster 2.

The interesting situation is, however, in the case of the "Access to basic services/resources (critical infrastructures) services index" where the clustering was formed by 5 groups. This may indicate that each of the 5 clusters formed represents a different profile of accessibility to basic services such as utilities, energy, healthcare or education. It can thus be affirmed, the existence of both respondents who declare very easy and constant access to all the mentioned services, and respondents who have major difficulties in at least one of these areas. This differentiation allows a more nuanced understanding of the real needs at the population level, providing a valuable starting point for the formulation of public policies or targeted interventions aimed at

reducing disparities and improving the quality of services according to the needs of each identified segment. Cluster 1, in which the highest scores are recorded, shows a predominance of Romanian counties, which are 8 in number, as opposed to the Republic of Moldova where only 2 counties are present. A similar situation is also in Cluster 2, only this time there are 16 counties from Romania and 12 from the Republic of Moldova. From this it can be deduced that respondents from several counties in Romania feel much more secure in terms of access to basic services compared to those from the Republic of Moldova, but unlike the previous index, this time the conclusion does not apply to all counties, Cluster 5 being made up of 2 counties in Romania in the case of this index.

In the case of the third index "Overall socio-economic perceptions", formed on the basis of the two mentioned above, the situation is similar to the one encountered in the case of I_1. The only difference to be mentioned is the migration of Ialomita county from Cluster 1 to Cluster 2, as it is a county on the territory of Romania. The fact that the county is in the best cluster for I_1 and in the worst Cluster for I_2, although the scores are relatively close (0.70-0.97 for I_1 and 0.77-0.78 for I_2), highlights a key point: the way respondents are grouped and the baseline values for each indicator are different, and the thresholds between clusters reflect distinct distributions and variations. In other words, for I_1 the county belongs to the most favorable cluster. This means that, relative to the rest of the counties, its score is among the highest and the perception of its inhabitants is positive. In contrast, for I_2, the county is in the weakest cluster, despite a close numerical score. This situation arises because the distribution of responses for I_2 is much narrower, and small differences can produce significant shifts in the cluster allocation. Thus, it falls in the lower range in the context of this indicator, resulting in inclusion in the weakest cluster. When the scores for the two indicators were combined in I_3 (the average between I_1 and I_2), the county ends up in Cluster 2, reflecting an overall average score, lower than expected based on I_1 performance alone. This shows that although perceptions of economic and socio-political factors, access to basic services is poor.

The importance of entrepreneurship for the existence of a dynamic economy has been observed over time, as entrepreneurs are those who create different employment opportunities, having the power to influence the economic performance of a country (Kritikos, 2024). The analysis carried out is of particular importance, because the groupings indicate the counties favorable for the development of the business environment. The more the population experiences a higher level of income security, job stability and reliable public services, the higher the domestic demand becomes, and the more the entrepreneurial spirit grows. Moreover, in places where access to utilities is easy, where education and health systems are well developed, the labor force is developed and production is increased. These areas (which are part of Cluster 1), were found to be dominated by Romanian counties, signaling low risk and high investment attractiveness. As far as the counties in the Republic of Moldova are concerned, the need for improvement of infrastructure and economic security is inferred.

In addition to helping different companies such as SMEs or local start-ups to adapt their business models according to each region, the research is also beneficial for local authorities. The differences observed between clusters can guide concrete actions according to the needs of each area. Thus, in counties where the population has a positive perception of the economic conditions, but access to services and infrastructure is poor, investments in health, education and utilities should be prioritized. In areas where infrastructure is good, but citizens feel low incomes and job insecurity, authorities should support initiatives to increase incomes (attracting investors, supporting vocational training). Moreover, the results of the analysis could be used as a basis for joint projects between Romania and the Republic of Moldova, focused on developing infrastructure and the local economy, with benefits for both sides.

4 Conclusions

Starting from the analysis of two aggregated indicators ("Economic and social policies" and "Access to basic services/resources (critical infrastructures) services"), and an indicator derived from them, namely "Overall socio-economic perceptions", it was assumed that the research can provide insight into the business environment at national level. Thus, based on a questionnaire applied to a total number of 3228 respondents from different counties both in Romania and in the Republic of Moldova, applying the K-means clustering method at the level of each index, representative clusters were created, the optimal number of clusters being chosen using the Silhoutte indicator. Clustering on the basis of the analyzed indicators makes it possible to identify regions with high potential for investment and entrepreneurial development, as well as vulnerable areas in need of specific support from the authorities.

Using the formed clusters, it can be observed that respondents from Romania tend to have a more favorable perception compared to respondents from the Republic of Moldova, thus providing a favorable environment for economic initiatives. For Romania, all counties tend to be grouped in Cluster 1. However, it is worth noting that

in terms of the I_2 index even if the majority of counties are found in the high performing clusters, the presence of some Romanian counties in the worst performing cluster emphasizes the need for targeted interventions even within Romania. In the case of the Republic of Moldova negative perceptions predominate, signaling the need for significant interventions in infrastructure and economic policies to support local development and investment attractiveness.

An important aspect that needs to be addressed are the limitations that were encountered during the conduct of this research. Data was collected using a questionnaire, the answers given by the respondents can be influenced by many factors, but this is one of the most popular data collection methods. Moreover, the questionnaire was administered only once. The analysis was carried out only at the level of Romania and the Republic of Moldova, without covering a wider geographical area such as the Eastern European economies.

Regarding future research, it would be proposed: to increase the number of respondents, to apply the questionnaire at a certain time interval (e.g. one year) in order to observe the changes that occurred over time in the population's thinking, to add other clustering methods (e.g. Density-Based Spatial Clustering of Applications with Noise or Gaussian Mixture Model), as well as to add other indexes (e.g. level of digitalization).

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6 Ethics declaration

The authors declare no ethical clearance for the research referred to in this paper

7 AI declaration

The authors declare no use of AI in elaborating this paper.

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Mapping Twin Transitions in Regional Innovation Systems: A Configurational Approach

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Abstract

Twin transition —integrating digitalisation and ecological sustainability— has become a structural priority for European regional development, as reflected in major frameworks such as NextGenerationEU and the 2021–2027 Cohesion Policy. These programmes aim not only to support recovery but also to reshape the technological and institutional foundations of regional economies. However, a significant knowledge gap remains: while the twin transition requires coordinated and systemic change, we still lack a clear understanding of how it unfolds across different regional contexts —particularly given persistent disparities in structural capacity and institutional agency. This paper addresses that gap by investigating the relationship between regional industrial path development and the capacity of regions to engage in twin transitions. Drawing on an established typology of development paths —including extension, upgrading, branching, diversification, creation and importation—and on a review of regional case studies, we develop a configurational framework that links these development paths to a set of structural and institutional causal conditions. These conditions are operationalised into indicators grounded in the literature, and applied to the Italian regional context through a fuzzy-set Qualitative Comparative Analysis covering the period 2007–2017. The findings show that regional engagement in twin transitions could result from distinct combinations of development paths and enabling conditions. Extension, upgrading, and importation path —when coupled with enabling regional conditions— are the most conducive to twin specialisation.
The study contributes to debates on bridging evolutionary economic geography and transition-oriented policy, and provides a scalable diagnostic tool to inform place-based strategies tailored to structurally diverse regional contexts.

Keywords: Twin Transition, Regional path development, Regional innovation systems, Complex systems, Fuzzy-set Qualitative Comparative Analysis

Paper type: Academic Research Paper

1 Introduction

In the 2021 Strategic Foresight Report (2021), the European Commission emphasised that the success of the twin transitions will depend on the capacity of regions to mobilise their technological, institutional, and cognitive resources. This recognition marks a critical shift in the EU policy discourse: the twin transition should no longer approached as a uniform, top-down process but as a territorially embedded challenge, unfolding unevenly across Europe (European Commission, 2024). Understanding how regions develop—or fail to develop—the necessary capabilities has therefore become a central concern for both researchers and policymakers (OECD, 2022).

The twin transition is positioned as a cornerstone of the European Union's strategic vision for sustainable growth and technological sovereignty(European Commission, 2022). Framed as both an ecological and economic necessity, it reflects the convergence of long-term climate objectives with the imperative to modernise industrial systems, enhance productivity, and secure Europe's position in global value chains. In this context, the EU has mobilised substantial policy and financial instruments, including NextGenerationEU and the 2021–2027 Cohesion Policy, to steer national and regional efforts towards an integrated transition (European Commission, 2024).

Yet the twin transition involves more than the adoption of green and digital technologies. It entails a complex, multi-dimensional reconfiguration of production systems, knowledge infrastructures, innovation ecosystems, and governance frameworks. These transformations are deeply embedded in territorial contexts and depend on the differentiated capacities of regions to absorb, adapt, and generate structural change (Rodríguez-Pose, 2018). As recent debates in regional studies and innovation policy underline, achieving an effective transition requires moving beyond aggregate indicators and engaging with the structural diversity of regions (Ron Boschma et al., 2023). Within this context, evolutionary economic geography (EEG) offers a valuable perspective, viewing regions as evolving systems whose development paths are shaped by inherited structures, institutional agency, and knowledge dynamics. The concept of regional path development provides

a framework for analysing how regions transform over time through mechanisms such as extension, upgrading, branching, diversification, creation, and importation (Hassink et al., 2019). These paths reflect the interplay between established capabilities and emergent opportunities, under both internal and external pressures (Boschma, 2017).

However, despite its growing analytical traction, the path development framework still lacks a shared operational architecture. Its empirical applications often rely on case-specific interpretations, limiting cross-regional comparability and hindering cumulative knowledge-building. Moreover, the relationship between specific regional development paths and regional engagement in twin transitions remains underexplored. In particular, there is a lack of comparative and configurational evidence on which combinations of structural and institutional factors are most conducive to supporting twin transition outcome.

This paper contributes to this endeavour in two ways. First, it systematises the application of the path development framework through a review and classification of empirical studies and case-based applications, helping to consolidate its conceptual and operational foundations. Second, it proposes a configurational model that links these path types with twin transition. The model is applied to Italian NUTS-2 regions using fuzzy-set Qualitative Comparative Analysis (fsQCA), covering the period 2007–2017, to identify combinations of cognitive relatedness, technological complexity, innovation performance, entrepreneurial capacity, institutional agency, and policy effort that enable regional engagement in such transformation.

The remainder of the paper is structures as follows. Section 2 outlines the theoretical background, reviewing key contributions from EEG. Section 3 presents the methodological approach, including case selection, operationalisation of variables, and the logic of fsQCA. Section 4 presents the model, while section 5 discusses the main results, highlighting the configurations of conditions conducive to twin transition outcome. Finally, Section 6 concludes by summarising the theoretical and practical contributions of the study, outlining its limitations, and proposing directions for further research.

2 Literature Background

Understanding how regions transform their industrial base in response to transformative pressures—such as decarbonisation and digitalisation- has become a central concern in EEG and regional studies (Boschma, 2017). In this context, the concept of regional path development has gained analytical traction as a lens for capturing differentiated trajectories of structural change (Grillitsch et al., 2018; Hassink et al., 2019). Grounded in the distinction between path dependence and path creation (Martin & Sunley, 2006), the framework has evolved into a typology encompassing mechanisms such as extension, upgrading, branching, diversification, importation, and creation (Grillitsch et al., 2018; Hassink et al., 2019; Trippl et al., 2020). These categories offer a nuanced understanding of how regions evolve by combining established assets with emergent opportunities, under varying degrees of disruption and directionality. Table 1 summarises the taxonomy of regional path development with their distinctive characteristics.

Despite its growing theoretical consolidation, the empirical application of this typology remains fragmented. Most studies adopt a descriptive approach, compare a small number of cases, and apply the typology without shared operational criteria or pursuing specific empirical research purposes. A number of illustrative examples exist. Bellandi et al. (2021) examine Macerata and Fermo as cases of path extension and renewal, showing how internationalisation activities reshape knowledge configurations through interactions between core and non-core firms. Isaksen and Trippl (2017) highlight how path creation in Arendal and Mühlviertel relies on exogenous knowledge sources and policy support in peripheral contexts. Corodescu-Roșca et al. (2023) investigate the cases of Cluj-Napoca and Timișoara, identifying contrasting developmental trajectories: Cluj-Napoca illustrates path upgrading catalysed by post-accession governance reforms, while Timișoara follows a path extension trajectory anchored in long-standing university–industry collaborations. In a distinct context, Morisson and Mayer (2021) examine Vierzon as a case of path creation through unrelated diversification, where the relocation of a blockchain start-up to a declining industrial town triggered a new trajectory via institutional mobilisation and symbolic repositioning. However, the link between development paths and the twin transition remains largely unexplored. Existing studies are predominantly qualitative and lack systematic, comparative insight into how specific trajectories support the green and digital transformation. To address this gap, we conducted a structured literature review and identified about thirty empirical case studies that could be consistently classified using the path development typology. This corpus forms the empirical foundation for our analysis.

Table 1. Types and mechanisms of regional industrial path development

Type of path development	Definition
Path extension	Continuation of an existing industrial path based on incremental innovation in existing industries along well-established technological trajectories.
Path upgrading	Major change of a regional industrial path related to enhancement of position within global production networks; moving up the value chain based on upgrading of skills and production capabilities.
I – Climbing GPN	
II – Renewal	Major change of an industrial path into a new direction based on new technologies or organisational innovations, or new business models.
III–Niche development	Development of niches through the integration of symbolic knowledge.
Path importation	Setting up of an established industry that is new to the region (for example, through non-local firms) and unrelated with existing industries in the region.
Path branching	Diversification into a new related industry for the region building on competencies and knowledge of existing industries.
Path diversification	Diversification into a new industry based on unrelated knowledge combinations.
Path creation	Emergence and growth of entirely new industries based on radically new technologies and scientific discoveries or as an outcome of search processes for new business models, user-driven innovation and social innovation.

Beyond these empirical limitations, a further constraint lies in the conceptual assumptions of the framework. While the typology captures a broad spectrum of regional transformation processes, it typically treats development paths as discrete and distinct. In reality, regional change often results from hybrid, overlapping, or even conflicting paths shaped by the interaction of multiple actors and institutional logics (Binz et al., 2016a; Grillitsch et al., 2018). This complexity becomes particularly salient in the context of the twin transition, which requires the simultaneous pursuit of decarbonisation and digitalisation. These processes often involve concurrent mechanisms of the typology but demanding a more integrated analytical lens.

To the best of our knowledge, no study has systematically examined whether—and how—specific combinations of path development underpin regional engagement in the twin transition. Nor has the typology been empirically validated through comparative, cross-regional evidence. To fill this gap, we propose a configurational framework that links types of path development with twin transition based on a structured literature review of empirical cases. Because regional transformation results from complex causal structures, fsQCA is particularly well suited to identifying the combinations associated with twin transitions outcomes (Ragin, 2014). Our empirical focus is on Italian regions, selected for their structural diversity and relevance within EU transition policy.

As shown in figure 1, this study forms part of a broader research project centred on simulating regional policy scenarios through an agent-based model. The empirical component—grounded in a systematic review of case-based evidence—complements the ABM by strengthening its empirical underpinnings. Building on this foundation, the fsQCA analysis integrates the path development framework with observed enabling conditions, generating policy-relevant configurations and transition scenarios that may inform scenario design within simulation models.

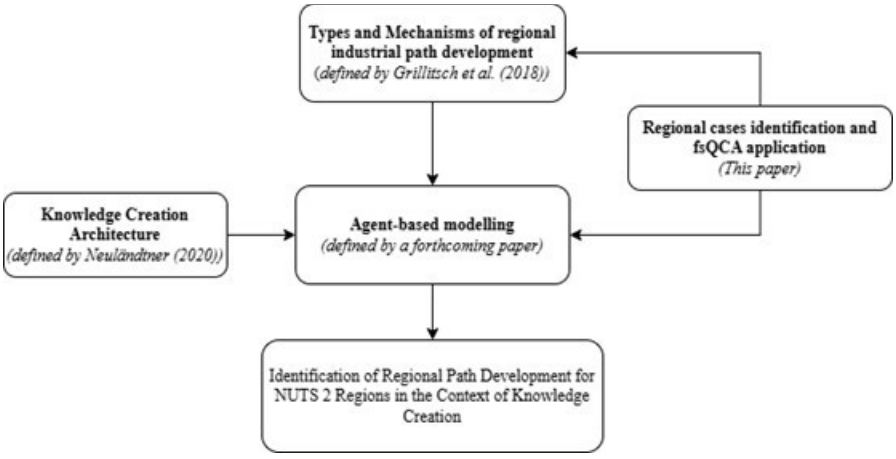


Figure 1. Pilot case for twin transition within the thematic priority of transformation pathways and strategies

3 Methodology

Based on the conceptual framework outlined above, we conducted a structured literature review aimed at identifying empirical studies that explicitly apply the paths development typology across regional contexts. The review followed a multi-stage protocol.

We queried Scopus using a combination of relevant keywords—including “regional innovation”, “pathway”, “path development”, “smart specialisation”, “industrial district”, “extension”, “branching”, “diversification”, “upgrading”, “importation”, and “creation”. The search was limited to peer-reviewed articles written in English. No restriction was placed on geography or time. Exclusion criteria were applied to filter out studies from unrelated disciplines (e.g., psychology, medicine, arts and humanities). Each abstract was screened for references to European countries and NUTS-2 regions to focus the selection on case studies. This yielded a set of 228 publications. Thirteen items were subsequently excluded due to the unavailability of full-text access, resulting in a final corpus of 215 articles subjected to full-text analysis. Additional papers were included based on the research team’s expert judgement. In total, 33 cases were systematically classified according to their dominant path development trajectory. Figure 2 summarises the literature review protocol.

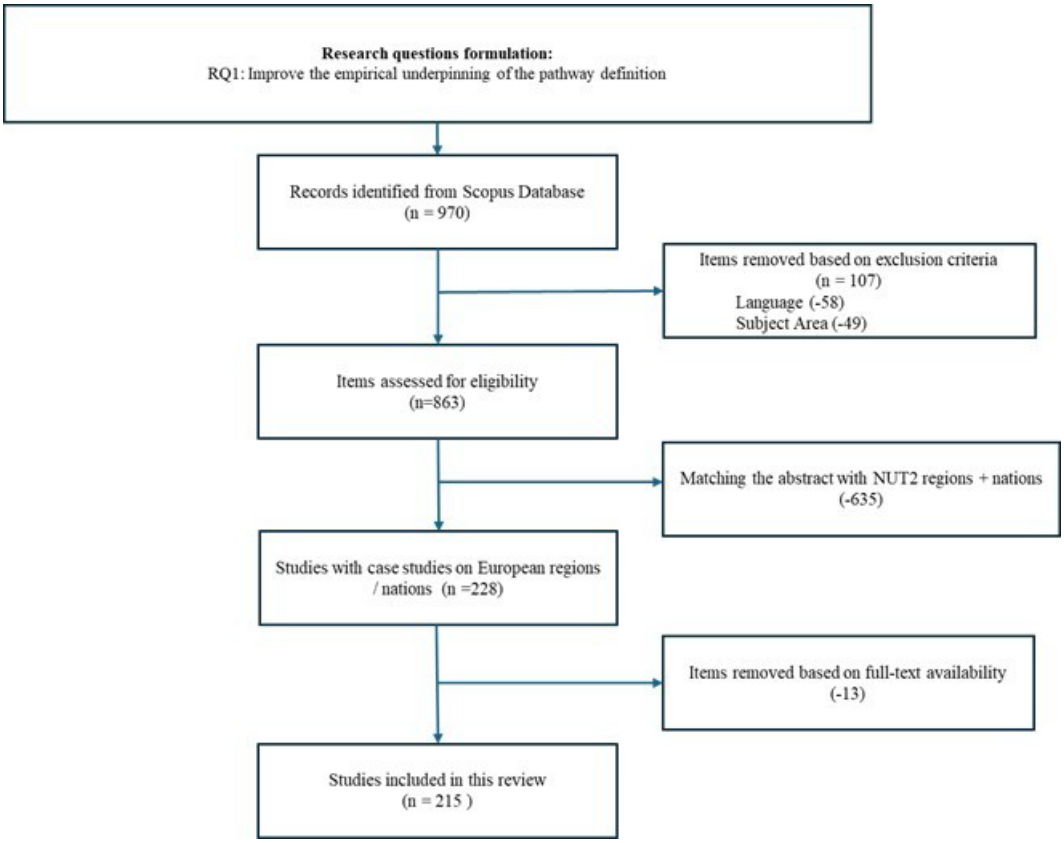


Figure 2. Literature review protocol

The outcome of the systematic review is summarised in Table 2, which reports the reference of the empirical case, the regional context investigated, and the corresponding types of regional development path (RDP) identified. This review was conducted by applying the taxonomy drawn from the literature (Grillitsch et al., 2018) to each case, based on the mechanisms explicitly described by the original authors. This systematic review provided the empirical foundation for the selection of causal conditions used in the fsQCA analysis.

Building on the review of regional development paths, we adopt a configurational approach to investigate whether specific combinations of path types are conducive to twin transitions. This methodological choice is grounded in a growing body of literature that conceptualises regional innovation systems as Complex Adaptive Systems —dynamic structures characterised by non-linearity, feedback loops, and emergent properties arising from interactions among heterogeneous agents (Ponsiglione et al., 2018). These systems are not reducible to simpler additive components, thus requiring approaches that prioritise interdependencies and context-specific mechanisms (Cooke, 2013).

Table 2. Regional Cases Classified by Path Development Mechanisms

Reference	Region	RDP
(Morisson & Mayer, 2021)	Vierzon	Path creation, Unrelated diversification
(Bellandi et al., 2021)	Macerata, Fermo, Sassuolo	Path Extension, Path Renewal
(Isaksen & Trippl, 2017)	Arendal-Grimstad, Mühlviertel	Path creation
(Trippl & Otto, 2009)	Styria, Saarland	Path creation, Path extension, unelated diversification
(Asheim, 2019)	Mazovia, Emilia Romagna	Path creation, Unrelated diversification, Path importation, Path upgrading
(Chaminade et al., 2019)	Prato, Boras	Path creation, Path extension, Path renewal
(Ostapenko et al., 2024)	Douro	Related branching, Path renewal
(Nieth & Radinger-Peer, 2023)	Aalborg, Kaiserslautern, Twente	Path creation, Path extension, Path upgrading, Path importation
(Nilsen & Njøs, 2022)	Norway	Path importation
(Corodescu-Roșca et al., 2023)	Timisoara, Cluj Napoca	Path extension, Path upgrading
(Binz & Gong, 2022)	California, Hamburg	Path creation, Path importation
(Wang et al., 2012)	Zhongguancun, Bangalore, Silicon Valley	Path creation
(Cassia et al., 2008)	Cambridge, Goteborg, Baden-Württemberg, Singapore, Pittsburgh, Milwaukee	Path renewal
(Simmie, 2012)	Denmark	Path creation
(Isaksen, 2015)	Lister	Path creation, Path extension
(Binz et al., 2016b)	Beijing	Path creation

This complexity is further emphasised by the need to account for geographically mediated knowledge transfer, influenced by institutional frameworks, scientific infrastructures, financial systems, and policy environments (Asheim et al., 2011). A configurational methodology such as fsQCA is particularly well suited to investigating these dynamics, as it captures the causal asymmetry and equifinality that typify socio-economic transformation in regional contexts (Ragin, 2014; Rihoux & Ragin, 2012).

Unlike regression-based techniques, fsQCA does not assume additive or independent effects, but instead focuses on identifying combinations of conditions that are jointly sufficient for a given outcome (Schneider & Wagemann, 2009). This approach also aligns with the configurational paradigm in innovation studies, which emphasises that socio-economic outcomes emerge from specific combinations of interdependent conditions, rather than the net effects of isolated variables (Misangyi et al., 2017).

In this study, fsQCA is applied to Italian NUTS-2 regions, where the outcome corresponds to revealed technological advantage (RTA) score in twin transition domain. Both the outcome and causal condition variables were calibrated into fuzzy sets using the direct method. Each condition is first tested for necessity, adopting a consistency threshold of 0.90. Subsequently, sufficiency is assessed by constructing and logically minimising the truth table, following standard procedures to derive complex, intermediate, and parsimonious solutions. A minimum consistency threshold of 0.65 was applied to identify configurations considered empirically sufficient. The analysis was performed using fsQCA 3.1 software.

4 The model

This section describes the model used to investigate how combinations of regional development paths influence technological specialisation in twin transition domains.

The selection of causal conditions builds on both theoretical insights from EEG and empirical patterns emerging from the literature review. In particular, the conditions reflect two overarching categories: structural assets, which shape the baseline capacity of regions to innovate and diversify, and enabling mechanisms, which activate or sustain transformative processes.

Table 3 presents the set of causal conditions included in the analysis, along with their operational definitions, sources, the association with different typed of path development, and the references.

Table 3. Causal Conditions

Label	Dimension	Index	Source	References
UV	Unrelated Variety	Unrelated Variety	Eurostat	(Frenken et al., 2007)
EKIA	Structural complexity	Employment in Knowledge-intensive activities	Regional Innovation scoreboard	(European Commission, 2023)
FDI	FDI Intensity	FDI inward stock % GDP	OECD	(Fu, 2007)
ICOLL	Collaborative R&D activity	Innovative SMEs collaborating with others	Regional innovation Scoreboard	(European Commission, 2023)
PP	Policy Pressure	Historic EU payments annual timeseries - modelled	Cohesion Data	(Mohl & Hagen, 2010)
RII	Innovation Performance	Regional Innovation Index	Regional Innovation Scoreboard	(European Commission, 2023)
NEWB	Entrepreneurial Activity	Business entries	OECD Data Explorer	(Fritsch, 2011)

The outcome is constructed using the indicator of revealed technological advantage (RTA), a widely used proxy for regional technological specialisation derived from patent data (Balland et al., 2019). RTAs were calculated separately for green and digital technologies using regionalised patent application data from the OECD REGPAT database. Green technologies correspond to the "environment-related technologies" domain, while digital technologies include patents classified under "ICT" and "artificial intelligence-related technologies", following the OECD taxonomy. It is calculated as follows:

$$RTA_{r,d} = \frac{\frac{P_{r,d}}{P_r}}{\frac{P_d}{P_T}}$$

where:

- $P_{r,d}$ is the number of patent applications in domain d filed in region r,
- P_r is the total number of patent applications filed in region r,
- P_d is the total number of patent applications in domain d across all regions,
- P_T is the total number of patent applications in all domains and regions.

An RTA value greater than 1 indicates that a region is more specialised than the national average in that domain. We construct three outcome variables: green RTA, digital RTA, and twin transition RTA A region is considered engaged in the green or digital transition in a given year if its RTA exceeds 1 in the respective domain. Engagement in the twin transition is defined as meeting both conditions (green RTA > 1 and digital RTA > 1) in the same year. For each region, we compute the number of years (2018–2021) in which this twin condition is satisfied. The outcome is calibrated into fuzzy scores as follows: 0 years = 0.00 (full non-membership), 1 year = 0.33 (weak membership), 2 years = 0.66 (crossover), and 3–4 years = 1.00 (full membership). This dynamic operationalisation captures the persistence of twin specialisation over time.

5 Results

The necessity analysis confirms that no individual condition satisfies the established consistency threshold of 0.90 for necessity, indicating that none of the enabling factors is universally present across regions engaging in the twin transition. The highest consistency is observed for unrelated variety (0.71) and entrepreneurial activity (0.64), but neither is systematically present in all positive cases. This supports the configurational logic of the study, where regional engagement emerges from context-specific combinations of enablers. Summary results are provided in Table 4.

Table 4. Necessity analysis for the twin transition outcome.

Causal Condition	Consistency	Coverage
EKIA	0.600925	0.472031
ICOLL	0.533521	0.439423
NEWB	0.641922	0.477724
FDI	0.564872	0.463005
UV	0.706146	0.508689
PP	0.599844	0.508321
RII	0.546390	0.440798

The sufficient analysis identifies six solutions sufficient to explain regional engagement in the twin transition. These configurations reflect diverse combinations of structural and institutional enablers and are interpreted through the lens of path development, drawing on empirical case knowledge. The overall solution coverage is 0.91, while the overall solution consistency is 0.75. Table 5 presents the complex solutions with core (large circles) and peripheral conditions (small circles) and their associated regional cases and path types.

Table 5. Sufficiency analysis for the twin transition outcome

	1	**2**	**3**	**4**	**5**	**6**
EKIA	●	⊗	⊗	⊗	●	●
ICOLL	⊗	⊗	⊗	●	⊗	●
NEWB	⊗	●	●	⊗	⊗	●
FDI	⊗		●	⊗	●	●
UV		⊗		⊗	●	●
PP	⊗	●	●	⊗	⊗	●
RII	⊗	⊗	⊗	●	●	●
Consistency	0.861	0.732	0.636	0.683	0.799	0.686
Raw coverage	0.283626	0.188135	0.250357	0.112691	0.0788863	0.253384
Unique coverage	0.21112	0.0287886	0.0907133	0.0828447	0.0331668	0.249775
Cases with greater than 0.5 membership in term	Abruzzo (0.5422,0.67) Basilicata (0.5422,0.67)	Sicilia (0.7274,0.67), Calabria (0.5249,0.33)	Campania (0.9208,0.33) Puglia (0.7670,0.67) Sicilia (0.7274,0.67)	Provincia Autonoma di Trento (0.7274,0.67)	Liguria (0.5382,0.67)	Piemonte (0.9375,0.67), Lazio (0.6734,0.67), Lombardia (0.6609,0.67)
RDP	Path extension	Path Creation	Path Creation Path importation	Path Upgrading	Path Upgrading Path importation	Path Upgrading Path Creation Path Branching Path Importation Unrelated diversification

Among the six solutions identified, only two exceed the standard consistency threshold of 0.75 and can be considered informative. These configurations offer a differentiated view of how distinct path development mechanisms interact with enabling conditions to support regional engagement in the twin transition.

The first solution corresponds to a path extension trajectory, observed in Abruzzo and Basilicata. It combines low levels of innovation, policy support, and external knowledge flows, while showing sufficient consistency to be considered conducive to the outcome. This suggests that, under specific conditions, even inertia-based trajectories may result in partial alignment with transition goals—though likely in a limited or structurally fragile form. The fifth configuration aligns with a hybrid of path upgrading and importation, observed in Liguria. It combines cognitive sophistication, innovation performance, and foreign investment—factors typically associated with more advanced forms of regional transformation. This configuration points to a cumulative logic, in which external inputs complement existing capacities to support the twin transition.

These findings substantiate the configurational premise of the study: twin transition outcomes are not driven by single dominant paths, but by multiple viable combinations of path development and enablers. These results reinforce the need for differentiated, place-based policy strategies: while structurally advanced regions may leverage upgrading and knowledge recombination, weaker areas require targeted support and institutional agency to activate new paths.

6 Conclusion

This paper has investigated whether different combinations of regional path development mechanisms are conducive to the twin transition. Drawing on a structured literature review and a fsQCA applied to Italian NUTS-2 regions, we proposed a configurational approach linking path development trajectories to empirical patterns of structural and institutional conditions. The findings support the assumptions of causal complexity and equifinality: no single condition is necessary, and multiple sufficient configurations are associated with twin transition outcomes. Importantly, the emerging configurations reveal combinations of path mechanisms underscoring the interdependence of trajectories rather than their mutual exclusivity.

Thus, our results suggest that diverse development paths —such as extension, upgrading, and importation— can support regional engagement, depending on their interaction with enabling conditions like innovation capacity, foreign direct investments, and institutional support. This reinforces the need for policy approaches that are sensitive not only to regional structural diversity, but also to the combinatory nature of development paths.

The contribution of this study is intended to be twofold. Conceptually, the study advances the empirical operationalisation of the path development framework. Methodologically, it introduces a configurational approach to regional transition analysis grounded in empirical evidence.

Nonetheless, this study has limitations. Calibration thresholds may influence sensitivity; fsQCA's cross-sectional design limits temporal inference; and the classification of regions into discrete path types is a simplification that does not fully capture the hybrid and overlapping nature of real-world trajectories.

Future work should extend this framework to cross-country comparisons and adopt dynamic QCA to capture the temporal sequencing of regional transformations. Integration with policy evaluation tools could further enhance its relevance for place-based transition strategies.

7 Ethics declaration

This research did not require ethical approval, as it is based exclusively on publicly available secondary data and does not involve human participants, personal data, or sensitive information.

8 AI Declaration

During the preparation of this work the authors used ChatGPT 4o in order to check grammar and spelling of the work and to improve the language style. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Addressing the Complexity of the Green Hydrogen Value-Chain: An Agent-Based Modelling Approach

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Abstract

The global energy sector is undergoing a deep transition to mitigate climate change and enhance energy security through sustainable sources (International Energy Agency, 2023). Green hydrogen (GH2) has emerged as a strategic solution for decarbonizing hard-to-abate sectors, aligning with Paris Agreement targets to limit global warming to 1.5°C (Deloitte, 2023; Fuel Cells and Hydrogen 2 Joint Undertaking, 2019). The GH2 value chain operates as a complex adaptive system, characterized by nonlinear relationships, emergent behaviors, and evolving stakeholder interactions (Peyerl & van der Zwaan, 2024; Zhang & Li, 2024). This work examines the economic, social, and environmental impacts of innovations in GH2 production within a European-funded project focused on developing a photocatalytic reactor for water splitting into hydrogen and high-value co-products. Using an Agent-Based Model (ABM) developed in NetLogo, the research simulates stakeholder interactions, capturing emergent dynamics often overlooked by traditional top-down models (Macal & North, 2010). The model is able to estimate the number of plants required to meet Spain's GH2 demand by 2030 (Pawelec et al., 2023) and highlights how stricter sustainability criteria can promote best practices, stimulate innovation, and open economic opportunities. The model demonstrates the strategic potential of GH2 in driving decarbonization, technological advancement, and social inclusion. Moreover, by embedding sustainability across the value chain, the ABM provides policymakers and industry stakeholders with actionable insights to optimize GH2 deployment, lower costs, and support the broader transition to a low-carbon energy system (World Economic Forum, 2021). This research contributes to the growing body of knowledge needed to guide future investments, policy frameworks, and cross-sector collaborations.

Keywords: Green Hydrogen, Agent-Based Modelling, Innovation, Sustainability, Complexity

Paper type: Academic Research Paper

1 Introduction

Climate change, shaped historically by geological processes, has driven major extinctions. Human industrial activities have intensified greenhouse gas emissions, severely impacting ecosystems (Zou et al., 2021). Over time, the Conference of the Parties and various international agreements have committed to addressing climate change. International climate agreements have fostered national policies for emission reduction and sustainability. This has played a crucial role in building capacity for greenhouse gas reporting, accounting, and the creation of emission markets (Calvin et al., 2023). Hydrogen, strongly supported by science and policy, has emerged as a key energy carrier due to its potential to store energy without CO_2 emissions, enabling a sustainable energy transition. As global efforts to mitigate climate change intensify, the focus on hydrogen production technologies has gained renewed attention, particularly for their potential to support deep decarbonization (Goel & Sen, 2024). Currently, approximately 96% of global hydrogen production relies on fossil fuels (Hwang et al., 2023; Kamil et al., 2024) with only a small share generated through electrolysis. This latter method, which produces so-called green hydrogen, is widely regarded as the most promising pathway for large-scale decarbonization (Capurso et al., 2022), due to its minimal environmental impact (Kochanek, 2022). Green hydrogen has the potential to replace fossil fuels particularly in hard-to-abate sectors, where alternative low-carbon solutions remain limited (Griffiths et al., 2021; Kovač et al., 2021). This research explores the economic, social, and environmental implications of green hydrogen production based on a novel photocatalytic reactor, developed within a European-funded project. The study examines how GH2 adoption, alongside co-product valorization and access to certification markets, could reshape value chains and support sustainability-oriented business models. To this end, an Agent-Based Model is developed to simulate interactions among stakeholders across the GH2 value chain. The choice of an ABM approach is particularly justified by the complex and interconnected nature of the GH2 system (Peyerl & van der Zwaan, 2024), which involves a diverse set of actors, ranging from renewable energy producers and industrial manufacturers to end consumers. The interactions between these agents create dynamic value chains characterized by non-linearity, interdependencies, and emergent behaviors—features that are difficult to capture using traditional top-down modeling approaches. Conventional models typically rely on predefined agent characteristics and deterministic relationships, limiting

their ability to reflect adaptive and evolving market dynamics. In contrast, ABMs adopt a bottom-up approach, capturing emergent effects through interactions among agents (Kahn, 2015). This modeling work has been carried out within the European project "GH2 – GreenH2 production from water and bioalcohols by full solar spectrum in a flow reactor" (Grant Agreement No. 101070721), which aims to develop innovative photocatalytic solutions for sustainable green hydrogen production. The technological advancements targeted by the GH2 project underpin the innovation scenarios and stakeholder interactions analyzed through the agent-based modeling framework presented herein.

2 Theoretical background

Although fossil fuels still dominate the global energy mix, their environmental impact has accelerated the shift toward cleaner alternatives. Among emerging solutions, green hydrogen is central to decarbonising energy-intensive sectors and reshaping global industrial systems (Yue et al., 2021). Its widespread adoption is expected to reshape industrial systems and create new economic opportunities for countries strategically positioned in the green hydrogen market. Value chains are essential to understanding these transformations. Eicke & De Blasio (2022) define a value chain as the broader network of business relationships that support the large-scale development and commercialization of a technology—distinct from supply chains, which focus on optimizing product or service delivery for a single stakeholder. In the case of green hydrogen, value chains encompass a diverse ecosystem of actors and activities, spanning research, production, marketing, and distribution (Peyerl & van der Zwaan, 2024). The concept of Global Value Chains (GVCs) further expands this framework, redefining international trade and industrial organization, and influencing how firms and workers contribute to the production and distribution of goods and services from conception to final use (Cattaneo et al., 2013; Porter, 1985). As GVCs become increasingly embedded in business strategies, they open new opportunities for socio-economic development. However, to fully harness these benefits and avoid systemic risks, trade, competitiveness, and development policies must be carefully aligned. Furthermore, the growing emphasis on sustainability is reshaping GVC structures, emphasizing the need for adaptive strategies in international economic relations (Cattaneo et al., 2013; Gereffi & Fernandez-Stark, 2011). At the core of global value chains is their role in establishing connections between companies, labor forces, and consumers across different regions. This interconnectedness creates opportunities for businesses and workers, particularly in emerging economies, to integrate into the global market (Gereffi & Fernandez-Stark, 2011). Today, as sustainability becomes central to industrial and policy agendas, value chains must adapt accordingly. Unlike traditional energy value chains, which rely on well-established fossil fuel infrastructures, the green hydrogen value chain requires the integration of innovative technologies, policy support, and coordinated stakeholder engagement. Robust governance structures, corporate responsibility frameworks, and stakeholder engagement strategies are essential to balancing economic, social, and environmental priorities in this transition. The shift to green hydrogen requires robust governance and corporate responsibility, with coordinated efforts among industries, governments, and communities. Corporate Social Responsibility (CSR) and stakeholder theory offer a suitable theoretical lens to analyse GH2 adoption. CSR frameworks encourage companies to align technological development with social and environmental goals (Wilburn & Wilburn, 2011),while stakeholder theory emphasizes inclusive engagement of governments, firms, and communities (Frynas & Yamahaki, 2016; Hörisch et al., 2014; Montiel & Delgado-Ceballos, 2014). Given the complex interplay between technological advancements, market dynamics, and regulatory frameworks, the adoption of green hydrogen as a clean energy carrier requires broad collaboration. This ensures equitable access to resources and maximizes the socio-economic benefits of the transition. In this framework, companies involved in green hydrogen development must not only focus on technological innovation but also on aligning their strategies with CSR principles. This includes fostering transparent governance, ensuring fair labor practices, minimizing environmental impact, and contributing to local economic development. By integrating CSR principles, businesses can strengthen their legitimacy, enhance stakeholder trust, and secure a leading role in the sustainable energy transition. These theoretical perspectives provide the foundation for modeling agent behavior within the ABM framework developed in this study, enabling the simulation of sustainability-oriented decision-making, intersectoral cooperation, and the impact of policies on the green hydrogen value chain.

3 Methodology

Given the inherent unpredictability and emergent behaviors within complex systems, traditional deterministic modeling approaches often fall short in capturing their dynamics. Complexity Theory suggests that such systems evolve through self-organization and adaptive interactions, making them difficult to analyze using rigid, top-down frameworks (Etkin, 2016). This is particularly relevant for the green hydrogen value chain, which

consists of a vast and interconnected network of stakeholders, ranging from agricultural producers to industrial end-users. These actors engage in multiple layers of interactions, forming highly intricate value chains that exhibit non-linear dynamics. Such interdependencies cannot be effectively captured through conventional models, which typically rely on top-down structures where individual agents are pre-programmed with fixed characteristics and behaviors. In contrast, Agent-Based Models adopt a bottom-up approach, wherein agents dynamically interact with both other agents and their environment. These localized interactions give rise to emergent system-wide behaviors that are not directly predictable from individual-level actions (Columbia University Mailman School of Public Health., n.d.). This adaptive and decentralized nature of ABMs makes them particularly well-suited for analyzing complex and evolving value chains, such as those observed in the GH2 sector. Moreover, ABMs enable the exploration of emergent phenomena, allowing researchers to study how policy changes, market dynamics, and technological innovations propagate through the hydrogen economy (Klugl & C Bazzan, 2012). Given these advantages, the adoption of an ABM framework provides a robust methodological foundation for examining the GH2 value chain's structure, adaptation mechanisms, and long-term sustainability.

3.1 Model overview

The agent-based model is designed to simulate the structure, evolution and sustainability performance of the green hydrogen value chain. Heterogeneous stakeholders are involved in decentralized decision-making processes, forming supply chains that dynamically evolve based on economic, environmental and social criteria. Through these interactions, the model reproduces the complex emerging dynamics that characterize real-world innovation ecosystems and sustainability transitions. To reflect the spatial and temporal dimensions of the GH2 supply chain, the model operates at two interrelated levels. Temporally, the simulation unfolds in monthly time steps (ticks), enabling the monitoring of seasonal cycles and annual production flows. Spatially, the model encompasses a transcontinental network from sugarcane farms and biorefineries in Brazil to hydrogen production and certification centers in Europe. While geographic coordinates are currently abstracted, future versions will integrate real-world distances and positions to enhance spatial realism. Designed as a decision-support tool, the model allows users to explore how different policy instruments, investment strategies, and market incentives propagate through the value chain. It helps assess the systemic impact of innovation adoption, sustainability certification, and stakeholder coordination.

3.1.1 Agent typologies

The model simulates a heterogeneous set of agents, which interact dynamically, forming decentralized networks that evolve over time to support the production and distribution of green hydrogen and related co-products. Each type of agent is defined by specific roles, behavioral rules, and decision-making strategies that reflect their position within the supply chain, and role in actual value chains. The supply chain starts with farmers; they are responsible for growing sugarcane, the main raw material used for bioethanol production. Ideally, they are located in Brazil, where there is most of the world's sugarcane production (Bordonal et al., 2018). Then the processed sugarcane is transported by first movers, who handle the road transport from agricultural sites to first-tier processing plants. First production plants are modeled as biorefineries that convert sugarcane into sugar, bioethanol, and bioelectricity once they receive their input. These plants play a central role in the system as they generate both energy products and intermediate goods essential for further processing. Second transporters handle maritime logistics between Brazil and Europe. Their role is to ensure the efficient and timely shipment of bioethanol to European processing plants, which are assumed to be located in Spain. By simplifying suppositions, the model abstracts the intermediate steps of transportation and assumes a direct link between Brazilian ports and Spanish plants. Second production plants, represent the final transformation stage, where imported bioethanol is converted to green hydrogen using advanced photocatalytic technologies. In addition to generating green, zero-impact hydrogen, these new plants produce high-value chemical by-products such as acetic acid, acetal, and acetaldehyde, thus improving the economic viability of the process. The value chain is governed by regulatory bodies, which act as institutional agents responsible for ensuring compliance throughout the entire supply chain by certifying sustainable production practices. These entities are capable of monitoring adherence to environmental, economic, and social sustainability standards and play a pivotal role in enabling access to the green certificate market. Their decisions influence agent behavior through a system of incentives and sanctions, thereby promoting the adoption of sustainable practices. Each agent is characterized by a set of internal attributes that evolve over time through interactions and feedback from the environment. These differentiated agent types and their interconnections form the foundation of the model's ability to simulate emergent behaviors and adaptive system dynamics.

3.1.2 Production and market mechanisms

Agents are distributed across two complementary market mechanisms: one segment represents the conventional market, focused on the exchange of tangible products, while the other captures an alternative market based on green certificates. This second mechanism serves as an incentive system that rewards supply chains meeting predefined sustainability criteria. The model supporting the green hydrogen value chain unfolds in three distinct phases: *Build Supply-Chain Networks*, *Supply-Chain Networks Development* and *Supply-Chain Networks Growth*. Each agent type follows specific production dynamics, decision-making routines, and market behaviors, collectively generating emergent system-level outcomes. The underlying mechanism is illustrated in Figure 1:

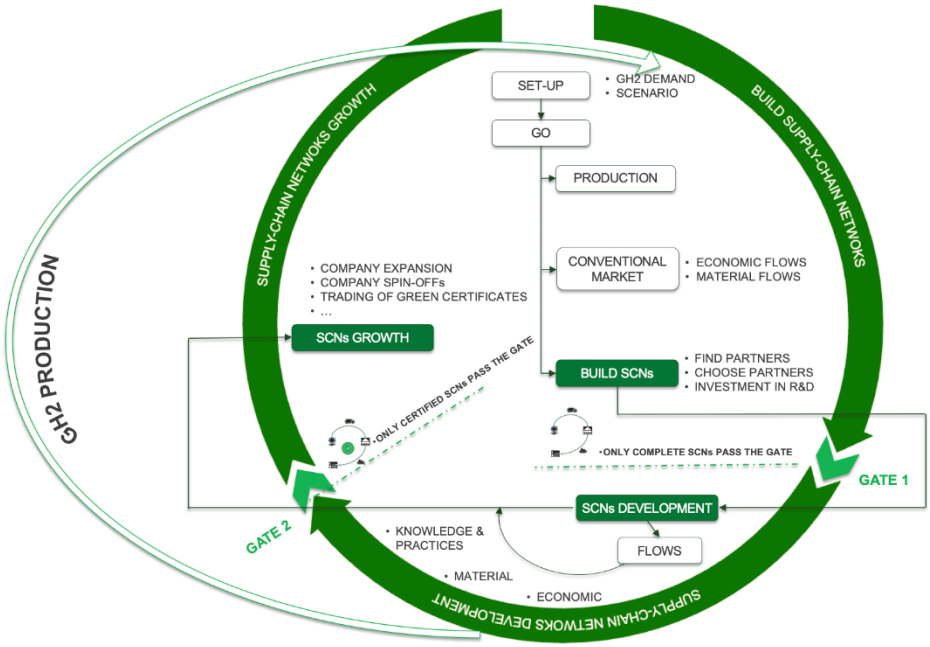


Figure 1: Structure of The Model

The simulation begins with agents autonomously identifying and selecting potential partners based on multiple criteria, including price, distance, technological performance, and sustainability orientation. Once a partner and a transporter are chosen, a link is established between the agents. These links represent supply relationships, enabling the flow of goods and services throughout the value chain. During this phase, agents actively construct supply chains by evaluating their production capacity, market demand, and alignment with prospective partners. The successful formation of a complete supply chain—from farmers to GH_2 production plants—allows the network to pass through the first decision gate (*Gate 1*), enabling the initiation of operations. The second phase focuses on the internal dynamics of the supply chain. Production flows are activated based on the capacity and operational efficiency of each actor. Output volumes are determined by technology levels, workforce availability, and current operating conditions. The production of GH2 and its co-products is modeled through resource transformation processes that simulate technological conversion efficiency based on stoichiometric chemical relationships. During this phase, the model assesses environmental, economic, and social impacts, enabling a collective evaluation of network performance. Stable supply chains that meet specific thresholds pass through *Gate 2* and gain access to the alternative certification market. In the third phase, agents demonstrating resilience, innovation, and sustainability are granted access to green certificate markets and can further expand their operations. Certification mechanisms are fully embedded within the model and account for life cycle emissions and resource efficiency across the entire supply chain. Agents are rewarded with financial incentives based on avoided emissions and verified sustainability performance. Conversely, agents that fall short of certification thresholds may face penalties or be required to purchase credits on the secondary market. Regulatory entities enforce these mechanisms and safeguard systemic integrity. The model's decentralized logic—based on individual decision-making, dynamic partner selection, and iterative adaptation—enables the emergence of value networks that vary in performance, structure, and market orientation, thereby realistically simulating the behavior of actual markets.

3.1.3 Tracking impact and performance

The model integrates a comprehensive impact monitoring system to assess the performance of the value chain in meeting the projected GH2 demand by 2030. This assessment is carried out through the continuous tracking of economic, environmental, and social indicators, both at the individual agent level and at the system level. These metrics are dynamically updated throughout the simulation, offering insights into the emergent outcomes produced by decentralized interactions and strategic decisions. From an *economic perspective*, the model captures the evolution of capital, operating costs, and revenue streams for each agent. It specifically monitors turnover generated from product and co-product sales within both the conventional market and certified value chain segments, as well as the levels of R&D investment and income derived from participation in alternative mechanisms such as green certificate markets. In terms of *environmental performance*, the simulation estimates CO_2 emissions, water usage, and energy consumption per production cycle. These indicators are calculated based on agent-specific emission and consumption factors across the different stages of the value chain. Tracking these variables over time allows the model to reflect the effects of technological evolution and adaptation strategies, enabling an assessment of the system's contribution to broader decarbonization and sustainability goals. With regard to *the social dimension*, the model evaluates workforce dynamics by monitoring increases and decreases in employee numbers due to overproduction cycles, as well as the spread of innovation and sustainability through learning and educational spillovers. It also tracks the number of agents exiting the system, providing a proxy for failure due to structural weaknesses or market misalignment. These social indicators contribute to a holistic understanding of the value chain's resilience and inclusiveness. Performances are not only evaluated at the individual level, but also across interconnected networks. This integrated monitoring framework supports scenario comparison and sensitivity analysis, making the model a powerful decision-support tool for policymakers and industry stakeholders. By providing ex-ante insight into the potential implications of different strategies, the model serves not only as a forecasting tool but also as a flexible and adaptable platform that can be tailored to reflect evolving real-world conditions.

3.1.4 Model parameters and calibration data

The model relies on a set of dynamic parameters that define the behavior, decision-making logic, and adaptive capacity of each actor within the green hydrogen value chain. These parameters have been carefully selected and calibrated to reflect the operational, financial, environmental, and strategic characteristics of real-world stakeholders. Rather than assigning fixed behaviors, the model incorporates heterogeneity and adaptability through a set of interrelated state variables that evolve over time in response to internal dynamics and external stimuli. At the core of the model are production-related parameters, including annual capacity levels, which represent each agent's ability to transform inputs into value-added outputs. These variables are not static; they are influenced by technology adoption, workforce availability, and strategic positioning, and are recalculated at each time step to reflect learning, investment decisions, and operational efficiency. Financial parameters—such as available capital, operating costs, and revenue generation—directly affect an agent's ability to remain competitive and resilient, influencing its capacity to engage in R&D, adopt sustainable practices, or enter new markets. Strategic orientation is modeled through innovation and sustainability parameters, which shape agents' preferences in partner selection and impact their long-term performance. These variables are endogenous: they evolve through interaction with other agents, participation in certified value chains, and investment in innovation. The simulation accounts for these dynamics by integrating feedback loops, enabling the emergence of diverse trajectories among agent populations. All parameters have been calibrated using a combination of primary and secondary sources, including academic publications, technical reports from the hydrogen and bioenergy sectors, international sustainability databases, and GH2 project-specific datasets. This structured parameterization lays the foundation for the simulation experiments discussed in the following section, where Design of Experiments techniques are applied to analyze the sensitivity of model outcomes to key variables and to explore strategic policy implications.

4 Expected results

As the experimental phase is currently ongoing, the simulation is expected to generate insights through three experimental scenarios, each designed to explore different structural or policy variables influencing the green hydrogen value chain in Spain. The *first scenario* estimates the optimal number of medium-sized second-generation production plants needed to meet the national demand for green hydrogen by 2030, assuming a fixed number of farmers and production facilities based on real-world data from the São Paulo region. Determining the ideal number of plants allows us to assess triple impacts: economic (e.g., R&D investments, revenues, income from green certificates), environmental (e.g., CO_2 emissions, energy and water consumption),

and social (e.g., employment, operator turnover, welfare distribution). The *second scenario* modifies the spatial configuration of key agents—such as farmers and First Production Plants—to test the model's ability to adapt to geographically heterogeneous systems. This experiment evaluates how location shifts influence value chain efficiency, economic returns, and systemic resilience. The *third scenario* analyzes the effect of environmental certification thresholds on market access and enterprise behavior. By adjusting innovation requirements for certification (e.g., under schemes like CertifHy), the model explores how policy design can influence green hydrogen demand, stimulate technological adoption, and foster sustainable entrepreneurship. All scenarios are monitored by considering the co-production of chemical by-products — such as acetal, acetic acid, and acetaldehyde — which significantly affect process efficiency, production cycles, and the overall issuance of green certificates. The experimental analysis provides a robust framework for interpreting system dynamics under varying infrastructural, geographical, and policy design conditions, allowing for a comparative assessment of which by-product is most advantageous to valorize according to the specific needs of the value chain. A key insight emerging from these simulations is the potential to commercialize by-products on secondary markets, thereby generating additional revenue streams beyond the primary hydrogen production. This secondary market not only enhances the economic sustainability of the entire value chain, but also becomes a critical parameter in scenario evaluation: the choice of which by-product to valorize can thus be driven not only by technical considerations, but also by its marketability, contributing to more integrated and circular production strategies.

5 Conclusion

This study has developed an agent-based model to simulate the structure, evolution, and sustainability of green hydrogen value chains, with the aim of providing a decision-support tool for the energy sector. By capturing the adaptability and heterogeneity of the actors involved, the model offers a realistic representation of the complexity that characterizes decarbonization processes. From a scientific perspective, this work contributes to the discourse on sustainability transitions and complex systems by introducing a flexible methodology to analyze alternative scenarios and design targeted policies. On the practical side, the model delivers operational insights for policymakers, businesses, and stakeholders, allowing for the ex-ante exploration of the systemic impacts of technological innovations, regulatory measures, and spatial configurations. Although the model successfully captures the key dynamics of emerging value chains, its current structure has not yet been fully calibrated on a real-world case, an activity planned for future developments. In particular, it will be necessary to integrate real geospatial data, perform a more precise calibration of parameters using empirical datasets, and implement dynamic scenarios applied to specific case studies. Looking ahead, the model can evolve into an interactive and participatory platform—supporting co-design processes, strengthening cross-sector collaboration, and guiding sustainable development strategies in the green hydrogen sector. The model's modular architecture also allows it to be adapted to different national contexts, application sectors (such as industry, mobility, or decentralized energy systems), and strategic goals. This flexibility makes it a promising tool to support the energy transition toward more equitable, resilient, and low-carbon systems.

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7 Ethics declaration

No ethical approval was required for the research presented in this paper.

8 AI declaration

During the preparation of this manuscript, the authors made use of ChatGPT-4.0 to support grammar and spelling checks, as well as to enhance the overall language style. This tool was used strictly to improve the clarity and fluency of the text, given that the authors are not native English speakers. The intellectual content of the work remains entirely original and unaltered, and the tool was not used in the design, coding, or execution of the computational model. The authors have thoroughly reviewed and revised the entire manuscript and assume full responsibility for its final content.

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Organisational Resilience and Decision-Making Modes: An Agent-Based Analysis

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Abstract

Organisational resilience, defined as the capacity to absorb and recover from shocks affecting an organisation's operations, becomes increasingly more important in today's environment. While existing research has mainly explored structural and strategic factors contributing to organisational resilience, the role of managerial decision-making modes in this context remains underexamined. This paper addresses this gap by developing an agent-based model that simulates how different modes of decision-making affect resilience. The model captures stylised organisations as collections of interdependent departments operating on performance landscapes with varying complexity. The study compares silo-based, sequential, collaborative, and proposal-based decision-making across 144 simulated scenarios, incorporating shocks of varying severity. The results reveal that collaborative and proposal-based decision-making modes enhance shock absorption and recovery in complex task environments, while simpler modes perform well in settings where tasks are less complex. Proposal-based coordination offers balanced performance.

Keywords: Organisational resilience, decision-making modes, agent-based modelling, disruptions, task interdependence

Paper type: Academic Research Paper

1 Introduction

The growing probability of disruptions, including economic, technological, and operational disruptions, makes it crucial for organisations to respond to crises and develop capabilities, enabling them to anticipate, absorb, adapt to, and recover from shocks. However, how daily business practices affect an organisation's resilience remains largely unknown (Kantabutra and Ketprapakorn, 2021). A large proportion of existing research has focused on coping strategies and how they can be employed during and after shocks. More recently, the focus has shifted to strategies to anticipate shocks and how to prepare organisations to remain effective during crises (Grego et al., 2024). Another stream of research has analysed resilience through the lens of organisational structure, resource allocation, and strategic decision-making mechanisms (Banihashemi et al., 2024; Dahmen, 2023; Garcia-Diaz, 2024; Swaminathan, 2022). For instance, Leitner (2025a, 2023) explores how emergent task allocation affects an organisation's resilience, and You and Williams (2023) conclude that the design of intra-organisational relationships is key to increasing organisational resilience. However, a significant gap remains unexplored: how do models of managerial decision-making – that is, modes of generating and coordinating decisions – shape an organisation's capability to deal with shocks? Even though this dimension appears to be a critical determinant for organisational resilience, it has only received limited attention in research.

This paper addresses this gap by developing an agent-based model of a stylised organisation to analyse how different decision-making modes affect an organisation's ability to absorb and recover from shocks. The model is based on the NK framework (Levinthal, 1997; Wall et al., 2024; Wall and Leitner, 2021) that allows for modelling interdependent decision-making in organisational contexts. Specifically, the stylised organisations are conceptualised as a collection of departments that jointly operate on a performance landscape representing the task environment, whereby the ruggedness of the landscape is externally controlled and shaped by the interdependencies between tasks. Decision-making modes are conceptualised as different modes of how information is shared between departments and how adaptation finally takes place. The key decision-making modes analysed include proposal-based, silo-based, collaborative, and sequential approaches. The results indicate that not all decision-making modes are equally effective, depending on the complexity of an organisation's task. Decision-making modes that facilitate information exchange and mutual adaptation are advantageous in complex task environments, whereas simpler methods work well when organisational departments work on less complex tasks.

The remainder of the paper is structured as follows: Section 2 introduces the model and discusses the scenarios analysed in this paper. Section 3 presents and discusses the results. Section 4 concludes the paper.

2 Model and simulation experiments

This paper's model of a stylised organisation builds on the NK framework (Levinthal, 1997; Wall and Leitner, 2021). The model is populated by $M \in \mathbb{N}$ agents representing departments. Agents operate on a NK-landscape that defines the task environment. More specifically, the task environment captures an N-dimensional binary decision problem ($N \in \mathbb{N}$) with $K \in \mathbb{N}_0$ interdependencies between decisions, shaping the complexity of the decision problem.

2.1 Task environment and decomposition

Let us denote the N-dimensional decision problem by $\boldsymbol{d} = [d_1, \dots, d_N]$, where $d_i \in \{1, 0\}$ and $n = 1, \dots, N$. Each decision d_i contributes $f(d_i) \sim U(0,1)$ to overall organisational performance. There exist K interdependencies between decisions, which is why the contribution of the decision $f(d_i)$ in addition to d_i is affected by K other decisions. Let us formalise this payoff function by $f(d_i) = f(d_i, d_{i_1}, \dots, d_{i_K})$, where $\{i_1, \dots, i_K\} \subseteq \{1, \dots, i-1, i+1, \dots, N\}$. The overall performance of a solution vector $\boldsymbol{d}$ to the decision problem is defined as the average of all performance contributions: $P(\boldsymbol{d}) = 1/|\boldsymbol{d}| \sum_{i=1}^{N} f(d_i)$.

The decision problem $\boldsymbol{d}$ is sequentially and symmetrically divided into M disjoint sub-problems, and every department oversees one sub-problem, each consisting of $Q = N/M$ decision-making tasks. The allocation follows the following rule: $d_m = [d_{\{Q\cdot(m-1)+1\}}, \dots, d_{\{Q\cdot m\}}]$. In consequence, when there are $N = 15$ decisions and $m = 5$ departments, every department oversees 3 decisions.

2.2 Shocks to the task environment

The task environment might be affected by shocks. Specifically, the performance contributions $f(d_i)$ can change due to disruptions in the organisation's environment. Consequently, the shape of the NK-landscape might change as well. The model considers correlated shocks using a method proposed by Demirtas (2014) that uses a correlation parameter $\rho \in \{-1, 1\}$ *to* control the severity of shocks. To do so, first two random numbers $v_i \sim U(0,1)$ and $w_i \sim B(a, 1)$ are drawn, where the shape parameter of the Beta distribution is a function of the correlation parameter, $a = 1/2\left(\sqrt{49 + \rho/1 + \rho} - 5\right)$. Then, the two random numbers are used to compute the correlated performance contribution according to the following rule:

$$f^c(d_i) = \begin{cases} |w_i - f(d_i)|, & v_i < 0.5\,, \\ 1 - |1 - w_i - f(d_i)|, & v_i \geq 0.5\,. \end{cases}$$

2.3 Utility function and decision-making modes

Departments are modelled to be myopic utility maximisers, meaning they aim to immediately increase their utility (without considering long-term effects). Let us denote the utility of the department m as follows:

$$U(\boldsymbol{d}_{mt}, \boldsymbol{d}_{-mt}) = \lambda \cdot P(\boldsymbol{d}_{mt}) + (1-\lambda) \cdot P(\boldsymbol{d}_{-mt})\,,$$

where $\boldsymbol{d}_{mt}$ and $\boldsymbol{d}_{-mt}$ denote the department m's own and residual decisions, respectively, and departments are characterised by a linear incentive mechanism where the parameter λ is used to weight the department's own and residual performance.

Over time, departments can change their decisions at every time step, and departments can exchange information during this adaptation process according to the following decision-making modes (see also Blanco-Fernández et al., 2025; Siggelkow and Rivkin, 2005).

2.3.1 Silo-based decision-making

In silo-based decision-making, departments gather information independently and do not share it with their colleagues. This means that departments are unaware of their colleagues' decisions at a specific point in time and rather rely on their colleagues' behaviours $\boldsymbol{d}_{-m(t-1)}$ that have been observed in the previous period. In every period, every department identifies an alternative set of actions within their area of responsibility and in the neighbourhood of the currently implemented actions. Please note that the neighbourhood is defined by a Hamming Distance of 1 around $\boldsymbol{d}^*_{mt}$. In every period, every department must choose between either sticking with the status quo or adopting the newly discovered alternative. They do so according to the following rule:

$$\boldsymbol{d}_{mt} = \underset{\boldsymbol{d}' \in \left(\boldsymbol{d}_{m(t-1)}, \boldsymbol{d}^*_{mt}\right)}{\arg\max} U\left(\boldsymbol{d}', \boldsymbol{d}_{-m(t-1)}\right).$$

Then, the collective solution to the overall decision problem in period t is the combination of all actions taken by departments: $\boldsymbol{d}_t = \bigcup_{m=1}^{M} \boldsymbol{d}_{mt}$.

2.3.2 Collaborative decision-making

In the collaborative decision-making mode, departments are connected in a ring network, and with fixed probability P, they perform collaborative decision-making as described below. In contrast, with the likelihood of $(1-P)$, they perform silo-based decision-making.

Collaborative decision-making is implemented as adjacent hill-climbing (Yuan and McKelvey, 2004). Specifically, if departments m and n engage in collaborative decision-making, each of them identifies their alternatives $\boldsymbol{d}^*_{mt}$ and $\boldsymbol{d}^*_{nt}$ in the neighbourhood of $\boldsymbol{d}_{m(t-1)}$ and $\boldsymbol{d}_{n(t-1)}$, respectively. They share information during decision-making, which is why their joint residual decisions (i.e., the actions taken outside of department m's and n's areas of responsibility) are denoted by $\boldsymbol{d}_{-(mn)(t-1)} = \boldsymbol{d}_{t-1} \setminus \left(\boldsymbol{d}_{m(t-1)} \cup \boldsymbol{d}_{n(t-1)}\right)$.

Then, the two departments make a decision that maximises their joint utility according to the following rule:

$$\left(\boldsymbol{d}_{mt}, \boldsymbol{d}_{nt}\right) = \underset{\substack{\boldsymbol{d}'_m \in \left(\boldsymbol{d}_{m(t-1)}, \boldsymbol{d}^*_{mt}\right) \\ \boldsymbol{d}'_n \in \left(\boldsymbol{d}_{n(t-1)}, \boldsymbol{d}^*_{nt}\right)}}{\arg\max} U^{adj}\left(\boldsymbol{d}'_m, \boldsymbol{d}'_n, \boldsymbol{d}_{-(mn)(t-1)}\right),$$

where the joint utility function $U^{adj}(\cdot)$ is defined as the mean of the two individual utilities: $U^{adj}\left(\boldsymbol{d}_{mt}, \boldsymbol{d}_{nt}, \boldsymbol{d}_{-(mn)(t-1)}\right) = \frac{1}{2}\left(U\left(\boldsymbol{d}_{mt}, \boldsymbol{d}_{-m(t-1)}\right) + U\left(\boldsymbol{d}_{nt}, \boldsymbol{d}_{-n(t-1)}\right)\right)$.

2.3.3 Sequential decision-making

In the sequential decision-making mode, departments make decisions one after another, with each department passing on information about its choices to those that have yet to decide, thereby reducing uncertainty for subsequent decision-makers. For simplicity, let us assume that the decision-making order follows the department indices. This means that the department $m = 1$ starts with the decision-making procedure and informs departments 2 to M about their decisions and, thereby, reduces the uncertainty about their residual actions. Let us redefine the vector of residual decision for the sequential decision-making mode as follows:

$$\boldsymbol{d}^{seq}_{-mt} = \left(\boldsymbol{d}_{1t}, \ldots, \boldsymbol{d}_{(m-1)t}, \boldsymbol{d}_{(m+1)(t-1)}, \ldots, \boldsymbol{d}_{M(t-1)}\right).$$

As in the previous decision-making modes, department m identifies an alternative course of action $\boldsymbol{d}^*_{mt}$ in the neighbourhood of $\boldsymbol{d}_{m(t-1)}$, and next, the department assesses the two choices according to

$$\boldsymbol{d}_{mt} = \underset{\boldsymbol{d}' \in \left(\boldsymbol{d}_{m(t-1)}, \boldsymbol{d}^*_{mt}\right)}{\arg\max} U\left(\boldsymbol{d}', \boldsymbol{d}^{seq}_{-mt}\right).$$

2.3.4 Proposal-based decision-making

In the proposal-based method, departments explore and rank alternative lines of action locally and propose their ranked alternatives to a central authority. The central authority aggregates the proposals and makes the final decision, assuring global coherence of actions. Specifically, every department m identifies an alternative $\boldsymbol{d}^*_{mt}$ in the neighbourhood of the status quo $\boldsymbol{d}_{m(t-1)}$. The two options (the alternative and the status quo) are ranked concerning expected utility (using the utility function introduced in Section 2.3.1). Then, the ranked options $\left(\boldsymbol{d}^{(1)}_{mt}, \boldsymbol{d}^{(2)}_{mt}\right)$ are forwarded to a central coordinating unit. The central unit combines the proposals of all M departments by concatenating all proposals ranked first and second, respectively, according to the rule $\boldsymbol{d}^{(j)}_t = \bigcup_{m=1}^{M} \boldsymbol{d}^{(j)}_{mt}$, where $j \in \{1, 2\}$. Finally, the coordinating unit evaluates the combined proposals concerning the highest performance and makes the final decision as follows:

$$\boldsymbol{d}_t = \underset{\boldsymbol{d}' \in \{\boldsymbol{d}^{(1)}_t, \boldsymbol{d}^{(2)}_t\}}{\arg\max} P(\boldsymbol{d}').$$

2.4 Simulation experiments

The following four parameters of the model are considered variables to construct scenarios:

The performance landscape on which departments operate follows the logic of the NK model introduced above. Specifically, landscapes with two levels of complexity are considered, whereby the interactions follow the patterns in Figure 1. Specifically, in the case of (i) small diagonal blocks, tasks are organised into modular structures, meaning interdependencies exist within departments but not between them. This structure simplifies decision-making and is referred to as *decomposable tasks*, as each department operates independently. In the case of (ii) *reciprocal interdependencies*, tasks assigned to departments are highly interconnected, with interdependencies both within and between departments. This pattern requires coordinated decision-making across departments to manage complexity effectively (Leitner, 2024).

Four decision-making modes, namely (i) silo-based decision-making, (ii) collaborative decision-making (with different probabilities of *joint* decision making), (iii) sequential decision-making, and (iv) proposal-based decision-making, are considered. For details on the decision-making modes, see Sections 2.3.1 to 2.3.4.

Two configurations are considered for the incentive mechanism: $\lambda \in \{0.25, 1\}$ for group-based and individualistic incentives, respectively. For details on how the incentive parameter affects utility, see Section 2.3.

Shocks of different severity are considered, ranging from severe ($\rho = -0.5$) to moderate ($\rho=0$) and slight shocks ($\rho=0.5$). For details on how shocks are implemented, see Section 2.2.

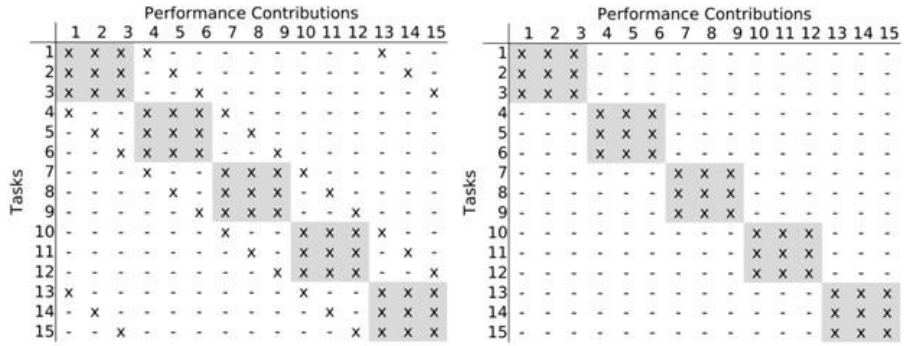


Figure 1: Interdependence patterns
Left: reciprocal interdependencies, right: decomposable tasks

The dimensionality of the decision problem is fixed at $N = 15$, and the number of departments is set to $M = 5$. The parameter variations yield a total number of 144 scenarios. For these scenarios, simulations per scenario have been performed, whereby based on the coefficient of variation, the number of simulations per scenario is set 150. Each simulation run spans 500 timesteps, with shocks occurring after 250 timesteps. Statistical tests confirm that the performance time series (both before and after a shock) reaches stationarity after approximately 240 timesteps. The simulation model is implemented in Python.

3 Results and Discussion

At the core of this paper is the organisation's ability to absorb and recover from shocks. Before shocks occur in the task environment, decision-making modes already shape an organisation's position within that environment, influencing whether it operates near a global or local maximum when a shock occurs (Leitner, 2025b). In task environments with (nearly) decomposable tasks, most decision-making modes lead to organisations (almost) achieving the global maximum. In contrast, when task decomposition is characterised by reciprocal interdependencies, the global maximum cannot be reached in most cases, whereby proposal-based and collaborative decision-making modes lead to higher task performance compared to silo-based and sequential modes (Siggelkow and Rivkin, 2005). These findings align with existing literature, and the proposed model successfully replicates them (Rand and Wilensky, 2006). This replication confirms that the model has a relatively high construct validity, indicating that the model is capable of capturing core features of organisational adaptation theorised using NK model and complex system approaches.

During the simulations, organisations experience a shock to their task environment after 250 timesteps and are modelled to resume operations immediately afterwards. Shock absorption is assessed by comparing performance immediately before and after the shock, while recovery is evaluated based on performance after 250 additional time steps. Differences are evaluated using the Mann-Whitney U test, and the U statistic is used to compute the rank-biserial correlation as an effect size measure. To efficiently report the results, k-means

clustering was applied to group the 144 scenarios into nine distinct clusters. The optimal number of clusters was determined using the Davies-Bouldin and Caliński-Harabasz indices. Clustering of scenarios allows for detecting structural patterns rather than merely reporting isolated scenarios. A log-likelihood ratio test assessed the significance of different parameters for the clustering solution. In consequence, the analysis approach allows for the interpretation of resilience as emerging from interactions with the organisational context. The results indicate that *interdependence pattern*, *decision-making mode*, and *shock correlation* significantly influence the clustering structure; the results are organised along these dimensions.

Table 1 presents the cluster profiles for organisations operating in environments with decomposable tasks, while Table 2 focuses on environments with reciprocal interdependencies. Scenarios are further grouped within each table based on shock severity (slight vs. moderate to severe shocks). Both tables report two primary outcomes: (i) the capability to absorb shocks, comparing performance immediately before (period 249) and immediately after the shock (period 250), and (ii) the capability to recover from shocks, comparing performance before the shock (period 249) and after a recovery period (period 500). For each cluster, the average rank-biserial correlation (as a measure of effect size) and its standard deviation are reported. Additionally, the dominant decision-making modes characterising each cluster are indicated.

Table 1**:** Results for decomposable tasks

# Scenarios	Absorbing shocks (period 249 vs. 250)		Recovering from shocks (period 249 vs. 500)		Decision-making mode
	Average	Std	Average	Std	
Slight shocks:					
8	-0.6092	0.0705	0.1618	0.0284	Collaborative (low/mean probability) Proposal-based
18	-0.6401	0.0975	0.0755	0.0212	Collaborative (high probability) Sequential Silo-based
Moderate to severe shocks:					
30	-0.8831	0.0580	-0.0065	0.0258	Collaborative (low/mean probability) Proposal-based
19	-0.9061	0.0575	0.0202	0.0202	Collaborative (high probability) Sequential Silo-based

The results indicate that organisational resilience – more specifically, an organisation's capability to absorb and recover from shocks – is contingent on both the decision-making mode that is effective in the organisation and the complexity of the task environment. In low-complexity task environments, where tasks assigned to departments have minimal interdependencies and are perfectly decomposable into disjoint areas of responsibility, organisations exhibit higher overall performance, and decision-making modes play a lesser role in resilience. When a shock disrupts the task environment, organisations using proposal-based and collaborative decision-making modes experience a smaller initial performance drop than those relying on silo-based or sequential decision-making mechanisms in environments with decomposable tasks (see Table 1). This observation is driven by almost independently operating departments (on smooth performance landscapes), leading to even simple decision-making rules performing well. However, the cost of uncoordinated action increases as the task environment becomes more complex and the performance landscape becomes more rugged (see Table 2). Here, organisations employing collaborative or sequential decision-making modes experience a more pronounced drop in performance. This observation can be explained by the fact that the proposal-based and collaborative decision-making modes facilitate mutual adaptation. Specifically, these modes allow departments to align their decisions, leading them to favourable positions in the landscape, i.e., positions that are likely also viable after a shock.

Table 2**:** Results for non-decomposable tasks

# Scenarios	Shock absorption (period 249 vs. 250)		Recovering from shocks (period 249 vs. 500)		Decision-making mode
	Average	Std	Average	Std	
Slight shocks:					
15	-0.2273	0.0731	-0.0993	0.0377	Collaborative (low probability) Silo-based
19	-0.3563	0.1023	0.0331	0.0360	Collaborative (mean/high probability)

# Scenarios	Shock absorption (period 249 vs. 250)		Recovering from shocks (period 249 vs. 500)		Decision-making mode
	Average	Std	Average	Std	
Moderate to severe shocks:					
6	-0.4361	0.0676	-0.2344	0.0483	Silo-based
19	-0.5680	0.0833	-0.0134	0.0312	Collaborative (mean/high probability)
110	-0.5698	0.1034	-0.1209	0.0243	Sequential

Recovering from shocks depends on shock severity and an organisation's capability to coordinate actions after the shock. In complex environments, collaborative decision-making modes facilitate better recovery because they facilitate coordinated adaptations across departments. In contrast, organisations using silo-based and sequential decision-making modes often struggle to regain previous performance levels, leaving them trapped in suboptimal positions. In task environments of low complexity, organisations regain pre-shock performance in all cases. The relationship between task complexity and effectiveness of the decision-making mode is further moderated by shock severity: Slight shocks only result in moderate shifts in the performance landscape, enabling recovery over time in all decision-making modes. Interestingly, when the task environment is of low complexity and shocks are moderate, collaborative and proposal-based decision-making modes can help organisations achieve significantly better performance post-shock. In contrast, severe shocks lead to drastic performance drops, and when there is a lack of coordination across departments, as in silo-based modes, recovery is difficult. On the other hand, collaborative and proposal-based decision-making modes support tight coordination, allowing for effective recovery.

These findings are relevant for the design of real-world organisations. The results confirm that decentralising decisions to the department level can achieve high performance and strong recovery capability in modular and relatively stable environments, such as traditional manufacturing lines or standardised service operations. In more complex and volatile environments, such as emergency response coordination and digital product development, cross-departmental coordination and joint action (as in the collaborative mode) become increasingly essential. The results also indicate that organisations are better off in dynamic environments when they not only support communication between departments but also facilitate joint exploration and mutual adjustment.

4 Conclusion

This paper presents an agent-based model of a stylised organisation operating in a dynamic task environment subject to external shocks. The model investigates how different decision-making modes influence an organisation’s ability to absorb and recover from such shocks. The findings suggest that specific decision-making modes offer advantages depending on the complexity of the environment. Complex task environments characterised by reciprocal interdependencies benefit from decision-making structures that support information exchange and mutual adaptation. In contrast, simpler decision-making modes may work efficiently in less complex settings. These results highlight the importance of aligning decision-making structures with environmental complexity. The study contributes to resilience research by incorporating an organisation’s pre-shock positioning within the task environment into the resilience analysis. It highlights that crisis response mechanisms do not solely determine resilience but are also influenced by the decision-making architecture in place before the shock.

Future research could account for the fact that firms differ in their ability to respond to crises. Prior performance plays a critical role: organisations that perform well before a shock can often accumulate slack resources, enabling a more immediate and effective response, while less successful organisations may lack this capacity (Smallbone et al., 2012). Extending the model to incorporate this dynamic would enhance its realism. Moreover, to increase the generalizability of results, future studies should explore additional interdependence patterns and examine whether consistent behavioural patterns emerge across different organisational contexts. Future research could also examine how decision-making modes evolve and investigate the influence of additional contextual factors such as organisational culture and leadership.

5 Ethics declaration

No ethical clearance was required for the research presented in this paper.

6 AI declaration

No AI tools were used for the creation of this paper.

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Institutional Conditions in Entrepreneurial Education Ecosystems: Effects on Entrepreneurial Knowledge and Culture

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Abstract

Entrepreneurial education ecosystems are increasingly recognized as strategic environments within universities that foster entrepreneurial knowledge, culture, and venture creation. However, the interplay between institutional factors and educational outcomes in these ecosystems remains underexplored, particularly from a dynamic, system-level perspective. This study addresses this gap by developing a theory-driven agent-based model—the Entrepreneurial education ecosystems Model: "3E Model"—to simulate how formal (e.g., corruption, bureaucracy, access to credit) and informal (e.g., social perception of entrepreneurship, cultural diversity) institutional factors influence entrepreneurial learning dynamics in university-based ecosystems.

Grounded in entrepreneurial ecosystem theory, stakeholder theory, and institutional theory, the model captures the interactions of heterogeneous agents including students, faculty, investors, and institutional actors. The simulation results reveal that institutional quality significantly shapes the accumulation of entrepreneurial knowledge, the formation of entrepreneurial culture, and the motivation to launch startups. In particular, corruption and bureaucratic burden emerge as major impediments, reducing both knowledge diffusion and entrepreneurial activity. Conversely, favorable social perceptions of entrepreneurship significantly enhance ecosystem performance, with evidence of threshold effects: only after surpassing a certain level of societal support does venture creation accelerate. Cultural diversity also contributes positively by enriching knowledge exchanges, though its impact is more gradual.

The model demonstrates the non-linear and interdependent nature of institutional influence in 3Es, confirming that both formal (structural) and informal (cultural) institutions jointly determine ecosystem vitality. Practically, the 3E Model serves as a decision-support tool for universities and policymakers, enabling the simulation of interventions to strengthen entrepreneurial education. The findings suggest that aligning institutional reforms with cultural initiatives—such as reducing administrative barriers while promoting entrepreneurship as a legitimate career path—can generate synergistic effects that boost entrepreneurial outcomes. The study concludes by outlining future research directions, including model refinement through empirical calibration and the inclusion of feedback loops between education and institutional change.

Keywords: Entrepreneurial Ecosystems; Entrepreneurship Education Ecosystems; Institutional Factors; Agent-Based Modeling

Paper type: Academic Research Paper

1 Introduction

Universities today are increasingly recognized as key engines of innovation and entrepreneurship, extending their traditional missions of teaching and research to actively support economic development through venture creation (Etzkowitz, 2004; Audretsch & Belitski, 2021). One critical pathway for fulfilling this "third mission" is by fostering entrepreneurial mindsets among students through dedicated entrepreneurship education programs (Matlay, 2008; Breznitz & Zhang, 2022). Prior research highlights that entrepreneurship education can significantly boost entrepreneurial intentions and startup rates (Nabi et al., 2017), but its effectiveness is heavily influenced by the broader entrepreneurial ecosystem in which it operates (Fayolle et al., 2016; Liu et al., 2021).

Entrepreneurial ecosystems (EEs) are dynamic networks of interdependent actors, institutions, and resources that facilitate or hinder entrepreneurial activities (Isenberg, 2010). These ecosystems exhibit the characteristics of complex adaptive systems, where non-linear interactions among diverse stakeholders produce emergent, often unpredictable, outcomes (Levin, 2003; Roundy et al., 2018). Within this context, universities serve as critical hubs, both producing human capital and facilitating stakeholder interactions (Audretsch & Belitski, 2017).

Recent studies emphasize the emergence of entrepreneurial education ecosystems—a focused subset of broader ecosystems that integrates academic training, institutional support, cultural attitudes, and stakeholder collaboration to stimulate student entrepreneurship (Belitski & Heron, 2017; Liu et al., 2021). These ecosystems are multi-actor environments involving students, faculty, entrepreneurs, investors, and policymakers, whose coordinated interactions critically determine entrepreneurial outcomes (Freeman, 1994; Bischoff et al., 2018).

Building an effective entrepreneurial education ecosystem, however, remains challenging. The interplay between formal institutional structures (e.g., regulations, financial access) and informal elements (e.g., cultural

perceptions, social norms) creates a highly complex environment where interventions can have non-obvious effects (North, 1990; Urbano & Guerrero, 2013). There is a growing call for systemic approaches that capture this complexity and guide universities in ecosystem development (Cavallo et al., 2019).

To address these challenges, this study employs a theory-driven agent-based simulation model—the 3E Model (Entrepreneurial Education Ecosystem Model)—as a virtual laboratory for analyzing the impact of institutional conditions and stakeholder configurations. Unlike traditional empirical studies, agent-based modeling enables the exploration of emergent ecosystem dynamics by simulating the behavior and interactions of heterogeneous agents (Epstein, 2012; Macal & North, 2010).

We specifically aim to answer the following research question:

How do variations in formal and informal institutional factors influence the accumulation and diffusion of entrepreneurial knowledge, the development of entrepreneurial culture, and the motivation to engage in venture creation among actors within a university-based entrepreneurial ecosystem?

Drawing upon entrepreneurial ecosystem theory, stakeholder theory, and institutional theory, the model investigates how factors such as bureaucratic barriers, corruption levels, financial accessibility, cultural attitudes, and network diversity affect entrepreneurial knowledge accumulation, cultural development, and venture formation.

This study makes two primary contributions. First, it offers a dynamic, system-level analysis of entrepreneurial education ecosystems, providing quantitative insights into how institutional conditions shape entrepreneurial knowledge and culture (Brush, 2014; Secundo et al., 2021). Second, it demonstrates the practical utility of agent-based modeling as a decision-support tool, allowing universities and policymakers to simulate interventions and predict potential outcomes, thus fostering evidence-based and proactive ecosystem management (van Rijnsoever, 2020).

2 Theoretical Background

Entrepreneurial ecosystems (EEs) offer a systemic lens to understand the networked, non-linear interactions among actors, institutions, and resources that foster entrepreneurship (Stam & Van de Ven, 2021; Wurth et al., 2022). Conceptualized as complex adaptive systems, EEs evolve through dynamic feedback loops where entrepreneurial success or failure can reinforce ecosystem vitality or fragility (Roundy et al., 2018; Levin, 2003). Unlike linear models of innovation, EEs emphasize the emergent properties arising from the interplay of diverse components, including capital, mentorship, cultural attitudes, and supportive policies (Isenberg, 2011; Spigel, 2017).

Universities are increasingly pivotal in these ecosystems, functioning not only as knowledge producers but also as entrepreneurial hubs (Etzkowitz, 2004; Audretsch & Belitski, 2021). Through infrastructure like incubators, accelerators, and venture funds, universities promote startup creation and serve as connectors between academia, industry, and government (Guerrero et al., 2016; Wright et al., 2017). This role is central in the Triple Helix model of innovation, positioning universities as anchors of regional entrepreneurial development (Etzkowitz & Leydesdorff, 2000).

Expanding on this, scholars have conceptualized entrepreneurial education ecosystems as university-centered subsystems aimed at nurturing entrepreneurial capacities among students (Belitski & Heron, 2017; Liu et al., 2021). These ecosystems integrate educational programs, institutional support structures, cultural incentives, and stakeholder networks to create fertile environments for entrepreneurship (Guerrero et al., 2021). Effective entrepreneurial education ecosystems blur the campus-community boundary by engaging external actors such as investors, entrepreneurs, and policymakers (Secundo et al., 2021).

Stakeholder theory is critical in understanding these ecosystems (Freeman, 1994). Internal stakeholders—students, faculty, and administrators—interact with external ones—entrepreneurs, investors, government agencies—to co-create entrepreneurial learning experiences (Bischoff et al., 2018). Strong stakeholder coordination enhances knowledge flows, mentoring, and venture support, reinforcing the ecosystem's effectiveness (Wraae & Thomsen, 2019; Brush, 2014).

Underlying both ecosystems and stakeholder dynamics are institutional factors. Formal institutions—policies, curricula, funding mechanisms—shape the structural conditions for entrepreneurship (North, 1990; Urbano & Guerrero, 2013). Supportive formal measures, such as entrepreneurship majors or startup grants, can lower barriers to entry and boost entrepreneurial activities (Guerrero et al., 2016; Wright et al., 2017). However, bureaucratic red tape or restrictive regulations can inhibit these efforts (Van Stel et al., 2007).

Equally important are informal institutions—the cultural norms, values, and peer attitudes that influence entrepreneurial behavior (Liñán et al., 2011). A vibrant entrepreneurial culture that legitimizes risk-taking and innovation can enhance students' self-efficacy and motivation, often compensating for weaker formal structures

(Bergmann et al., 2018). The interplay between formal and informal institutions is critical: ideally, they align to reinforce entrepreneurial engagement, but mismatches can hinder outcomes (North, 1990; Guerrero & Urbano, 2013).

Finally, the broader macro-institutional context—such as national corruption levels or access to finance—also shapes the university's entrepreneurial ecosystem performance (Anokhin & Schulze, 2009). Recognizing these multi-level influences, our study develops an agent-based model that dynamically simulates how variations in institutional factors and stakeholder interactions impact entrepreneurial knowledge diffusion, cultural development, and venture formation within a university-based entrepreneurial ecosystem.

3 Methodology

To investigate the dynamics of a university-based entrepreneurial education ecosystem, we employed an agent-based modeling (ABM) approach. ABM is particularly suitable for this context as it enables the simulation of heterogeneous agents and the observation of emergent macro-level outcomes resulting from micro-level interactions (Epstein, 2012; Macal & North, 2010). This method aligns with the complex adaptive systems perspective of entrepreneurial ecosystems, allowing for non-linear behaviors and feedback loops that cannot easily be captured through traditional analytical methods (Levin, 2003; Sterman, 2002).

We developed a custom model, termed the 3E Model (Entrepreneurial Education Ecosystem Model), using the NetLogo platform (Wilensky & Rand, 2015). Model development was guided by an extensive theoretical framework, ensuring that key stakeholders, institutional conditions, and environmental factors identified in the literature were represented. To ensure transparency and reproducibility, the model was documented following the ODD (Overview, Design concepts, Details) protocol (Grimm et al., 2006; 2020).

Figure 1 shows the actors in the 3E model.

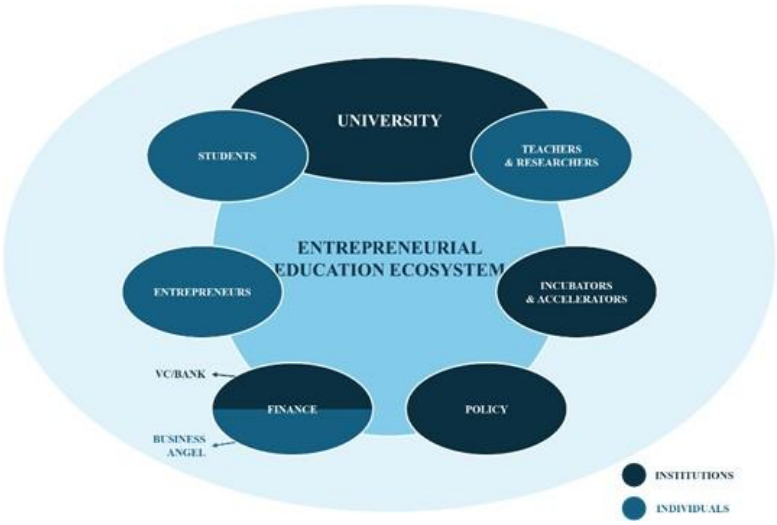


Figure 1: 3E model actors

The model features several types of agents:

Student agents: Representing university students or recent graduates, these agents possess evolving attributes such as entrepreneurial knowledge, skills, and attitudes. Students decide whether to launch a startup based on accumulated knowledge, perceived opportunities, and access to resources, reflecting real-world entrepreneurial decision-making patterns (Zhang et al., 2014).

Educator/Faculty agents: These agents deliver formal and informal knowledge, mentorship, and entrepreneurial role modeling to student agents. They simulate the roles of professors, entrepreneurship instructors, and staff involved in startup support, thereby influencing student learning and self-efficacy (Cope, 2005; Diegoli et al., 2018).

Investor/Business Mentor agents: Representing venture capitalists, angel investors, and industry mentors, these external stakeholders provide critical financial and social capital to student ventures. They offer investments based on project attractiveness and mentor students by bridging the gap between academic learning and market realities (Spigel, 2017; Secundo et al., 2021).

Additionally, two environment-level components shape the ecosystem:

University/Institutional parameters: Formal institutional conditions, such as bureaucratic burden, availability of internal grants, and entrepreneurship support infrastructure, are modeled as global variables. These factors directly impact students' startup likelihood by influencing the effort or incentives required for venture creation (Van Stel et al., 2007; Guerrero et al., 2016).

Culture/Social Environment settings: Informal institutions, such as the entrepreneurial culture and prevalence of role models, modulate student behaviors. A positive culture lowers perceived risks, boosts aspiration levels, and increases the probability of entrepreneurial activity among students (Liñán et al., 2011; Bergmann et al., 2018).

Through the 3E Model, we systematically vary these institutional and stakeholder configurations to observe their impact on entrepreneurial knowledge accumulation, culture development, and startup formation. This simulation approach enables experimentation with hypothetical interventions (e.g., reducing bureaucracy or enhancing mentorship programs) that would be difficult to implement empirically, thus offering a powerful tool for understanding and designing entrepreneurial education ecosystems.

4 Results

4.1 Impact of Formal Institutional Factors

The simulation results demonstrate that formal institutional factors—namely corruption, bureaucratic burden, and access to credit—significantly influence the evolution of entrepreneurial knowledge, culture, and new venture creation within the entrepreneurial edu99cation ecosystem.

Corruption emerged as the most detrimental factor. Higher corruption levels (i.e., lower transparency) consistently led to lower average entrepreneurial knowledge, a weaker entrepreneurial culture, and fewer student entrepreneurs. As summarized in Table 1, raising corruption from low to high decreased mean student entrepreneurial knowledge from 7.53 to 7.21, university entrepreneurial culture from 6.48 to 6.30, and reduced the average number of new entrepreneurs from 154.1 to 151.9. Kruskal–Wallis tests confirmed these differences as highly significant ($p < 0.001$).

Bureaucracy similarly exerted a negative, albeit slightly weaker, impact. Heavier bureaucratic burdens decreased entrepreneurial indicators modestly. For example, the mean number of entrepreneurs dropped from 153.5 under low bureaucracy to 152.3 under high bureaucracy, a significant but smaller effect compared to corruption ($p < 0.001$).

In contrast, access to credit exhibited a limited short-term impact. Although easier credit conditions marginally improved knowledge and culture scores, variations in interest rates (from 3.5% to 6.5%) did not significantly change the final number of entrepreneurs ($p = 0.78$).

Overall, the elimination of corruption showed the greatest potential gains in entrepreneurial outcomes, followed by streamlining bureaucratic processes. Improvements in credit conditions enhanced the ecosystem marginally but with diminishing returns within the tested range.

Table 1**:** Impact of Formal Institutional Factors on 3E Outcomes

Institutional Factor	Level	Mean Student Entrepreneurial Knowledge	Mean University Entrepreneurial Culture	Mean No. of New Entrepreneurs	Max No. of New Entrepreneurs	Significance (p-value)
Corruption	Low	**7.53**	**6.48**	**154.1**	**169**	<0.001
	Medium	7.41	6.40	153.2	165	
	High	7.21	6.30	151.9	164	
Bureaucracy	Low	**7.50**	**6.47**	**153.5**	**167**	<0.001
	Medium	7.37	6.36	153.1	165	
	High	7.29	6.33	152.3	163	
Access to Credit	Easy (Low)	7.45	6.43	153.2	167	0.78
	Medium	7.38	6.40	153.0	166	
	Hard (High)	7.31	6.37	152.8	165	

4.2 Impact of Informal Institutional Factors

Higher societal perception levels (i.e., a more favorable view of entrepreneurship) strongly enhanced entrepreneurial knowledge, culture, and venture creation. Increasing societal support from low (index 0.35) to high (index 0.80) raised the mean university entrepreneurial culture from 6.33 to 6.48, and mean student entrepreneurial knowledge from 7.22 to 7.59. The average number of new entrepreneurs increased from 152.6 to 154.0 (Table 2), with results statistically significant across all variables ($p < 0.001$). Notably, a threshold effect was observed: improvements in societal support translated into higher venture creation only after surpassing a critical perception index (~0.65), as illustrated in Figure 1B.

Cultural diversity similarly benefited the ecosystem, although with more gradual effects. A high melting pot index (0.35) improved entrepreneurial knowledge and culture modestly compared to low diversity (0.05), increasing new entrepreneurs from 152.0 to 153.5 on average ($p < 0.001$). The model suggests that diversity enhances creativity and opportunity recognition, although moderate diversity changes (e.g., 0.15 to 0.25) had limited effect—consistent with an adaptive equilibrium in the ecosystem.

Certain ecosystem components, such as incubators and accelerators, remained relatively resilient to informal changes, maintaining a strong entrepreneurial culture even under low societal support or low diversity. This buffering effect highlights the stabilizing role of specialized entrepreneurial institutions

Table 2**:** Impact of Informal Institutional Factors on 3E Outcomes

Institutional Factor	Level	Mean Student Entrepreneurial Knowledge	Mean University Entrepreneurial Culture	Mean No. of New Entrepreneurs	Max No. of New Entrepreneurs	Significance (p-value)
Social Perception	Low (0.35)	7.22	6.33	152.6	163	<0.001
	Medium (0.50)	7.37	6.38	153.0	165	
	High (0.80)	**7.59**	**6.48**	**154.0**	**170**	
Cultural Diversity (Melting Pot)	Low (0.05)	7.23	6.30	152.0	162	<0.001
	Medium (0.15)	7.32	6.35	152.8	164	
	High (0.35)	**7.50**	**6.48**	**153.5**	**168**	

5 Discussion

The findings of this study offer a robust contribution to the literature on entrepreneurial education ecosystems (3Es) by demonstrating how formal and informal institutional conditions shape the evolution of entrepreneurial knowledge, culture, and venture creation within university settings. While previous research has underscored the critical role of universities in fostering entrepreneurship and connecting with external stakeholders (Etzkowitz, 2004; Guerrero & Urbano, 2013), empirical analyses have often lacked the analytical tools to capture the complex, systemic nature of 3Es (Roundy et al., 2018). In response, this study integrates agent-based modeling (ABM) with institutional theory to analyze how institutional conditions—both formal and informal—influence the diffusion of entrepreneurial knowledge, the formation of entrepreneurial culture, and the motivation to start ventures within a university-centered ecosystem.

The simulation results clearly demonstrate that institutional configurations significantly shape entrepreneurial outcomes. In particular, formal institutions such as corruption, bureaucratic burden, and credit access modulate the probability that individuals engage in learning and startup activity. These findings resonate with earlier empirical work showing that institutional inefficiencies—especially high corruption—undermine entrepreneurship by reducing trust, increasing transaction costs, and limiting opportunities (Li & Wu, 2010; Anokhin & Schulze, 2009). Our simulations reinforce these insights: under high-corruption scenarios, student and faculty motivation to participate in entrepreneurial education diminishes, eroding collective knowledge and stalling new venture creation. Furthermore, we observe that once corruption crosses a certain threshold, its marginal impact on seasoned actors (e.g., business angels or established entrepreneurs) declines, suggesting a

behavioral adaptation or normalization of dysfunction—a phenomenon observed in studies of institutional decay (Transparency International, 2023).

Bureaucratic burden also emerges as a demotivating force, though its effects are more nuanced. While it significantly impacts students and nascent entrepreneurs by reducing their self-efficacy and willingness to participate in entrepreneurial programs (Griffiths et al., 2009; van Stel et al., 2007), the knowledge levels of external investors are less affected. This discrepancy likely reflects investors' peripheral role in education-centered initiatives, as their decision-making is driven more by investment logic than learning needs. Nonetheless, high bureaucratic costs serve as barriers to both participation and course delivery, which aligns with previous work identifying regulatory friction as a deterrent to early-stage entrepreneurship (McMullen et al., 2016; Sendra-Pons et al., 2022).

Access to credit plays a more moderate yet important role. While minor variations in interest rates have limited effects on venture formation, more pronounced credit constraints discourage participation in educational programs, particularly when entrepreneurial education entails upfront costs. This confirms existing evidence that financial inclusion facilitates not only startup formation but also engagement in learning pathways that foster entrepreneurial competencies (Bourlès & Cozarenco, 2018; Sendra-Pons et al., 2022).

Among the informal institutions examined, the societal perception of entrepreneurship proves most influential. Simulations reveal a strong positive association between favorable social attitudes and increased motivation, cultural legitimacy, and entrepreneurial activity. This aligns with the theory of planned behavior (Liñán & Chen, 2009) and prior findings emphasizing the role of social legitimacy in shaping entrepreneurial intentions (Hayton et al., 2002; Liñán et al., 2011).

Finally, while cultural diversity had a less pronounced effect than other factors, its contribution to knowledge exchange and network expansion supports the view that heterogeneous ecosystems foster innovation and creativity (Audretsch & Belitski, 2017). The model confirms that diverse actors enrich the learning environment, even if effects appear more gradual and context-dependent.

Taken together, the results reinforce the importance of considering entrepreneurial ecosystems as multi-layered and interdependent. The evidence supports the proposition that institutional quality—both formal and informal—not only affects individual agency, but also collectively determines the knowledge infrastructure and emergent properties of the ecosystem (North, 1990; Stam & Van de Ven, 2021). Thus, future interventions should aim not only to reform regulations, but also to shift cultural narratives and promote entrepreneurship as a valued societal endeavor (Urbano et al., 2017; Guerrero & Marozau, 2023).

6 Conclusions

This study presents an original contribution to entrepreneurial education research by developing a theory-driven agent-based model (the 3E Model) that simulates how formal and informal institutional conditions influence entrepreneurial learning and behavior in university ecosystems. Integrating stakeholder theory (Freeman, 1994) and institutional theory (North, 1990), the model captures interactions among heterogeneous agents—students, faculty, investors, and university structures—thus extending the theoretical lens beyond the student-centric view that dominates much of the existing literature (Brush, 2014; Liu et al., 2021).

Theoretical implications include a refined conceptualization of entrepreneurial education ecosystems as complex adaptive systems, where outcomes emerge from feedback-rich processes involving multiple actors and contextual dependencies (Roundy et al., 2018). The results highlight the distinct and complementary roles of formal and informal institutions, demonstrating that soft factors such as cultural norms and social perception can have as much impact as structural reforms in shaping entrepreneurial activity. Moreover, the findings suggest potential threshold and nonlinear effects, pointing to the existence of institutional "tipping points" that either unlock or constrain ecosystem performance.

From a practical perspective, the 3E Model functions as a decision-support tool for policy makers and university administrators. It enables the simulation of diverse institutional scenarios—e.g., reducing bureaucracy, enhancing role model exposure, or fostering cultural inclusiveness—and allows stakeholders to anticipate the systemic impact of these interventions. Our findings suggest that policies aimed at promoting entrepreneurial culture and legitimacy may be especially effective when combined with formal institutional improvements such as deregulation and increased funding opportunities. Additionally, fostering diversity and inclusion within academic communities can catalyze innovation by expanding the scope of ideas and networks accessible to nascent entrepreneurs.

Future research could enhance the model by refining the representation of motivational dynamics, which in the current version evolve in parallel with knowledge accumulation but could follow independent or nonlinear trajectories. Empirical validation of agent attributes through survey data or expert interviews would strengthen

the model's calibration and applicability. Furthermore, extending the model to include feedback loops—whereby improved education affects institutional quality—could open new avenues to investigate how ecosystems co-evolve over time. Finally, future studies may explore additional actor types or contexts (e.g., non-university incubators, secondary education systems), providing a more comprehensive picture of entrepreneurial knowledge systems.

7 Ethics Declaration

The authors declare that they have complied with all ethical standards required for this research. No human participants or animals were involved in the study. No conflict of interest exists.

8 AI Declaration

The authors declare that no generative artificial intelligence (AI) tools were used in the writing, editing, or content development of this manuscript.

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Technology Leaders and Followers: An Agent-Based Approach

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Abstract

In this dynamic and full-opportunity world, firms must face challenges in markets and technologies. One of the main assets that firms can use to address these challenges is innovation, and an important element is to define the most appropriate innovation strategy. Inside innovation strategy, fundamental decisions are about selection, acquisition, and timing. The innovation selecting consists of the selection of the innovations to develop; the innovation acquiring consists of how firms acquire the innovation (the main strategies can be simplified with insourcing (make), outsourcing (buy), or collaborating (collaborate). In particular, with respect to timing, firms are heterogeneous and two main approaches can be identified: technological leaders and technological followers that work on the technological knowledge developed by the technological leaders. In this paper, the two approaches have been investigated to study the impact on the firm's performance. To conduct this investigation, the Patent Agent-Based Innovation Model and Simulator (PABIM has been enhanced. The PABIM is characterized by heterogeneous firms that are organized as a directed random graph. The use of an agent-based model allows for the exploration of emergent dynamics and their subsequent effects on performance. The results indicate that when a firm can adopt all the acquisition strategies (make, buy, collaborate), the optimal strategy concerning timing for firm performance is the leaders' approach, independently of the sector innovation intensity. The study recommends that managers and policymakers adopt a comprehensive approach to innovation management, integrating pertinent technical knowledge related to product or process development with the necessary resources for effective implementation.

Keywords: technology leaders, technology followers, patent, agent-based model

Paper type: Academic Research Paper

1 Introduction

In this dynamic and full-opportunity world, firms must face challenges in markets and technologies (Looney and Hardin, 2009).

One of the main assets that firms can use to address these challenges is innovation (Kline and Rosenberg, 2010), and an important element is to define the most appropriate innovation strategy (Pearson, 1990).

According to Porter and Stern (2001), the innovation strategies consist of three key elements, which correspond to three key decisions: the selection of the innovation to develop, whether to be a leader or follower, and whether to sell the innovation or not.

Thus, innovation strategy is characterized by three categories of decisions: innovation selecting, innovation acquiring, and innovation timing. The decisions have to be considered jointly; in fact, the decision about the selection of the innovation on which to invest cannot be kept separated from the mode of acquisition and the timing of innovation development and introduction (Chiesa, 2001).

The first category, the innovation selecting, consists of the selection of the innovations to develop based on the coherence of the innovation choices with the firm's basic strategy, and the test of whether the innovation change is desirable for the firm.

The second category is the innovation acquiring, i.e., how firms acquire the innovation. Each firm addresses the acquisition of resources for innovations in a different way, but the main strategies can be simplified with insourcing (make), outsourcing (buy), or collaborating (collaborate), i.e., a hybrid and plural sourcing approach, with the creation of strategic alliances (Veugelers and Cassiman 1999, Belderbos et al., 2014, Chesbrough, 2003).

The third category focuses on the timing decision. The two main approaches that can be identified are technological leaders and technological followers (Chiesa, 2001, Tidd and Bessant, 2020), who work on the technological knowledge developed by the technological leaders.

For the sake of simplicity, we hypothesize that technological leaders use the make strategy or make and collaborate strategy, and the technological followers mainly use the buying strategy, as they exploit innovations produced by others. We know that this is a rough simplification, but it can be useful to investigate the effects of opposite or significantly different strategies.

Relying on this background, this work aims to investigate the presence of different strategic decisions of innovation strategies and the companies' performance for technological leaders and technological followers in sectors characterized by different innovation intensity when firms can use both the "making" (alone or opening

to collaborations with other companies) or "buying" innovation strategy. Thus, the paper answers the following research question:

In sectors with different innovation intensity, do firms adopt different strategic decisions of timing? If yes, how do the innovation strategies impact the company's innovation and economic performance? In particular, the study aims to see if these strategies, i.e., making or buying, eventually with collaboration, for technology leaders or followers, impact in terms of firm performance.

To answer the research question outlined above, an agent-based model and simulator have been developed (Iandoli et al., 2012; Ponta et al., 2018, 2020, 2023, 2024, 2025; Nieddu et al., 2024; Cincotti et al, 2024).

The agent-based model developed is characterized by heterogeneous firms that are organized as a directed random graph. To simulate their behaviour, each firm is characterized by an identifier, the number of employees, an amount of cash, a propensity to buy or do innovation S, the percentage of turnover invested in R&D research, an industrial sector, and a probability to patent.

At each iteration step, the economic and innovation performance are evaluated respectively using turnover and the Innovation Patent Index (IPI) (Ponta et al., 2020, 2021).

The model proposed provides a lab setting in which it is possible to test the effect of different innovation strategies: make and buy (eventually with collaboration) for different kinds of innovators.

ABM approach overcomes the limits of other classical methodologies, such as surveys or case studies.

Results show that the most convenient strategy for each kind of innovator depends on the sector innovation intensity.

This contributes to the theory showing the importance of using collaboration and buying innovation in challenging and uncertain environments to create a complete knowledge chain towards successful innovation (Kennedy et al., 2017). Especially, the adoption of an agent-based model allows understanding of emerging dynamics and their effect on performance for different types of innovators, leaders, and followers.

For managers and policy-makers, it suggests the need to see the innovation process with a comprehensive view, including the understanding not only of the technical knowledge of the product or process produced, but also the resources that need to be used or acquired to make it, and the timing

The remaining of the manuscript is organized as follows: Section 2 describes the model implemented, Section 3 reports the results of the study, and Section 4 provides the discussion and conclusion of the study.

2 The Model

To investigate the main objective of the study outlined above, an enriched version of the Patent Agent-Based Innovation Model (PABIM) has been used (Ponta et al., 2023, 2024, 2025).

The model includes heterogeneous agents that represent firms organized as a directed random graph, i.e. the interactions are unidirectional and characterized by a weight w_{ij}, assumed a positive real number.

The graphical representation of the present PABIM model in terms of firms (circles) and interactions (lines) is shown in Figure 1.

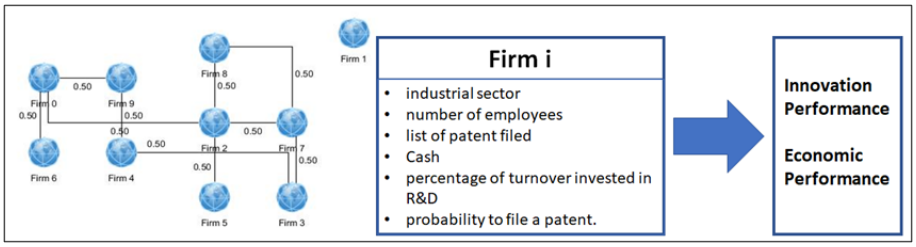


Figure 1: Graphical representation of the agent-based model in terms of firms (circles) and collaborations (lines). On the right, for each company the main features are listed

At the beginning of the simulation, all the firms have the same output node degree, defined as the number of outgoing arrows, and are endowed with the same quantity of cash and the same number of employees. During the simulation, the output node degree of each firm is directly proportional to the firm's size, i.e., it increases if the firm's size increases and decreases if the firm's size decreases, thus the number of employees, proportional to the firm's size, varies during the simulation.

In the enriched version of the model, a firm i is characterized by an identifier id_i, a number of employees N_i, a list of its filed patents P_i, an amount of cash C_i, the turnover Tu_i, the percentage of turnover invested in R&D α_i, an industrial sector IS_i and a probability to patent ρ_i. Moreover, firms are characterized by a propensity S_i to create or buy innovation. S ranges between 0 and 1. If S_i =1 means that firm i only creates innovation, i.e., new

patents. If S_i =0 means that firm i only buys technology from the outside and so it buys licenses. Then all nuances are possible. The propensity S does not change over time.

The percentage of turnover invested in R&D research is different for each firm and proportional to the firms' dimension. At each iteration step, each firm invests a fraction of the turnover in R&D research, necessary to innovate. Propensity S is correlated with the investment in R&D research. If the investments are small the propensity to buy innovation is large.

The probability ρ_i of firm i to innovate is set to depend on the cumulated R&D research investment Mc_i employed by firm i since the latest innovation filed, as follows:

$$\rho_i^t = Si(1 - \frac{1}{1 + \eta\, Mci\,_i^t}) \qquad (1)$$

where Si is the propensity of firm i to innovate, η is a shape parameter, homogenous across all firms, setting the sector innovation intensity, i.e., the higher is η, the higher is the probability to innovate, for any level of cumulated R&D research investment Mc_i employed. At each time step t the firm i checks if it is possible to innovate alone. If innovating alone is not possible firms check the connected firms if co-innovation is possible. The probability of making innovation using shared knowledge between firms i and j is given by Eq. 1 where the cumulated R&D research is the sum of the cumulated R&D research of firms i and j.

If also a co-innovation is not possible firms can extend an innovation issued in time step t-1 and can buy innovation if firms have enough cash. Innovation is modeled and measured with patents.

The patent is characterized by an identifier, an IP class, one or more countries in which the patent is extended, and the number of forward and backward citations. It is worth remembering that the backward citations are the patents cited when the new patent is issued, whereas the forward citations are the ones received by the patent. Moreover, a patent is characterized by a cost composed of a part that represents the cumulated (discounted) cost of filing and maintaining a patent and another part that depends on the R&D investment done until the year of filing. Moreover, a patent is also characterized by an extensions cost which represents the cumulated (discounted) cost of extending and maintaining the extensions of a patent. Management costs have also been considered.

The value of the patent, intended as the cumulated (discounted) turnover generated by the patent is defined by firms proportional to costs, through a multiplier $\mu_{p,i}$ defined at the beginning of the simulation and constant during the simulation. $\mu_{p,i}$ is a positive real number to consider both the case of success and failure of a patent. In particular, $0 < \mu_{p,i} \leq 1$ represents the failure case, whereas $\mu_{p,i} > 1$ represents the success case.

The revenues for firm i of a patent p filed at time t is:

$$R_{p,i^t} = \begin{cases} V_{p,i}^t & \text{if firm } i \text{ files a patent alone at time step } t \\ V_{p,i}^t \, \nu \frac{Mc_i^{t-2}}{Mc_i^{t-2} + Mc_j^{t-2}} & \text{if firm } i \text{ files a patent at time step t using shared knowledge with firm } j \ (copaten_i) \end{cases} \qquad (2$$

where ν is a coefficient positive and less than 1, which simulates the management costs between firm i and j. Furthermore, the turnover of firms is updated. and firms determine the number of employees to hire or fire at each iteration step, according to their revenues. The license cost is equal to a percentage δ of the patent value. If firm i buys a license l of the patent p at time step t the cost of the license is formed by a forfeit part that is paid at time t and by royalties that are paid for Tr years. The forfeit part is evaluated as a percentage δ of patent It is worth noting that the percentage δ is decided by means of a contract between the licensing firm i and the selling firm j. The royalties are evaluated as a percentage ξ of the turnover of the firm that is buying the license. The royalties r are paid by the firm that has been buying the license for a number of years Tr. The license remunerates a percentage of the patent value. Firms choose to buy the last patent issued in their technological sector. At each iteration step, the economic performance is evaluated as its profit whereas the firms' innovation performance with the Innovation Patent Index (IPI) (Ponta et al., 2020, 2021). Moreover also the number of sold and bought licenses has been considered. In the model leaders are identified as the firms that use mainly the "making" and "making and collaborating" strategy, whereas the followers as the firms that use mainly the buying strategy. In order to validate the two groups, the average percentage of investment in R&D of the leaders and followers groups has been evaluated.

At each iteration step, the economic and innovation performance of firms is updated. The economic performance is approximated with the profit, whereas the innovation performance is with the number of

innovations and the Innovation Patent Index (IPI) (Goldstein et al., 2001; Ponta et al., 2021). IPI is a more complete measure of innovation performance as it considers not only the classical measure of the number of patents but also other characteristics of patents (Dziallas et al., 2018).

3 Computational experiments

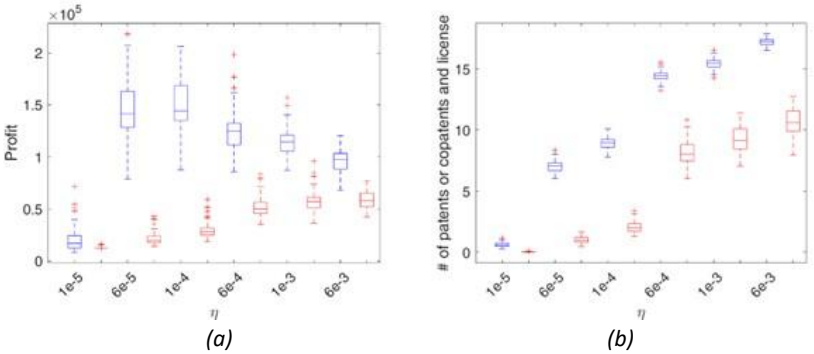
To investigate the firm performance, with respect to different innovation strategies, the economic and innovation performance have been evaluated for different sector innovation intensity.

Simulations have been performed ceteris paribus. In particular, one hundred firms, working in fifty different sectors, have been simulated. It is worth noting that each firm can create an innovation maximum per year. Table 1 summarizes the initialization data of the simulations.

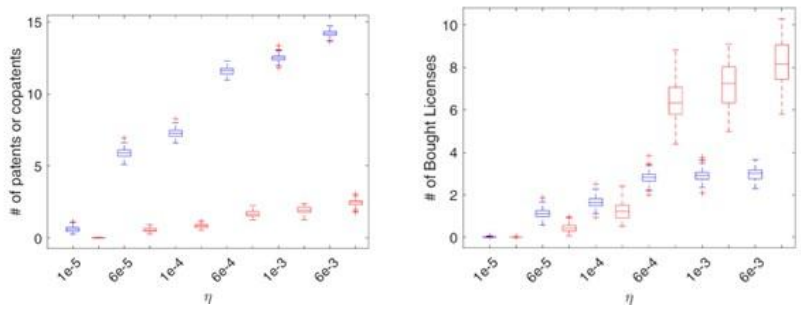
Table 1: Simulation Parameters

Symbol	Description	Value
T	Years	20
I	Number firms	100
ES	number of economic sectors	50
Do	number of initial output connections	0, 10
T_u	Turnover init	20000
H	Sector innovation intensity	0.000002 to 0.2
A	% of turnover invested in R&D	[2 - 17]
μ	Multiplicator	[0.5 - 2]
ξ	coeff management cost	0.9
C_e	patent extension cost	350
C_f	patent filed fixed cost	500
δ	% of patent value for the licence cost	30

Figure 2 shows the economic and innovation performance for technological leader's and follower's groups in blue and red, respectively. Leaders are characterized by using mainly the making and collaborating strategies. In particular, Figure 2 (a) shows the economic performance approximated with the profit. It is worth noting that for small medium and large sector innovation intensity, for firm it is more convenient to be a leader instead of a follower. Thus, for a firm, it is more remunerative to reach enough knowledge to patent alone or using shared knowledge to create a copatent than to pay royalties. Figure 2(b) shows the innovation performance approximated with the number of innovation measured as the sum of new patents and bought licences. Independently form the sector innovation intensity the leader group has better innovation performance. If the sector innovation intensity is small the difference among the leaders and followers is small, but when η increases also the difference increases. Looking more in details the innovation performance, Figure 2 (c) shows the number of patents, whereas Figure 2 (d) the number of bought licences. For every η, the number of patents is larger in the leaders group, whereas the number of bought licences for small η is lager for leaders group whereas for large η for follower group. Figure 3(a) shows the normalized number of patents with respect to the firm size. Figure 3 (b) and (c) show the number of IPC classes and the number of backward citations patent features, respectively. Figure 3(d) and (e) show the number of extensions, the number of months between the publication date of the youngest and the oldest patent of the family, and patent features. It is worth noting that for all η the five IPI dimensions are larger in the case of leaders group.



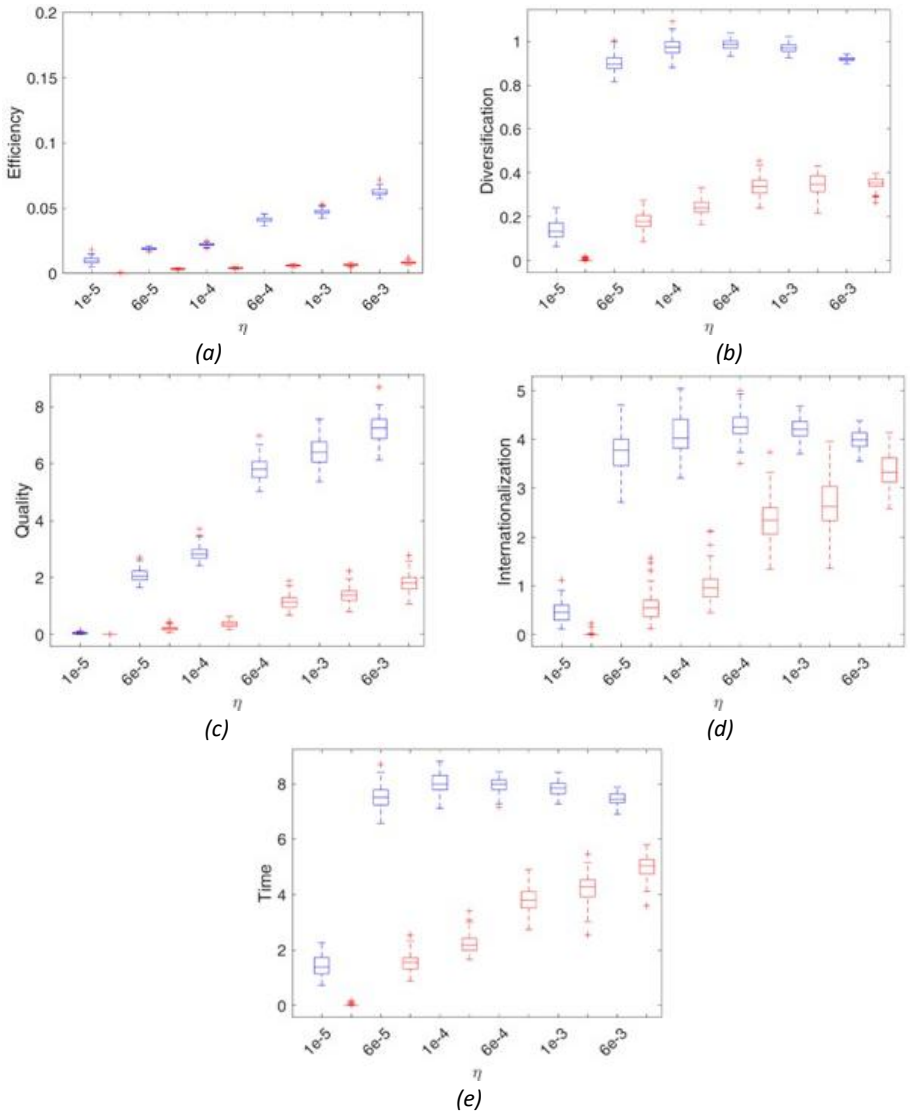
(a) *(b)*



(c) (d)

Figure 2 – Distribution of economic performance approximated with profit (a) , of innovation performance approximated with the number of innovations (b), of number of patents (c) and number of bought licences (d). The blue boxplots correspond to technological leaders' group, whereas the red boxplots to technological followers' group.

Moreover, Efficiency, diversification, and quality behave in the same way, whereas internationalization and time, in the case of leaders, have a maximum for medium η, whereas in the case of followers, the dimensions increase, and for large η, the values are similar to those of the leader group.



(a) (b)

(c) (d)

(e)

Figure 3 - Distribution IPI components: efficiency (a), diversification (b), quality (c), internationalization (d), and time (e) for technological leaders' group in blue and technological followers in red.

4 Discussions and conclusions

The computational results presented in the paper can capture the impact of innovation strategies on firm performance. The paper has proposed a methodological approach, i.e., an agent-based model, that provides a more complete understanding of acquiring and timing strategies concerning innovation and economic performance (Greco et al., 2016).

Furthermore, the firm performance dynamics that emerged from the simulations show important results, both at the economic and innovation levels. Focusing on the timing strategy, the economic performance, for small, medium, and large sector innovation intensity is better for leaders firms. In particular, for larger η, the economic performance for both leaders and followers is very similar. In the case of leader firms, there is also a U-shaped form, whereas in the case of followers, the curve is increasing, reaching a plateau. This result confirms that if the sector innovation intensity is small is important to be a leader, in order to take first mover advantages (Barney, 1991). Moreover, the inverted U-shaped curve demonstrated that when increasing the sector innovation intensity, there is a sort of maximum. High sector R&D intensity could lead to lower economic benefit, probably because of difficulties in capturing the innovation value, and high R&D expenses cannot generate higher sales. If the sector innovation intensity is high the economic performance of being leaders or followers are similar meaning that a firm cannot be always leader but should also be follower helping to be ready with new technology in less time with respect to start to research and develop a new technology (Schilling and Phelps, 2007). To be a follower is preferred by firms with respect to the collaboration, probably because collaboration could lead to higher complexity and managerial costs, confirming also more recent studies about the non-linearity of the relationship (Greco et al., 2016).

Instead, as expected, innovation performance is more effective in the case of leader firms. In particular, in terms of the number of patents developed, the leaders show better performance. The use of internal knowledge and collaborations permits filling internal lack of competencies and developing a larger number of innovations, and taking the first mover advantage.

In conclusion, the agent-based model developed here provides a tool that is very suitable for making a classic what-if analysis. In particular, it is a sort of computational laboratory where to perform experiments and find the most cost-efficient policy to improve the performance of firms. This allows for taking a further step towards understanding the outcomes tied to applying a leader or follower strategy that has not yet been widely analyzed, due to a lack of data. This simulator will be a very useful tool for managers because they will be able to simulate a chosen strategy before applying it in the real world. Nevertheless, this study is not without limitations. Although patents are widely used to measure innovation performance, they represent only a limited set of company innovation assets. Furthermore, in some sectors, patents are not widely adopted as mechanisms to protect innovations because other innovation assets that are more difficult to measure, such as R&D expenditures, intellectual assets, human resources skills, and aesthetic design, also provide information to measure innovation performance (Grazzi et al., 2021; Ardito et al., 2015).

This contributes to the theory showing in innovation literature the importance of being a leader or follower in challenging and uncertain environments to create a complete knowledge chain towards successful innovation. Especially, the adoption of an agent-based model allows understanding emerging dynamics and their effect on performance. For managers and policy-makers, it suggests the need to see the innovation process with a comprehensive view, including the understanding not only of the technical knowledge of the product or process produced, but also the resources that need to be used or acquired to make it.

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6 Ethics declaration

No ethical clearance is needed.

7 AI declaration

No AI tool have been used in developing the paper.

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Circular Economy Yes or No? This is the Dilemma. An Agent-Based Approach

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Abstract

Circular economy has emerged as an industrial approach that aims to overcome the traditional "take-make-dispose" economic model, which is based on the intensive extraction of raw materials and the design of products with a limited lifespan. The circular economy approach consists in a closed system in which products, materials and resources are continuously reused, remanufactured and recycled. The implementation of circular economy principles in companies requires a gradual redesign of products, which consists of a concurrent design of products and related manufacturing processes that enhance competitiveness measures, rationalize product/process/resource design decisions and improve operational efficiency in product development. Given this premise, the transition of companies towards a circular economy paradigm challenges companies to rethink their linear approach of doing business, leading to the research dilemma of answering: Is it economically convenient for a company, in terms of economic margin, to develop circular products starting from a linear positioning? To answer this research question, an agent-based model and simulator (ABM) has been developed characterized by four kinds of heterogeneous firms: the supplier, the manufacturer, the user and the recycler.
The adoption of an agent-based model, which is coherent with the approaches of complexity science, allows for investigating the phenomenon considering its complex nature, and the consequent dynamic non-linear relations among the various actors involved: manufacturers, suppliers, customers and consumers, recyclers. Results show that the manufacturer only partially follows consumer sentiment, as it retains a large proportion of linear products. Even when consumer sentiment is low, it is in the manufacturer's interest to move even slightly towards circular products.

Keywords: linear economy, circular economy, agent-based model

Paper type: Academic Research Paper

1 Introduction

Circular economy has emerged as an industrial approach that aims to overcome the traditional "take-make-dispose" economic model, which is based on the intensive extraction of raw materials and the design of products with a limited lifespan (Urbinati et al., 2017). In the circular economy premises, the economic system is designed to minimise waste and keep materials and resources in use for as long as possible to allow the earth sufficient time to regenerate resources (Kirchherr et al., 2017).

The circular economy approach consists in a closed system in which products, materials and resources are continuously reused, remanufactured and recycled, thus creating a virtuous and sustainable technical cycle (Ghisellini & Ulgiati, 2020), and when can no longer be used to make new products, they can also biodegrade and return to the earth safely (Navare et al., 2021).

Accordingly, the implementation of circular economy principles in companies requires a gradual redesign of products, which consists of a concurrent design of products and related manufacturing processes that enhance competitiveness measures, rationalize product/process/resource design decisions and improve operational efficiency in product development (Sassanelli et al., 2020). Practices enabling the redesign of products aim at closing the loop at both company and supply chain levels and addressing a sustainable use of resources (e.g., through design for recycling, remanufacturing, or reusing).

Notwithstanding the importance of shifting from a linear economy to a circular one to preserve the environment and the humankind, several issues may emerge that characterize the economic feasibility for companies to implement this approach (Corvellec et al., 2022). For example, several scholars highlight that the adoption of a circular economy practice – either the reuse or remanufacture or recycle – could be simultaneously associated with a positive economic result and a reduction in environmental impacts (Zink & Geyer, 2017; Lowe et al., 2024). In addition, it is not certain that the economic and environmental benefits resulting from the implementation of a circular economy practice that is virtuous for an individual company are reflected in similar benefits for the supply chain in which the case company operates (Castro et al., 2022). While it is true that the implementation of circular practices should contribute to the generation of environmental benefits for companies and supply chains, such as the reduction of both climate-changing emissions and natural resource

requirements (Nowicki et al., 2023), it should also ensure a positive economic return on the circular investment (Dagilienė & Varaniūtė, 2023).

Given the premise above, the transition of companies towards a circular economy paradigm challenges companies to rethink their linear approach of doing business, leading to the research dilemma of answering: Is it economically convenient for a company, in terms of economic margin, to develop circular products starting from a linear positioning?

To answer this research question, an agent-based model and simulator (ABM) has been developed (Iandoli et al, 2012, Ponta et al, 2020, Ponta et al, 2023), with the aim to investigate if the gradual shift from a linear business, implemented completely through linear products, to a circular business, implemented by adding elements of circularity in product design, such as biodegradable or compostable materials, makes economic and environmental sense for a producer-based company. The adoption of an agent-based model, which is coherent with the approaches of the complexity science, allows for investigating the phenomenon considering it complex nature, and the consequent dynamic non-linear relations among the various actors involved: manufacturers, suppliers, customers and consumers, recyclers. In particular, given the heterogeneous requests of the customers about linear and circular goods, our paper contributes to the existing research on the dynamics of circular product development due to the customer engagement in the producer's circular transition (Urbinati et al., 2020).

2 Model

ABM is particularly fitting for this research because developing circular products is a process composed of different and multiple steps that define a complex and nonlinear process (Garud, 2013), and ABM is acknowledged for being among the most appropriate methods to cope with complexity (Arthur, 2013). Once agents and interaction rules are implemented, system evolution is studied by analyzing the output of several simulations in search of macroscopic regularities (Epstein, 2006).

Thus, agent-based models provide a tool suitable for making a classic what-if analysis, creating a sort of computational laboratory to perform experiments. The ABM developed in this research is characterized by heterogeneous firms that are organized in linear and circular supply chains.

Four kinds of heterogeneous firms characterize the agent-based model developed: the supplier provides raw (virgin) materials and recycled materials to manufacturers; the manufacturer has two principal task: the production of goods and the sales of goods (the manufacturer buys the virgin raw materials and the recycled materials to produce two typology of products, i.e., linear and circular goods); the user buys linear and circular products; the recycler recycles the goods at the end of their lifecycle. Figure 1 shows the link among the different types of agents.

Figure 1 shows the firms characterizing the agent-based model developed, along with the circular and linear supply chains.

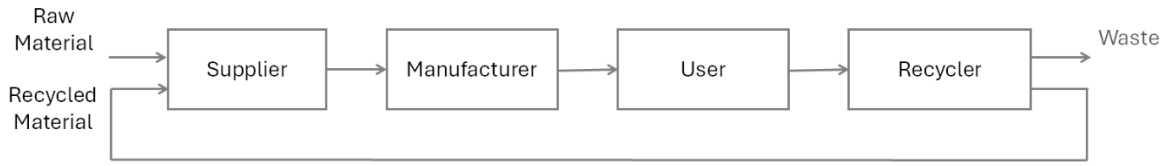


Figure 1: Linear and circular supply chain

The supplier agent provides raw and recycled material to the manufacturer agent. The supplier mines the raw material. The recycler agent provides the recycled material that is sold to the supplier agent. The quantity of raw material mined at time step t is fixed. The cost of raw material is constant and represents the cost of mining and the cost of the CO_2 emission. The recycled material is bought from the recycler with lowest price, that is linked to the supplier. The raw material is sold at price p_r evaluated as a markup of the cost of raw material. The markup varies according to the inventory. Analogously, for the recycled material price $p_Y(t)$.

The manufacturer has two principal tasks: the production of goods and the sale of goods. For the production, the manufacturer buys raw materials and recycled materials from the supplier. All the profit is used to buy raw and recycled materials. The quantity of recycled material bought is defined by the percentage ρ. The remaining part 100-ρ is the percentage of raw material bought. ρ is fixed during the simulations. The manufacturer produces 3 types of final goods: the brown good, the green good, and the mixed good. The brown goods are produced with 2 units of raw material. The green goods are produced with 4 units of recycled material. The

mixed goods are produced with 1 unit of raw material and 2 units of recycled material. The number of brown, green and mixed goods produced depends on the quantity of available raw and recycled material. The priority in the production is for the mixed goods. The price of the final goods is decided by the manufacturer with a markup over the costs, and the markup varies according to the inventories as for the supplier. The final goods are sold to the users.

The user buys the final goods, i.e., the brown, mixed, and green goods. The user is characterized by a sentiment "S" that ranges between [-1,1] which is responsible for the choice of buying brown, green, and mixed goods. If the sentiment is negative, γ represents the percentage of brown products that the user will buy. The user received money from the use of each final good; in particular, the user receives a utility coefficient of the cost of the good. The lifetime of brown, green, and mixed goods is T years. When a final good arrives at the end of its life, it is sold to the recycler.

The recycler agent creates recycled materials from the final goods. The green goods cannot be recycled being already made with recycled material. In this model, recycling is possible only once. All the raw material of the brown goods is recycled. In the mixed goods, only the quantity of raw material is recycled. The cost of recycling is fixed during the simulation. The price of recycling material varies according to the inventory during the simulation. To simulate their behaviour, each firm is initialized with an amount of cash. The user is also characterized by S which is responsible for the choice of buying linear or circular products. At each iteration step, the economic performance, approximated with the cumulated economic margin, of each agent is evaluated.

3 Computational experiments

3.1 Design of experiments

To investigate the effect of linear and circular businesses, five different scenarios have been investigated. In particular, for 10 different values of γ, six values of ρ are considered. Table 1 details the scenario values. In scenario (i), the manufacturer firm can only adopt a linear business. In scenarios from (ii) to (v), the manufacturer firm uses an increasing percentage of recycled material in its production. Simulations have been performed ceteris paribus, meaning that all the parameters are identical except for the strategy. In particular, one firm per typology has been simulated. The five scenarios previously described are explored with ten different values of γ, the parameter that controls the sentiment of the customers; in this way, 50 different scenarios are obtained.

Table 1: Scenarios description

Scenario	ρ	Description	color
(i)	0	No recycled material bought	blue
(ii)	0.2	20% of the total quantity of material bought is recycled	orange
(iii)	0.4	40% of the total quantity of material bought is recycled	yellow
(iv)	0.6	60% of the total quantity of material bought is recycled	violet
(v)	0.8	80% of the total quantity of material bought is recycled	green
(vi)	1	100% of the total quantity of material bought is recycled	azure

The methodology used is based on Monte Carlo computational experiments: each scenario is simulated with eleven different seeds of the pseudorandom number generator. So, a total of 660 simulations were considered to conduct the investigation. The computational results are presented in the form of boxplots. Each boxplot shows the distribution of the time averages of relevant variables over one-hundred-time intervals, concerning the eleven simulations characterized by different seeds. Boxes enclose the values from the first to the third quartile; they also include whiskers that extend up to the minimum and maximum data points that are not considered outliers; the horizontal segments inside boxes represent the median of the distribution. The analysis aims to investigate the impact of using different percentages of recycled material on manufacturers' economic performance. Table 2 summarizes the initialization data of the simulations. The values of the variables and parameters used in the simulation have been chosen either from the literature or from previous empirical analysis.

Table 2: Simulation parameters

Supplier	markup	1.1
	Initial turnover	20000
Manufacturer	markup	1.1
	Initial turnover	20000
User	Sentiment	[-1;1]
	cash	20000
	Utility coefficient	1.1
	Recycled cost coefficient	0.05
Recycler	markup	1.1
	Consumer goods lifetime	5

3.2 Results

Figure 2 shows the economic performance of the manufacturer firm for scenario (i) in blue, scenario (ii) in orange, scenario (iii) in yellow, scenario (iv) in violet, and scenario (v) in green. Scenario (i) is characterized by linear business model. Scenarios from (ii) to (v) are characterized by the possibility of buying a percentage from 20% to 80% of recycled material to produce goods.

The economic performance is evaluated as cumulated economic margin.

Figure 1 shows the cumulated economic margin of the manufacturer when the sentiment S of the user is negative, i.e., the user propensity is to buy brown goods. It is worth noting that the blue boxplot in Figure 1 corresponds to the linear supply chain, as the manufacturer produces only brown goods.

It is worth noting that the linear model, i.e., scenario (i), is the best strategy only when the user buys only brown goods. If the propensity of the user is to buy brown, green, and mixed goods, the best strategy for the manufacturer is to produce with a large fraction of recycled material.

Finally, the maximum cumulated economic margin is available when the user sentiment for brown goods is around 50%.

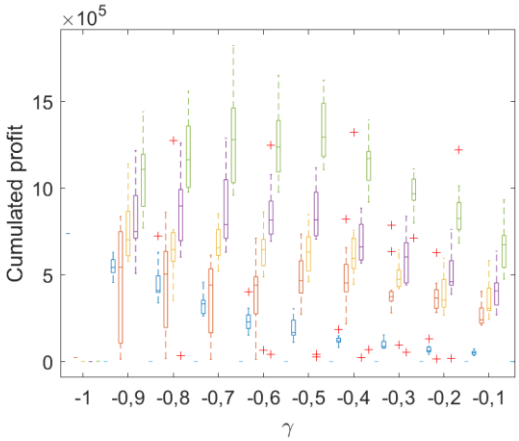


Figure 2: Distribution of: the economic performance of firm manufacturer for scenario (i) (linear business) in blue. Scenario from (ii) to (v) are characterized by the possibility of buying a percentage from 20% to 80% of recycled material to produce goods, colors orange, yellow, violet and green, respectively.

4 Discussion

The proposed model provides a lab setting in which it is possible to test the effect of firm strategy on firm performance. For example, the effect of the linear and circular supply chain on manufacturer's performance can be tested. Preliminary results show that the most convenient strategy for the manufacturer changes according to the user's sentiment with respect to the typology of products, i.e., linear vs. circular products.

In particular, the model suggests that the manufacturer only partially follows consumer sentiment, as it retains a large proportion of linear products. Even when consumer sentiment is low, such as in the cases of γ equals to -0.9 (i.e., 90% of linear products and 10% of circular products) or -0.8 (i.e., 80% of linear products and 20% of circular products), it is in the manufacturer's interest to move even slightly towards circular products. This notwithstanding, up to -0.5 sentiment (which means 50% of linear products and 50% of circular products), the manufacturer must incorporate more than proportionally recycled material into its products (see the green curve of cumulative economic margin).This evidence contributes to the existing studies investigating the trade-off in producer activities when the purchasing behaviour of the customer changes in front of linear or circular

products (Khitous et al., 2022). In this case, given that customers represent a key stakeholder in a circular economy transition, their perception about the value incorporated by circular products can allow producer companies to create and transfer these products into the market in a more effective way, and capture value from them over time in a more sustainable way.

In conclusion, the agent-based model developed here provides a tool that is very suitable for making a classic what-if analysis. In particular, it is a sort of computational laboratory where to perform experiments and find the most cost-efficient policy to improve the economic performance of firms. This allows for taking a further step towards understanding the outcomes tied to applying different investments in recycling materials. This simulator will be a very useful tool for managers because they will be able to simulate a chosen strategy before applying it in the real world.

For managers and policymakers, our research suggests the need to see the circular supply chain process with a comprehensive view, which conceives how the transition from a linear economy to a circular economy is a gradual pathway based not only on the pursuit of lower environmental impact, achieved through the implementation of circular economy principles in product design, but also on the economic sustainability of the manufacturer's business – along with that of the others supply chain companies. This observation aligns with the current scientific research dealing with circular economy as a paradoxical tension between economic growth and environmental benefit (Dagilienė & Varaniūtė, 2023).

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6 Ethics declaration

No ethical clearance is needed.

7 AI declaration

No AI tool have been used in developing the paper.

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Artificial Intelligence for a Sustainable Future: Unraveling its Impact on Circular Economy

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Abstract

Artificial Intelligence (AI) is rapidly transforming organizational practices and enabling more sustainable business models, especially in the context of the circular economy. While its potential is widely acknowledged, empirical evidence on the factors that influence AI adoption and its actual impact on circular economy practices—particularly in the context of small and medium-sized enterprises (SMEs)—remains limited. This study investigates the drivers of AI adoption among innovative Italian SMEs and assesses how AI contributes to the implementation of circular economy strategies. Grounded in the Unified Theory of Acceptance and Use of Technology (UTAUT), the study explores the role of four key constructs—Performance Expectancy, Effort Expectancy, Social Influence, and Facilitating Conditions—in shaping AI adoption decisions. It also examines the extent to which AI adoption promotes circular economy practices. The empirical analysis is based on data collected through a structured online questionnaire distributed to 1,664 innovative SMEs across Italy, of which 52 provided complete responses. Data were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM), a technique particularly suitable for testing complex models with small to moderate sample sizes. The findings partially validate the proposed theoretical framework. Performance Expectancy, Social Influence, and Facilitating Conditions are found to significantly influence AI adoption, while Effort Expectancy does not emerge as a significant predictor—suggesting that ease of use is less critical, possibly due to growing digital literacy or available technical support. Most importantly, the results show that AI adoption positively affects circular economy practices, supporting the view of AI as not only a technological asset but also a strategic enabler of sustainability. This study contributes to the literature by bridging the gap between technology adoption theories and circular economy research. It also offers practical insights for managers and policymakers aiming to promote digital and sustainable transitions. Emphasizing AI's strategic value, the study encourages investment in both technological infrastructure and supportive organizational environments to foster innovation and sustainable development.

Keywords: Artificial intelligence; UTAUT ; sustainability; circular economy practices; PLS-SEM.

Paper type: Academic Research Paper

1 Introduction

Environmental harm has become one of today's foremost global challenges, driven by the reckless exploitation of natural resources that critically undermines ecosystem stability. Addressing global warming, protecting the environment, and combating climate change demands the implementation of innovative strategies grounded in advanced technological expertise (Yucedag et al., 2018; Al-Ghussain, 2019).Within this framework, the circular economy stands out as a fundamental strategy to reduce environmental pressures, offering a regenerative system designed to limit resource waste and enhance their continuous utilization across interconnected production networks (Geissdoerfer et al., 2017). Unlike the conventional linear production model characterized by the "take, make, dispose" pattern, the circular economy encourages a more sustainable and efficient management of resources (Ness, 2008; Ghisellini et al., 2016; Sauvé et al., 2016). A crucial factor for implementing effective circular economy practices is digitalization (Cagno et al., 2021), which plays a key role in reshaping sustainable business models (Ellen MacArthur Foundation, 2019), facilitating the transition of manufacturing firms toward digital servitization and advanced automation (Kastalli and Van Looy, 2013; Frank et al., 2019; Liu et al., 2024). This process not only enhances operational efficiency but also opens new opportunities for value creation. Digital technologies in services—including Artificial Intelligence, Big Data Analytics, the Internet of Things, Machine Learning, Additive Manufacturing, Virtual Reality, Augmented Reality, and the Metaverse—contribute to improving systemic efficiency and actively support the achievement of the Sustainable Development Goals (SDGs), facilitating the shift toward a circular economy (Korhonen et al., 2018; Prieto-Sandoval et al., 2018; Xing and Liu, 2023). One of the most relevant aspects of digitalization is the ability to extract valuable knowledge from large volumes of data, supporting more informed decision-making, personalizing service offerings, optimizing service delivery processes, and enhancing the overall customer experience (Chauhan et al., 2022). Among the technologies of Industry 4.0, artificial intelligence (AI) plays a crucial role in improving resource management and promoting sustainable practices along the supply chain (Gupta et al., 2019).AI allows for the optimization of resource use, waste reduction, and the promotion of

sustainable behavior (Duan et al., 2019; Tutore et al., 2024), as well as enabling the creation of digital platforms that foster collaboration among companies engaged in sustainable practices (Tutore et al., 2024). AI also plays a significant role in enhancing circular economy practices (Montes-Pineda and Garrido-Yserte, 2024). The benefits of AI refers to its descriptive, diagnostic, predictive, and prescriptive capabilities (Madanaguli et al., 2024), which give multiple opportunities for circularity; in the development and adoption of circular business practices and operations, the design of circular products, components, and materials, including also the optimization of infrastructures to support circular resource flows (Ellen MacArthur Foundation, 2019). Moreover, AI can optimize recycling plant operations or encourage consumer engagement in adopting more circular behaviours (Tutore et al., 2024). Finally, the adoption of Artificial Intelligence can support the sustainable transformation of production processes by enabling the design of closed-loop systems that monitor and optimize resource consumption while minimizing waste generation. In this context, AI emerges as a strategic tool to reduce the environmental impact of industrial activities (Ronaghi, 2023). While acknowledging the already identified benefits, it becomes essential to delve deeper into both the positive effects and potential challenges arising from the use of AI-based technologies, analyzing their overall impact on environmental sustainability and circular economy practices (Al-Sharafi et al., 2023).Indeed, the literature reveals a lack of consensus regarding the role of Artificial Intelligence as either a strategic driver or an integral component in addressing environmental sustainability challenges (Kopka and Grashof, 2022). According to Vinuesa et al. (2020), AI has the potential to positively influence 134 targets (79%) across all Sustainable Development Goals (SDGs); however, 59 targets (35%) may be negatively affected by its development, highlighting the dual nature of AI's impact across the SDG framework. Overall, although some studies have examined the potential effects of AI on resource consumption, a systematic empirical analysis is still lacking—particularly concerning its influence on circular economy performance (Khakurel et al., 2018). Furthermore, the specific implications of AI for sustainable business practices, especially within small and medium-sized enterprises (SMEs), remain underexplored in the academic debate. As a result, significant knowledge gaps persist, particularly with regard to the actual effectiveness and tangible impact of AI adoption on organizational sustainability performance. In this perspective, the primary aim of this research is to investigate the factors influencing the adoption of AI by innovative SMEs, while also evaluating the implications of these technologies on circular economy. To achieve this goal, the research employs the theoretical framework of UTAUT (Unified Theory of Acceptance and Use of Technology). The structure of the paper is as follows. Section 2 presents the theoretical background and research hypotheses. Section 3 outlines the methodology, while Section 4 illustrates the results. Finally, Section 5 discusses the main conclusions drawn from the study.

2 Theoretical background and research model

The Unified Theory of Acceptance and Use of Technology (UTAUT), developed by Venkatesh et al. (2003), identifies four key constructs that influence users' behavioral intentions and actual technology usage: Performance Expectancy (PE), Effort Expectancy (EE), Social Influence (SI), and Facilitating Conditions (FC). Performance Expectancy refers to the perceived benefits associated with the use of a technology—namely, the extent to which an individual believes that adopting a particular system will enhance their personal or professional performance (Davis, 1989; Venkatesh and Davis, 2000; Venkatesh et al., 2003). In the context of Artificial Intelligence (AI), PE reflects how individuals perceive AI as a tool to strengthen their capabilities. Several studies confirm a positive relationship between performance expectancy and technology adoption (Pillai et al., 2024), with specific evidence supporting this link in the AI domain (García Blanes Sebastián et al., 2022; Pillai et al., 2024; Salifu et al., 2024).

Based on this evidence, we propose the following hypothesis:

H1. Performance Expectancy positively and significantly impacts the adoption of Artificial Intelligence.

Effort Expectancy (EE) concerns the perceived ease of use of a technology—that is, how intuitive and accessible users find the system to be (Davis et al., 1989; Thompson et al., 1991; Yoon et al., 2020). It measures the degree of effort, both cognitive and physical, that individuals believe is required to use a technology effectively (Acquah et al., 2024). In relation to AI, EE captures how simple and user-friendly people consider AI tools to be. Several studies have shown a positive relationship between EE and technology adoption (Al-Adwan et al., 2024; Du and Liang, 2024). For example, Chatterjee et al. (2023) found that employees' perceptions of ease of use significantly influenced their adoption of AI-driven CRM systems. Accordingly, we formulate the following hypothesis:

H2. Effort Expectancy positively and significantly impacts the adoption of Artificial Intelligence.

Social Influence (SI) reflects how individuals perceive that important people around them—such as peers, colleagues, or family members—believe they should use a specific technology (Venkatesh et al., 2003). This

construct captures the role of social norms and identification processes in shaping behavioral intentions. Social influence can lead individuals to conform to group expectations, internalize shared norms, and model the behavior of influential others. Prior research highlights the impact of close individuals' social environments—thoughts, emotions, and behaviors—on technology adoption decisions (Irani et al., 2009; Venkatesh and Brown, 2001). In light of these findings, we hypothesize that:

H3. Social Influence positively and significantly impacts the adoption of Artificial Intelligence.

Facilitating Conditions (FC) refer to users' perceptions of the resources and support available to enable the use of technology, such as infrastructure, training, and technical assistance (Oliveira et al., 2014). Studies indicate that the availability of tools like internet connectivity, software integration, and organizational support plays a critical role in the successful adoption and continued usage of a technology (Lee et al., 2013). In the context of AI, FC can determine whether individuals feel empowered to incorporate AI into their workflows. Therefore, we propose the following hypothesis:

H4. Facilitating Conditions positively and significantly impact the adoption of Artificial Intelligence.

The integration of Artificial Intelligence has proven to be a key driver in enhancing organizational sustainability (Gupta et al., 2019) and in supporting companies' engagement in circular economy initiatives (Montes-Pineda and Garrido-Yserte, 2024). It also strengthens firms' capabilities across various analytical dimensions, including descriptive, diagnostic, predictive, and prescriptive functions (Madanaguli et al., 2024). These advancements are largely due to AI's ability to process and make sense of vast amounts of data generated throughout the production lifecycle (Ramadoss et al., 2018). Ghoreishi and Happonen (2020) identify three main ways in which AI can support circular practices: by improving the selection and disassembly processes, enabling the remanufacturing of components, and enhancing materials recycling. Additionally, AI can significantly optimize reverse logistics systems, boosting their efficiency and traceability (Schluter et al., 2021).

Based on these considerations, we propose the following hypothesis:

H5. AI adoption positively influences circular economy practices.

Figure 1 below presents the conceptual framework developed for this study.

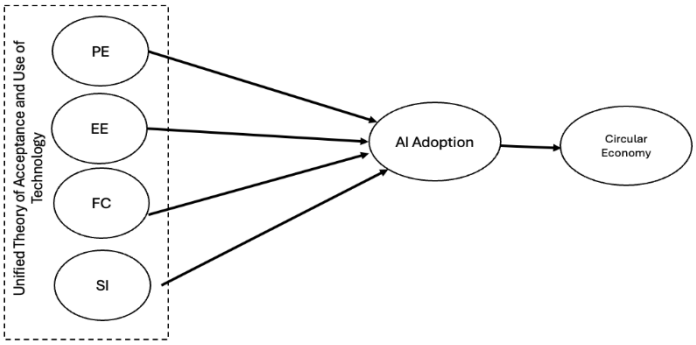


Figure 1 – The proposed model

3 Methodology

3.1 Measurement of constructs and construct design

To collect data, we will use a quantitative research design using a survey questionnaire method based on pre-validated scales (Zahid et al., 2022; Ali et al.,2022). The initial version was prepared in English, and subsequently translated into Italian through a rigorous translation and back-translation process, following established methodological guidelines (Saunders et al., 2009). About the constructs, 5 UTAUT constructs were employed, adapted from Venkatesh et al. (2003) and Chen et al., (2021): 4 items for PE, 4 items for EE, 4 items for SI, 3 items for FC, and 3 items for ADP. For CE 3 items adapted from Baudier et al. (2020) were used.The questionnaire is structured into three distinct sections designed to enhance clarity and ease of completion for participants. Section (A) aims to minimize social desirability bias by clearly outlining the study's objectives, explaining the data collection procedures, and assuring complete confidentiality and anonymity to respondents (Chidlow et al., 2015). Section (B) gathers detailed organizational information and demographic data from participants, including geographic region, industry sector, gender, age, technological experience, and organizational role. Lastly, section (C) comprises questions related to the theoretical constructs of the UTAUT model and dimensions concerning the circular economy, thereby fully capturing the dynamics explored in the

study. The constructs are measured using a five-point Likert scale ranging from "1 – strongly disagree" to "5 – strongly agree" (Luck and Rubin, 1987; Premkumar and Ramamurthy, 1995).

3.2 Data collection and sample

The research aims to understand the factors influencing the adoption of artificial intelligence (AI) and the resulting impact on circular economy practices. To this end, the questionnaire was specifically targeted at innovative Italian SMEs, introduced by Legislative Decree No. 3 of 2015 (DL 3/2015), as these enterprises are particularly suitable for this study. Innovative SMEs were selected primarily due to their inherent propensity for innovation, defined according to specific regulatory criteria. According to Legislative Decree 3/2015 (Article 4) and the European Commission Recommendation of May 6, 2003 (2003/361/EC), these firms must meet at least two of the following criteria: significant expenditure on research and development, employment of highly qualified personnel, and ownership or exclusive licenses of industrial patents relevant to their business activity. These attributes ensure that the companies possess the organizational structure and capabilities necessary to effectively integrate advanced technologies such as artificial intelligence. Data collection was conducted using an online questionnaire distributed via email to the aforementioned companies. The questionnaire was distributed across various Italian regions to gather representative data by leveraging the cultural and behavioral diversity of innovative SMEs nationwide. Before commencing data collection, necessary authorization was obtained from the institutions involved in the research. To ensure the quality and accuracy of the questionnaire, four academic experts conducted a detailed review of the questions, providing valuable feedback to enhance clarity and comprehension. Following this stage, actual data collection began through online platforms, aiming to reach as many participants as possible and ensuring extensive and diverse geographic coverage. For the analysis, out of 2,457 registered innovative SMEs, we retrieved the email addresses of 1,664 companies, to which the questionnaire was submitted. From these, we received a total of 52 completed responses.Among the respondents, the average age is 45 years, 70% are men and 30% are women. The average work experience is 17 years, while the average experience with artificial intelligence is 3 years.In terms of geographic location, most of the responding companies are based in Northern Italy (53%), followed by Southern Italy (26%) and Central Italy (19%).The companies involved have an average of 21 employees. Moreover, most of them have been operating for more than 10 years, with an average company age of 16 years.

3.3 Data analysis procedure

Then, to test our model, we will use the Partial Least Squares method for Structural Equation Modeling,(Hair et al., 2023). This technique stands out from other multivariate analyses due to its ability to simultaneously examine multiple constructs, making it particularly useful for understanding complex phenomena. Moreover, the absence of rigid assumptions regarding the distribution of items and latent variables represents a significant advantage, especially in contexts like ours, characterized by moderately sized samples (Hair et al., 2023).

4 Results

4.1 Measurement model

The evaluation of a measurement model composed solely of reflective indicators in a PLS-SEM framework is conducted by verifying that the data meet four key criteria: convergent validity, internal consistency, reliability, and discriminant validity.

According to Hair et al. (2023), outer loadings should exceed 0.60. Based on this threshold, we excluded the indicators FC2, PE2, and SI2, and subsequently re-estimated the model. To assess internal consistency and reliability, we used Composite Reliability (CR) and Cronbach's Alpha. Specifically, both Cronbach's Alpha and Composite Reliability values should be greater than 0.70 for each construct (Hair et al., 2023). The results presented in Table 1 confirm that the criteria for convergent validity, internal consistency, and reliability are fully met. Regarding discriminant validity, the Fornell-Larcker criterion was applied. This approach verifies that the square root of the Average Variance Extracted (AVE) for each construct is greater than its correlations with all other constructs, as shown in the off-diagonal elements of the correlation matrix. The results presented in Table 2 confirm that the model satisfies the discriminant validity requirement.

Table 1: Convergent validity, internal consistency and reliability

Costructs	Items	Outer loadings	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)	R square
AI Adoption	ADP1	0,970	0,946	0,948	0,966	0,904	0,805
	ADP2	0,961					
	ADP3	0,920					
CE practices	CE1:	0,883	0,917	0,959	0,947	0,855	0,142
	CE2:	0,935					
	CE3:	0,955					
Effort expectancy	EE1	0,825	0,834	0,853	0,888	0,666	
	EE2	0,751					
	EE3	0,862					
	EE4	0,822					
Facilitating conditions	FC1	0,881	0,749	0,756	0,888	0,799	
	FC3	0,907					
Performance expectancy	PE1	0,955	0,869	0,929	0,919	0,793	
	PE3	0,933					
	PE4	0,772					
Social Influence	SI1	0,936	0,940	0,947	0,962	0,893	
	SI3	0,952					
	SI4	0,946					

Table 2 : Discriminant validity

	ADP	CE	EE	FC	PE	SI
ADP	0,951					
CE	0,377	0,925				
EE	0,426	0,339	0,816			
FC	0,812	0,304	0,461	0,894		
PE	0,619	0,578	0,544	0,401	0,890	
SI	0,721	0,281	0,412	0,565	0,588	0,945

4.2 Structural model

The quality of the Structural model is checked using the R^2 of the endogenous constructs (see Table 1). After this first test, we use a bootstrap procedure with 5.000 resamples (Hair et al., 2023) to test our hypotheses. The results of this procedure are reported in Table 3. All the hypotheses are supported except for H2.

Table 3: Hypotheses testing

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
ADP -> CE	0,377	0,383	0,128	2,952	0,003
EE -> ADP	-0,115	-0,109	0,073	1,573	0,116
FC -> ADP	0,604	0,615	0,104	5,791	0,000
PE -> ADP	0,288	0,269	0,112	2,579	0,010
SI -> ADP	0,257	0,262	0,096	2,688	0,007

5 Conclusions

The findings of this research partially confirm the proposed theoretical model, highlighting key factors influencing the adoption of Artificial Intelligence (AI) and its impact on circular economy practices. Specifically, Hypothesis H1 was supported, indicating that Performance Expectancy positively and significantly affects AI adoption. This suggests that perceived improvements in operational performance are a critical driver for organizations. Similarly, Hypotheses H3 and H4 were confirmed, underscoring the roles of Social Influence and Facilitating Conditions in fostering AI adoption. Conversely, Hypothesis H2 regarding Effort Expectancy was not supported, implying that ease of use is not a decisive factor in the analyzed context—potentially due to increased familiarity with digital tools or adequate technical support. Finally, Hypothesis H5 was validated, demonstrating that AI adoption positively contributes to the implementation of circular economy practices. This reinforces the view of AI as not only an efficiency tool but also a strategic enabler of more sustainable business model. Overall, the study enriches the literature on technology adoption with a sustainability perspective, providing valuable insights for both business leaders and policymakers promoting advanced, sustainability-driven technologies. This study contributes to the literature on AI adoption and its role in promoting the circular economy. The findings partially validate the UTAUT model, revealing that not all theoretical constructs have the same influence in the context of AI. In particular, the lack of significance for Effort Expectancy highlights the need to reassess traditional models in light of rapidly evolving technologies like AI. Additionally, the empirical evidence linking AI adoption to circular economy practices represents a meaningful theoretical extension. It positions AI not only as a technological tool but also as a strategic enabler of environmental sustainability. The research helps bridge the gap between technology adoption studies and circular economy literature, offering a foundation for future interdisciplinary investigations.

From a managerial perspective, the results offer practical insights for companies seeking to pursue digital transformation and achieve a sustainable transition. First, the perception of performance benefits emerges as a key driver for AI adoption. Managers should, therefore emphasize AI's positive impact on efficiency, quality, and competitiveness during change management processes. Second, the effects of Social Influence and facilitating conditions highlight the importance of a supportive organizational environment. This calls for investments not only in technology but also in training, internal communication, and the development of internal champions to lead innovation. Finally, the confirmed link between AI and circular economy practices offers business leaders an additional incentive for adoption—not only for economic gains but also to position their organizations as sustainability-driven enterprises.

6 Ethics declaration

We declare that ethical clearance for the research referred to in this paper was not required.

7 AI declaration

An AI-based tool was used to improve the English language and writing style of the paper.

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Skilling and Upskilling within Port Authority Management: A Strategic Approach to Industry 5.0 Requirements

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Abstract

The transition toward Industry 5.0 has brought forth a new paradigm within maritime logistics and port governance, where the focus shifts beyond automation to embrace resilience, sustainability, and above all, human-centric innovation. In this context, Port Authorities, particularly those operating under the Landlord model, face unprecedented demands to align infrastructural and technological transformation with comprehensive workforce development strategies. While infrastructure and digital systems have been historically prioritised, the capabilities and adaptability of the human workforce—especially blue-collar maritime workers—have received comparatively less strategic attention.

This study investigates the alignment of workforce development with Industry 5.0 principles, focusing on the evolving competencies, training gaps, and strategic responses of Port Authorities operating under the Landlord model. Framed by the Resource-Based View and the Dynamic Capabilities Theory, the research explores how human capital—particularly blue workers—functions as a core asset for competitive advantage, technological readiness, and organisational resilience.

Employing a qualitative methodology, the study draws on twelve semi-structured interviews with executives, HR managers, and operational staff from Italy's maritime sector. Thematic content analysis revealed three core patterns: a widespread digital skills gap among blue workers, the fragmented nature of training initiatives across port authorities, and a misalignment between strategic HR objectives and operational governance.

Findings suggest that for Port Authorities to meet the expectations of Industry 5.0, workforce development must be fully integrated into port governance frameworks. Human-centric innovation, environmental sustainability, and digital transformation are not achievable without a skilled and empowered workforce.

The performed analysis additionally underscores the need for cultural and institutional shifts that reframe blue workers as, active agents of technological co-creation and environmental stewardship.

Ultimately, the study advocates for the establishment of structured, collaborative skilling frameworks, potentially through regional Port Skills Councils or transnational maritime academies, to harmonise training standards and close capability gaps. Such interventions would not only strengthen organisational performance but also affirm the role of Port Authorities as key enablers of a resilient and inclusive maritime ecosystem in line with Industry 5.0 values.

Keywords: Industry 5.0, maritime sector, blue workers, port authority governance, competencies

Paper type: Research Paper

1 Introduction

Industry 5.0 introduces a specific view wherein technology and humans collaborate rather than compete. As such, the need to upskill and reskill workers in areas such as digital literacy, sustainability management, and adaptive logistics practices has become a critical issue. Port Authorities must evolve beyond their traditional role as physical asset managers to become facilitators of human capital innovation and learning ecosystems. This transformation aligns with the foundational assumptions of the Resource-Based View (Barney, 1991), which frames human capital as a valuable, rare, inimitable, and non-substitutable (VRIN) resource, and the Dynamic Capabilities Theory (Teece, Pisano, & Shuen, 1997), which emphasises an organisation's ability to integrate, build, and reconfigure internal and external competencies in response to a rapidly changing environment.

As ports serve as critical nodes within global value chains, ensuring the strategic alignment of workforce skills with technological and ecological advancements is not only a matter of operational efficiency but also of long-term resilience and competitiveness.

The transformation ushered in by Industry 5.0 has introduced a human-centric, resilient, and sustainable paradigm in the maritime sector, positioning skilling and upskilling as strategic imperatives within Port Authority management. This study investigates the alignment of workforce development with Industry 5.0 principles, focusing on the evolving competencies, training gaps, and strategic responses of Port Authorities operating under the Landlord model. Framed by the Resource-Based View (Barney, 1991) and the Dynamic Capabilities Theory (Teece et al., 1997), the research explores how human capital—particularly blue workers—functions as a core asset for competitive advantage, technological readiness, and organisational resilience.

Employing a qualitative methodology, the study draws on twelve semi-structured interviews with executives, HR managers, and operational staff from Italy's maritime sector. Thematic content analysis revealed three core

patterns: a widespread digital skills gap among blue workers, the fragmented nature of training initiatives across port authorities, and a misalignment between strategic HR objectives and operational governance. While many port stakeholders acknowledged the critical importance of digital and sustainable competencies, their efforts were largely reactive, underfunded, and not embedded in long-term strategy. Nonetheless, innovative cases such as the Port of Genoa demonstrated how strategic investments in training ecosystems and learning technologies can enhance digital maturity and institutional adaptability.

Findings suggest that for Port Authorities to meet the expectations of Industry 5.0, workforce development must be fully integrated into port governance frameworks. Human-centric innovation, environmental sustainability, and digital transformation are not achievable without a skilled and empowered workforce. This research underscores the need for cultural and institutional shifts that reframe blue workers not as passive recipients of automation but as active agents of technological co-creation and environmental stewardship.

Ultimately, the study advocates for the establishment of structured, collaborative skilling frameworks, potentially through regional Port Skills Councils or transnational maritime academies, to harmonise training standards and close capability gaps. Such interventions would not only strengthen organisational performance but also affirm the role of Port Authorities as key enablers of a resilient and inclusive maritime ecosystem in line with Industry 5.0 values.

2 Literature Review

The conceptual basis of Industry 5.0, as outlined by Grabowska et al. (2022), promotes a socio-technical system where humans and machines collaborate to create value in ways that are inclusive, sustainable, and resilient. This philosophy builds upon the automation principles of Industry 4.0 but shifts the emphasis towards human-centric design and ethical innovation. Within the maritime sector, this transition has significant implications, given that ports are traditionally conservative and infrastructure-driven institutions. Digitalisation, artificial intelligence, and cyber-physical systems are transforming port operations, yet many port governance models have not concurrently updated their human resource strategies.

A growing body of work recognises the importance of strategic skilling in maritime operations. For instance, Acciaro et al. (2020) argue that Port Authorities play a pivotal role in enabling digital transformation through human resource innovation. Similarly, Ghobakhloo et al. (2022) demonstrate that the success of digitalisation efforts in industrial environments is closely linked to an organisation's dynamic learning capabilities and adaptability, both of which depend on the continuous development of human skills.

Within the context of the Landlord port governance model, Port Authorities act as facilitators of public-private collaboration (Verhoeven, 2010), although they often lack the mandate or mechanisms to enforce skilling policies across stakeholder organisations. Poulsen and Sornn-Friese (2015) note that such decentralised governance structures, while flexible, tend to lead to fragmented training efforts and inconsistent standards.

In line with the Resource-Based View, human capital can become a source of sustained competitive advantage if nurtured strategically (Barney, 1991). Moreover, the Dynamic Capabilities Theory, as articulated by Teece et al. (1997), emphasises that organisational resilience hinges on learning, sensing, and transformation capabilities. When applied to ports, these theories suggest that human capital development is not merely a support function but a central axis of innovation and adaptability.

2.1 Industry 5.0 and Maritime Sector Transformation

The notion of Industry 5.0 represents an important evolution from the previous industrial paradigm. While Industry 4.0 emphasized automation, cyber-physical systems, and data exchange in manufacturing and logistics, Industry 5.0 pivots toward human-centricity, resilience, and sustainability as core organizing principles (European Commission, 2021). This conceptual shift foregrounds the value of integrating human creativity and intuition with technological advancement. Industry 5.0 does not seek to displace human labor with automation but rather to facilitate collaborative intelligence—where machines augment human capabilities rather than replace them (Nahavandi, 2019).

In the context of the maritime and port sectors, the shift from Industry 4.0 to 5.0 is especially significant. Ports have long been focal points for industrial and logistical transformation, playing central roles in the diffusion of automation technologies such as container cranes, terminal operating systems, and digital tracking interfaces. Under Industry 4.0, smart ports became increasingly data-driven, leveraging IoT (Internet of Things), digital twins, and AI to optimize operations and minimize downtime (Acciaro et al., 2020). However, this automation often overlooked the role of human adaptability and knowledge, creating skill gaps and in some cases alienating port labor forces from decision-making processes.

Industry 5.0 reorients this trajectory by stressing the synergy between human intelligence and digital tools. In ports, this transformation entails redefining work processes so that digital systems (such as predictive maintenance algorithms or AI-based port scheduling software) do not operate in isolation but are interpreted and managed by skilled human operators. This demands new training paradigms focused not only on technical skills but also on ethical reasoning, collaborative decision-making, and sustainable practices.

This transformation is gradually taking root in major global ports. For example, the Port of Rotterdam has launched human-in-the-loop digitalisation initiatives where operators work alongside AI systems for predictive maintenance and berth optimization. Similarly, the Port of Singapore emphasizes augmented intelligence, whereby AI tools are co-designed with frontline workers to enhance decision accuracy without eliminating human judgment (Ng & Liu, 2020). The Port of Genoa, a key Mediterranean node, is also investing in hybrid governance models where labor unions and digital firms co-create training content—a development aligned with the principles of Industry 5.0.

2.2 Skilling and Upskilling: Definitions and Strategic Importance

In the maritime sector, skilling refers to the foundational training provided to new entrants, reskilling denotes equipping workers with new competencies to shift to different roles, and upskilling involves deepening or expanding current knowledge to meet emerging technological or regulatory demands (World Economic Forum, 2020). These concepts are increasingly critical in an environment where port digitalisation is accelerating but institutional mechanisms for workforce adaptation are lagging.

The strategic importance of these interventions cannot be overstated. Ports operate as complex socio-technical systems requiring real-time coordination among human operators, digital infrastructures, and physical logistics networks. As ports transition toward green shipping, AI-driven logistics, and blockchain-enabled customs procedures, there is an urgent need to close the skills gap between legacy practices and digital innovation.

Case studies provide compelling evidence of this transformation. The Port of Rotterdam, for instance, has invested in a Digital Twin environment of the entire port area, enabling real-time data simulations for berth planning and traffic forecasting. However, despite technological advancement, reports show that many employees lack the training to interpret or act on these insights effectively (Chhetri et al., 2021). In Singapore, the Maritime and Port Authority has launched the "Sea Transport Industry Transformation Map," which explicitly identifies upskilling as a priority for enabling digital port services. Meanwhile, Genoa faces challenges in bridging generational knowledge divides as older workers often lack formal training in digital tools, whereas younger recruits may be unfamiliar with core operational workflows.

Collectively, these examples underline a growing disconnect between technological ambition and human capital readiness. Without deliberate skilling strategies, ports risk reinforcing inequalities and inefficiencies, ultimately undermining the very objectives of digitalisation.

2.3 The Landlord Port Governance Model

The Landlord Port Governance Model—dominant across Europe and Asia—positions Port Authorities primarily as facilitators and coordinators of infrastructure development, while operational services are delegated to private terminal operators and logistics firms. As described by Verhoeven (2010), this model seeks to harmonize public objectives (e.g., sustainability, regional development) with private efficiency and investment capacity.

This hybrid arrangement creates complex governance dynamics, especially concerning human capital development. Port Authorities, being asset owners rather than employers of operational labor, often lack direct control over workforce training and development. Instead, these responsibilities fall to private operators who may prioritize short-term efficiency over long-term skill-building.

The result is often fragmented skilling ecosystems, where training initiatives are developed in isolation without systemic coordination. In ports like Genoa, for example, digitalisation projects funded by EU regional innovation schemes have failed to include parallel investments in workforce education, leading to implementation delays and operational friction (Monios & Wilmsmeier, 2021). Additionally, the Landlord model's reliance on contractual governance inhibits agile responses to evolving skill demands, as job descriptions, labor roles, and workflows are rigidly defined by concessions and procurement processes.

Thus, the model presents both institutional constraints and opportunities. On one hand, it limits the Port Authority's ability to directly intervene in workforce strategy. On the other hand, it provides a platform for public-private collaboration, where strategic skilling alliances can be formed—if governance structures prioritize human capital as a strategic asset.

2.4 Theoretical Foundations

Two key theoretical frameworks underpin the analysis of human capital in digitalised port governance: the Resource-Based View (RBV) and the Dynamic Capabilities Theory (DCT).

According to Barney (1991), the RBV posits that sustainable competitive advantage arises from resources that are valuable, rare, inimitable, and non-substitutable (VRIN). In this framework, skilled human capital, particularly workers who combine maritime operational knowledge with digital and sustainability fluency, becomes a strategic resource. These individuals enable organizational learning, improve decision-making in uncertain environments, and foster innovation. Yet, most ports still undervalue human capital, treating labor as a cost rather than a strategic input.

By contrast, port authorities that recognize the VRIN nature of skilled workers—such as those in Rotterdam and Singapore—invest in long-term human capital development through partnerships with universities, vocational institutes, and technology firms. These ecosystems generate not just workforce readiness but also knowledge spillovers and collaborative innovation—key drivers of port competitiveness in an Industry 5.0 context.

The Dynamic Capabilities Theory, advanced by Teece et al. (1997) and later applied to digital transformation by scholars like Ghobakhloo et al. (2022), provides another interpretive lens. It emphasizes the capacity of organizations to sense, seize, and reconfigure internal and external competencies to address rapidly changing environments. In maritime governance, this translates to an ability to recognize emerging skill needs, mobilize learning resources, and realign governance frameworks accordingly.

Port Authorities that internalize DCT logic treat learning and reconfiguration as ongoing processes. For example, the Port of Singapore's transformation programs are designed as iterative learning loops, wherein feedback from workforce performance informs successive rounds of curriculum redesign and job rotation. Genoa has initiated similar programs on a smaller scale, with micro-credentialing systems allowing blue-collar workers to gradually build digital proficiency.

Together, RBV and DCT underscore the strategic and adaptive value of human capital. They provide theoretical justification for viewing workforce development not merely as a social obligation, but as a core governance challenge that directly affects operational agility and institutional resilience.

3 Methodology

This study adopts a qualitative research design grounded in interpretivist epistemology to explore how Port Authorities and maritime stakeholders perceive and address skilling and upskilling challenges. The research seeks to understand the lived experiences, attitudes, and institutional strategies related to workforce development in the context of digital transformation and sustainable logistics.

Data are collected through six semi-structured interviews involving one human resources manager from a prominent maritime firm, and 5 maritime workers employed as ship crew.

The diversity of participants allowed for a multifaceted perspective on how skills gaps are perceived and addressed at different organisational levels. All interviews were conducted online, recorded with consent, and transcribed verbatim.

The transcripts were then subjected to thematic content analysis following the guidelines of Braun and Clarke (2006), allowing for the emergence of inductively derived themes reflective of participant experiences and institutional practices.

4 Findings

One of the central findings was the widespread recognition of a skills gap in both digital competencies and environmental management. Respondents pointed to insufficient familiarity with technologies such as Internet of Things (IoT), digital twins, and data analytics among both administrative and operational staff. This deficit was particularly pronounced among blue workers, who reported limited access to structured training programs. Despite this, there was also evidence of high adaptability and willingness to learn among these workers when provided with hands-on learning and peer-supported education.

Another significant theme was the absence of an institutionalised framework for workforce development. Port Authorities across Italy demonstrated a fragmented approach to skilling, with initiatives often tied to EU-funded projects or one-off collaborations with academic institutions. These efforts lacked continuity and were seldom embedded within broader strategic planning processes.

Interestingly, a disconnect emerged between the strategic vision articulated by HR managers—who often emphasised sustainability, digital HRM, and corporate learning—and the operational focus of port governance

structures, which remained centred on infrastructure maintenance and logistical throughput. This disconnect often led to underinvestment in human capital, even when there was clear recognition of its value.

However, the study also revealed promising practices, such as in the Port of Genoa, where strategic investments in dynamic learning systems and digital training labs have led to higher levels of digital maturity and stakeholder engagement. These cases align closely with the principles of the Dynamic Capabilities Theory, suggesting that ports which internalise continuous learning as a core function are better positioned to thrive in the Industry 5.0 era.

5 Discussion

The research findings support the thesis that skilling and upskilling in port governance represent a strategic requirement. By failing to embed workforce development into long-term planning, many Port Authorities are missing a vital opportunity to align with the principles of Industry 5.0 and the broader digital transformation agenda. The human-centric ethos of Industry 5.0 demands that blue workers are not treated as passive recipients of technology but as active contributors to innovation.

From the lens of the Resource-Based View, it is clear that human capital, particularly when it embodies digital and sustainable competencies, constitutes a valuable and inimitable asset. Yet, this potential remains underleveraged due to outdated governance paradigms. Likewise, from a dynamic capabilities perspective, those ports that succeed in reconfiguring their training ecosystems, sensing environmental changes, and building institutional knowledge loops demonstrate superior adaptability.

The evidence suggests a need for cultural transformation in how human capital is viewed. Port Authorities must shift from being custodians of infrastructure to orchestrators of knowledge-based ecosystems. This transition will require not only strategic vision but also institutional reforms that prioritise workforce empowerment and capacity-building at all levels.

6 Conclusion

As shown by the literature review performed throughout the present analysis, Port Authority Management in the Industry 5.0 era is undergoing profound transformations due to digitalisation, sustainability mandates, and increasing stakeholder complexity. The skilling and upskilling of maritime workers—especially blue workers operating under the Landlord port governance model—emerges as a strategic lever to ensure competitiveness, human-centric innovation, and adaptability.

Theoretical frameworks such as the Resource-Based View (RBV) and Dynamic Capabilities Theory (DCT) provide robust conceptual anchors for understanding workforce development as a strategic asset and a driver of transformation. Recent research underscores the need for Port Authorities to transition from infrastructure facilitators to orchestrators of digitally capable, resilient ecosystems by investing in human capital development aligned with Industry 5.0 values.

Hence, Port Authorities must adopt a more strategic and systemic approach to workforce development that aligns with the principles of Industry 5.0. This entails institutionalising training programs, fostering cross-sector collaboration in curriculum design, and empowering blue workers through participatory learning models. Establishing national or regional Port Skills Councils, aligned with the European Union's Blue Economy strategy, could serve as a platform for standardising competencies and fostering innovation. Moreover, investment in digital infrastructure must be matched by investment in people, recognising that ports of the future will be defined not only by their cranes and cargo systems but by the intelligence and adaptability of their workforce.

7 Ethics declaration

No ethical clearance is needed for the research referred to in this paper.

8 AI declaration

An AI tool was used in the process of editing and completing the references section.

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The Bridge Maker's Role in Industry 5.0 Ecosystems: Driving Collaboration and Innovation for Sustainable Outcomes

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Abstract

The transition to Industry 5.0 marks a paradigm shift towards innovation ecosystems that prioritize human-centricity, sustainability, and resilience. This paper advances the understanding of innovation ecosystem governance by introducing the concept of the "Bridge Maker" - a strategic intermediary that plays a pivotal role in aligning diverse stakeholders, fostering collaborative governance, and embedding Industry 5.0 values systemically across ecosystems. Grounded in insights from Complex Adaptive Systems (CAS) theory, Open Innovation (OI), and recent developments in ecosystem orchestration and governance, the Bridge Maker (BM) is positioned as a crucial enabler of ecosystem adaptability and success.

Through a conceptual analysis, this paper addresses two primary research questions: (*1) How do Bridge Makers align stakeholders to drive collaboration and innovation within human-centered Industry 5.0 ecosystems? (2) What role do Bridge Makers play in embedding sustainability and human-centric values as systemic ecosystem features?* Drawing from recent theoretical advancements (Chesbrough, 2003; Holgersson et al., 2022; Tedesco, 2019) and extending the Adaptive Open Innovation Systems (AOIS) framework, the study proposes a model highlighting the competencies, behaviors, and governance mechanisms required for effective Bridge Making.

The findings suggest that BM operates through trust-building, sense-making, strategic foresight, and adaptive orchestration practices that promote long-term ecosystem resilience. In doing so, they bridge institutional gaps, overcome organizational inertia, and create the conditions necessary for sustainable innovation trajectories. The paper offers practical implications for innovation managers, policymakers, and educators seeking to operationalize Industry 5.0 principles within complex multi-actor environments.

Finally, the study calls for further empirical research to explore the dynamic practices of BM across various industry contexts and to develop actionable guidelines for their identification, training, and support within innovation ecosystems.

Keywords: Bridge maker, collaboration, ecosystem governance, Industry 5.0, innovation

Paper type: Academic Research Paper

1 Introduction

Contemporary transformations in industrial paradigms reveal an increasing urgency to rethink the structures and governance mechanisms that underlie innovation ecosystems towards sustainability and implementation of SDG. The transition toward Industry 5.0 reflects a growing consensus that technological innovation, while essential, must be recalibrated to respond to broader societal needs, including human well-being, environmental stewardship, and systemic resilience (Chesbrough, 2003; Holgersson et al., 2022). This evolution challenges traditional conceptions of technological progress, requiring a synthesis of digital prowess and normative societal goals. Yet, within this shifting landscape, the management of innovation ecosystems has struggled to keep pace, revealing persistent gaps between technological capability and socio-environmental responsibility.

Innovation ecosystems have evolved into highly intricate, decentralized constellations of actors, each contributing distinct capabilities, visions, and agendas. Firms, academic institutions, startups, public agencies, and civic organizations interact in increasingly fluid and dynamic configurations. While such ecosystems have been heralded for their capacity to spur innovation through open and distributed knowledge exchanges, their operational realities are often marked by coordination failures, trust deficits, and divergent strategic orientations (West and Bogers, 2014). The innate complexity of these systems, compounded by the characteristics of Complex Adaptive Systems (CAS)—nonlinear feedback loops, emergent order, and decentralized adaptability—poses profound challenges for ecosystem governance (Tedesco and Serrano, 2019). Classical governance models, which assume stable roles, predictable exchanges, and hierarchical control, are ill-suited to the realities of contemporary innovation ecosystems.

Emerging scholarship increasingly emphasizes that sustainable success in innovation ecosystems hinges not solely on technological excellence but on the ability to cultivate new forms of relational governance and strategic alignment across heterogeneous actors (Majchrzak et al., 2023). Such governance must be capable of dynamically orchestrating contributions, resolving tensions, and enabling collective sense-making under conditions of uncertainty. However, most current practices lack the mechanisms to bridge the micro-level activities of individual organizations with the macro-level goals of ecosystem sustainability and human-centric

impact. The absence of actors or mechanisms dedicated to creating strategic and normative cohesion among diverse stakeholders has been a critical blind spot in ecosystem development strategies.

In response to these challenges, the present study advances the concept of the BM as an indispensable strategic intermediary within human-centered innovation ecosystems. Distinct from traditional brokers or facilitators, the BM is conceptualized as an actor capable of cultivating emergent trust architectures, catalyzing strategic convergence across competing logics, and embedding normative aspirations such as sustainability and resilience into the operational logic of the ecosystem itself. Rather than simply connecting actors or facilitating transactions, BM are envisioned as systemic enablers who foster the adaptive capabilities necessary for ecosystems to thrive under the demands of Industry 5.0. Their role is dynamic, context-sensitive, and deeply interwoven with the relational and value-generating processes that underpin resilient ecosystems.

The present inquiry is structured around two interrelated research questions: first, how BM strategically align stakeholders to promote collaboration and innovation within the multifaceted environments of Industry 5.0 ecosystems; and second, how these actors contribute to embedding human-centric and sustainability-oriented values as enduring systemic features. By addressing these questions, the paper seeks to not merely describe the emerging complexities of ecosystem governance but to propose actionable, theoretically grounded strategies for fostering innovation environments that are simultaneously technologically advanced and socially responsive.

Beyond its conceptual contribution, this paper aspires to deliver practical value to innovation managers, policy architects, and educational leaders who are grappling with the operationalization of Industry 5.0 principles. By elucidating the competencies, mechanisms, and structural supports necessary for effective bridge making, the study offers a roadmap for cultivating more coherent, adaptive, and resilient ecosystems. Ultimately, the work contributes to the ongoing redefinition of innovation governance by demonstrating how strategic intermediaries can play a foundational role in navigating the complex adaptive realities of human-centered technological futures.

Following this Introduction and the clarification of the research approach, the next section situates the discussion within relevant theoretical frameworks, drawing from contemporary scholarship on innovation ecosystem theory, governance of complex systems, open innovation dynamics, and Industry 5.0 paradigms. Building upon these foundations, the paper then elaborates the conceptualization of the BM role, discusses practical implications for innovation managers and policymakers, and concludes with reflections and directions for future research

1.1 Research Approach

This study adopts a conceptual research approach grounded in systematic literature analysis and theory synthesis. Building on insights from Complex Adaptive Systems (CAS) theory, Open Innovation (OI) paradigms, innovation ecosystem governance frameworks, and the emerging Industry 5.0 paradigm, the research advances a novel conceptualization of the BM role. Rather than collecting primary empirical data, the study engages in integrative theoretical reasoning, critically analyzing existing models and frameworks to propose a structured and actionable model for strategic intermediation within human-centered, sustainable innovation ecosystems. The conceptual framework developed herein serves both to address identified gaps in current governance models and to provide a foundation for future empirical validation.

2 Theoretical Foundation

Innovation ecosystems are increasingly recognized as dynamic, complex structures requiring new forms of governance and orchestration to navigate today's volatile and interconnected environments. Traditional models of centralized management and linear innovation trajectories are no longer sufficient to explain or support the distributed, emergent, and adaptive behaviors observed across modern innovation landscapes. In response, several theoretical frameworks have evolved to guide understanding and intervention in these ecosystems. This section synthesizes five key streams—Complex Adaptive Systems theory, Open Innovation paradigms, Industry 5.0 framing, sustainability orientation, and strategic intermediation theory—to build the conceptual foundation necessary for introducing the BM role as an advanced governance intermediary aligned with human-centric and sustainable innovation outcomes.

Complex Adaptive Systems (CAS) theory provides critical insights into the fundamental dynamics underpinning innovation ecosystems. CAS is composed of autonomous agents interacting according to local rules, with no centralized control, leading to emergent system-level properties (Holland, 1992; Chan, 2001). They are characterized by nonlinearity, feedback loops, path dependency, and self-organization (Mitleton-Kelly, 2003). Within innovation ecosystems, these dynamics manifest as unpredictable patterns of collaboration, knowledge exchange, and strategic adjustment. Governance in CAS settings must thus move away from rigid

command-and-control models toward enabling conditions for decentralized learning, distributed coordination, and emergent strategic coherence (Möller and Halinen, 2017; Ansell and Gash, 2008).

Recognizing innovation ecosystems as CAS emphasizes the centrality of trust-building, flexible governance, and strategic sense-making among heterogeneous actors. Trust becomes a critical enabler of adaptive behaviors, allowing stakeholders to collaborate across institutional and sectoral divides under uncertainty (Edelenbos and Klijn, 2007). Innovation governance frameworks must therefore be designed to foster relational resilience, collective learning, and normative alignment in the face of environmental volatility.

Complementing CAS perspectives, Open Innovation (OI) paradigms focus on the permeability of organizational boundaries and the critical importance of external knowledge flows for innovation performance (Chesbrough, 2003; Chesbrough and Bogers, 2014). OI encourages collaborative ideation, co-development, and distributed commercialization processes, leading to more dynamic and networked innovation landscapes (West and Bogers, 2014; Bogers et al., 2017). However, implementing OI at scale amplifies challenges of coordination, trust, and strategic alignment, particularly in multi-stakeholder ecosystems where diverse objectives and knowledge asymmetries must be reconciled (Dahlander and Gann, 2010; Ritala and Almpanopoulou, 2017).

The emerging Industry 5.0 paradigm intensifies these governance demands. Consolidated by the European Commission's strategic vision (Breque et al., 2021; European Commission, 2021), Industry 5.0 reframes the purpose of technological advancement toward enhancing human-centricity, resilience, and sustainability. It positions innovation ecosystems not merely as drivers of competitiveness, but as critical infrastructures for addressing grand societal challenges (Gomes et al., 2018). This reframing requires embedding normative objectives—such as well-being, inclusion, and environmental stewardship—into the structural and operational logics of innovation ecosystems (Carayannis and Campbell, 2009).

Incorporating sustainability paradigms into innovation governance demands a long-term, systems-oriented approach that prioritizes value creation across environmental, social, and economic dimensions. Traditional transaction-focused intermediaries often lack the competencies to embed such systemic values (Majchrzak et al., 2023). Instead, strategic governance actors must foster collective identity, promote value-based decision-making, and nurture systemic learning processes aligned with normative goals.

Finally, the literature on ecosystem intermediation highlights the crucial role of orchestrators and brokers in facilitating knowledge flows, resource mobilization, and network coordination (Dhanaraj and Parkhe, 2006; Hurmelinna-Laukkanen and Nätti, 2018). However, classical intermediaries typically emphasize operational efficiency over systemic resilience and normative coherence. Addressing this gap, Banga and Gaile-Sarkane (2024) propose the concept of the BM.

By synthesizing CAS theory, OI paradigms, Industry 5.0 principles, sustainability imperatives, and advanced intermediation concepts, this paper establishes the theoretical platform necessary for conceptualizing the BM as a foundational enabler of ecosystem resilience and human-centric innovation.

Table 1**:** Key theoretical lenses and their contributions to BM Role in Industry 5.0 Ecosystems. Author created.

Theoretical lens	**Key contribution**
Complex Adaptive Systems (CAS) Theory	Provides understanding of ecosystems as emergent, non-linear, and adaptive networks requiring decentralized governance and continuous updates.
Open Innovation (OI)	Highlights the importance of external knowledge sourcing, collaborative networks, and distributed innovation processes in ecosystem evolution.
Industry 5.0 Framework	Reframes the purpose of innovation toward human-centricity, sustainability, and resilience, challenging traditional technocentric innovation models.
Sustainability	Emphasizes systemic, long-term thinking across environmental, societal, and economic dimensions, requiring innovation ecosystems to embed normative values.
Bridge Maker Concept	Introduces a strategic intermediary role focused on fostering strategic alignment, value embedding, and adaptive governance in human-centered innovation ecosystems for Sustainable Outcomes.

3 Conceptualization of the Bridge Maker Role

The increasing complexity and normative demands shaping innovation ecosystems under Industry 5.0 principles have revealed critical limitations in traditional intermediary models. While brokers, coordinators, and facilitators have played important roles in supporting collaboration and transactional knowledge flows, they frequently lack the strategic depth necessary to drive systemic alignment or to embed broader human-centric and sustainability values into ecosystem governance. Without governance actors capable of fostering both strategic coherence and normative embedding, innovation ecosystems risk fragmentation, short-termism, and erosion of resilience (Provan and Kenis, 2008; Edelenbos and Klijn, 2007).

To address these emerging challenges, Banga and Gaile-Sarkane (2024) introduced the concept of the BM, developed through deep research into the evolving functions of ecosystem intermediaries, orchestrators, and governance frameworks across multiple theoretical domains. Building on this analytical foundation, the BM is defined as:

"An intermediary focused on developing infrastructure and frameworks that support continuous collaboration, ensuring effective resource sharing and the efficient flow of knowledge within innovation ecosystems, to drive sustained innovation and ecosystem resilience."

This definition positions the BM not simply as a transactional broker but as a strategic enabler of dynamic, value-driven system evolution. BMs' interventions are oriented toward sustaining innovation ecosystems over time through systemic collaboration, strategic resource orchestration, and the embedding of shared values at all levels of governance.

Specifically, the BM plays a critical role in aligning heterogeneous stakeholders to drive collaboration and innovation within human-centered Industry 5.0 ecosystems (RQ1). By cultivating systemic trust—extending beyond interpersonal relationships to institutional structures and governance frameworks—the BM creates a durable foundation for inclusive, strategic alignment. Trust-building mechanisms include the establishment of transparent, predictable interaction platforms; the mediation of cross-sectoral interests; and the facilitation of equitable knowledge exchanges that reinforce collective ownership of innovation trajectories (Ansell and Gash, 2008; Edelenbos and Klijn, 2007).

Complementing trust-building, BM act as sense-makers in environments characterized by high volatility and uncertainty. Through orchestrated multi-stakeholder dialogues, strategic foresight processes, and participatory visioning activities, they foster shared cognitive frameworks that allow diverse actors to synchronize innovation strategies and initiatives. Strategic sense-making ensures that collaborative activities are integrated within a coherent, human-centered system strategy rather than remaining opportunistic or fragmented (Provan and Kenis, 2008).

Beyond orchestrating collaboration, BM are pivotal in embedding sustainability and human-centric values as systemic features within innovation ecosystems (RQ2). They institutionalize normative frameworks that guide ecosystem behavior, translating abstract commitments to resilience, inclusivity, environmental stewardship into tangible operational practices (Teece, 2018; Carayannis and Campbell, 2009). BM creates governance infrastructures that embed sustainability principles into decision-making, resource allocation, and project evaluation processes, ensuring that normative considerations are a core component of ecosystem evolution rather than peripheral aspirations.

The competencies of BM - trust building, strategic sense-making, normative value embedding, and adaptive orchestration - are deeply interconnected. Trust lays the groundwork for alignment; alignment enables normative embedding; normative embedding fosters systemic resilience and long-term adaptability. By dynamically coordinating ecosystem interactions, BM empower systems to self-adjust while maintaining coherence around human-centric, sustainability-driven objectives.

This dynamic orchestration role is illustrated in Figure 1 below, which conceptualizes the BM as the central systemic actor translating diverse stakeholder [S_n] inputs into coherent, sustainable innovation outcomes aligned with Industry 5.0 and Open Innovation concept.

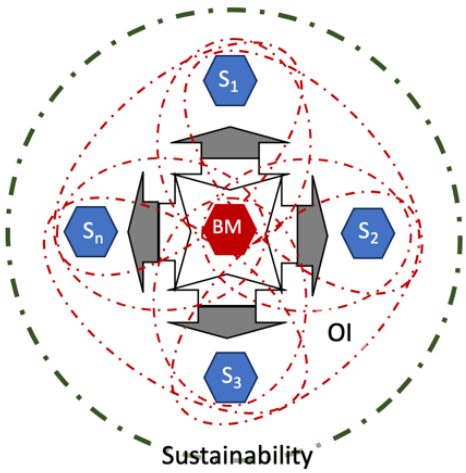


Figure 1: Bridge Maker (BM) as a strategic bridger of multi-stakeholder (Sn) interactions, enabling sustainable innovation outcomes under Industry 5.0 and Open Innovation (OI) paradigms. Author created.

By structuring relational trust, strategic alignment, and normative frameworks into the operational fabric of innovation ecosystems, BM enables the evolution of complex innovation environments into resilient, human-centered systems. Their interventions ensure that innovation is not pursued merely for competitive advantage, but consistently directed toward enhancing societal well-being, ecological integrity, and systemic resilience. In doing so, BM provides a critical governance mechanism for operationalizing Industry 5.0 principles within complex, multi-actor innovation environments.

Through this conceptualization, the paper not only advances the theoretical understanding of strategic intermediation but also establishes a foundation for future empirical exploration of BM roles, competencies, and impacts in diverse innovation ecosystems.

Previous research by Banga and Gaile-Sarkane (2024) has established the distinctiveness of the BM role compared to adjacent intermediary concepts such as brokers, orchestrators, knowledge intermediaries, and ecosystem champions. Through systematic conceptual differentiation, the BM was shown to uniquely integrate trust-building, strategic sense-making, and normative value-embedding functions within innovation ecosystems. In the present study, this distinctiveness is further reinforced within the context of Industry 5.0. The paradigm's explicit focus on human-centric innovation and sustainability goals intensifies the systemic governance challenges facing innovation ecosystems, thereby elevating the critical need for strategic intermediaries who can embed various normative imperatives into ecosystem evolution. Consequently, the findings presented here not only build upon previous differentiations but confirm the growing relevance and necessity of the BM role for the resilient and value-driven innovation ecosystems envisioned under Industry 5.0 principles.

4 Practical Implications

4.1 Implications for Innovation Managers

The conceptualization of the BM role presents significant actionable insights for innovation managers orchestrating complex, human-centered innovation ecosystems. Managers must shift from transactional coordination to strategic ecosystem governance by identifying and supporting individuals or units capable of fulfilling advanced bridging functions. Recognizing potential BM requires evaluating relational competencies—trust building, strategic sense-making, and normative alignment—as well as the ability to operate across organizational, sectoral, and disciplinary boundaries (Nambisan and Sawhney, 2011; Ritala and Almpanopoulou, 2017).

Governance frameworks within innovation ecosystems must evolve to enable dynamic, decentralized collaboration. This involves creating transparent interaction infrastructures, participatory decision-making processes, and platforms for shared vision building. Empowering BM through flexible structures fosters trust-based alignment and systemic coherence essential for sustainable innovation outcomes. Managers must also integrate capability development initiatives, providing opportunities for BM to hone strategic foresight, ethical leadership, and adaptive orchestration skills (Teece, 2018).

Moreover, embedding relational governance mechanisms, such as trust circles, stakeholder foresight processes, and collaborative sense-making workshops, can further enhance the effectiveness of BM in fostering coherent innovation trajectories.

4.2 Implications for Policymakers and Public Sector Leaders

For policymakers and public sector leaders, the emergence of the BM role underscores the need to redesign innovation policies and ecosystem support mechanisms. Traditional instruments focusing narrowly on funding R&D or facilitating basic knowledge transfer are insufficient in addressing the systemic governance challenges of Industry 5.0 ecosystems. Policies must explicitly encourage the development of trust-building infrastructures, collaborative governance platforms, and value-driven ecosystem orchestration (Klerkx and Aarts, 2013; Carayannis and Campbell, 2009).

Public innovation agencies should incentivize projects and ecosystem initiatives that demonstrate the integration of sustainability and human-centric principles into their governance processes. Funding frameworks should reward not just technological outputs but systemic relational achievements, such as the creation of trust-based multi-actor collaborations and the institutionalization of normative value systems. Furthermore, regulatory frameworks must be made more flexible to accommodate adaptive governance structures, allowing BM to navigate complexity without bureaucratic constraints (Ansell and Gash, 2008).

By fostering environments where strategic intermediaries like BM can emerge and thrive, public sector leaders can accelerate the evolution of innovation ecosystems toward resilience, sustainability, and societal value creation, in line with the Industry 5.0 vision.

5 Conclusions

This paper conceptualized the BM as a strategic intermediary crucial for the dynamic governance of human-centered Industry 5.0 innovation ecosystems. By systematically addressing the research questions, the study demonstrated that BM aligns heterogeneous stakeholders through trust-based collaboration and strategic sense-making (RQ1) and institutionalizes human-centric and sustainability values as systemic ecosystem features (RQ2).

The research advances the theoretical understanding of innovation ecosystem governance by positioning BM as enablers of systemic coherence and normative alignment, extending beyond traditional facilitation and brokering roles. Practically, the study offers actionable insights for innovation managers and policymakers on recognizing, supporting, and structurally empowering BM to drive adaptive, value-driven innovation trajectories.

The study's conceptual nature represents a limitation, highlighting the need for empirical investigations into the identification, development, and operationalization of BM competencies across diverse industries and regions. Future research should explore concrete methodologies for training BM and assessing their impact on ecosystem resilience, adaptability, and human-centric innovation outcomes over time.

In shaping governance models for Industry 5.0 ecosystems, BM represents a critical mechanism for fostering sustained innovation, strategic alignment, and societal impact, pointing toward a transformative evolution of innovation ecosystem practice and theory.

6 Ethics declaration

This research did not involve the use of any data from companies or individuals. As such, ethical approval was not required for this study.

7 AI declaration

During the preparation of this manuscript author used OpenAI ChatGPT solely to refine grammar and improve readability. After using the tool, author critically reviewed and edited all AI-suggested text and take full responsibility for the integrity and accuracy of the content. The AI system was not employed to generate original ideas, analyze data, draw scientific conclusions, or create figures, and it is not listed as an author. No confidential, personal, or proprietary data were provided to the system.

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Evolution of HRM: Longitudinal Analysis of HR Specialists' Skills in Italy

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Abstract

This study explores the evolving profile of Human Resource (HR) professionals in Italy through a longitudinal analysis of the skills possessed by new entrants in the HR area from 2017 to 2024. In the face of rapid digital transformation, sustainability challenges, and post-pandemic organizational changes, the role of HR has shifted significantly from administrative support to strategic business partnership. Based on data from the Excelsior Information System, the research investigates the development of ten key competencies, grouped into four categories—social, intellectual, volitional, and managerial—based on the framework by Kolot et al. (2022). Findings reveal that the most developed competencies among new HR specialists are teamwork, problem-solving, and flexibility/adaptability, with consistently high scores and low standard deviation, indicating strong and homogeneous preparation in these areas. In contrast, the capacity to apply Industry 4.0 technologies and communication in foreign languages remain underdeveloped and highly variable, highlighting key areas for future improvement. Digital competencies, while relatively strong, still show moderate variation across candidates, suggesting that digital readiness is progressing but not yet universally embedded. The analysis also highlights important longitudinal trends. Volitional and managerial competencies show both high average performance and remarkable stability over time, while social and intellectual skills present more heterogeneous trends. The data reflect a clear need for HR professionals to enhance their technological and international communication capabilities, particularly given their strategic role in managing change, fostering cultural alignment, and driving organizational transformation. This research contributes to the understanding of how the HR function is adapting to contemporary demands, emphasizing the need for continuous upskilling and alignment between education, professional training, and labor market expectations. The findings support the call for stronger collaboration between academia and organizations, to ensure that HR professionals are equipped with the necessary skills.

Keywords: Human Resource Management, HR, skills, competencies, longitudinal analysis

Paper type: Academic Research Paper

1 Introduction

The context in which HR managers operate has been rapidly evolving in recent years, both globally and in Italy. HR specialists are facing significant transformations for which they must be adequately prepared. Focusing on the Italian HR professional landscape, several interesting insights emerge regarding the activities, responsibilities, and competencies required to effectively manage these critical changes. The analysis of the articles published on the HR managers professional blog "Risorseumane-HR.it" in 2024 evidences the growing interest in the evolution of HR managers profile in the current context. A recurring theme that emerges is related to the importance of digital and technological skills, as evidenced by discussions on HR innovation (RisoreUmane - HR, 2024) and leveraging gamification and AI for HR processes (Piccininno, 2024). Another focus area is interpersonal and communication skills, underscored by articles on active listening, empathy, and linguistic competence (Sambugaro, 2024). Strategic and change management abilities are also prominently featured, with articles addressing talent intelligence, budget planning, and guiding organisations through transformations (RisorseUmane-HR, 2024/2). Moreover, there is a growing emphasis on skills related to sustainability and circularity. In some articles there are evidences about the importance of HR manager skills to implement Circular and Sustainable HR practices (RisorseUmane-HR, 2024/3). Several articles also highlight the importance of marketing and sales-related competencies for HR managers. They emphasise the importance of persuasive communication and influence as everyday skills for HR managers in promoting organisational change and innovation. The ability to sell ideas to their teams and colleagues, building trust and engagement and communicating the value of new initiatives becomes a very important to foster a shared vision within the organisation (RisorseUmane-HR, 2024/4). Moreover, the article of Labate (2024) explores the possibility to apply marketing principles to HR practices to strengthen employee alignment and motivation. Moreover, leadership agility and overcoming biases are highlighted as vital for navigating challenges and fostering inclusivity and wellbeing of employees in decision-making (RisorseUmane-HR, 2024/5).

The objective of this study is to understand how the profile of HR specialists has evolved in recent years, mapping the competencies needed in the modern business landscape against those actually possessed by individuals within the corporate HR domain. A specific focus of the research is to analyse the impact of the pandemic on the competencies demanded of HR specialists and to identify the key trends shaping the post-pandemic period.

The structure of the paper is as follows: The first section establishes the theoretical framework, analysing relevant and recent studies that address the transformation of the HRM domain, the evolving role of HR specialists, and the necessary adaptations in terms of competencies and preparation for HR professionals. The second section describes the research methodology, which is based on a longitudinal analysis of the Excelsior Information System, representing the competencies of new entrants in the corporate HR field from 2017 to 2023. The final section discusses the findings of the study, identifying the main limitations of the research and proposing potential directions for future investigation.

2 Theoretical framework

The transformation brought about by digitalisation, new working paradigms, automation and environment complexity has fundamentally reshaped organisations and their approach to human resource management (HRM), introducing concepts such as digital workplaces, streamlined digital HRM processes, and enhanced digital employee services (Zhang & Chen, 2024). Hybrid work models implemented in the post-pandemic period demand that the HR function demonstrates proficiency in collaboration tools and virtual communication platforms, ensuring employees remain connected, engaged, and productive by leveraging digital tools (Dutta et al. 2024). Moreover, the automation, AI-powered tools and chatbot systems handle monotonous tasks, freeing up HR specialists for more creative and strategic activities (Dhanpat & Stanz, 2024). Some recent studies view HR managers as “heroes" tasked with repairing workplace challenges in a post-pandemic work environment (Kulik et al., 2022). With the transition to the hybrid work forms, HR has a unique opportunity to build an ideal workplace based on the autonomy and flexibility gained during the pandemic, fostering trust-based relationships, psychological safety, and social connectivity. In the context of these changes, HR managers are increasingly seen as strategic partners and change agents within organisations. Dhanpat et al. (2020) emphasise that HR professionals play a vital role in aligning workforce capabilities with the demands of Industry 4.0, moving beyond traditional administrative functions to contribute to strategic decision-making, particularly in areas such as workforce planning and talent development. Moreover, HR managers now play a crucial role in advancing corporate sustainability strategies helping to integrate economic, social, and environmental dimensions into organisational practices (Amalia, 2024). HR managers can be considered key actors in promoting the environmental sustainability of organisations. Some studies highlight the significant influence of Green HRM in fostering employees' green behaviours and driving environmental management initiatives, underscoring its importance in advancing sustainability goals (Iqbal, 2020). Ed-Dahhani et al. (2024) stress the responsibility of HR specialists in steering organisational change, ensuring the alignment of strategic objectives with employee development. As outlined by Alfes et al. (2019) the HR departments adopt dual roles for effective change management, being drivers and facilitators of change and adapting a proactive approach. Moreover, in an organisational context where the implementation and adoption of AI systems is spreading, HR professionals emerge as a crucial facilitator, ensuring AI adoption is aligned with human values and organisational goals (Fenwick et al., 2024).

Considering the characteristics of the context in which HR managers operate, and the transformation of their role in the organisation, the skills required by HR managers are changed and becoming more multifaceted. As the environment becomes more complex and unpredictable, HR specialists need to possess relevant skills such as develop strategies jointly with top management, leverage insights through innovative HR practices, and better connect employees through technology (Ravi & Sumathi, 2023). Dhanpat et al. (2020) identify three primary areas for competency development for HR specialists: understanding the industry environment, fostering development programmes, and building networks. The ability to leverage the latest insights across various HR practices, co-develop strategic agendas, align the company’s activities with customer needs, and connect people through technology are the main skills that modern HR should focus on. Another essential set of skills is related to digital technologies. The readiness of HR specialists to acquire new digital competencies is a fundamental requirement to develop their professional skills and personal abilities for the transition from a traditional organisation to a digital one (Kapitanov et al., 2021). The interaction of the HR area with employees using digital tools, feedback management and predictive HR analytics are identified as the most important features of a digital organisation. Equally important are skills related to change management. The ability to navigate uncertainty, foster adaptability, and promote continuous learning within the workforce is crucial (Ed-Dahhani et

al., 2024). Dhanpat et al. (2020) evidence the importance of collaboration and teamwork skills, as HR managers increasingly operate within complex, interconnected networks. Kolot et al. (2022) propose a comprehensive model of transferable competencies for HR managers, categorised into 4 key areas: 1) social, 2) intellectual, 3) volitional, and 4) managerial (Fig. 1). The development of these competencies is essential for HR managers to operate successfully in remote and hybrid environments all over the world.

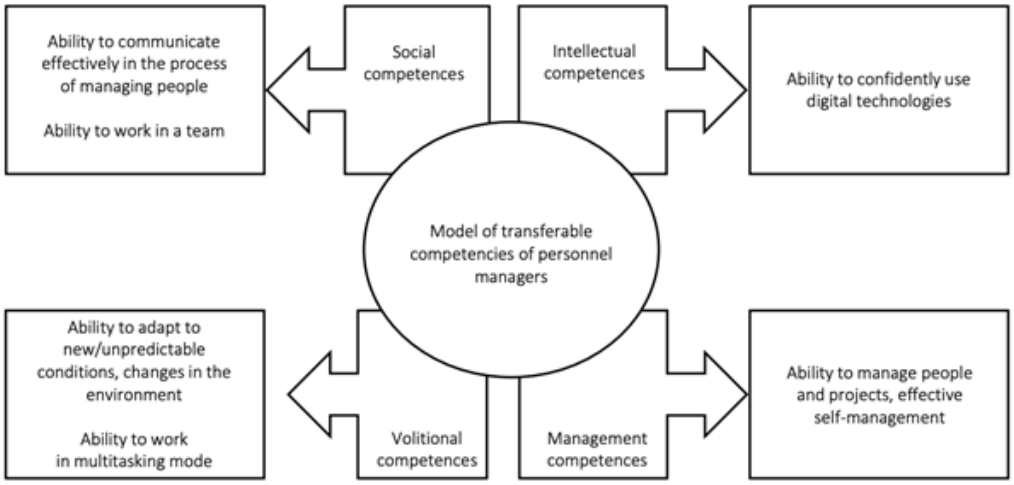


Figure 1:Model of transferable competencies of HR managers
Source: Kolot et al., 2022

3 Methodology

The data from the Excelsior, an Italian information system created by Unioncamere and the Italian Ministry of Labor that collects data on hiring programs relating to a universe of over 1 million 300 thousand Italian companies, has been taken into consideration for the skills analysis. In particular, data regarding skills of individuals who joined the area of Personnel Management and Human Resources Organisation in Italian companies during the period from 2017 to 2024 has been extracted and examined. The following competencies were evaluated using a scoring scale from 1 to 5 (where 1 indicates a low level and 5 indicates a high level): 1) communication skills in the Italian language, 2) communication skills in foreign languages, 3) mathematical and IT skills, 4) digital competencies, 5) problem-solving abilities, 6) teamwork skills, 7) ability to work independently, 8) flexibility and adaptability, 9) attitude towards energy conservation, and 10) capacity to apply 4.0 technologies.

The ten competencies mentioned above were classified into four categories proposed by Kolot and colleagues (2022) (Table 1):

Table 1**:** Skills assessed by competence area

Competence area	**Skill assessed**
Social	communication skills in the Italian language communication skills in foreign languages teamwork skills
Volitional	flexibility and adaptability attitude towards energy conservation
Intellectual	mathematical and IT skills digital competencies capacity to apply 4.0 technologies
Management	ability to work independently (self-management) problem-solving abilities

Source: Our elaboration

From the database, we extracted the number of new entrants in the HR area along with the evaluation of each individual competency, rated on a scale from 1 to 5. Based on this information, we calculated the average level of each competency possessed by new entrants for each year of observation (2017, 2018, 2019, 2020, 2021, 2022, 2023,2024). All types of contracts (not necessarily dependent work) are considered as new entries.

In addition to the longitudinal evaluation of changes in the competency profile over the years, an assessment of the profile of new entrants in the HR area in 2024 was designed in order to map the most developed, as well as under-developed skills of HR specialists.

4 Results

As stated in the previous section, the evaluation of competencies among individuals who entered the HR area over the years was carried out according to four categories: (1) social, (2) intellectual, (3) volitional, and (4) managerial. For each category, we calculated the total number of new entrants, the average competency level, and the standard deviation (Table 2):

Table 2: Evolution of the new entries' skills from 2017 to 2024

Area	Year	2017			2018			2019			2020			2021			2022			2023			2024		
	Skill	*N.*	*Mean*	*SD*	*N.*	*Mean*	*SD*	*N.*	*Mean*	*SD*	*N.*	*Mean*	*SD*	*N.*	*Mean*	*SD*	*N.*	*Mean*	*SD*	*N.*	*Mean*	*SD*	*N.*	*Mean*	*SD*
Social	*Communication skills in Italian*	18220	3,60	1,12	18410	3,32	1,31	18740	3,53	1,37	10980	3,16	1,48	19510	3,16	1,25	17660	3,13	1,56	19770	3,25	1,49	18960	3,00	1,62
	Communication skills in foreign languages	18220	2,46	1,49	18410	2,57	1,49	18740	2,73	1,48	10980	2,53	1,41	19510	2,64	1,23	17660	2,24	1,40	19770	2,33	1,3	18960	2,35	1,35
	Teamwork skills	18220	4,05	0,98	18410	4,05	1,21	18740	4,21	0,99	10980	4,07	1,09	19510	3,88	1,00	17660	4,20	0,90	19770	4,24	1,00	18960	4,13	0,95
Volitional	*Flexibility and adaptability*	18220	4,34	0,81	18410	4,21	0,83	18740	4,35	0,81	10980	4,16	1,00	19510	3,86	0,95	17660	4,31	0,86	19770	4,36	0,74	18960	4,22	0,87
	Attitude towards energy conservation	18220	2,7	1,18	18410	2,96	1,34	18740	3,15	1,31	10980	3,13	1,37	19510	2,9	1,14	17660	2,79	1,29	19770	3,2	1,20	18960	3,16	1,20
Intellectual	*Mathematical and IT skills*	18220	3,09	1,16	18410	2,87	1,21	18740	3,24	1,11	10980	2,97	1,11	19510	2,8	1,19	17660	2,73	1,28	19770	3,04	1,24	18960	2,93	1,21
	Digital competencies	18220	3,6	0,97	18410	3,64	1,33	18740	3,56	1,13	10980	3,6	1,01	19510	3,33	1,05	17660	3,61	1,21	19770	3,82	1,16	18960	3,58	1,19
	Capacity to apply 4.0 technologies	18220	1,87	1,20	18410	2,35	1,33	18740	2,45	1,33	10980	2,33	1,31	19510	2,33	1,26	17660	2,14	1,27	19770	2,32	1,36	18960	2,47	1,40
Management	*Self-management*	18220	3,72	0,96	18410	3,81	1,2	18740	3,93	1,03	10980	3,82	1,17	19510	3,56	1,08	17660	3,96	0,99	19770	3,94	1,00	18960	3,87	1,09
	Problem-solving abilities	18220	4,08	0,87	18410	4,08	1,09	18740	4,2	0,92	10980	3,95	1,07	19510	3,66	1,13	17660	4,19	0,91	19770	4,23	0,87	18960	4,03	1,01

To better understand the evolution of skills of new entrants in the HR area, figures 2, 3, 4, 5 are shown below, which represent the change in skill levels over the years for each of the above areas.

Figure 2 shows the evolution of social competencies among new entrants in the HR area within Italian companies from 2017 to 2024. Over the years, teamwork skills have remained consistently high, peaking at 4.24 in 2023 and showing only a slight decline in 2024. Communication skills in Italian have shown a modest but steady decrease, dropping from 3.60 in 2017 to 3.00 in 2024. Communication skills in foreign languages have remained the weakest area, with a downward trend from 2.46 in 2017 to 2.35 in 2024, despite a brief improvement around 2020. It is possible to conclude that while teamwork remains a strong point, the data indicate a need for improvement in language-related communication competencies among new HR professionals.

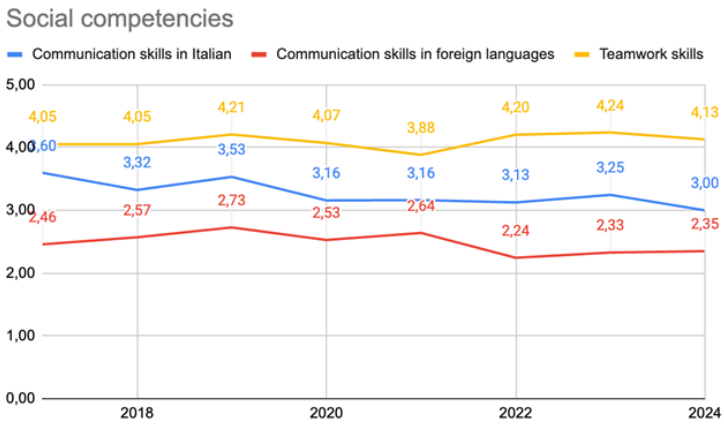


Figure 2: Evolution of social competencies of new entries in HR area from 2017 to 2024

In figure 3 it is possible to observe the trend in volitional competencies. Flexibility and adaptability show consistently high ratings across all years, with a slight dip in 2021 (3.86) followed by a recovery and stabilization above 4.20. This suggests that adaptability remains a strong and stable competency among new HR professionals. In contrast, the attitude towards energy conservation displays more fluctuation. It rises steadily from 2.70 in 2017 to 3.15 in 2019, then declines until 2022, before recovering to 3.16 in 2024. This indicates a growing but still developing awareness of sustainability-related behaviors among new HR entrants.

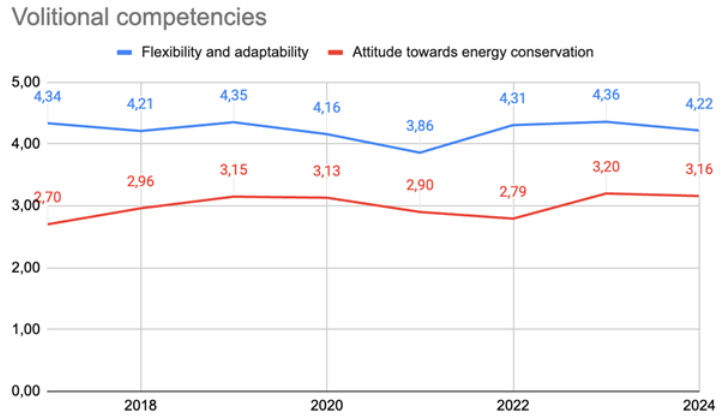


Figure 3: Evolution of volitional competencies of new entries in HR area from 2017 to 2024

Figure 4 shows the trend regarding intellectual competencies that include mathematical and IT skills, digital competencies, and the capacity to apply 4.0 technologies. Digital competencies consistently show the highest ratings, peaking at 3.56 in 2019 and remaining above 3.30 throughout the period, suggesting a solid and growing digital foundation among HR newcomers. Mathematical and IT skills fluctuate modestly, ranging from a low of 2.73 in 2022 to a high of 3.24 in 2019, indicating moderate but stable proficiency. In contrast, the capacity to apply 4.0 technologies remains the weakest area, starting at 1.87 in 2017 and only reaching 2.47 in 2024, despite gradual improvement in recent years. It is possible to conclude that while the digital readiness seems robust, the application of advanced technological tools in HR still represents a developmental challenge for new professionals and organizations.

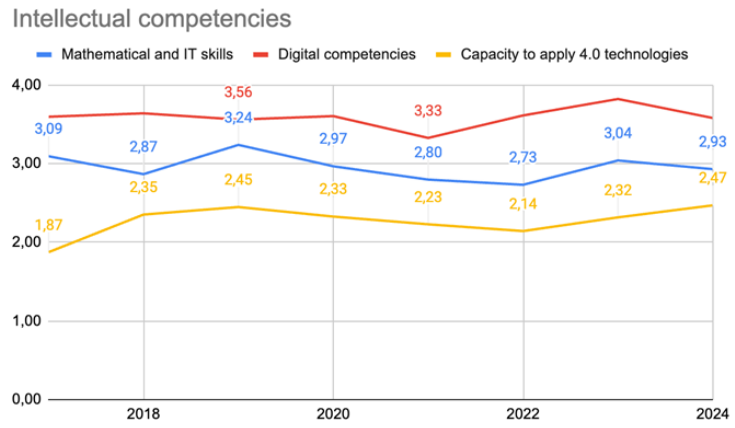


Figure 4: Evolution of intellectual competencies of new entries in HR area from 2017 to 2024

In Fig.5 it is evident the evolution of management competencies, focused on self-management and problem-solving abilities. Both competencies maintain consistently high levels throughout the observed period. Problem-solving abilities start at 4.08 in 2017, reach a peak of 4.23 in 2023, and slightly decline to 4.03 in 2024. Self-management follows a similar trend, rising from 3.72 in 2017 to a high of 3.96 in 2022 before settling at 3.87 in 2024. The data suggest that managerial skills are well-developed among new HR professionals, with only minor fluctuations over time.

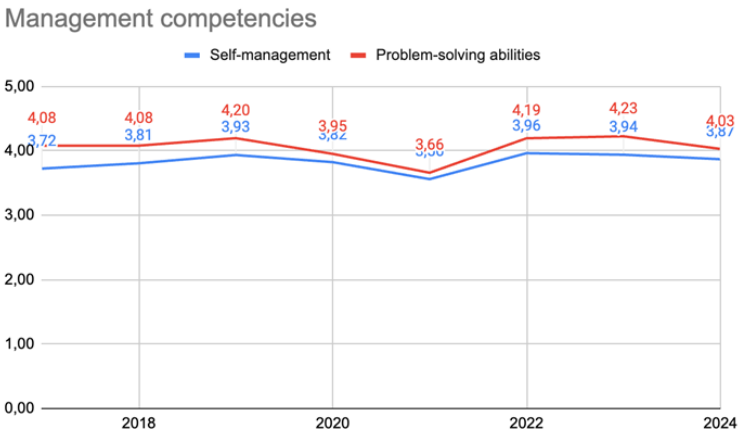


Figure 5: Evolution of management competencies of new entries in HR area from 2017 to 2024

5 Discussion

The longitudinal study on the evolution of the skills of new HR specialists has highlighted a significant transformation in the expectations and demands of the role over recent decades. The findings confirm how the HR specialist has progressively shifted during the last years.

The data shows that the most developed competencies are “teamwork skills”, “flexibility and adaptability”, and "problem-solving abilities”, each maintaining average scores above 4.0 across all years. In contrast, the least developed competencies include the “capacity to apply 4.0 technologies" and "communication skills in foreign languages”, which remain below an average of 2.7 throughout the entire observed period.

Looking at trends over time, some competencies (e.g. teamwork, problem-solving, and digital competencies) appear to be the most stable, showing consistent average values across the years. On the other hand, communication in Italian and energy-saving attitude exhibit fluctuating trends, suggesting shifts in candidate preparation or institutional emphasis during the analyzed period.

When considering variability among candidates (based on standard deviation), communication in Italian, foreign language skills, and capacity to apply 4.0 technology are among the most variable, indicating heterogeneous skill levels among the new entrants in HR. Along with this, teamwork, self-management, and problem-solving abilities show lower standard deviations, suggesting greater homogeneity across the population of new HR professionals.

In fact, combining the results of previous studies with the results of this research, it can be argued that one of the main changes that has emerged is the increasing digitisation of the HR function. The introduction and spread of technological tools (HRIS, analytics, AI in recruiting) have radically changed the way HR processes are managed (Zhou, Fey & Yildiz, 2021; Zhang&Chen, 2024). HR professionals are now required to possess advanced digital skills and to be able to interpret data to make evidence-based decisions, a key skill to contribute to the competitive advantage of the company (Manuti & De Palma, 2018). In fact, based on the findings of this study, digital skills appear to be relatively well developed among new HR entrants in Italy, maintaining an average score consistently above 3.5 across all years. However, the standard deviation remains above 1.0, indicating variability across candidates and highlighting a margin for improvement that organizations and training programs should not overlook. Another interesting point is related to the ability to apply Industry 4.0 technologies. While still the least developed intellectual competency (starting at a low 1.87 in 2017), this competence has shown a gradual upward trend, reaching 2.47 in 2024. Although the growth is slow, the data suggest a positive progression, reflecting a growing integration of advanced technological skills in the HR field. Continued investment in digital and technological upskilling is therefore essential.

In parallel, a strong appreciation of soft skills has emerged. Recent studies (Dhanpat & Stanz, 2024; Bogdány, Gaál & Szabó, 2025) highlight how skills such as emotional intelligence, communication skills, cognitive flexibility and change management are increasingly in demand (Ed-Dahhani et al., 2024). The study findings highlight that flexibility and adaptability stand out as one of the most developed competencies among new entrants in the HR field, maintaining high average scores across all the observed period (ranging from 4.16 to 4.36) and low standard deviations, indicating a strong and consistent presence of this skill across the candidate population. On the other side, though, communication skills (particularly in foreign languages) remain an area for growth. This evidence signals a critical developmental need, especially considering the strategic role HR plays in communicating organizational values and supporting the effective dissemination of ongoing or planned organizational changes. Enhancing linguistic competencies, especially in international contexts, could therefore be essential for reinforcing HR's integrative and change-driving functions within modern organizations.

The evolution of the HR specialist profile also reflects a broader change in the perception of the HR function within organisations. It is now seen as a strategic partner, able to contribute directly to corporate performance through value-oriented human capital management practices (Boselie et al., 2005). Ulrich's (1997) HR Business Partner model has found increasing application, prompting HR to develop an entrepreneurial and outcome-oriented mindset. Furthermore, the HR specialists are becoming increasingly strategic within organizations and must align with both corporate objectives and organizational culture, especially in light of the ongoing transformations driven by the need to adapt to Industry 4.0 environments and sustainability goals.

6 Conclusion

This study underscores the dynamic nature of the HR profession and the need for continuous adaptation. HR specialists should cultivate a blend of technical expertise, digital literacy, and soft skills to thrive in the modern organizational environment. The results of the study confirm that the HR profession is constantly evolving, driven by factors such as digital transformation, globalisation, and increasing organisational complexity. The new HR specialist is a hybrid professional, capable of integrating analytical, digital and relational skills, with a strong ability to read the context, strategic orientation and solve the problems.

The analysis of the data reveals clear differences in the development of competencies across the four main categories (social, intellectual, volitional, and managerial) among new HR professionals in Italy. Volitional and managerial competencies emerge as the most developed and consistent over time. In particular, flexibility and adaptability stand out with high average scores and low variability, indicating that new entrants are generally well-prepared to cope with change and uncertainty. Similarly, problem-solving and self-management show strong performance, reflecting a solid foundation in individual responsibility and operational autonomy.

Intellectual competencies present a more fragmented picture. While digital skills are relatively advanced and stable, suggesting some alignment with the digital transformation of HR, the ability to apply Industry 4.0 technologies remains notably underdeveloped. This indicates a growing yet insufficient integration of advanced technological skills in HR practice, which should be a strategic focus for future development.

Social competencies also show mixed trends. Teamwork is well-developed and widely shared among the population, while communication skills, especially in foreign languages, lag behind and show high variability. This point is of particular importance given the strategic role of HR in shaping organizational culture and driving internal communication, especially in increasingly international work environments with a high level of diversity.

In the light of these findings, it is essential that universities and training centres update their teaching courses, including modules on people analytics, change management, technology applied to HR and the

development of soft skills. A stronger link between academia and business is also desirable to ensure consistency between training programs and the skills actually required and valuable in the labour market. Companies instead should invest in continuous upskilling and reskilling programmes for their HR professionals, promoting a culture of lifelong learning. The creation of internal HR practice communities, mentoring programmes and customised career paths can foster the growth of strategic competencies within the HR function.

Regarding the limitations, the study is based on secondary data from the Excelsior Information System, which, although comprehensive, may not fully capture the qualitative aspects of competency development. Furthermore, the focus is limited to the Italian context, which restricts the generalizability of the findings to other countries. Future studies could delve into the impact of artificial intelligence and automation on HR competencies, as well as explore the differences in HR job profiles across sectors and countries. It would also be useful to examine longitudinally how regulatory changes (e.g. agile working, data regulations) affect the role and skills required of HR professionals.

7 Acknowledgements

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8 Ethics declaration

No ethical approval was required for this research, as no humans were involved in the primary data collection and no sensitive data was used.

9 AI declaration

Artificial intelligence tools were used exclusively to support the translation of content into English. All research design, analysis and interpretation were conducted by the authors.

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Educational Diversity Affecting Enterprise Performance: The Lens of Upper Echelons Theory

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Abstract

This study investigates the relationship between Top Management Teams' (TMTs) educational diversity and enterprise performance within the Upper Echelons Theory (UET) framework. It integrates data from ten qualitative interviews with senior managers and a quantitative survey of 765 small and medium-sized Latvian enterprises (SMEs) representatives. The study explores how educational background—a form of deep-level diversity—affects strategic decision-making, innovation, and financial outcomes across organizational contexts.

Findings suggest educational diversity is a valuable strategic asset, particularly in medium to large enterprises and knowledge-intensive sectors. Respondents highlighted that diverse academic backgrounds support problem-solving, particularly in crisis situations. However, the perceived value of education varied by demographic and organizational factors, including age, gender, language group, company size, and industry sector. While 64% of survey participants rated educational background as "very important" or "extremely important" for financial decision-making, others emphasized the complementary role of practical experience and collective managerial tenure.

The analysis confirms that education is not always the dominant factor in executive performance. Meanwhile, when combined with other dynamic traits such as risk tolerance and shared values, it significantly influences organizational outcomes. Sector-specific findings underscore that in industries with high complexity and change, such as technology, services, and manufacturing, educational diversity in TMTs plays a more critical role. In smaller companies—particularly those with 10 to 49 employees or annual revenues below €300,000—hands-on experience is often viewed as more important than formal education, as shown by lower support for educational diversity in these groups. In contrast, 63.92% of all surveyed enterprise representatives rated educational diversity in Top Management Teams (TMTs) as “very” or “extremely important” for financial decision-making, with this figure rising significantly in firms with over 50 employees or annual revenues above €5 million. Using these findings for companies in practical terms, it means that developing their leadership teams and being willing to stay competitive, should consider not only formal education but also ensure a diverse blend of academic backgrounds among top managers. The study supports the development of a mathematical model that incorporates both the educational and behavioural characteristics of TMTs. It also contributes to the broader understanding of how diversity management impacts firm-level performance and innovation in a regional context.

Keywords: Diversity Management, Top Management Teams, Upper Echelons Theory, Educational diversity, Enterprise Performance

Paper type: Practical Paper

1 Introduction

The Upper Echelon Theory (UET) suggests that the diverse backgrounds of TMT members—including education, work experience, demographic data, cognitive skills, risk appetite, decision-making styles, values, and social networks (deep-level diversity)—can influence an enterprise's financial outcomes. Understanding these dynamics is crucial for identifying how educational investments in employee skills and knowledge drive productivity and competitive advantage, thereby contributing to sustainable economic growth. This study examines how TMT members' educational backgrounds and attitudes toward education influence financial performance.

As business performance evolves, education’s role in TMTs has gained attention. The research integrates data from ten qualitative interviews with senior managers and a quantitative survey of 765 small and medium-sized Latvian enterprises (SMEs) representatives.

Work structures have evolved from collective to individual roles and, with globalization, back to team-centric approaches (Taylor, 2024). This shift highlights the need for effective, adaptable teams with diverse skills. Analysing team diversity, including education, is crucial for linking team composition to financial outcomes. Educational fields reflect personal values and cognitive styles, making TMTs’ educational diversity a strategic asset. The authors' overarching goal is to identify critical variables that combine elements of Upper Echelon Theory (deep-level diversity) and Diversity Management (surface-level diversity) into a unified model – systemic diversity management for optimizing TMT configurations to enhance firm performance, exploring the aspect of education. By combining qualitative and quantitative insights, the study aims to develop criteria for creating a

robust mathematical model that evaluates the impact of TMTs on organizational performance. This work will serve as a foundation for understanding the meaningful solutions that business professionals can focus on to compile TMTs better.

2 Literature review

Upper Echelon Theory (UET) states that diverse backgrounds, including education, work experience, demographic data (gender, age, nationality, cognitive skills, risk appetite, style of decision-making, values, and beliefs), and social networks, influence a firm's performance (Hambrick & Mason, 1984). Studying the education aspect of Top Management Teams (TMT) is crucial because it can reveal how education directly affects productivity, innovation, and competitive advantage, ultimately contributing to sustainable economic growth and success. More importantly, the perception of education in the minds of TMT, which is responsible for the business's strategic decisions, needs to be analysed.

Historically, work evolved from collective efforts to individual roles, but globalization has shifted organizations back toward team-centric structures. This transition highlights adaptability and team effectiveness as key drivers of firm performance (Kozlowski & Ilgen, 2006). Analysing team diversity—particularly educational backgrounds and cognitive traits—is crucial for building effective TMTs. The authors argue that team composition directly influences financial outcomes, underscoring the measurable benefits of well-structured teams.

While education's role in firm performance is widely recognized, Jouber (2021) highlights that educational diversity within TMTs notably influences corporate social responsibility (CSR) and financial decision-making. Staff with higher education, especially in social and human sciences, show greater commitment to CSR. Meanwhile, a study by Herrmann and Datta shows a positive correlation between TMTs' educational levels and their tendency for international diversification (Herrmann & Datta, 2005). Higher education equips TMT members with a logical, global mindset essential for complex decision-making and international strategy development. While education supports global objectives, Woodfield and Kennie (2008) note that senior teams in higher education face challenges similar to those faced by corporate teams but operate within different cultures and policies, recommending engaging facilitators to boost team effectiveness.

Although TMT characteristics shape strategy, external and internal factors often have a greater impact (Papadakis & Barwise, 2002). Higher education improves information processing and judgment (Tulungs & Ramdani, 2016). Although business experience is not essential, business and economics education helps people make better decisions, especially in crises. It also helps board members cope with tasks and remain competitive (Tulungs & Ramdani, 2016). Educated leaders tend to process information more effectively and innovate (Gottesman & Morey, 2006). Despite Adnan et al. (2016) not finding a strong link between educational diversity and performance, many studies emphasize the key role of education in improving performance and outcomes.

Most studies show that higher education boosts growth, innovation, and competitive advantage (Magoutas, Agiomirgianakis & Papadogonas, 2011). TMTs need varied skills to adapt to changing business environments (Yamak & Üsdiken, 2006). Education generally improves firm performance, often measured by return on assets (ROA), a key indicator of how efficiently a company uses its resources (Ittner & Larcker, 2003; Jewell & Mankin, 2011). Since leadership shapes strategy, TMT composition matters. Research links TMT diversity to better financial performance (Bistrova, Lāce & Kasperovica, 2021; Ting, Azizan & Kweh, 2015) and stronger CSR and sustainability practices (Gupta, 2019; Zumente & Lāce, 2020; Al-Matari, 2022).

3 Methodology

This study uses a mixed-method approach to explore the role of education perception in Latvian SMEs, combining qualitative interviews and a standardized survey. It examines how educational backgrounds influence firms' innovation strategies and financial performance. Between January and February 2024, ten in-depth interviews were conducted with TMT members from diverse industries, covering education, work experience, cognitive traits, decision-making, and social networks. The sample included representatives from sectors like broadcasting, food production, exports, real estate, energy, IT, retail, and transportation, offering a broad view of Latvia's economic landscape. The selected companies averaged over 200 employees, with annual turnovers between 23 and 375 million euros, offering insight into education's impact on the financial performance of enterprises in Latvia. Using open-ended questions, researchers explored how characteristics of Upper Echelons Theory (UET), particularly education, influence the performance of enterprises. The analysis revealed key themes and insights into how education shapes firm performance.

Telephone interviews were conducted by a specialized company, targeting firms with over ten employees across various sectors (excluding farming)—the concise questionnaire captured company demographics and

detailed information on education-related aspects. The survey was conducted in Latvian and Russian to accommodate Latvia's linguistic diversity. This approach ensured that respondents could comfortably provide accurate and comprehensive responses, improving the data quality. This study's sample size is n=765 SMEs. This sample size ensures representativeness across the Latvian population of small and medium-sized companies. The sample accurately reflects the distribution of SMEs in terms of industry sectors, company sizes, and geographical locations.

4 Data analysis

4.1 Insights from in-depth interviews: Thematic patterns

Thematic content analysis of the in-depth interviews identified several education-related themes that offer insight into how top management teams perceive and understand the multifaceted impact of education. Authors grouped these themes into seven broad categories. Furthermore, the most popular themes are:

- Continuous learning and adaptability were noted 9 times (13%), emphasizing the need for ongoing education and the development of TMT skills in changing environments;
- Criticism of formal education appeared 8 times (12%), highlighting concerns that traditional systems may not meet modern job requirements;
- The value of diverse educational backgrounds in TMTs was mentioned 10 times (15%), suggesting that variety enhances problem-solving and innovation.
- Education’s impact on decision-making appeared 7 times (10%), showing its role in shaping informed choices;
- Leadership and education were mentioned 10 times (15%), highlighting education’s contribution to leadership development.
- The debate between practical and formal education emerged most often, 13 times (19%), confirming the value placed on hands-on experience.
- Specific business education needs were noted in 16% of cases.

Overall, findings show a balanced view: continuous learning, diverse backgrounds, and leadership development are valued, but practical experience is crucial alongside formal education. The authors conclude that educational diversity should be incorporated into models to improve firm performance.

4.1.1 Aspect of education among other characteristics in the UET

In the framework of upper echelons theory, senior managers' educational background is recognized as a relevant but not dominant characteristic that influences financial decision-making. While education provides the fundamental knowledge and cognitive tools that shape how leaders perceive and interpret complex business environments, its overall importance appears moderate compared to other top-level characteristics such as collective work experience, risk-taking behaviour, and shared values within the management team. The findings suggest that while education influences leadership outcomes, it is often combined with—and sometimes less important than—practical experience and personal behaviour. The following table and analysis explore how education is valued in relation to other key characteristics, providing a comparative perspective on its perceived significance within executive decision-making processes.

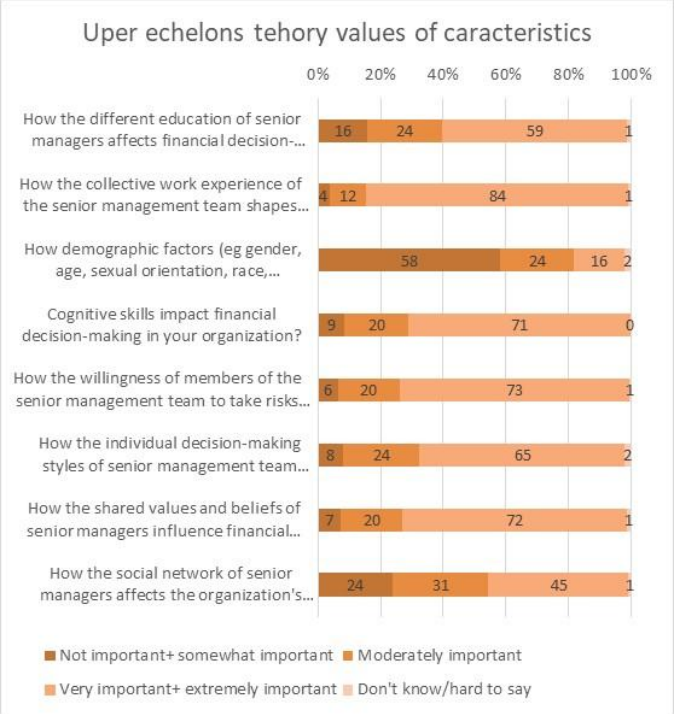


Chart 1. Values and characteristics of Upper Echelons theory, importance. Results of the survey.
Created by authors.

Discussions on education's impact reflect how individuals value education personally. Only 59% of respondents rated senior managers' educational background as "very" or "extremely" important for financial decision-making, much lower than collective experience (84%), risk willingness (73%), shared values (72%), and cognitive skills (71%). This suggests that while education is seen as relevant, it is not dominant in executive decision-making. These findings align with Upper Echelons Theory, emphasizing that dynamic traits like experience and behaviour are stronger predictors of strategic ability than static attributes like education. Education in the context of Upper Echelons Theory—specifically, how the different education of senior managers affects financial decision-making—takes a moderately strong position. However, it is not the most emphasized characteristic in the dataset. Education is placed in the mid-to-high importance category, compared to other variables.

Education is less influential than traits like collective experience (84%) or risk-taking willingness (73%). While 24% view it as moderately important and 16% as unimportant or somewhat important, only 1% were unsure, indicating that education is a well-formed but secondary consideration. These results suggest that while education is valued, experiential and behavioural factors are more predictive of financial decision-making, reinforcing Upper Echelons Theory's focus on experience, values, and cognitive styles over static traits.

4.1.2 Synthesis of Findings

This section presents the findings from the survey of 765 enterprise representatives focusing on how educational diversity in Top Management Teams (TMTs) is perceived in financial decision-making. The analysis highlights key demographic differences, sectoral and positional attitudes, and thematic insights related to the role of education in strategic leadership.

Across the full respondent base of 765 enterprise representatives, 63.92% rated educational diversity in Top Management Teams (TMTs) as "very important" or "extremely important" for financial decision-making. This high percentage signals a strong, shared belief among most business professionals that education is not merely a background variable, but a strategic asset that informs the quality and depth of executive decision-making. Respondents likely associate educational diversity with a broader range of analytical tools, problem-solving methods, and risk-assessment capabilities—essential competencies in today's complex business environments. Data also reveals that 15.68% of respondents rated education as "unimportant" or "somewhat important." This minority reflects a critical counterpoint: not all leaders view formal education as a primary determinant of strategic success. This group may prioritize experiential learning, industry-specific intuition, hands-on operational expertise, or entrepreneurial instincts over academic credentials. Particularly in smaller firms or traditional sectors, practical decision-making based on direct market feedback may be more valuable than

theoretical knowledge. The difference in views highlights a significant perceptual divide in how education is understood and leveraged in executive functions. It suggests that while educational diversity is broadly endorsed, its practical relevance varies depending on firm maturity, sector complexity, leadership culture, and generational factors. For mathematical model development, this implies that education should not be viewed in isolation, but in dynamic interaction with other top management traits such as risk tolerance, leadership style, and accumulated experience.

In summary, while the dominant trend is a strong endorsement of education in executive decision-making, opposite views reinforce the need for a context-sensitive approach to TMT evaluation that balances formal educational indicators with behavioural and experiential dimensions of leadership effectiveness.

4.1.3 Demographic segmentation of perceptions

The survey results reveal that sociocultural and generational factors significantly influence how educational diversity in Top Management Teams (TMTs) is perceived, particularly regarding its relevance for financial decision-making. A notable finding is that Russian-speaking respondents expressed a slightly higher appreciation for the role of educational diversity in shaping financial decisions than their Latvian-speaking counterparts. This suggests underlying cultural or historical influences on how education is perceived as a strategic asset. One potential explanation may be differing educational traditions and experiences across linguistic communities. Russian-speaking managers—many of whom may have received formal education during or soon after the Soviet era—might place greater value on formal qualifications, structured expertise, and academic rigor as essential tools in leadership. Latvian-speaking respondents, while generally supportive, expressed a slightly more moderate view, suggesting a shift toward flexible, experience-driven management styles. This cultural variation highlights the need to calibrate models by linguistic or cultural backgrounds to predict better how educational diversity impacts firm performance through the lens of Upper Echelons Theory.

Among age groups, respondents aged 41–50 are visible in Chart No. 2, which shows the strongest support for educational diversity in leadership, likely reflecting a generation that bridges traditional education with the demands of a globalized economy. Their views underscore how interdisciplinary and international education enhances strategic agility, innovation, and market responsiveness. By contrast, both younger respondents (<40) and older respondents (>60) exhibited more varied or neutral responses. This may reflect a stronger emphasis on entrepreneurialism, digital fluency, and skill-based learning over formal degrees for younger managers. For older respondents, it may be tied to professional trajectories shaped more by experience, tenure, and network capital than by educational credentials. These findings suggest that age should be treated as a moderating variable when examining the impact of TMT education on performance, as it shapes attitudes toward education and interacts with traits like openness to innovation and risk tolerance. Educational diversity is perceived differently across sociocultural and generational lines, highlighting for Upper Echelons Theory researchers and practitioners the importance of considering factors like language, culture, and age.

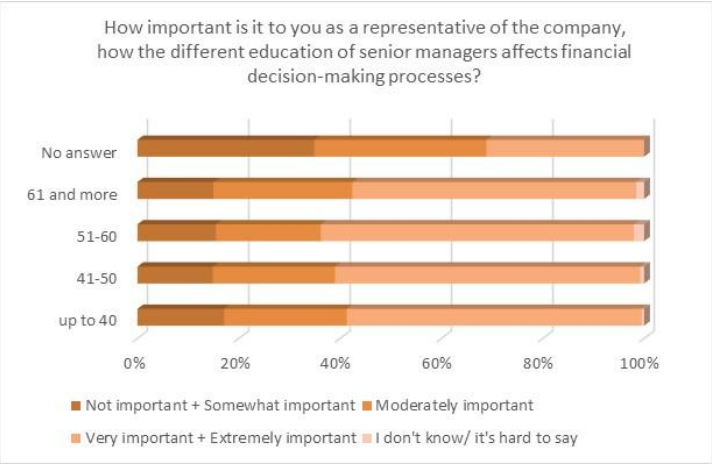


Chart 2. Perceived importance of senior managers' education by age group. Results of the survey.
Created by authors.

Accounting for these nuances is essential for developing effective leadership strategies and culturally sensitive models linking TMT characteristics to firm outcomes. Survey results show that female respondents placed slightly greater importance on educational diversity in financial decision-making than male respondents.

This aligns with existing literature suggesting that gender diversity, particularly when combined with educational heterogeneity, enhances inclusive and collaborative decision-making. The finding indicates that women in executive roles may be more inclined to recognize the strategic value of diverse educational backgrounds, reinforcing the relevance of gender as a contextual variable within the Upper Echelons Theory framework.

4.1.4 Structural dimensions of enterprises and impact on attitudes toward education

The survey findings suggest that organizational characteristics—specifically company size and financial turnover—are significant determinants of how educational diversity in Top Management Teams (TMTs) is perceived in relation to economic decision-making. Firms employing between 50 and 249 staff demonstrated the highest valuation of educational diversity among all size categories. This trend indicates that as organizational scale increases, so does the recognition of the strategic benefits derived from diverse academic backgrounds within senior leadership. These medium-sized enterprises often face growing operational complexity, the need for specialization, and more formalized decision-making processes, which may elevate the importance of cognitive and disciplinary diversity in top-level roles.

By contrast, smaller firms (10–49 staff) were significantly less likely to view educational diversity as critical. In these environments, leadership roles are often concentrated among a few individuals, and decision-making tends to be informal and experience-driven. Consequently, the added value of educational heterogeneity may not be perceived as necessary or actionable. This suggests that organizational complexity is a moderating factor—the larger and more structured the organization, the more valuable diverse educational inputs are in guiding strategy and performance. A similar pattern emerges when analysing the data by annual financial turnover, visible in Chart No. 3. Enterprises with revenues exceeding €5 million per year showed the strongest positive attitudes toward educational diversity in TMTs. These firms typically operate in more competitive, dynamic, or internationalized markets, where leaders must engage in complex decision-making, manage cross-functional teams, and respond to rapid environmental changes. In such contexts, educational diversity is likely viewed as a resource that enhances adaptability, strategic foresight, and innovation.

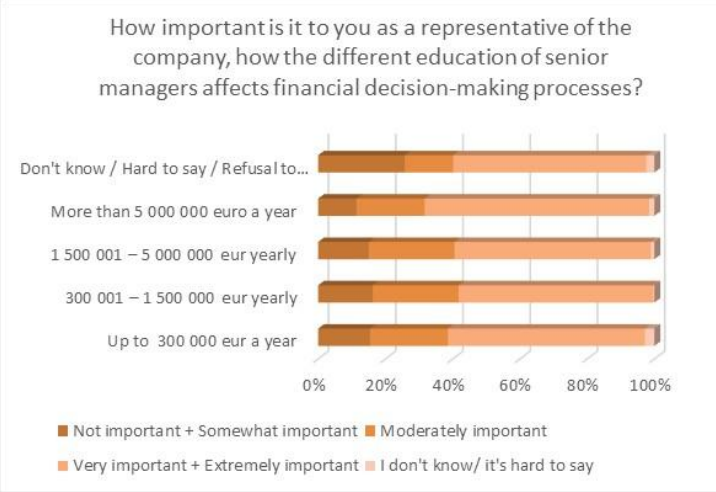


Chart 3. Perceived importance of senior managers' education by company annual turnover. Results of the survey. Created by authors.

In contrast, micro and small enterprises with annual revenues below €300,000 reported the lowest recognition of the relevance of TMT educational diversity. These firms may prioritize operational continuity and efficiency over strategic innovation, and decision-making is often driven by direct market experience or founder intuition. Formal educational differences may appear less consequential for these firms than pragmatic concerns. The findings across company size and turnover categories support the proposition that organizational scale and resource intensity influence how educational diversity is valued in leadership. Both variables point to a broader pattern: as firms become more structurally and financially complex, they are more likely to recognize and benefit from diverse educational inputs at the top management level. These insights are critical for refining any model of TMT performance, suggesting that education-related variables should be weighted differently across firm types, with firm size and turnover acting as essential contextual moderators within the Upper Echelons framework—perceptions of educational diversity varied by organizational role, visible in Chart No. 4.

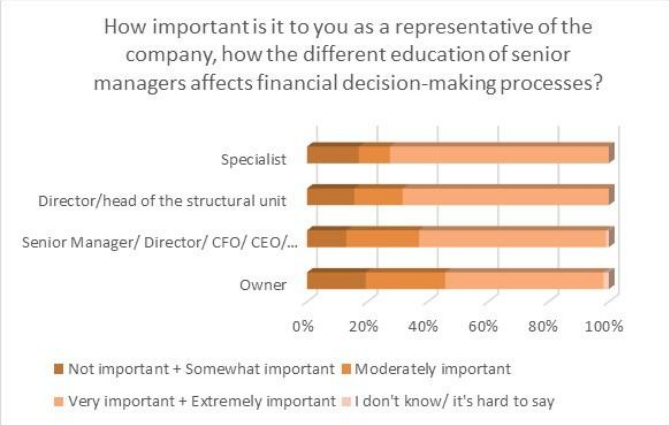


Chart 4. Perceived importance of senior managers' education by respondents' job position. Results of the survey.
Created by authors.

Top executives like CEOs, CFOs, and board members rated education essential for financial decision-making, reflecting their strategic focus. Department directors were similarly supportive but slightly less so, while specialists and small business owners showed more moderate or sceptical views, favouring practical experience. These patterns illustrate a core idea of Upper Echelons Theory: strategic outlooks and the value placed on education are shaped by functional roles and proximity to executive decision-making.

4.1.5 Industry-specific perceptions of educational diversity

The analysis reveals notable sectoral differences in how Top Management Teams (TMTs) educational diversity is perceived visible in Chart No. 5. In particular, respondents from the trade, services, and manufacturing sectors rated educational diversity as "very important" or "extremely important" in over 60% of responses, indicating a strong recognition of its relevance for strategic and financial decision-making. These sectors often operate at the intersection of operational efficiency and market responsiveness, where diverse educational backgrounds can enhance logistics, supply chain management, and customer engagement decision-making.

However, high-tech and professional service firms observed the most pronounced emphasis on educational diversity. Organizations in these sectors face rapidly evolving technologies, knowledge-intensive operations, and heightened expectations around corporate social responsibility (CSR) and innovation. Here, education is viewed not only as a qualification but as a cognitive asset that equips leaders to interpret complexity, manage uncertainty, and drive transformative initiatives. This finding is remarkably consistent with Upper Echelons Theory, which suggests that TMT characteristics—especially those influencing cognitive processing—are most impactful in dynamic, uncertain, and competitive environments.

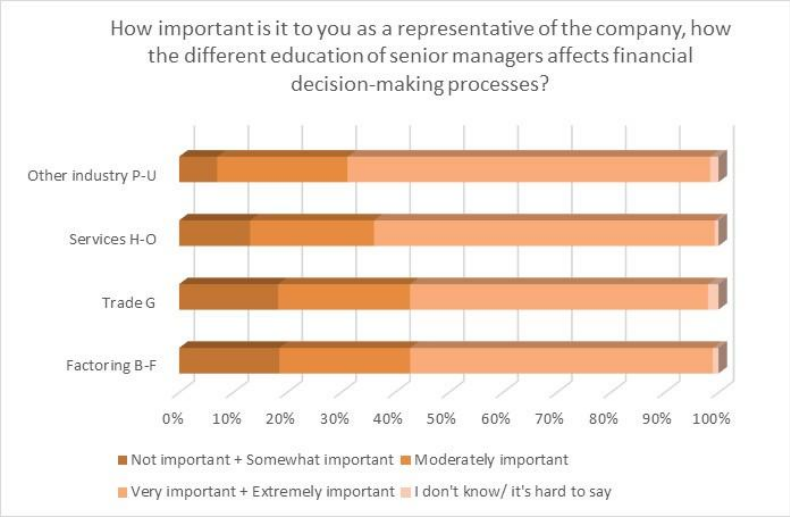


Chart 5. Perceived importance of senior managers' education by industry sector. Results of the survey.
Created by authors.

The differences across sectors underscore the context-dependent value of educational diversity, suggesting that its strategic utility increases with the industry's environmental dynamism and knowledge intensity. These sectoral patterns should be accounted for in any predictive modelling of TMT effectiveness, as they provide critical insights into how the organizational environment interacts with leadership attributes to shape firm outcomes.

5 Summary of key findings

This study identified several meaningful findings regarding Top management Teams' educational diversity and its impact on enterprise performance. First, educational background—particularly when combined with industry experience—enhanced strategic decision-making and innovation capacity, supporting the principles of Upper Echelons Theory. Second, it confirms that cognitive diversity from varied educational fields contributes positively to problem-solving dynamics within TMTs, especially in knowledge-intensive sectors. Third, survey results indicated that while education alone was not always considered essential, over 60% of business representatives acknowledged its role in improving leadership competence and adaptability. Fourth, qualitative data revealed that leaders with interdisciplinary education foster more open communication, collaboration, and innovative thinking across teams. Finally, the study showed that educational diversity has a stronger positive effect in large or complex organizations, where it helps improve performance. In smaller companies, however, practical experience often matters more..

6 Conclusions

This study clarifies the importance of educational diversity within Top Management Teams (TMTs) as a strategic driver of organizational performance, particularly in fast-changing, knowledge-intensive sectors. Empirical data gathered from 765 enterprise representatives and in-depth interviews reveal that while a formal education is not universally seen as the primary driver of executive success, it is broadly recognized as a cognitive resource that enhances strategic decision-making, influencing the financial performance of the enterprises. Research confirms the fundamentals of the Upper Echelons Theory (UET), which states that combining formal education with practical experience helps leaders develop broader perspectives and become more flexible in complex and rapidly changing business environments. Organizations—especially those undergoing digital transformation or operating in uncertain markets- should prioritize educational heterogeneity in their executive hiring and development practices. However, practitioners must also contextualize the value of education within their firm’s size, sectoral demands, and leadership culture. A one-size-fits-all approach may be ineffective; instead, tailoring TMT configurations to balance formal education with experiential insights will yield better strategic outcomes. Findings of the article can be used in predictive models of TMT effectiveness and offer actionable guidance for professionals in human relations and corporate leaders seeking to build high-performing leadership teams.

6 Ethics declaration

This research complies with institutional ethical standards. All participants gave informed consent, and confidentiality was maintained. The authors declare no conflicts of interest.

7 AI declaration

This article was developed using OpenAI's ChatGPT (version 4.0) to enhance the clarity and precision of the language.

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Shifting Operational HRM to AI: Opportunities, Challenges and Strategic Pathways

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Abstract

This paper explores the transition of operational human resource management (HRM) tasks to artificial intelligence (AI) and examines the resulting opportunities, challenges, and strategic pathways. We develop a theoretical analysis grounded in recent HRM literature and Tursunbayeva's (2024) configurational framework, which views HRM practices as consisting of operational, relational, and transformational dimensions. The study is conceptual in nature, integrating insights from technology adoption (e.g., the technology-organization-people perspective) and responsible AI principles to extend and refine existing theory. We argue that delegating operational HRM activities to AI can significantly enhance efficiency and decision-making—such as through automation of repetitive administrative tasks and data-driven analytics—while freeing HR professionals to focus on higher-value relational and strategic roles. However, this shift also introduces notable challenges, including algorithmic bias, privacy and transparency concerns, workforce skill gaps, and employee resistance to AI-driven change. To address these issues, we propose strategic pathways for organizations, emphasizing the adoption of Responsible AI governance (ensuring fairness, accountability, and human oversight), proactive change management and upskilling of HR personnel, and alignment of AI initiatives with broader HR strategy (e.g., leveraging AI to support diversity and inclusion goals). In doing so, the paper contributes to HRM theory by extending Tursunbayeva's framework with a more detailed examination of the operational HRM–AI interface and by incorporating multi-level and human-centric considerations. The resulting model offers a holistic view of AI integration in HRM, highlighting that AI's benefits in operational HRM are maximized only when accompanied by ethical safeguards and strategic alignment. The paper concludes with theoretical implications and recommendations for HR practitioners seeking to responsibly navigate the AI transformation of HRM.

Keywords: Artificial Intelligence, Human Resource Management, Automation, Ethical Decision-Making, Workforce Transformation

Paper type: Academic Research Paper

1 Introduction

The rise of Artificial Intelligence (AI) is reshaping the landscape of Human Resource Management (HRM), promising transformative improvements alongside significant uncertainties. AI's potential to automate and augment HRM practices is profound, offering unprecedented efficiency and data-driven insights. At the same time, it presents complex challenges in terms of ethics, inclusivity, and sustainability (Tursunbayeva, 2024). Recent analyses emphasize that while AI could revolutionize HRM, our understanding of how this transformation is unfolding in practice remains limited (Tursunbayeva, 2024). There are dual narratives surrounding AI in HRM: a "hype" perspective celebrating AI's augmentative potential, and a "fear" perspective cautioning against disruptive impacts on jobs and decision quality (Tursunbayeva, 2024). These divergent views underscore the need for rigorous theoretical examination of AI integration into HRM.

HR scholars and practitioners have long advocated leveraging technology to relieve HR professionals from routine administrative work, enabling a stronger focus on strategic and value-adding activities (Ulrich, 1997). Early waves of e-HRM and automation streamlined many operational HR tasks, reducing paperwork and human error (Tursunbayeva, 2024). AI-driven "algorithmic management" represents a new wave of this evolution, introducing complex data analytics and autonomous decision-making into HR processes (Tursunbayeva, 2024). However, the managerial playbook for effectively adopting AI in HRM is still emerging. A recent systematic review found that academic literature "has not yet offered a strategic framework" for guiding AI-assisted HRM implementation, even as organizations increasingly experiment with AI applications (Malik et al., 2023). Notably, Tursunbayeva's (2024) framework addresses this gap by viewing HRM technology through a configurational lens – distinguishing operational, relational, and transformational HRM elements – and by stressing responsible, multi-level implementation of AI (Tursunbayeva, 2024).

Building on this foundation, the present theoretical study explores the central question: What opportunities and challenges arise when shifting operational HRM activities to AI, and what strategic pathways can enable organizations to harness AI's benefits while mitigating its risks? The thesis put forward is that AI can significantly enhance the efficiency and strategic impact of HRM by taking over operational tasks, but realizing these benefits requires addressing substantial ethical, organizational, and human-centric challenges through carefully crafted

strategies. In examining this thesis, we extend and critique Tursunbayeva's (2024) framework by integrating additional theoretical perspectives and recent empirical insights. The paper is organized as follows. First, we review the theoretical background on AI in HRM, including Tursunbayeva's configurational approach. Next, we analyze the key opportunities and challenges of shifting operational HRM to AI. We then discuss strategic pathways for implementing AI in HRM responsibly and effectively. Finally, we outline the theoretical contributions of this work – particularly in relation to Tursunbayeva's framework – and conclude with implications for research and practice.

2 Theoretical Background.

2.1. AI in HRM: Evolution and Perspectives.

Technology has pervaded HRM for decades in efforts to increase efficiency and strategic focus. The introduction of electronic HRM systems and automation allowed HR departments to offload repetitive administrative work and improve accuracy, thus freeing HR staff to focus on higher-value initiatives (Ulrich, 1997; Marler & Parry, 2016). This evolution is exemplified by the widespread adoption of self-service portals, applicant tracking systems, and HR analytics tools. These technologies were largely rule-based and required human configuration, but they set the stage for more sophisticated AI-driven solutions. Today, AI algorithms enable what is often termed "algorithmic management", where certain managerial decisions and workflows are partially or fully automated (Tursunbayeva, 2024). AI-driven systems can autonomously screen résumés, schedule interviews, or monitor attendance – executing tasks that were once manual. AI applications now span nearly all HR functional areas, from recruitment and selection to training, performance management, and compensation (Tursunbayeva, 2024).

With this expansion of AI capabilities, HRM scholars describe two contrasting perspectives on its impact. On one hand, the optimistic transformative view posits that AI will augment human decision-making, enhance productivity, and create more strategic roles for HR professionals (Tursunbayeva, 2024). From this perspective, AI is a catalyst enabling HRM to deliver greater value through data-driven insights and by reallocating human effort to complex relational and strategic tasks. On the other hand, a concerned view warns that heavy reliance on AI could have disruptive effects – potentially displacing HR jobs, reducing the human touch in people management, and introducing new risks of error or bias (Tursunbayeva, 2024). This "hype versus fear" dichotomy is evident in recent literature on AI in the workplace. Both views contain some truth: AI can indeed dramatically improve efficiency, but uncritical implementation may lead to unintended consequences. This duality underlines why a balanced, theory-driven approach is needed when examining AI in HRM.

2.2 Tursunbayeva's (2024) Configurational Framework

A key emerging theoretical perspective on AI in HRM is provided by Tursunbayeva (2024). In her framework, HRM practices are viewed through a configurational lens comprising three interrelated configurations: operational HRM, relational HRM, and transformational HRM (Tursunbayeva, 2024). Operational HRM refers to transactional administrative activities (e.g., record-keeping, payroll) necessary for running the organization but not directly strategic. Relational HRM covers activities in managing employee relationships and development (for example, recruitment and selection, training, performance management, compensation). Transformational HRM involves strategic, change-oriented practices (e.g., strategic workforce planning, succession management) aimed at long-term organizational development. Tursunbayeva's framework posits that AI can play distinct roles in each of these configurations. Notably, Tursunbayeva addresses the dual perspectives by acknowledging both AI's promise and its perils within her framework. She highlights that AI can "streamline routine administrative tasks through automation and algorithmic management" and "enhance relational HRM throughout the employee life cycle", while also supporting strategic objectives like diversity and inclusion (Tursunbayeva, 2024). This reflects the optimistic view that AI augments HRM at all levels – automating the operational, assisting the relational, and informing the transformational.

At the same time, her framework explicitly acknowledges the "ethical...minefield" that AI introduces (Tursunbayeva, 2024). It emphasizes Responsible AI principles and alignment at multiple levels of the organization (Tursunbayeva, 2024), thereby integrating ethical considerations (fairness, transparency, inclusivity) into AI adoption in HRM (Tursunbayeva, 2024).

Tursunbayeva's configurational framework provides a structured way to analyze where AI fits into HRM and what consequences may arise. It suggests that operational HRM tasks are the most amenable to full AI automation, whereas relational HRM might benefit from AI-assisted decision support (e.g., chatbots aiding

employee inquiries or algorithms recommending training content), and transformational HRM can leverage AI-driven analytics for strategic insights. This study adopts Tursunbayeva's framework as a foundation and focuses on the operational HRM component – essentially examining the implications of "leaving operational HRM to AI." By zooming in on the operational level, we explore the direct opportunities AI creates in automating HR tasks and the cascading challenges for relational and transformational HRM. We also integrate complementary insights from other scholars – for instance, Budhwar et al. (2022) highlight that successful AI adoption requires alignment of technology, organization, and people (the TOP factors) (Malik et al., 2024). By incorporating such perspectives, we extend Tursunbayeva's framework to consider the key enabling conditions and context for AI-driven HRM.

In the following sections, we discuss the major opportunities and challenges that AI presents for operational HRM, before elaborating strategic pathways to navigate this change.

3 Opportunities of AI for operational HRM.

AI technologies offer a range of opportunities to improve operational HRM processes. In this context, "operational HRM" includes the routine, high-volume tasks and transactions that support the employee lifecycle (such as recruiting administration, record maintenance, payroll, scheduling, etc.). By delegating these tasks to AI systems, organizations can achieve greater efficiency and consistency, while potentially unlocking new strategic value from HR data. Key opportunity areas are outlined below.

3.1 Automation and Efficiency Gains.

A primary benefit of applying AI to operational HRM is automation of repetitive tasks, leading to efficiency gains. AI systems can perform many administrative duties faster and with fewer errors than humans. For example, AI-driven recruiting platforms can instantly screen large volumes of résumés and rank candidates, a task that would otherwise consume substantial recruiter time (Dima et al., 2024). This acceleration in response time "significantly enhances the candidate experience" by keeping applicants informed and engaged (Dima et al., 2024). Similarly, AI chatbots can handle common employee queries (e.g., about benefits or leave) instantly and consistently, freeing HR staff from many routine interactions. By automating these processes, organizations can operate with leaner HR teams or redeploy staff to more complex work (Budhwar et al., 2022). Furthermore, automation often brings cost savings and improved accuracy – algorithms follow prescribed rules consistently, eliminating many errors of manual processing (Dima et al., 2024). Overall, the efficiency gains from AI-driven automation in operational HRM translate into faster service delivery, lower transactional costs, and more reliable execution of HR processes.

3.2 Data-Driven Decision Making and Analytics

Beyond task automation, AI offers the opportunity to transform operational HR decisions through advanced data analytics. Many HR decisions that were once based on intuition or limited information can now be augmented by AI algorithms that detect patterns across vast datasets. For instance, machine learning models can analyze employee data to predict outcomes like turnover risk or performance potential (Dima et al., 2024), enabling HR to address issues (e.g., proactive retention efforts) far earlier than traditional methods. In talent acquisition, AI can search across multiple databases to identify and engage potential candidates much faster than a human recruiter (Dima et al., 2024), thus significantly expanding the talent pool. By grounding HR decisions in data, organizations can make choices that are not only faster but also more objective. Studies have found that introducing AI into selection processes encourages a shift from gut-feel to evidence-based decision-making (Dima et al., 2024).

3.3 Enhanced Stakeholder Experience and Fairness

Another opportunity area is the improvement of experiences for HR's stakeholders – namely employees (including job candidates) and managers – along with potential gains in fairness. From the stakeholder experience standpoint, AI can make HR services more responsive and personalized. As noted above, candidates benefit from quicker communications (such as instant application updates or interview scheduling), which leads to a more positive recruitment experience (Dima et al., 2024). Employees, too, may appreciate the convenience of AI-enabled self-service tools for simple HR queries, allowing them to resolve matters without delay. Managers can also benefit from AI-driven decision support (for example, AI-based analytics that flag disengaged employees or recommend learning opportunities), which can make their HR-related tasks easier and more informed Kshetri (2021).

In terms of fairness, AI has the potential to reduce certain biases that human decision-makers may unwittingly introduce. When properly designed and audited, AI algorithms can focus on job-relevant criteria and ignore extraneous attributes, which can help mitigate discrimination in hiring or promotions (Albert, 2019). For example, an AI screening tool could be programmed to disregard demographic information, basing its recommendations purely on candidates' skills and experience. AI can also reveal patterns in HR data that hint at bias – for instance, if performance scores consistently differ by gender – thereby alerting management to potential inequities that need correction. While realizing these fairness benefits requires careful oversight, the opportunity is that AI might support more consistent, merit-based decision-making. If successful, such improvements could increase employees' and applicants' perceptions of justice in HR processes, strengthening the employer's reputation.

3.4 Elevating the Strategic Role of HR

By taking over operational tasks, AI frees up human resources professionals to engage in more strategic and high-touch activities – effectively elevating the role of HR in the organization (Budhwar et al. 2022). This is both a direct consequence of workload automation and an indirect effect of the richer insights AI can provide. With administrative burdens reduced, HR practitioners can allocate more time to strategic planning, talent development, and consulting with business leaders. Rather than spending hours on transactional duties like compiling reports, an HR manager might use AI-generated analytics to advise leadership on workforce planning or diversity initiatives. Indeed, research suggests that organizations are beginning to "strategize HR with the aid of AI" as a means to better achieve both productivity and employee-related outcomes (Dima et al., 2024). AI tools can serve as a decision-support system for HR strategists – for example, identifying skill gaps that could impact future business goals or modeling the workforce implications of a new initiative. Armed with such analytics, HR leaders can make more informed contributions to business strategy discussions.

Furthermore, the integration of AI into HRM amplifies the strategic emphasis on managing change and innovation in organizations. HR professionals, freed from day-to-day drudgery, can champion initiatives like culture change, leadership development, or organizational redesign while relying on AI to monitor progress and flag issues in real time. Over time, as routine work is ceded to intelligent systems, the HR function can reposition itself from an administrative support unit to a strategic partner role (Ulrich, 1997). This shift aligns with the long-standing vision of HR as a driver of organizational capability and competitive advantage. AI's contributions – whether through efficiency gains or advanced analytics – reinforce HR's ability to deliver strategic value. The net result is an opportunity for HR professionals to enhance their influence and for the HR function to be more deeply involved in high-level decision-making. In summary, deploying AI in operational HRM not only improves process metrics but can also catalyze a transformation of the HR function itself, enabling it to focus on strategic, value-adding activities that were previously neglected due to time and resource constraints.

4 Challenges of AI Implementation in HRM

While AI presents compelling opportunities, it also brings a spectrum of challenges and risks that organizations must navigate. Many of these challenges correspond to the ethical and strategic concerns raised by the "fear" perspective of AI in HRM (Tursunbayeva, 2024). If not properly addressed, such issues can negate the benefits or even cause harm to organizational culture and stakeholder trust. We categorize the challenges into two broad domains: (1) ethical and legal challenges, and (2) human and organizational challenges.

4.1 Ethical and Legal Challenges

One of the foremost concerns is the risk of algorithmic bias and discrimination. AI systems learn from historical data, and if those data reflect biased human practices, the algorithm may perpetuate or even amplify those biases. For example, if past hiring data are biased, an AI recruitment tool could learn to unfairly screen out underrepresented candidates. This creates a serious ethical issue as well as legal liability, since employment laws prohibit discriminatory practices. Ensuring algorithmic fairness requires ongoing audits of AI decision criteria, careful curation of training data, and adjustments to counteract bias. However, establishing accountability is challenging when AI decision-making is a "black box" that stakeholders do not understand. Opaque algorithms make it difficult to explain or contest decisions, which can undermine trust and may run afoul of emerging regulations that demand explainability.

Closely related are privacy and data protection concerns. AI-based monitoring of employees (e.g., analyzing emails or wearable sensor data) can easily cross into perceived surveillance, prompting employee pushback (Dima et al., 2024). Data security is also paramount: breaches or misuse of sensitive HR information can erode

trust and violate data protection laws. Organizations must navigate strict privacy regulations regarding how personal information is collected, used, and stored, or risk legal penalties and reputational damage.

Another challenge is maintaining ethical accountability and compliance when AI plays a major role in HR decisions. If an algorithm makes a flawed decision (e.g., unjustly rejecting a qualified candidate), it may be unclear who is responsible – the vendor, HR, or the developers. Clear governance frameworks are needed to assign responsibility and oversight for AI outcomes. Without proper oversight, AI in HRM can become an "ethical – if not legal – minefield" (Tursunbayeva, 2024). Organizations should establish ethical guidelines (under the banner of Responsible AI) that encompass fairness, transparency, and accountability, in alignment with employment laws and human rights. In practice, it is wise to keep a human in the loop for important decisions, to catch potential errors or biases before actions are finalized. Ultimately, Responsible AI requires embedding ethical considerations into every stage of the AI lifecycle – from data selection and algorithm design to deployment and ongoing monitoring – to prevent pitfalls and sustain trust in AI-driven HRM.

4.2 Human and Organizational Challenges

Beyond ethics and legality, the shift to AI-driven HRM raises substantial human and organizational challenges. A prominent issue is the fear of job displacement and role change among HR professionals. As AI takes over tasks like résumé screening or attendance tracking, some HR staff naturally worry about their own job security (Chen, 2023). This anxiety can breed resistance – indeed, HR professionals unfamiliar with AI may be especially resistant if they believe it will make their roles obsolete. Addressing this fear requires clear communication that AI is a tool to assist rather than replace humans, and a refocusing of HR roles on the uniquely human skills (e.g., relationship-building, empathy) that AI cannot replicate.

Relatedly, introducing AI in HR requires careful change management to overcome cultural resistance. Employees or managers might be skeptical of algorithmic recommendations – especially if they lack digital literacy or inherently mistrust the technology. Building acceptance necessitates involving end-users early, providing training, and demonstrating quick wins. If people do not understand or trust an AI system, they may circumvent it, so fostering a culture open to data-driven decision-making is essential. This cultural shift can be difficult, particularly in organizations where intuition and personal judgment have traditionally dominated HR decisions.

Another major challenge is the skills gap that AI implementation exposes. To effectively leverage AI, HR professionals and managers must develop new competencies. Employees will need to "leverage [AI's] advantages while compensating for its deficiencies" by developing both new technical knowledge and enhanced human skills (Dima et al., 2024). In essence, organizations are cultivating an "AI-hybridized workforce" where humans and AI work in tandem, which requires continuous learning and upskilling. However, implementing these upskilling programs is non-trivial. Employees less comfortable with technology (often older workers) tend to struggle more with retraining, which can create generational divides or morale issues. Additionally, there is a shortage of HR professionals with strong analytics and AI skills, so organizations may find themselves competing for a limited pool of qualified talent (Dima et al., 2024).

On an organizational level, the infusion of AI into HRM can necessitate changes in structure and processes. Decision-making workflows may need to be redesigned to incorporate algorithmic inputs, and new governance bodies or roles (such as an AI ethics committee or HR analytics specialist) may be required. There could also be shifts in power dynamics: if line managers feel that decisions are dictated by algorithms, tension may arise over the locus of control. In fact, AI's encroachment on certain HR "fields of expertise" could alter internal power structures and even spark labor relations issues. These factors underscore that implementing AI is not just a technical project but a socio-technical transformation. Organizations must cultivate a learning-oriented culture that encourages experimentation and adaptability – continuous learning is "essential for the successful implementation of AI" (Rajeshwari et al., 2019). Without a supportive culture, even the best AI tools may fail to deliver value because they will not be fully embraced by the people in the organization.

In summary, the human and organizational challenges of AI in HRM revolve around managing fear and resistance, developing new skills and roles, and adapting organizational structures and culture. Proactively addressing these challenges is as important as the technical deployment of AI tools. The next section discusses strategic pathways that organizations can adopt to capitalize on AI's opportunities while mitigating the challenges identified.

5 Strategic Pathways and Recommendations

To fully realize the benefits of AI in HRM while mitigating the above challenges, organizations need to adopt deliberate strategic pathways. These involve instituting governance mechanisms, developing people and

culture, and aligning AI initiatives with broader organizational goals. Based on the literature and frameworks discussed, we outline several key strategies for effective integration of AI into HRM.

5.1 Embracing Responsible AI and Governance

The first strategic imperative is to embrace Responsible AI principles and build a robust governance structure around AI use in HRM. Organizations should establish clear internal policies for AI in HR – covering issues like bias prevention, data privacy, transparency, and accountability. For example, any AI used in hiring might be required to undergo bias audits and to inform candidates of automated screening. These measures signal a commitment to ethics and guide the development or selection of HR AI tools.

Implementing Responsible AI also entails multi-level oversight. This means taking measures at multiple levels (individual, organizational, even societal) to ensure ethical outcomes (Tursunbayeva, 2024). In practice, for example, an organization might form an AI ethics committee to regularly review AI-driven HR decisions and handle any grievances or exceptions. Ensuring human oversight (a human-in-the-loop) is advisable for high-stakes decisions, and transparency should be maximized by providing explanations for AI decisions and clearly communicating how AI systems are used. Such steps can alleviate fears and build trust. It has been stressed that AI systems in HR should remain "transparent and unbiased and comply with all laws" and should complement rather than replace human judgment (Dima et al., 2024). Ultimately, Responsible AI requires embedding ethical considerations into every stage of the AI lifecycle – from data selection and algorithm design to deployment and ongoing monitoring – to prevent pitfalls and sustain trust in AI-driven HRM.

5.2 Change Management and Skill Development

Technical solutions alone are not enough; the success of AI in HRM hinges on effective change management and skill development. A prudent approach is to start with small pilot programs. For example, an organization might first deploy an AI tool in a single, low-risk HR process and closely evaluate the outcomes and user acceptance. Early successes can then be communicated to build confidence before scaling up. Throughout this process, communication is key – employees should be informed about what the AI system does and how it benefits them. Emphasizing that AI reduces drudgery and assists people (rather than replaces them) can preempt resistance.

Training and upskilling efforts form another pillar of this strategy. Organizations should strive to cultivate an AI-ready workforce with a mix of technical and human skills (Dima et al., 2024). HR staff may need training (via workshops, e-learning, etc.) in analytics tools and AI ethics, and line managers who will use AI outputs should also be educated about their proper use and limitations. By improving digital literacy and comfort with AI, the organization narrows the skill gap and reduces fear of the unknown.

HR departments may also need to redefine roles (for example, adding HR data analysts) and encourage cross-functional collaboration (between HR, IT, and data science teams) to ensure AI tools meet HR's needs and values. Involving HR staff in the design and rollout of AI systems – rather than imposing tools on them – increases buy-in and yields feedback to refine the system. Top management support is also critical; leaders should visibly champion the responsible use of AI in HR and provide resources for training. Finally, organizations should establish feedback channels (e.g., surveys or forums) for employees to voice concerns about AI decisions, and use that input to adjust policies or algorithms over time.

5.3 Aligning AI with Strategic HRM Objectives

For AI in HRM to deliver maximum value, it should be closely aligned with the organization's broader strategic objectives and human capital strategy. Rather than adopting AI for its own sake, organizations should use AI to advance explicit HR goals (such as improving workforce diversity, driving innovation, or enhancing employee well-being). For example, if a company's strategic aim is to foster a more inclusive workforce, AI tools can be leveraged to widen sourcing channels for diverse talent and to detect biased language in job postings. Likewise, if continuous learning and innovation are priorities, AI can be applied in employee development (through personalized training recommendations or coaching chatbots) to support those objectives.

In addition, organizations should define Key Performance Indicators (KPIs) for their AI-enhanced HR processes that link to strategic outcomes. For example, if strategic focus is agility, a relevant KPI might be reduction in time-to-fill positions; if the focus is employee experience, a KPI might be improvement in engagement survey scores. Tracking such metrics helps HR demonstrate AI's contribution to organizational performance, sustaining executive support for AI initiatives and ensuring projects remain driven by clear business needs rather than technology hype. Scholars also suggest using a Technology-Organization-People

perspective to achieve alignment (Malik et al., 2024) – in essence, the AI technology must fit the organizational context and the people who use it. In practice, this means choosing AI solutions appropriate for the company's scale and culture, and tailoring implementation to the organization's specific context.

Finally, aligning AI with HR strategy requires a commitment to the sustainability of AI initiatives. Organizations should treat AI integration as a continuous journey rather than a one-off project – regularly reevaluating whether HR AI systems are meeting their intended purpose and adjusting them as business needs evolve. This includes staying attuned to external changes (such as new AI regulations or shifts in the labor market) and adapting accordingly. In essence, AI should be managed as an ongoing enabler of the HR vision (whether it is becoming an employer of choice, building a high-performance culture, etc.), with its use continually calibrated to serve that vision. Done successfully, this ensures that AI not only helps achieve strategic HR goals, but that the pursuit of those goals also guides the ethical and effective evolution of AI in the organization.

6 Discussion and Theoretical Contributions

The foregoing analysis provides several theoretical contributions to the understanding of AI integration in HRM. First, by focusing explicitly on the operational HRM domain, we extend Tursunbayeva's (2024) configurational framework by deepening the analysis of the operational HRM–AI nexus and addressing the implementation challenges. Our analysis shows that "leaving operational HRM to AI" is not merely a technical change but one that requires redistributing HR efforts across operational, relational, and transformational domains. We reinforce Tursunbayeva's idea that efficiency gains at the operational level must be accompanied by adjustments at the relational and strategic levels (e.g., upskilling HR staff and refocusing their roles) to fully realize AI's benefits. This extension adds nuance by illustrating that automating operational tasks creates an imperative for HR professionals to assume more consultative and strategic functions – a dynamic her framework implies but does not detail.

Second, we integrate complementary theoretical perspectives (e.g., the Technology–Organization–People lens) to broaden her framework, emphasizing that technological innovation must be coupled with organizational readiness and human factors. This synthesis yields a more holistic model for AI-driven HRM that can better guide empirical research. Future studies might, for example, examine which organizational contexts or leadership behaviors best facilitate the transition of operational HRM to AI.

Third, we extend the practical relevance of Tursunbayeva's framework by translating its abstract principles into actionable recommendations. Our proposed strategic pathways – from establishing AI governance committees to phasing in adoption and aligning AI with HR strategy – operationalize the idea of responsible, inclusive AI integration. These propositions offer a basis for future empirical research (for example, investigating whether organizations with formal AI governance in HRM experience higher stakeholder trust) and advance the conversation initiated by Tursunbayeva.

Overall, this study supports and extends Tursunbayeva's (2024) framework by deepening the exploration of the operational HRM–AI interface and by integrating additional lenses that address implementation challenges. It also provides a more balanced narrative that neither celebrates AI uncritically nor rejects it, but rather outlines conditions under which AI's promises can be realized in harmony with human values and strategic objectives. By doing so, we hope to advance the theoretical discourse on AI in HRM from broad frameworks toward more refined models that account for the socio-technical complexity of this transformation.

7 Conclusion

Artificial Intelligence is driving a paradigm shift in how operational HRM activities are carried out. This paper has examined the opportunities, challenges, and strategic pathways associated with shifting operational HRM to AI. On the opportunity side, we found that AI can dramatically improve efficiency, accuracy, and decision quality in routine HR tasks, while also freeing human professionals to engage in more strategic, high-impact work. On the challenge side, we identified critical ethical risks (such as bias and privacy issues) and human factors (such as skill gaps and resistance) that must be managed to ensure successful AI adoption. The analysis led to a set of strategic recommendations, including adopting responsible AI practices, investing in change management and skills, and aligning AI initiatives with the organization's strategic HR goals.

The overarching thesis of this study is that AI will augment rather than replace the human element in HRM – but only if organizations deliberately design it to do so. In other words, the shift of operational HRM to AI can create tremendous value, but it requires a thoughtful approach that safeguards ethical principles and elevates the role of HR practitioners. This perspective extends and enriches Tursunbayeva's (2024) framework,

underlining the importance of coupling technological innovation with organizational strategy and human-centric considerations.

For researchers, this work opens avenues to further investigate AI in HRM through a multi-faceted lens, and for practitioners it offers a roadmap for navigating AI implementation in HR. As AI technologies continue to evolve (e.g., the rise of generative AI tools in HR), the core insight remains that the ultimate effectiveness of AI in human resource management will depend on how well we integrate the "human" with the "artificial." By embracing AI's capabilities while upholding human values and strategic clarity, HRM can transform into a function that is both operationally excellent and a driver of sustainable organizational success.

8 Ethics declaration

The paper doesn´t need ethic approval or declaration. It doesn´t use data collection.

9 AI declaration

The authors used ChatGPT to assist in the literature search and to improve the clarity of the English language in some sections. The outputs from the tool were critically reviewed and validated by the authors to ensure academic rigour and integrity.

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Artificial Intelligence and Microfinance: Enhancing Social Inclusion and Value Creation for Immigrant Communities

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Abstract

This paper explores how Artificial Intelligence can transform microfinance to promote social inclusion and value creation for immigrant communities. Despite immigrants' significant potential to contribute to local economies, they often encounter substantial barriers to accessing formal financial services, including limited credit histories, regulatory challenges, and cultural or linguistic differences. AI technologies, particularly machine learning, predictive analytics, and Natural Language Processing, provide innovative pathways to overcome these challenges by enabling inclusive credit scoring, automated multilingual support, and scalable, personalized financial services.

Employing a Systematic Literature Review guided by Preferred Reporting Items for Systematic reviews and Meta-Analyses and structured through the Population, Intervention, Comparison, and Outcome framework, this study critically evaluates 52 peer-reviewed sources to assess the effectiveness and impacts of AI-driven microfinance compared to traditional microfinance methods. Findings indicate that AI significantly enhances financial accessibility, facilitates immigrant entrepreneurship, and fosters broader social inclusion through culturally and linguistically adapted financial solutions.

A central contribution of this research is the integration of the Intellectual Capital framework, comprising human, structural, and relational capital, to examine the essential conditions for successful AI adoption in microfinance institutions. Human capital is crucial for developing skills in ethical AI deployment, structural capital ensures robust technological infrastructures, and relational capital builds essential trust between institutions and immigrant communities, thus ensuring sustainable and inclusive outcomes.

This study aligns with Sustainable Development Goals 8 (Decent Work), 9 (Industry, Innovation, and Infrastructure), and particularly SDG 10 (Reduced Inequalities). It provides actionable insights and strategic recommendations for financial institutions, policymakers, and fintech firms. To realize AI's full potential in immigrant social inclusion, the paper emphasizes the necessity of ethical AI frameworks, targeted capacity-building initiatives, and trust-based service models, ultimately contributing to more inclusive and equitable societies.

Keywords: Artificial Intelligence, Intellectual Capital, Microfinance, Social Inclusion, Value Creation.

Paper type: Academic Research Paper

1 Introduction

The persistent financial exclusion of immigrants poses a significant barrier to their social and economic integration in host societies. Although immigrants contribute meaningfully to labour markets, entrepreneurship, and cultural diversity, they often lack access to formal financial services due to undocumented credit histories, unstable employment, and institutional biases (Chibba, 2009; Ozili, 2020; Biswas & Gupta, 2022). Traditional banking systems, reliant on rigid credit scoring models and identification documentation, tend to overlook the informal economic activities in which many immigrants engage (Moro Visconti, 2020; Sarma & Pais, 2011). As a result, many turn to informal lending channels that are costly, unreliable, and unregulated, further deepening their economic vulnerability.

Microfinance has emerged as a viable tool to bridge this gap by offering small-scale financial services to underserved populations. However, despite its contributions, traditional microfinance institutions (MFIs) still face limitations such as inefficient manual processes, narrow credit assessment tools, and a lack of scalability (Armendáriz & Morduch, 2010; Haefner & Morf, 2021; Lwesya & Mwakalobo, 2023). These limitations highlight the need for digital innovation to enhance financial inclusion.

Artificial Intelligence (AI) has introduced transformative capabilities into the financial sector. With technologies like machine learning, predictive analytics, and Natural Language Processing (NLP), AI enables data-rich, automated, and inclusive financial services. For immigrant communities in particular, AI facilitates alternative credit scoring using data such as remittances, mobile transactions, and behavioural patterns, thereby reducing reliance on traditional metrics (Kaplan & Haenlein, 2019; Gama & Magistretti, 2025). NLP-driven virtual assistants also address language barriers, improving user experience and financial literacy (Russell & Norvig, 2024; Suleiman & Kwok, 2025).

The integration of AI not only supports financial access but also contributes to broader value creation. Immigrants gain economic empowerment through entrepreneurial support and more inclusive credit options,

while MFIs benefit from operational efficiency, fraud detection, and cost reduction (Li & Duan, 2025; Sachs, 2015). Socially, AI strengthens community networks and trust through adaptive service delivery and peer-support platforms (Granovetter, 1985; Putnam, 2000). Yet, ethical risks such as algorithmic bias, privacy concerns, and opacity in decision-making remain key concerns in digital lending (Binns, 2020; Mittelstadt et al., 2016). Addressing these issues requires ethically governed AI systems that are transparent, explainable, and inclusive.

In this context, this study investigates how AI-powered microfinance models enhance social inclusion and value creation for immigrant communities. It also examines the enabling role of Intellectual Capital (IC), including human, structural, and relational dimensions, in ensuring ethical, sustainable, and inclusive adoption of AI in financial services (Edvinsson & Malone, 1997; Bontis & Serenko, 2022; Kianto et al., 2017).

The study is guided by the following research questions:

- How does AI-driven microfinance enhance social inclusion by expanding financial accessibility and economic participation for immigrant communities?
- In what ways does AI-driven microfinance contribute to value creation, fostering economic empowerment, financial stability, and entrepreneurial opportunities for immigrants?
- How does Intellectual Capital (human, structural, and relational) influence the successful adoption of AI in microfinance, ensuring socially inclusive and sustainable financial solutions aligned with Sustainable Development Goals (SDGs) 8, 9, and 10?

To address these questions, this study adopts a Systematic Literature Review (SLR) methodology. The review follows the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines to ensure transparency, rigor, and replicability (Moher et al., 2009) while employing the Population, Intervention, Comparison, and Outcome (PICO) framework to structure the research focus on immigrant populations, AI-based interventions, traditional finance comparisons, and social and economic outcomes (Vesperi & Coppolino, 2023).

This article is structured into five key sections. Following this introduction, the next section presents the theoretical background, exploring the role of AI and IC in microfinance and their implications for social inclusion. The third section outlines the methodology, detailing the SLR process. The fourth section presents the main findings, focusing on how AI enhances financial accessibility, value creation, and institutional scalability for immigrant communities. Finally, the last section offers a discussion of the results and presents conclusions, highlighting practical implications, ethical considerations, and directions for future research.

2 Theoretical Background

This section provides the theoretical foundations underlying the transformative role of AI in microfinance, particularly in enhancing social inclusion and value creation for immigrant communities. It begins by exploring how AI technologies can mitigate traditional barriers to financial inclusion faced by immigrants. It then discusses the economic value created through AI-powered microfinance, focusing on entrepreneurial empowerment and institutional efficiency. Subsequently, the section examines Intellectual Capital as an essential framework facilitating the ethical and effective adoption of AI technologies. Finally, research gaps are identified, underscoring this study's unique contributions to existing scholarship on AI, microfinance, and immigrant integration.

2.1 Artificial Intelligence and Microfinance: A Path to Social Inclusion and Value Creation

Artificial Intelligence is increasingly reshaping financial services, offering powerful tools for enhancing efficiency, personalization, and accessibility. In the context of microfinance, AI technologies such as machine learning, predictive analytics, and Natural Language Processing provide innovative solutions for addressing the needs of underserved populations, particularly immigrant communities (Kaplan & Haenlein, 2019; Russell & Norvig, 2024).

Microfinance has traditionally served as a gateway for financial inclusion by offering small loans, savings mechanisms, and financial education to marginalized groups (Chibba, 2009). However, legacy models rely on conventional credit scoring and manual processes, which often exclude immigrants due to a lack of formal financial history or identification (Ozili, 2020; Biswas & Gupta, 2022). AI mitigates these barriers by leveraging alternative data such as digital transactions, remittance flows, and behavioral patterns to assess creditworthiness more inclusively (Moro Visconti, 2020).

Moreover, NLP-powered tools break language barriers, enabling immigrants to access multilingual support, participate in digital banking, and improve financial literacy (Haefner & Morf, 2021). These applications support

deeper integration into the host economy and social systems, reinforcing AI's role as an enabler of both financial and social inclusion.

2.2 Economic Value Creation through AI in Microfinance

Beyond inclusion, AI contributes to economic value creation by empowering immigrant entrepreneurship, improving risk assessment, and enhancing operational scalability for microfinance institutions (Sachs, 2015; Gama & Magistretti, 2025). Predictive analytics enable customized loan offerings and more accurate credit scoring, which in turn reduce default rates and improve financial sustainability (Moro Visconti, 2020; Lwesya & Mwakalobo, 2023).

AI-driven automation also allows MFIs to reduce administrative costs and reallocate resources toward client services, extending outreach to hard-to-reach populations (Li & Duan, 2025). These efficiencies make microfinance more scalable and sustainable, while simultaneously fostering immigrant-led business development and community resilience.

2.3 Intellectual Capital and the Adoption of AI in Microfinance

The successful implementation of AI in microfinance depends not only on technology, but also on the strength of an institution's Intellectual Capital the intangible assets that support innovation and performance (Edvinsson & Malone, 1997; Kianto et al., 2017). The IC framework includes:

- Human Capital – The skills, ethical awareness, and digital competencies of staff and users. Financial professionals must be trained in responsible AI use to avoid unintended bias in decision-making (Kaplan & Haenlein, 2019).
- Structural Capital – The technological and organizational infrastructure that supports AI integration. This includes data systems, secure platforms, and adaptive credit scoring algorithms (Gama & Magistretti, 2025).
- Relational Capital – The trust-based relationships between MFIs and immigrant communities. Transparent and explainable AI models foster trust and encourage financial engagement (Haefner & Morf, 2021).

The interplay among these dimensions determines how effectively AI can be deployed to support inclusive, ethical, and sustainable financial systems. Yet, this link between IC and microfinance remains underexplored. This study addresses that gap by positioning IC as a foundation for AI-powered financial inclusion strategies.

2.4 Research Gaps and Study Contributions

Although AI's role in finance is well documented, its specific application to immigrant-focused microfinance remains limited. Prior research has primarily concentrated on corporate banking and generalized fintech solutions, often overlooking the nuanced challenges of immigrant communities (Kaplan & Haenlein, 2019; Ozili, 2020). Moreover, studies often fail to connect AI adoption with the IC necessary for sustainable implementation (Bontis & Serenko, 2022; Kianto et al., 2017).

Additionally, ethical concerns such as algorithmic bias and data misuse are frequently acknowledged but lack robust frameworks for mitigation (Binns, 2020; Suleiman & Kwok, 2025). This study contributes by:

- Synthesizing evidence on AI-powered microfinance and immigrant inclusion
- Exploring the IC-based enablers of responsible AI adoption
- Aligning findings with SDGs 8, 9, and 10 to ensure relevance to sustainable development

By filling these gaps, the study provides actionable insights for MFIs, fintech firms, and policymakers seeking to implement AI-driven financial solutions that are both effective and equitable.

3 Methodology

This study employs a SLR to examine the transformative potential of AI-driven microfinance in enhancing financial inclusion and value creation for immigrant communities. The SLR method was chosen for its structured, transparent, and replicable approach, which enables a rigorous synthesis of current knowledge across interdisciplinary fields (Nightingale, 2009; Caputo et al., 2018).

To ensure methodological rigor and clarity, the review process was guided by the PRISMA guidelines, which outline standardized procedures for identifying, selecting, and analyzing relevant literature (Moher et al., 2009; Thomé et al., 2016). Additionally, the PICO framework (Population, Intervention, Comparison, and Outcomes)

was used to organize the research focus and support a coherent structure for evaluating the literature (Vesperi & Coppolino, 2023).

The study defines its population as immigrant communities experiencing barriers to financial inclusion. The intervention of interest comprises AI-based microfinance tools, including predictive analytics, natural language processing, and machine learning applications. These are compared with traditional microfinance models that rely on manual credit scoring, conventional risk assessment, and paper-based administrative processes. The outcome dimension focuses on how AI-driven systems improve financial accessibility, foster entrepreneurial success, and contribute to broader social inclusion.

Table 1: Eligibility criteria for study inclusion (PICO Framework)

Component	**Definition**	**In This Study**
Population	Target group or problem area	Immigrant communities facing financial exclusion
Intervention	Approach being evaluated	AI-driven microfinance (ML, NLP, predictive analytics)
Comparison	Alternative or traditional method	Traditional microfinance relies on manual processing
Outcomes	Expected impact or benefit	Expanded financial access, entrepreneurship, and inclusion

To identify relevant studies, a comprehensive search was conducted across two major academic databases Scopus and Web of Science. These platforms were selected for their coverage of peer-reviewed literature across social sciences, technology, and development studies. Boolean logic and keyword combinations were used to narrow the search results and ensure precision.

Search queries included terms such as (“Artificial Intelligence” OR “Machine Learning” OR “AI-driven finance”) AND (“Microfinance” OR “Financial Inclusion”) AND (“Immigrants” OR “Migrant Communities”), as well as targeted combinations like (“Alternative Credit Scoring”) AND (“Social Inclusion” OR “Entrepreneurial Empowerment” OR “Value Creation”) and (“AI Ethics” OR “Algorithmic Bias”) AND (“Financial Services”).

Inclusion criteria were applied to ensure the relevance and quality of selected literature. Eligible studies had to be published between 2010 and 2024, written in English, and focus on AI applications in financial services, particularly in the context of microfinance or immigrant communities. Peer-reviewed journal articles, book chapters, and conference proceedings were prioritized. Studies were excluded if they were non-academic (e.g., blogs, reports), unrelated to the research focus, duplicates, or lacking theoretical and empirical depth.

The selection process proceeded in four key stages, consistent with PRISMA protocols. First, the initial database search produced 920 results. Second, titles and abstracts were screened for relevance, and duplicates were removed, narrowing the pool to 350 studies. In the third stage, a full-text review was conducted, eliminating articles that did not meet inclusion criteria or lacked sufficient focus on AI and immigrant financial access, resulting in 120 studies. Finally, after further quality assessment and relevance checks, 52 articles were selected for the final review. These studies were chosen for their strong conceptual grounding, methodological rigor, and direct engagement with issues related to AI-driven financial inclusion for immigrant populations.

After selecting the final set of studies, the bibliometric software *Vosviewer* was employed to enhance analysis and thematic clarity. Vosviewer facilitated the visualization of key literature clusters, highlighting prominent thematic interconnections, influential authors, and emerging trends within the research domain. Specifically, Vosviewer’s co-occurrence and bibliographic coupling analyses allowed for a robust identification of dominant themes and research gaps, enriching the manual thematic categorization and offering deeper insights into the scholarly landscape surrounding AI-driven microfinance and immigrant inclusion.

The selected studies were categorized into three thematic clusters based on the research objectives. The first theme, AI and financial inclusion, explored how intelligent systems enable access to credit and digital financial services for marginalized immigrant groups (Ozili, 2020; Biswas & Gupta, 2022). The second theme, AI and economic value creation, focused on how AI contributes to entrepreneurial development, cost efficiency, and scalable microfinance models (Moro Visconti, 2020; Lwesya & Mwakalobo, 2023). The third theme, Intellectual Capital and AI adoption, examined the critical role of human, structural, and relational capital in enabling inclusive, ethical, and effective AI integration in financial services (Bontis & Serenko, 2022; Kianto et al., 2017).

Triangulation and cross-referencing were applied to ensure the reliability and depth of findings. While the use of secondary data limits the ability to generalize across all contexts, the methodological design ensures a

comprehensive and up-to-date analysis. Moreover, the study acknowledges the rapidly evolving nature of AI technologies, calling for continued monitoring and further research as digital financial ecosystems expand.

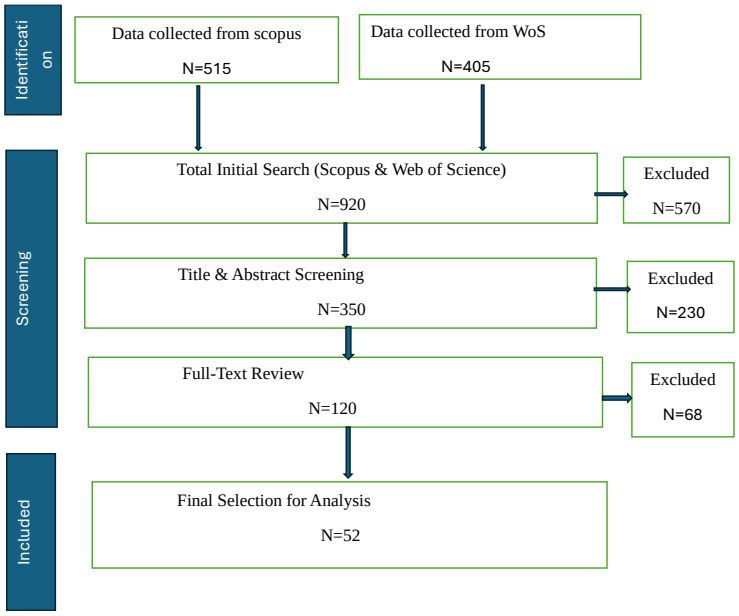


Figure 1: Study selection flow diagram.

4 Results

The findings from the systematic review highlight the significant potential of Artificial Intelligence (AI)-driven microfinance to foster social inclusion and economic empowerment among immigrant communities. Three central themes emerged clearly from the analysis of the 52 studies: (1) enhanced financial inclusion through AI technologies; (2) value creation via economic empowerment and institutional efficiency; and (3) the enabling role of Intellectual Capital (IC) in adopting inclusive AI systems.

Firstly, AI-driven microfinance significantly enhances financial and social inclusion for immigrant communities by addressing systemic barriers commonly experienced by these populations, including limited formal financial histories, linguistic barriers, and institutional biases. Several studies demonstrated that traditional microfinance institutions (MFIs), while instrumental in extending financial services, often fail to adequately reach immigrants due to reliance on conventional credit indicators (Chibba, 2009; Biswas & Gupta, 2022). In contrast, AI technologies, particularly machine learning and predictive analytics, use alternative data sources such as remittances, mobile transaction histories, and social behaviors, thus broadening eligibility and enabling immigrants to access formal credit and savings services (Gama & Magistretti, 2025; Ozili, 2020). This shift from conventional credit metrics directly supports social inclusion by reducing systemic discrimination in financial evaluations.

Moreover, the studies revealed the pivotal role of Natural Language Processing (NLP) in overcoming linguistic and cultural barriers to financial services, directly promoting inclusion. AI-powered multilingual chatbots and digital assistants provide real-time customer support, personalized financial literacy education, and culturally adapted financial products, significantly improving immigrants' understanding of complex financial services and fostering deeper engagement (Russell & Norvig, 2024; Suleiman & Kwok, 2025). Thus, AI technologies reduce informational and communicative barriers, empowering immigrant communities to actively participate in formal financial ecosystems.

Secondly, the analysis highlights how AI-driven microfinance promotes economic value creation, particularly by enhancing entrepreneurial capacities among immigrants. AI-based credit scoring and automated loan processing increase access to capital, enabling immigrants to launch and sustain businesses that contribute positively to local economies (Sachs, 2015; Moro Visconti, 2020). Additionally, studies found that AI systems help microfinance institutions optimize operational costs and reduce loan defaults through precise risk assessment, ultimately allowing MFIs to offer more affordable and accessible financial products (Li & Duan, 2025; Haefner & Morf, 2021). This combination of institutional efficiency and tailored services directly contributes to the economic stability and growth potential of immigrant entrepreneurs, further reinforcing their integration and social inclusion.

The third major theme identified from the literature was the critical enabling role of Intellectual Capital in ensuring the ethical, inclusive, and sustainable adoption of AI within microfinance institutions. The reviewed studies emphasize that successful AI integration depends significantly on human capital specifically the training of staff in ethical AI practices, bias mitigation, and inclusive service delivery strategies (Bontis & Serenko, 2022; Kianto et al., 2017). Equally crucial is structural capital, including robust technological infrastructure, data security, and transparent AI governance. The studies further highlight relational capital trust and strong community relationships as fundamental for AI systems to gain acceptance among immigrant populations, who may have historical reasons to distrust formal financial institutions (Haefner & Morf, 2021; Gama & Magistretti, 2025). Institutions leveraging these three dimensions of IC are best positioned to build AI systems that genuinely enhance social inclusion.

However, while recognizing these promising benefits, the reviewed literature also underscores significant challenges to fully realizing the inclusive potential of AI. Concerns related to algorithmic bias, data privacy, and digital literacy gaps were frequently noted. Specifically, AI systems trained on biased datasets risk perpetuating exclusion, disproportionately impacting immigrant groups (Binns, 2020; Mittelstadt et al., 2016). The findings suggest that addressing these ethical challenges requires proactive regulatory frameworks, transparent governance models, and targeted capacity-building initiatives to ensure that AI-driven microfinance remains truly inclusive and equitable.

Overall, these findings strongly suggest that AI-driven microfinance holds substantial promise for advancing the social inclusion and economic empowerment of immigrant communities. By explicitly addressing traditional barriers such as exclusionary credit practices, language obstacles, and institutional inefficiencies, AI technologies provide pathways toward genuine integration. At the same time, attention to Intellectual Capital highlights the importance of institutional readiness, ethical practices, and community trust-building as essential to unlocking AI's full potential for inclusive growth. These results provide valuable insights for policymakers, financial institutions, and technology providers committed to leveraging AI to meet the objectives of SDGs 8, 9, and especially SDG 10 (Reduced Inequalities).

Table 2: Thematic Clusters of Literature

Theme	Sample Authors	Key Contributions
AI & Financial Inclusion	Ozili (2020), Biswas & Gupta (2022)	Broadens credit access, uses alternative data, and enhances accessibility through NLP.
AI & Economic Value Creation	Moro Visconti (2020), Lwesya & Mwakalobo (2023)	Support entrepreneurship, reduce MFI costs, and enable scalable services.
IC in AI-driven Microfinance	Bontis & Serenko (2022), Kianto et al. (2017)	Human, structural, and relational capital enable ethical and effective AI adoption.

5 Discussion

This study aimed to examine the transformative role of Artificial Intelligence-driven microfinance in promoting social inclusion and economic empowerment for immigrant communities. The systematic literature review confirmed that AI significantly enhances financial inclusion by addressing traditional barriers, such as restrictive credit evaluations, linguistic and cultural barriers, and systemic institutional biases. By integrating alternative credit-scoring mechanisms based on remittances, digital transaction histories, and social financial behaviors, AI-driven systems offer a more inclusive evaluation of immigrants' creditworthiness (Ozili, 2020; Gama & Magistretti, 2025).

Furthermore, Natural Language Processing applications mitigate language-related obstacles, providing multilingual support and culturally adapted financial literacy programs, directly enhancing immigrants' integration into financial ecosystems (Russell & Norvig, 2024; Suleiman & Kwok, 2025). Thus, AI emerges as a powerful facilitator of social inclusion, enabling previously excluded populations to participate meaningfully in economic activities and financial systems.

Beyond fostering inclusion, the findings indicate that AI-driven microfinance contributes significantly to economic value creation. It supports immigrant entrepreneurship by providing timely access to working capital, reducing operational costs for microfinance institutions, and improving risk management through automated and precise risk assessments (Moro Visconti, 2020; Haefner & Morf, 2021). The resultant efficiencies allow MFIs to offer more accessible and affordable financial products, further supporting economic stability and growth within immigrant communities. These outcomes align closely with the broader sustainability objectives of the United Nations' Sustainable Development Goals, particularly SDG 8 (Decent Work and Economic Growth), SDG

9 (Industry, Innovation, and Infrastructure), and SDG 10 (Reduced Inequalities), reinforcing the strategic importance of AI applications in inclusive financial services.

The critical role of Intellectual Capital, encompassing human, structural, and relational dimensions also emerged prominently in the literature. Successful implementation of AI technologies in microfinance institutions hinges upon adequately trained human capital, including staff skilled in ethical AI practices and bias mitigation (Kianto et al., 2017; Bontis & Serenko, 2022). Structural capital, particularly robust digital infrastructures and transparent governance mechanisms, ensures scalability and secure service provision. Equally important is relational capital, defined by community trust, culturally sensitive communication, and institutional transparency, fostering enduring relationships with immigrant populations (Haefner & Morf, 2021; Gama & Magistretti, 2025). Investing in these intellectual capital dimensions can thus help MFIs realize the inclusive potential of AI-driven financial services.

However, despite these positive outcomes, the reviewed literature also identifies critical challenges related to algorithmic bias, data privacy, and digital literacy gaps, which could inadvertently reinforce exclusionary practices if left unaddressed (Binns, 2020; Mittelstadt et al., 2016). Addressing these ethical and practical challenges demands proactive regulatory frameworks, rigorous transparency standards, and targeted initiatives to enhance digital and financial literacy among immigrant communities. Institutional readiness and inclusive AI governance are essential for ensuring that AI-driven microfinance genuinely promotes equity and inclusion rather than deepening existing disparities.

6 Conclusion

In terms of practical and policy implications, this research offers several key insights. Policymakers should foster regulatory environments supportive of ethical AI standards, particularly emphasizing fairness, transparency, and data privacy. Financial institutions are advised to invest in human and structural capital, building robust technological capabilities alongside ethical AI training for staff. Fintech developers should prioritize co-designing AI solutions directly with immigrant communities, ensuring cultural sensitivity and practical relevance. Multilingual and inclusive platforms will further strengthen immigrant trust and facilitate deeper, more sustained integration into formal financial systems.

While comprehensive, this research acknowledges limitations inherent in systematic reviews, notably the reliance on secondary sources and the rapidly evolving nature of AI technologies, suggesting a need for continued, updated empirical investigation. Future studies should extend this research through field-based empirical analyses in diverse geographical contexts, particularly in developing countries or areas with significant immigration. Longitudinal studies exploring the sustained impact of AI-driven financial inclusion on immigrants' socio-economic resilience and integration would offer valuable additional insights.

In conclusion, this study demonstrates the significant potential of AI-driven microfinance to advance social inclusion, mitigate systemic inequalities, and create meaningful economic value for immigrant populations. By highlighting the critical role of Intellectual Capital and ethical considerations, the paper provides actionable guidance for policymakers, financial institutions, and fintech companies aiming to leverage AI technologies for inclusive and sustainable development. This research thus contributes not only to academic discourse but also to practical strategies for achieving global inclusivity aligned with the objectives of the Sustainable Development Goals.

7 Ethics Declaration

I, the author of this paper, affirm that the research was conducted with full adherence to academic and ethical standards. This study is based solely on the systematic review of existing academic literature from publicly accessible and peer-reviewed sources. No primary data involving human participants, personal data, or confidential materials was collected or analyzed. All scholarly contributions have been appropriately cited to ensure transparency, accuracy, and respect for intellectual property. I take full responsibility for upholding the principles of academic integrity and responsible research conduct.

8 AI Declaration

I confirm that no generative Artificial Intelligence tools were used in the authorship, drafting, or revision of this manuscript. While the subject matter of the paper includes the application of AI in financial services, the content presented here is entirely the result of the author's original analysis and synthesis of peer-reviewed academic literature. No AI-generated text, figures, or references were used in preparing this submission.

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AI-driven Transformation in the Pharmaceutical Industry: Value Creation through Strategic Collaboration

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Abstract

The pharmaceutical industry faces significant challenges, including prolonged drug development cycles (10-15 years), escalating costs (exceeding $1 billion per drug), and mounting pressures to align innovation with sustainability and transparency. This study investigates the transformative role of artificial intelligence (AI) in addressing these challenges, with a focus on value co-creation and environmental, social, and governance (ESG) integration (Prahalad and Ramaswamy, 2000, 2004; Vargo and Lusch, 2004). By analyzing sustainability reports and strategic documents from Johnson & Johnson (J&J) and NVIDIA through qualitative content analysis, this research identifies four thematic topics: AI in Sustainability Report, Value Co-Creation, AI and ESG and Transparency and Reporting. The study aims to find answers starting from how AI is represented in J&J and NVIDIA's reports, which initiatives are linked to the co-creation of value in drug discovery, development and distribution, to what extent are references to AI in line with ESG criteria, and finally what elements emerge regarding transparency and communication of AI practices.

Findings reveal that AI accelerates drug discovery through machine learning (ML) and deep learning (DL), enabling rapid analysis of genomic, proteomic, and clinical trial data. Applications such as virtual screening and predictive modelling reduce trial failures and optimize resource allocation, aligning with ESG goals like waste reduction and energy efficiency. The strategic collaboration between J&J and NVIDIA exemplifies value co-creation, merging pharmaceutical expertise with advanced computing to enhance R&D efficiency and patient-centric outcomes. For instance, NVIDIA's high-performance computing (HPC) infrastructure supports J&J's drug pipeline, reducing time-to-market while fostering sustainable practices.

The analysis highlights AI's dual role as a driver of operational innovation and a catalyst for stakeholder-driven sustainability. Transparency in AI reporting emerges as a critical factor, with both companies emphasizing ethical AI deployment and open communication. However, disparities exist in how AI's societal and environmental impacts are framed, underscoring the need for standardized ESG-aligned reporting frameworks. By bridging value co-creation theory (Prahalad & Ramaswamy, 2004) with empirical insights, this study demonstrates how cross-sector partnerships and AI integration can reconcile economic objectives with global sustainability imperatives. The research contributes practical insights for policymakers and industry leaders, advocating for collaborative, transparent AI adoption to advance both innovation and accountability in the pharmaceutical sector.

Keywords: Artificial Intelligence; Pharma Industry; Value Co-creation; ESG; Strategic Collaboration

Paper type: Academic Research Paper

1 Introduction

The pharmaceutical industry operates within a complex landscape marked by stringent regulatory frameworks, escalating R&D costs, and extended timelines for drug commercialization. Developing a single drug can require 10-15 years and investments exceeding $1 billion (Mohs & Greig, 2017), while stakeholders increasingly demand transparency, sustainability, and accountability. These pressures are amplified by global challenges such as climate change, health inequities, and the need for personalized medicine. In this context, environmental, social, and governance (ESG) criteria have become pivotal in shaping corporate strategies, compelling companies to align innovation with ethical and sustainable practices (Arvidsson & Dumay, 2022; Chen, 2024).

Artificial Intelligence (AI) has emerged as a transformative force in addressing these dual imperatives. Advances in machine learning (ML), deep learning (DL), and accelerated computing are revolutionizing the industry (Malsia, 2024; Kulkov, 2021), drug discovery, clinical trial design, and patient care. By analyzing vast datasets of biomedical studies, AI enables rapid identification of therapeutic targets, reduces trial failures, and personalised treatments (Secinaro et al., 2021). AI-driven tools like virtual screening and quantitative structure-activity relationship (QSAR) modelling optimize molecular design, while predictive analytics enhance diagnostic accuracy. Beyond operational efficiency, AI supports sustainability by minimizing resource waste and energy consumption in manufacturing.

However, AI's integration represents a paradigm shift in value creation. Grounded in value co-creation theory (Prahalad & Ramaswamy, 2004), this study examines how stakeholders - including corporations, technology

providers, and patients - collaborate to generate multidimensional value through digital and analogical communication in the context of unique management strategies (Centorrino et al., 2023). Value co-creation encompasses improved patient outcomes, reduces environmental footprints, and aligns with ESG objectives. AI supports open innovation models, where cross-sector partnerships, such as J&J-NVIDIA collaboration, merge pharmaceutical expertise with cutting-edge computing capabilities to accelerate drug discovery and delivery (Niewolny, 2024; J&J, 2024). NVIDIA's ecosystem enhances J&J's R&D through AI high-performance computing (HPC), demonstrating how alliances drive innovation and sustainability. These case studies offer implications for integrating AI-driven processes in the pharmaceutical sector within sustainable business frameworks, together with a source of value creation and competitive advantage. This can lead to innovation and strategy, and consequent optimization of the decision-making process (Cariola et al., 2007).

Despite AI's growing adoption, critical gaps persist in understanding its role in sustainability reporting and its alignment with ESG frameworks. Existing literature often focuses on AI's technical applications, overlooking its role in stakeholder-driven value creation and transparent reporting. This study addresses these gaps through four research questions:

- *RQ1: How is AI represented in the sustainability reports of J&J and NVIDIA?*
- *RQ2: Which AI initiatives are linked to value co-creation in drug discovery, development, and distribution?*
- *RQ3: To what extent do AI references in reports align with ESG criteria?*
- *RQ4: What elements emerge from the analyzed documentation regarding transparency, communication, and AI reporting?*

Adopting a qualitative framework, this research employs content analysis (Hsieh & Shannon, 2005) to examine sustainability reports and strategic documents from J&J and NVIDIA, uncovering AI as a driver of innovation and sustainability.

By bridging value co-creation theory with empirical analysis, this study advances understanding of AI's role in fostering sustainable, patient-centric healthcare. It highlights the importance of transparent AI reporting and cross-sector collaboration, providing actionable insights for industry leaders and policymakers.

The paper is structured as follows: after this introduction, the methodology will be explained in detail based on the content analysis framework, followed by findings organized around the four topics. The discussion contextualizes results within theoretical and practical implications, concluding with limitations and future research directions.

2 Methodology

This study adopts a qualitative content analysis approach (White & Marsh, 2006**;** Plakoyiannaki & Budhwar, 2021) to examine how J&J and NVIDIA integrate AI into their sustainability strategies and collaborative practices. Content analysis is a well-established methodology in business and sustainability research, particularly suited for systematically interpreting textual data from corporate disclosures (Krippendorff, 2018). By analyzing every document in a more in-depth approach, it is possible to provide information based on specific themes across different contexts (Conley & Tosti-Kharas, 2014). By examining sustainability reports, annual filings, and partnership documents, this method gives the possibility to identify recurring themes, emerging patterns, and implicit priorities in how these companies frame AI's role in value co-creation and ESG alignment.

Unlike quantitative methods that prioritize numerical data, qualitative content analysis offers a nuanced understanding of complex phenomena such as AI's societal impact or stakeholder collaboration by capturing contextual meanings and discursive strategies (Drisko & Maschi, 2016). This is especially relevant for our study, given the absence of standardized reporting frameworks for AI in the pharmaceutical sector. Corporate disclosures often vary in depth, terminology, and emphasis, making content analysis an ideal tool to navigate this heterogeneity (Wahyuningrum et al., 2023; Torelli et al., 2020).

2.1 Data collection and analytical framework

Data collection was obtained through a systematic analysis of NVIDIA and J&J's sustainability reports from 2019 to 2023. This timeframe was selected considering the presence of reliable public records of the two companies up to the most recent year (2023), to facilitate a balanced comparative background for the analysis. NVIDIA's 2024 report was publicly available, but it was intentionally excluded from the analysis to maintain temporal alignment with J&J, whose 2024 sustainability report had not yet been published at the time of the study. In both entities, the reports represent the main voluntary reporting tool for ESG performance and adhere to the leading global standards, which include the GRI (Global Reporting Initiative), the SASB (Sustainability

Accounting Standards Board), in some instances, the TCFD (Task Force on Climate-related Financial Disclosures), and the United Nations Sustainable Development Goals (UNSDG). The selected documents were downloaded from the official websites of the companies and examined manually using a content analysis method, which aimed to identify, classify, and code references to AI and its use in corporate strategy, sustainable practice, value co-creation initiatives, and reporting mechanisms. The coding was based on a conceptual matrix divided into four pre-established thematic macro-domains:

1. **AI in Sustainability Report**: captures citations in corporate sustainability reports, by paying close attention to the portrayal of AI at a strategic and operational level. Includes the application of AI as a digital innovation source, process automation, operational refinement, intelligent data management to enhance efficiency, cost reduction, and accelerate decisions for improving operational performance; finally, it includes tools for R&D, communication, or design.
2. **Value Co-creation**: Collaborative AI-driven strategies across drug development phases. It applies to how AI is used through collaborative logics in a manner that generates value co-shared by the subjects of the firm. Covers concepts on open innovation, strategic collaborations, and partnerships between private and public companies, institutions, and organizations in the healthcare industry.
3. **AI and ESG**: This topic tracks how AI is integrated with environmental, social, and governance objectives. All references related to inclusiveness, emission reduction, data governance, and resource management, as well as AI, will be included in this topic.
4. **Transparency and Reporting**: Focuses on how companies communicate AI initiatives and ethical considerations, as well as reporting of AI activities by companies, in terms of transparency, accountability, and performance reporting, together with strategic impact assessment where AI is mentioned. Strategic importance, risks involved, and expected effects will be considered in this topic.

Subsequently, the main topics were further divided into analytical subcategories briefly summarized in Table 1.

Table 1: Topic breakdown and search words.

Topic	Subcategory	Keywords
AI in Sustainability Report	Digital Transformation	AI-driven platform, generative AI, AI innovation, machine learning, deep learning
	Generative AI	
	Productivity	
Value Co-creation	Open Innovation	Collaborative R&D, AI-enabled diagnostics, cross-industry platforms, startup ecosystem, public-private partnerships
	Strategic Partnership	
	Collaboration	
AI and ESG	Emissions Reduction	ESG, Sustainable, digital health equity, ESG strategy, SDG, sustainable computing
	Inclusivity and AI	
	Data governance	
	Resource management and AI	
Transparency and reporting	Impact metrics	GRI, SASB, CDP score, transparency, stakeholder engagement, Code of Conduct, AI disclosure
	Strategic disclosure	
	ESG reporting	

Source: Our reworking

Each instance was mapped into one or more categories by an interpretive reading of the context for correspondence between the RQs and the theoretical objectives of the study. Finally, the evolution of the contents over time was followed through the longitudinal comparison of the reports, also structurally, sections dedicated to AI, and the purposes declared by the companies.

The analysis followed a three-step process:

1. Exploratory coding: Initial review of documents to identify explicit and implicit references to AI, sustainability, reporting, ESG, co-value creation, and collaboration;
2. Identifying topics: grouping of coded extracts into four predefined categories (Transparency and Reporting; AI and ESG; AI in sustainability report; Value co-creation);
3. Contextual interpretation: linking themes to theoretical frameworks (e.g., value co-creation theory) and industry-specific challenges. To improve rigor, we refined the categories and triangulated the results to compare the different reports**.**

Content analysis reveals both what companies are saying about AI and how they are saying it (Gioia et al., 2013). The sources retrieved from the respective companies' official channels were selected to analyze the evolution of relevant information over time. In this case, J&J and NVIDIA represent commonalities related to the object of analysis from the technological, pharmaceutical, and strategic collaboration point of view, coming from

both parties. The reports cover a five-year period, as previously indicated, and through the content analysis approach, it is possible to verify the actual temporal evolution and project development in the research area. The downloaded sustainability reports show an overall stable structure, with some variations over time in the amount of relevant content, which will be explained in the next section. Overall, the presence of content related to ESG and AI, implicit and explicit, is highlighted in several parts of the documentation in the most recent years of the timeline. The unit of analysis was defined following a comparison with the research group. The criteria for textual citations referring to AI and consequent related themes (i.e., digitalization, innovation, ethics, sustainability) were identified, along with their direct implications of the use of AI (i.e., data-driven approach).

Data coding was conducted manually, based on the extraction of references reported within the respective documents and subsequently reported on a conceptual grid, identifying the corresponding topic for each citation. It was therefore necessary to decode strategic expressions based on the context.

This methodology contributes to the academic debate on an innovative and rapidly growing topic, which we expect in the coming years will be of fundamental importance for the discovery of new drugs and new development practices, providing a replicable framework for future research on transparency and ESG alignment in emerging technologies.

In the next section, the research findings will be presented, with the aim of shedding light on the aspects related to each research question.

3 Findings

The qualitative analysis carried out by reading and extrapolating data from J&J and NVIDIA reports explored discursive methods, the narrative, and the differences in the structure with which the evolution of AI themes and the respective research topics evolved. The analysis of the impact of AI on J&J sustainability reports presents a fragmented evolution that has consolidated only over the years, starting to give greater relevance from 2020. AI in this sector is integrated into corporate practices as an enabling tool for public health, healthcare digitalization, and value co-creation in the clinical and pharmaceutical fields. Projects that involve the implementation of AI are those related to collaborations – i.e., Our Future Health, European consortia, and partnerships with regulatory bodies – mainly focused on early diagnosis, fairness of clinical trials, and the administration of healthcare data. In the ESG field, J&J integrates AI to Health for Humanity goals, showing emphasis on inclusion, transparency, and the reduction of inequalities. The language used is evaluative, with many references to ethical duty, equity, and social sustainability.

In NVIDIA's reports, AI becomes central. Since 2020, NVIDIA report that AI represents "*the most profound shift in our era, […] NVIDIA accelerates this revolution by creating advanced computing tools that serve as open platforms for developers, researchers…"*. It is therefore possible to deduce that there is great interest in supporting this technology, highlighting how it is possible to create value in strategic collaboration with companies and stakeholders. From 2021, generative AI, "trustworthy AI", and the transformational potential of platforms (i.e., NVIDIA Clara) gain prominence. Sustainability and performance intersect in application ranging from traditional to GPU-based accelerated computing. Despite the presence of ESG references, more technical than regulatory passages are noted; the concept of transparency is highlighted on the basis of information relating to international standards, but is not fully explored in the case of reporting on social impacts. The tone used in the evolution of reports is assertive, with a vision that reflects the company's technological leadership.

Below are the results collected and organized in the four interpretative topics, aligning them with the research questions previously mentioned and the aim of being able to highlight the evolutionary change over time, by both companies.

To answer RQ1 - i.e., how is AI represented in the sustainability reports of J&J and NVIDIA - it is necessary to refer to the evolving state of the reports. The analysis reveals two distinct visions. J&J initially mentioned AI sporadically in 2019, with references increasing notably from 2020 onward **(Figure 1)**. By 2022, AI became central to its Health for Humanity initiatives, portrayed as a tool for equitable healthcare access and ethical innovation, with terms like "patient-centric AI" and "data-driven clinical equity" in social sustainability field. In contrast, NVIDIA has mentioned AI more frequently since 2020, declaring it "the most profound change of our era" (NVIDIA, 2020). The company emphasizes its scalable infrastructure, with recurring terms such as "accelerated computing" and "open platforms". By 2023, 75% of NVIDIA's sustainability content refers to AI-based solutions, underscoring its role as a technology enabler rather than an end-user.

Specifically, the AI mentioned by J&J is mainly reported to health, innovation, operational efficiency, and clinical care contexts. The language used aims at ethical guarantees and community impact with regard to human health. The description made by NVIDIA about AI technology is more defined and detailed in its business model and business plan. In fact, the application of AI is reported in various fields, from healthcare to the energy

performance of data centers. As regards the evolution of the topic, the presence of AI emerges incrementally, on average following a growing trend in the case of J&J, and is stable for NVIDIA.

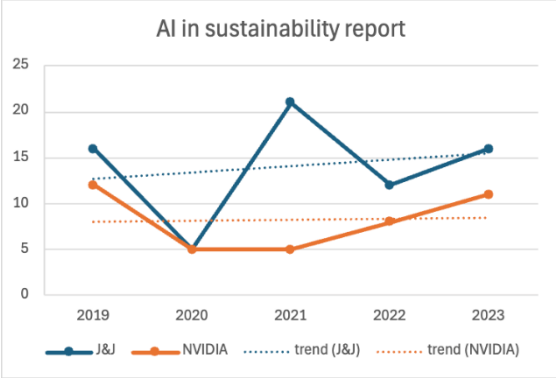


Figure 1: Topic 1 - AI and sustainability report

In more detail, at J&J, AI is often embedded in broader initiatives like data science, digital health, and transformation, becoming more visible from 2020 with integration into ESG strategies and healthcare innovation projects. The 2021 Health for Humanity report emphasizes AI and automation as key to transforming healthcare and strengthening internal digital skills. J&J uses a narrative centered on human well-being, focusing on AI for diagnostics and public health.

NVIDIA, by contrast, highlights AI's role in energy efficiency, sustainable computing, and overall business performance. While J&J views AI as an enabler of ethical and inclusive innovation in medicine, NVIDIA presents it as a core asset for strategic positioning and environmental impact. Both companies reference AI from 2019, with J&J offering more detailed insights from 2022–2023, and NVIDIA expanding its focus to generative AI starting in 2021.To answer RQ2 - i.e., which AI initiatives are linked to value co-creation in drug discovery, development, and distribution – the corresponding topic will give the possibility to know the collaborative paradigm of AI in the concept of value. Value co-creation allows to carry out partnerships between public and private networks, regulatory bodies, and research centers. As can be seen from the reports, the cases align pertinently to the designated topic.

As exemplified in **Figure 2**, a growing focus on value co-creation is confirmed, especially in 2023. J&J shows high frequency and narrative coherence, going from 13 citations in 2019 to 19 in 2023, while NVIDIA experiences a growth in 2023, from 3 citations in 2019 to 22 in 2023. According to this perspective, it can be noted that J&J possesses a consolidated and systematic approach, biased in the direction of concrete and long-term healthcare programs, whereas NVIDIA has intensified the communication related to the co-creation, together with project work in the pharma environment in recent times, reflecting a shift in gears over the last couple of years.

From a first consideration for J&J in a co-creation context, the Janssen pharmaceutical business part of the division uses AI to investigate medical datasets (i.e., medical records, generic data) in order to be able to verify the differences and genetic variations, thus implementing a predictive analysis on diseases. In this way, the process will be characterized by the presence of molecules that interact with specific targets, reducing side effects and optimizing potential drugs. A symbolic initiative is BLUE KNIGHT™, a collaboration with the Biomedical Advanced Research and Development Authority (BARDA) to accelerate innovation in breakthrough technologies to forecast emerging health threats (J&J, 2023). The initiative reflects the company's commitment to building private and public co-development ecosystems. J&J has also developed algorithms for tumor burden measurements, with collaboration from external actors, "*to better quantify tumor burden across several types of cancer and measure the effects of treatment more accurately and rapidly"* (J&J, 2023).

Another example of value co-creation implemented by the same company is to identify clinical research sites with suitable patients using AI, to facilitate the inclusion of diverse populations in trials. Treatments developed with this approach aim to improve accessibility and representativeness of the general population. Furthermore, in the field of the pharmaceutical supply chain, AI is used by the company to predict potential questions and to optimize the distribution of pharmaceutical products.

NVIDIA views co-creation from the infrastructure and facilitation perspective, constructing computing environments upon which participants in the pharmaceutical and healthcare sectors can collaborate to accelerate the R&D cycle. The Clara Discovery platform, "*…to bring AI to medical imaging systems and make it easier for all hospitals to adopt them"*, is designed to reduce the time and cost of the R&D cycle. The co-creation

rationale also arises, especially in partnership with Medtronic, the behemoth multinational business dealing in medical devices, for whom NVIDIA is building an AI platform for software-defined devices.

A public declaration of such an approach is found in the MONAI platform, which has been adopted by a consortium of ten UK hospitals, "*providing AI-enabled disease detection tools to healthcare professionals serving five million patients a year"* (NVIDIA, 2023). This is the model whereby NVIDIA facilitates the implementation of AI-based solutions even for public health entities, enabling higher-order diagnostics.

Finally, firms like Evozyne have leveraged NVIDIA's BioNeMo platform to design therapeutic proteins with generative models for *"novel proteins for diseases and even for climate change"*. NVIDIA's contribution in this regard comes in terms of providing scalable and interoperable tools, which make AI possible and integrable into biotech projects with significant transformative potential.

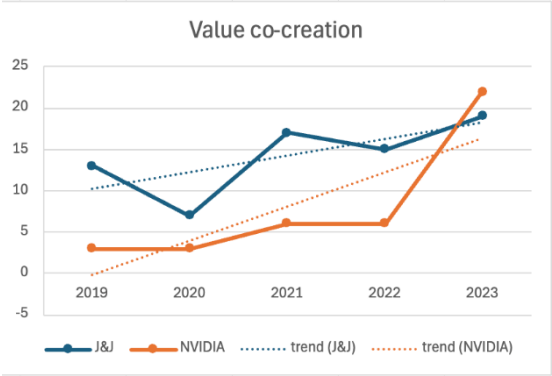


Figure 2: Topic 2 – Value co-creation

To answer RQ3 – i.e, to what extent do AI references in reports align with ESG criteria – the analysis reveals distinct priorities in how J&J and NVIDIA integrate AI into their sustainability narratives. Both companies link AI to ESG objectives, but emphasis diverges significantly, reflecting sector-specific agendas and reporting gaps.

As illustrated in **Figure 3**, J&J's ESG-linked AI citations grew steadily from 4 mentions in 2019 to 17 in 2023, while NVIDIA's peaked at 16 mentions in 2020 and 2022, with a dip in 2021. Over 70% of J&J's AI and ESG references focus on social equity. 65% of NVIDIA's AI and ESG citations highlight energy-efficient computing (e.g., 2022: "AI-optimized data centers reduce emissions by 25%") and sustainable infrastructure (e.g., "GPU acceleration lowers energy consumption in drug discovery").

J&J aligns AI with Social and Governance pillars, emphasizing "health equity", AI for equitable diagnostics, and "ethical oversight", human-centric AI governance frameworks. NVIDIA prioritizes Environmental and Governance criteria, focusing on sustainable computing, energy-efficient AI infrastructure, and technical compliance, alignment with GRI and SASB standards.

Despite social focus, only 20% of J&J's AI and ESG citations address environmental impacts (e.g., AI's role in reducing clinical trial waste). While leading in environmental metrics, NVIDIA's reports lack actionable metrics on AI's societal equity outcomes (e.g., workforce diversity in AI teams). Both companies use inconsistent ESG frameworks, making cross-sector comparisons challenging. For instance, J&J references the UNSDGs, while NVIDIA prioritizes the GRI.

In 2019 and 2020, references to AI and ESG were vague. J&J's 2020 report mentioned AI's "potential for social good" without metrics, while NVIDIA highlighted "efficiency gains" without ESG context. In the following years, from 2021 onwards, reporting matured. J&J quantified AI's impact on health equity (e.g., 30% faster diagnosis in rural clinics), and NVIDIA tied AI to emissions reductions (e.g., 2.5M tons of CO2 saved via AI-optimized workflows).

J&J and NVIDIA align AI with ESG criteria, their priorities reflect core business identities. In fact, J&J anchors AI in social dynamics, whereas NVIDIA leverages AI for environmental efficiency. In conclusion, gaps in holistic ESG integration, particularly NVIDIA's underreporting of social impacts and J&J's limited environmental focus, highlight the need for standardized frameworks to evaluate AI's role in sustainability.

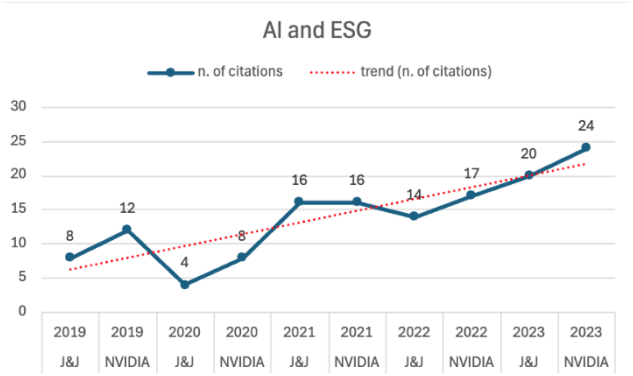


Figure 3: Topic 3 – AI and ESG

To answer RQ4 – i.e, what elements emerge from the analyzed documentation regarding transparency, communication, and AI reporting – the analysis of these topics reveals a nuanced interplay between sectoral priorities and ethical imperatives.

For J&J, transparency in AI reporting is deeply intertwined with its mission to advance equitable healthcare. The company's narrative emphasizes ethical accountability, presenting AI as a tool to bridge healthcare disparities. For instance, J&J's 2022 report states: "*Transparency in AI is not optional - it is a moral obligation to ensure equitable healthcare outcomes"* (J&J, 2022). However, J&J's transparency efforts lean heavily on qualitative narratives, with limited technical details on AI architectures or data governance frameworks. This gap aligned with its stakeholder-centric ethos, leaves questions unanswered about the scalability and environmental trade-offs of its AI infrastructure.

In contrast, NVIDIA prioritizes metrics-driven disclosures and compliance with global standards. Its reports include granular data, such as its 2023 claim of a "*0% reduction in power consumption per GPU topic"* through AI-optimized data centers. NVIDIA's emphasis on open-source platforms, like Clara, enables third-party scrutiny and aligns with its identity as a technology enabler. Yet, this technical focus often overshadows societal considerations. Despite NVIDIA's alignment with GRI/SASB standards, its reports sidestep discussions on AI's societal risks, such as workforce displacement or algorithmic bias. For example, NVIDIA's 2021 report asserts, "*Open-source AI frameworks and explainable models are foundational to trustworthy innovation"* yet lacks actionable metrics on equity outcomes or community impacts (NVIDIA, 2021).

Temporally, both companies evolved from vague early disclosures to more structured frameworks. As shown in **Figure 4**, in 2019-2020, J&J's references to "*ethical AI*" were lacking concrete examples, while NVIDIA highlighted technical advancements like GPU upgrades without ESG context. By 2022-2023, J&J introduced *AI impact assessments* to quantify health equity gains, such as "*30% faster diagnosis in rural clinics"*, and NVIDIA linked AI performance to emissions reductions, claiming "*2.5M tons of CO_2 saved via AI-optimized workflows".* Despite these advancements, benchmarks remain fragmented: J&J aligns with UNSDGs and NVIDIA reports under GRI/SASB frameworks.

Critical gaps persist. J&J's underreporting of environmental trade-offs, such as energy demands for AI-driven drug discovery, contrasts with NVIDIA's silence on workforce diversity in AI teams. Neither tackles privacy issues in genomic AI. These omissions underscore the need for harmonized standards that integrate technical rigor with societal accountability.

Ultimately, J&J and NVIDIA exemplify two paradigms of AI transparency – ethical storytelling vs. technical precision – highlighting the fragmented state of AI governance, urging policymakers to advocate for frameworks that reconcile these approaches. Only through holistic transparency AI can fulfill its promise as a force for sustainable, equitable innovation in healthcare and beyond.

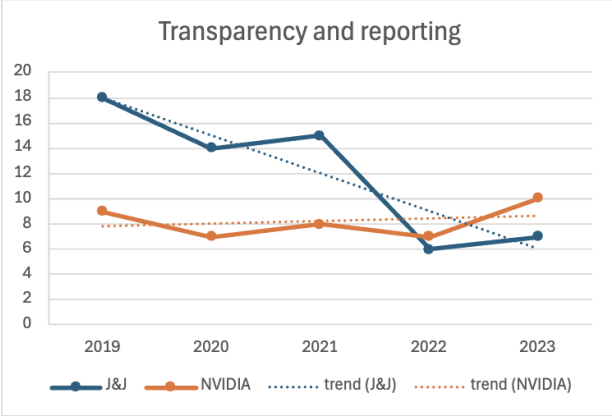


Figure 4: Topic 4 – Transparency and reporting

4 Discussion and conclusion

The findings of this study highlight the transformative role of AI in the pharmaceutical industry, particularly through the strategic collaboration between J&J and NVIDIA. Their partnership demonstrates AI's dual function: enhancing operational efficiency and advancing stakeholder-driven sustainability.

Rooted in value co-creation theory (Prahalad & Ramaswamy, 2004), the collaboration shows how cross-sector alliances create shared value. J&J leverages NVIDIA's AI tools—such as in digital surgery—to support training, collaboration, and diagnostics, advancing its goal of patient-centered care. NVIDIA's generative AI platform, BioNeMo, accelerates drug discovery by up to 40%, as shown in partnerships with firms like Genentech and Recursion Pharmaceuticals. These joint efforts reduce R&D time and resource use, contributing to ESG objectives such as emissions reduction and health equity.

J&J and NVIDIA offer complementary approaches: J&J emphasizes ethical, inclusive AI applications in clinical trials, while NVIDIA provides the high-performance infrastructure to scale them. Their 2024 collaboration on AI for surgical decision-making highlights this synergy, incorporating real-time analytics and edge computing into healthcare.

Despite shared goals, differences emerge in ESG reporting. J&J emphasizes social sustainability, equity, and ethical oversight, often referencing the UN SDGs. NVIDIA focuses on environmental performance, citing a 30% energy efficiency gain per GPU through AI-optimized data centers and adhering to GRI standards. These distinct ESG framings reflect broader challenges in standardizing AI sustainability reporting across sectors, as inconsistent frameworks complicate holistic assessments of impact (Arvidsson & Dumay, 2022Transparency practices further reveal divergent priorities. J&J adopts a narrative-driven approach, publishing *Responsible AI Guidelines* and prioritizing patient feedback, yet lacks technical details on data governance. NVIDIA, conversely, emphasizes technical transparency through open-source platforms and granular metrics (e.g., 30% energy reduction per GPU topic) but sidesteps societal risks like algorithmic bias. The rapid adoption of AI in healthcare, with 41% of biotech CEOs actively integrating generative AI, demands urgent policy action. These gaps underscore the need for harmonized standards that integrate ethical accountability with technical rigor, as advocated by recent policy initiatives (Moggi, 2023).

In conclusion, this study demonstrates that AI's integration into the pharmaceutical sector transcends technological adoption, it redefines value creation by merging innovation with sustainability imperatives. The strategic collaboration between J&J and NVIDIA reconciles pharmaceutical expertise with computational scalability, reducing drug development cycles while advancing ESG objectives. Sector-specific biases in AI and ESG alignment highlight the urgency for standardized frameworks to ensure holistic sustainability evaluations. Balancing ethical narratives with technical disclosures is critical to building stakeholder trust and ensuring AI's equitable deployment.

This study concedes its limitations. Future research could expand to include smaller firms or an analysis of AI's long-term ESG impacts. Additionally, the exclusion of NVIDIA's 2024 report (to maintain parity with J&J) suggests a need for updated studies as newer data emerges.

In conclusion, the promise of AI in the pharmaceutical industry lies in both speeding up innovation and promoting a sustainable and equitable healthcare ecosystem. By addressing reporting gaps and fostering collaborative governance, the industry can ensure AI serves as a force for global good, transforming drug discovery while upholding ethical and environmental stewardship.

5 Ethics declaration

The authors have no relevant financial or non-financial interests to disclose. The authors have no conflicts of interest to declare that are relevant to the content of this article. All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript. The authors have no financial or proprietary interests in any material discussed in this article.

6 AI declaration

The authors did not use any AI tools in the preparation of this paper.

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Remote Working and Public Administration: Implications for Relationships with External Users

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Abstract

The digital transformation has significantly reshaped organizational structures, particularly through the widespread adoption of remote working, which accelerated during the COVID-19 pandemic. While existing literature has explored internal impacts such as productivity and work-life balance, less attention has been paid to the effects on external relational dynamics, especially in the public sector. This paper investigates how remote working influences relational capital in public administration, focusing on the perceptions of external users such as citizens and institutional stakeholders. Relational capital (encompassing trust, reputation, and institutional networks) is critical for public entities delivering essential services. Using a qualitative approach based on semi-structured interviews within a medium-sized Italian municipality, the study explores users' experiences and perceptions of PA following the shift to smart working. Findings contribute to a growing body of research by addressing a literature gap concerning the implications of remote work on trust and relationship quality in the public sector.

Keywords: remote working, relational capital, digital transformation, intellectual capital

Paper type: Academic Research Paper

1 Introduction

In recent years, the ongoing digital transformation has significantly reshaped organizations' management approaches and business models across sectors (Lombardi and Secundo 2021). The rapid spread and continuous improvement of digital technologies have prompted a growing interest in understanding how to best leverage these tools to enhance organizational efficiency and effectiveness. These transformations have had a particularly profound impact on the management of human resources, requiring a wider and more diversified set of skills than ever before (Grigorescu et al. 2023; Jayabalan, Dorasamy, and Raman 2022). Among the most notable changes is the widespread adoption of remote working, which gained momentum during the COVID-19 pandemic and has since become a consolidated practice in many organizations (Battisti, Alfiero, and Leonidou 2022; Lord Ferguson, Smith, and Kietzmann 2022). The introduction of remote work has been analyzed by scholars from various perspectives, with a focus on its implications for productivity (Mele et al., 2021) and work-life balance (Toscano and Zappalà, 2021). Over time, remote working has become embedded in the operational and organizational structures of both private and public organizations.

In the public administration (PA) context, the shift has been especially significant, given the critical role that public entities play in delivering services to citizens and their traditionally slow pace in adopting technological innovations (Ahn and Chan, 2021). While remote working has introduced several advantages, it has also raised new challenges—most notably, those concerning the nature and quality of external relationships between public sector employees and a broad range of users, including citizens, businesses, and other institutions. These changes directly affect what is commonly referred to as relational capital, a key component of intellectual capital that enables organizations to build and sustain trust-based relationships with external stakeholders (Lombardi et al., 2021). Relational capital encompasses various dimensions, including institutional trust, organizational reputation, partnerships, and inter-organizational networks. Its role is especially critical in the public sector, where citizen trust and satisfaction are integral to service quality and institutional legitimacy.

In this context, the present study aims to investigate the relationship between remote working and relational capital in the public sector. Specifically, it focuses on the potential implications of remote working practices for external users of PA. Adopting a qualitative methodology, the research is based on semi-structured interviews conducted with a range of PA users. The objective is to explore how external relationships have evolved following the institutionalization of remote working, examining not only service efficiency but also perceived changes in image, reputation, and trust.

This contribution addresses a key gap in the current literature, as noted by Palumbo et al. (2024), who underline the scarcity of studies examining the impact of remote working on external organizational

relationships, particularly in public sector settings. While much of the existing research has focused on internal organizational outcomes—such as employee performance, collaboration, and team management—less attention has been devoted to how remote working affects the quality of public services, citizen trust, and overall user perception of the public administration. This study therefore aims to fill that void by providing new insights into the relational consequences of remote working in public sector organizations.

2 Literature review

2.1 Remote working and public sector

The concept of remote working has become a prominent theme in public sector management discourse, particularly in the wake of digital transformation and the disruptive impact of the COVID-19 pandemic. Remote working encompasses more than the physical dislocation of work; it embodies a broader reconfiguration of work processes and relationships, with digitalization, autonomy, and flexibility as its foundational pillars (Blackwell, 2008; Palumbo et al., 2021). In the public sector, remote working is increasingly seen not just as a reactionary measure but as a proactive strategy to improve responsiveness, efficiency, and the well-being of employees.

Remote working is defined as a flexible, digitally supported work arrangement that enhances employees' control over their tasks, aiming to balance organizational performance with individual autonomy and well-being (Raguseo, Gastaldi, & Neirotti, 2016). Unlike traditional teleworking, it is characterized by its integration into broader human resource and organizational strategies, combining technological enablers with cultural and managerial shifts (Dornelles, Ayala, & Frank, 2022). These features make remote working particularly relevant to the public sector, which has traditionally struggled with rigid structures and slow adaptability (Garavaglia, Sancino, & Trivellato, 2021).

The literature suggests that remote working can address long-standing challenges in public administration, such as bureaucratic inertia and low innovation capacity (Boselie, Van Harten, & Veld, 2021). However, its implementation is neither uniform nor unproblematic. Palumbo et al. (2024) emphasize the existence of five main clusters of research on the topic: institutional and policy frameworks, the nature of remotization, individual well-being, managerial strategies, and work-life balance. Each of these areas highlights specific dynamics and tensions within the process of smart work adoption.

From an institutional standpoint, the shift toward remote working is deeply influenced by national contexts and governance models. Liberalized policy environments, where public servants enjoy more autonomy and unions play an active role, tend to foster people-centred work arrangements (Mastracci & Thompson, 2007). However, even in such contexts, a focus on cost containment and austerity often undermines efforts to truly empower employees, resulting in a diluted version of remote working primarily aimed at budgetary efficiency (Baldwin, Gauld, & Goldfinch, 2012).

The literature also delves into the ambiguous outcomes of remote work, often described as both “smart” and “dumb” depending on how it is managed. While remote work can enhance flexibility, it may also lead to social disconnection, diminished trust, and reduced organizational identification if not supported by adequate management practices (de Vries, Tummers, & Bekkers, 2019). Scholars caution that the mere availability of remote work does not guarantee the realization of smart work benefits unless paired with tailored leadership approaches and meaningful employee engagement (Kim, Mullins, & Yoon, 2021).

Well-being is another focal point in the remote working debate. Flexible work arrangements have been linked to improvements in work-life balance and job satisfaction (Toscano & Zappalà, 2021). Yet, they may also lead to work intensification, stress, and blurred boundaries between personal and professional life, particularly when adopted under coercive conditions or without adequate support systems (Caillier, 2016; Ortiz-Lozano, Martínez-Morán, & Fernández-Muñoz, 2021).

To address these challenges, organizational culture and managerial style emerge as critical success factors. A culture that values trust, autonomy, and employee input is essential to the effective implementation of smart work (Hornung, Rousseau, & Glaser, 2009). Similarly, leaders must develop e-leadership skills to motivate and guide employees in hybrid or remote environments (Toleikienė, Rybnikova, & Juknevičienė, 2020). Without these cultural and managerial adjustments, remote working may remain superficial, resulting in increased alienation and decreased performance (Taskin & Edwards, 2007).

Another vital dimension is the role of remote working in supporting work-life balance, which has been one of the most cited motivations for its adoption in the public sector. However, if implemented with a focus solely on productivity, remote working may paradoxically undermine employee well-being and generate inequities in career progression (McDonald, Bradley, & Brown, 2008). Scholars therefore advocate for a shift toward socially

sustainable work models that integrate job sharing, fair task allocation, and inclusive performance evaluation systems.

2.2 Relational capital and remote working

Relational capital is a fundamental component of intellectual capital (Paoloni et al., 2021; Cosentino et al., 2024). It encompasses the set of external relationships that an organization develops and maintains with a wide range of stakeholders, customers, suppliers, partners, institutions, and, in the case of PA, with citizens and other public and private entities. Relational capital includes intangible yet strategic dimensions such as trust, reputation, image, loyalty, and institutional partnerships (Lombardi et al., 2021). These elements are crucial for the creation of value and the long-term sustainability of organizations, especially in service-oriented sectors where quality and trust are core to performance.

The accelerated digital transformation and the widespread adoption of remote working, particularly following the COVID-19 pandemic, have raised new questions about how relational capital is created, maintained, and transformed in a context of reduced physical interaction. While initial scholarly attention was mainly focused on internal organizational effects, such as employee productivity, well-being, and team cohesion (Toscano & Zappalà, 2021; Singh et al., 2022), the impact of remote work on external relationships remains largely underexplored, representing a notable gap in the literature (Palumbo et al., 2024).

The shift to remote working has radically altered traditional mechanisms of trust-building and relationship management, especially in public organizations. Historically, public services have relied heavily on in-person interactions to foster citizen trust, transparency, and satisfaction. In this regard, the relational dimension of PA goes beyond efficiency and effectiveness; it also concerns the ability of institutions to convey credibility, responsiveness, and fairness. The digitization of services and the remote management of interactions may weaken the symbolic and experiential dimensions that often underpin the relationship between citizens and institutions.

Several recent contributions have begun to investigate the implications of these changes. For instance, some authors (Pokrovskaia et al. 2021) emphasize the importance of being embedded in networks of trust, which were especially critical during the pandemic for ensuring continuity and maintaining stakeholder confidence. Similarly, a study highlights how digital technologies can foster social capital among micro-businesses by supporting online communities and virtual collaboration, thus extending the role of relational capital into the digital space (Reuschke et al. 2021). In more complex organizational settings, such as professional service firms or public institutions, the relationship between remote working and relational capital becomes even more nuanced. Rehman et al. (2023) link High-Performance Work Systems (HPWS) to the development of intellectual capital, arguing that communication tools—especially videoconferencing—play a vital role in managing relational dimensions during remote work. However, Toscani (2023) warns that remote work environments tend to reduce informal exchanges and social cues, with potential negative consequences for the exchange of tacit knowledge and the maintenance of interpersonal trust. This view is echoed by Child and Shumate (2007), who argue that common knowledge repositories and relationship-based knowledge systems are essential for effective team functioning, and that remote work may hinder the development of shared cognitive maps within teams. When transposed to the external dimension, this insight suggests that users' perceptions of public services may deteriorate in the absence of frequent or high-quality relational cues.

In the public sector, where user experience is deeply embedded in institutional credibility, these dynamics become particularly relevant. Ahn and Chan (2021) observe that public organizations often lag in adapting to technological changes and risk overlooking the relational and emotional components of service delivery in digital environments. The large-scale adoption of remote work may therefore require new frameworks for user engagement and trust management, particularly as face-to-face interactions are replaced by digital communication channels. Some authors have proposed strategies to mitigate these effects. Gong et al. (2023) suggest that relational capital within remote settings can be preserved by introducing structured but informal opportunities for interaction—such as virtual social events or randomized video meetings—to recreate the spontaneity of in-person encounters. The authors also stress the role of supervisory support and digital socialization processes in helping employees maintain strong relational ties with both colleagues and users. A complementary perspective is offered by Tomé et al. (2022), who emphasize the role of knowledge management and mutual trust in navigating crisis situations. The authors highlight that the alignment between technological systems, human resources, and process management is crucial for ensuring that relationships remain resilient in the face of uncertainty. Additionally, Steenkamp and Dhanesh (2023) propose an ethical-relational model for managing remote work based on empathy, purpose, and diversity climate. Although focused primarily on internal organizational dynamics, their framework can be extended to relationships with external users,

particularly when public institutions aim to demonstrate care, inclusivity, and ethical responsibility in digital service provision.

The literature also points to the double-edged nature of digital transformation in relational contexts. On one hand, digital tools can enhance accessibility and efficiency. On the other, they risk depersonalizing interactions, especially when not accompanied by thoughtful strategies for preserving the relational value of communication. Schinoff et al. (2020) explore how the cadence and rhythm of digital interactions affect the depth and authenticity of professional relationships, while Mazzucchelli (2017) emphasizes that remote working can both support and hinder work-life balance, depending on how relational systems are managed. Finally, the concept of sense of community, as discussed by Kabo (2022), emerges as a crucial mitigating factor. Even in the absence of physical co-presence, shared purpose, symbolic belonging, and regular digital touchpoints can sustain meaningful relational ties.

3 Method

This study adopts a qualitative research approach (Yin, 2009). The empirical investigation was conducted in a medium-sized municipality located in central Italy, which has approximately 50,000 inhabitants. This context was selected due to its representativeness in terms of administrative structure and the adoption of remote work practices following the COVID-19 pandemic. The municipality implemented smart working measures during the pandemic and continued to use them in the post-emergency phase, making it a suitable case for analyzing the impact of such organizational changes on external relationships. The data collection was carried out through semi-structured interviews, which are particularly suitable for capturing subjective interpretations and allowing respondents to express themselves freely while still focusing on specific themes. This method enables researchers to explore not only factual elements but also perceptions, expectations, and relational nuances that may otherwise remain hidden in more structured research designs.

Three individuals who maintain regular contact with the municipal administration were interviewed. These participants were purposely selected to represent different types of stakeholders: two with institutional roles and one private citizen. The inclusion diverse profiles was a deliberate choice, aimed at detecting potential variations in how remote working is perceived and experienced depending on the nature of the relationship with the public sector. The interviews were conducted in person. Each session lasted between 30 and 60 minutes. All interviews were recorded, transcribed verbatim, and anonymized to ensure the confidentiality of the participants. The interview guide included open-ended questions related to the quality of interaction with public employees, perceived efficiency of services, trust in the administration, and changes observed since the implementation of remote work.

The qualitative nature of the study does not aim to generalize findings but rather to provide an in-depth understanding of a specific context and offer interpretive insights that may inform broader reflections on the role of remote working in reshaping public sector relationships. The choice of a single-case study is consistent with this objective, allowing for a contextualized and nuanced analysis of the phenomenon under investigation.

4 Preliminary results

The analysis of the interviews conducted with three different stakeholders offers a multifaceted understanding of how remote working has impacted relational capital in PA. While the effects are generally perceived as limited or neutral in terms of service continuity and responsiveness, significant differences emerge in terms of expectations, access, and relational perceptions. Overall, institutional actors reported that the transition to remote work did not lead to a deterioration in the quality of interactions with the municipality. On the contrary, both highlighted the effectiveness of remote communication tools and organizational adjustments as factors that preserved, and in some cases even enhanced, the efficiency and continuity of administrative relations. One of institutional intervieweses emphasized that her regular dealings with municipal offices continued without major disruption. Digital tools, such as videoconferencing and email, were actively used to maintain contact, and meetings were scheduled regularly even during periods of complete remote work. According to her, the availability of municipal staff and the clarity of internal processes ensured that collaboration remained fluid, contributing to a stable institutional image and reinforcing mutual trust. Similarly, another institutional interviewee offered a positive assessment of the remote working arrangements implemented within the local government. From his perspective, the shift to remote meetings allowed for more agile and frequent interactions with both internal staff and external stakeholders. He noted that the previous logistical constraints tied to in-person meetings had often limited participation or delayed decisions. In contrast, the adoption of digital platforms enabled greater flexibility, broader involvement, and faster responses, particularly in multilateral projects or inter-organizational coordination. According to the second institutional

interviewee, this transformation not only preserved relational capital but redefined it in a more adaptable and responsive form, suited to the changing needs of public service delivery.

However, a contrasting view emerged from the citizen interviewee, who offered a user-centered perspective based on her personal experience with public services. Unlike the institutional actors, the citizen reported a noticeable decline in the quality of her interactions with municipal offices during the period of remote work. She recounted several episodes in which she physically visited the town hall to complete necessary paperwork, only to find no one available on site. The lack of clear information regarding remote work schedules and contact procedures generated frustration and uncertainty, leading her to perceive the municipality as disorganized and less accessible. His perception of the administration's image and reputation was negatively affected, as she associated the reduced presence of staff with inefficiency and disregard for citizens' needs. This experience reveals a significant disparity in how relational capital is perceived and experienced depending on the type of interaction and the user's role. While institutional actors benefit from structured communication channels and pre-established contacts, private citizens—especially those not digitally proficient—may encounter barriers that compromise the perceived accessibility and trustworthiness of the PA. The absence of face-to-face contact, in the absence of compensatory digital or procedural support, may be interpreted as a relational void rather than as an operational transformation. The citizen's dissatisfaction, however, points to an important limitation in the PA's digital transition strategy. While internal workflows may have been adapted effectively, the external communication of these changes, and their implications for access to services, was not always sufficient to meet users' expectations. This underscores the need for greater attention to relational equity, ensuring that all categories of users, regardless of their digital skills or familiarity with institutional procedures, can interact with the administration effectively and confidently.

The findings of the three interviews collectively suggest that relational capital within PA is not necessarily weakened by the adoption of remote work practices. On the contrary, when accompanied by structured procedures, appropriate digital tools, and a culture of responsiveness, remote working can support relational continuity and even foster greater organizational efficiency. However, the distribution of relational benefits is uneven, depending largely on the user's role, access to information, and familiarity with digital interfaces.

What emerges is the importance of differentiating between types of relationships within the public sector. On one hand, relationships between institutions are often governed by formal agreements and stable communication flows, making them more resilient to remote work. On the other hand, relationships with individual citizens rely more heavily on immediacy, visibility, and trust, elements that can be compromised if not explicitly safeguarded during digital transitions.

Furthermore, the data suggest that remote working in PA has not damaged relational capital. Rather, the quality of relational outcomes depends on how remote work is implemented, communicated, and supported. For institutional users, digitalization and remote interaction can enhance effectiveness. For private citizens, particularly those less digitally literate or more reliant on physical access, remote work can create a sense of detachment that erodes trust and satisfaction. These findings should emphasize the need for tailored strategies in public sector digitalization. Ensuring relational continuity requires not only technological infrastructure but also an inclusive communication strategy, user support systems, and a focus on maintaining visibility and empathy in interactions.

5 Conclusions

This study set out to explore the relationship between remote working and relational capital in the context of PA, particularly focusing on the perspectives of various external stakeholders. Through a qualitative analysis based on semi-structured interviews, the research aimed to assess how the transition to remote work has impacted the quality and dynamics of interactions between public employees and external users.

The findings highlight that, overall, remote working does not necessarily erode relational capital within the public sector (Principale et al., 2025). On the contrary, when supported by structured organizational practices, appropriate digital tools, and a responsive administrative culture, remote work can enhance flexibility and ensure continuity in institutional relations. Institutional respondents reported a generally positive or neutral experience. They emphasized the usefulness of remote communication platforms in facilitating more efficient and frequent interactions, especially in contexts requiring inter-organizational coordination. These findings suggest that public bodies can effectively maintain and even strengthen their relational capital with institutional stakeholders through appropriate digital strategies. However, the study also underscores important disparities. Citizens with limited digital literacy or without established communication channels with the administration appear more vulnerable to relational disruptions. The user-centered perspective brought forth by the citizen respondent revealed frustration stemming from the lack of physical presence and poor communication of

remote work arrangements. Furthermore, the results suggest that while internal workflows in the PA may adapt effectively to digital modes, external communication strategies often lag behind. Ensuring equitable and accessible interactions for all user categories remains a critical challenge. The notion of relational equity emerges as a key consideration in the design of future digital transitions, calling for a more inclusive and user-sensitive approach.

From a theoretical standpoint, the findings align with prior literature emphasizing the multidimensional nature of relational capital (Lombardi, 2021; Cosentino et al. 2024).

In practical terms, the study offers implications for public managers and policymakers. It calls for the development of targeted strategies to bridge the gap between internal efficiencies and external perceptions. This includes investing in communication protocols that clarify remote service availability, training programs to support citizen digital literacy, and hybrid models that maintain a minimal level of physical presence for those who require or prefer in-person interactions.

6 Ethics statement

This research did not require ethical clearance, as it did not involve human participants, personal data, or procedures requiring prior ethical approval.

7 AI declaration

No AI tools were used in the development, writing, or editing of this paper.

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Digital Therapeutics and Music: A Transdisciplinary Approach in Healthcare

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Abstract

Over the years, industries have increasingly implemented the transdisciplinary approach to research complex topics such as planetary and human health. Indeed, transdisciplinarity removes boundaries between disciplines to create new frameworks and approaches for solving real-world problems. Such an approach is particularly crucial in healthcare due to the systemic understanding required to solve its emerging challenges. At the same time, innovation literature affirms that the development of current technologies, which are also emerging in healthcare, is by nature transdisciplinary. Studies on digital health solutions reveal their central role in providing treatments, especially non-pharmaceutical ones. These are often developed by combining disciplines such as medicine, psychology, and art to treat diseases related to the emotional and behavioural sphere of the human being, while reducing healthcare costs. The emerging digital health solutions named "Digital Therapeutics" (DTx) are central in providing these care pathways. DTx are evidence-based, software-driven medical interventions providing cognitive-behavioural and emotional therapies. Despite the practical and theoretical relevance to transdisciplinary research, innovation and knowledge management literature still lack a comprehensive understanding of how DTx enhance a transdisciplinary approach to non-pharmaceutical treatments. The authors investigated two DTx providing music therapy by implementing a qualitative multiple case-study to explore the potential of such technology as a driver of new knowledge management strategies in healthcare. Three mechanisms emerged from a thematic analysis. The findings contribute to the current literature on knowledge and innovation and the emerging stream of research on DTx, which are presented as catalysts for integrating diverse forms of knowledge within therapeutic research. Moreover, this research supports practitioners in understanding how to approach digital health solutions when providing non-pharmaceutical treatments, increasing the effectiveness and accessibility of care, and reducing unnecessary costs.

Keywords: Digital Therapeutics; Music-Therapy; Transdisciplinarity; Innovation Management; Knowledge Management

Paper type: Academic Research Paper

1 Introduction

The rapidly evolving healthcare landscape presents a complex array of challenges that require innovative solutions and foster the emergence of new collaborative approaches to research where knowledge is developed by integrating different disciplinary perspectives. In recent years, increasing attention has been given to the transdisciplinary approach combining knowledge from various disciplines to address complex challenges (Gürdür Broo, Kaynak and Sait, 2022). In parallel, the advent of the Digital Transformation (DT) in healthcare led to the development of Digital Health (DH), encompassing technologies improving care delivery. DH technologies development requires collaboration among actors with diverse roles and expertise (Gürdür Broo, Kaynak and Sait, 2022; Oparin, Andrei and and Ermolaeva, 2021). An emerging subset of DH comprises Digital Therapeutics (DTx): digital interventions to prevent, manage, or treat medical diseases (DigitalTherapeuticsAlliance, 2025). Most of DTx avoid drug consumption. DTx, indeed, provide non-pharmaceutical treatments (Jeon, Yoon and Sohn, 2023). DTx has recently been designed for music-based therapy (Venkatesana, Demetrioua and Bowlingc, 2025) since their impact on driving behavioural and emotional changes. Thus, DTx integrate insights from multiple disciplines (Deloitte, 2019; Smits et al., 2022). Despite the growing attention to DTx, the scientific literature mainly focuses on clinical and technological aspects, neglecting an in-depth analysis of their transdisciplinary nature. In particular, in innovation and knowledge management, there is still a lack of understanding of how DTx contribute to promoting a transdisciplinary approach to healthcare. This paper aims to bridge this gap by answering the following research question (RQ): *How do DTx enhance transdisciplinary approach to non-pharmaceutical treatments?* To address the RQ, we conducted an exploratory multiple case-study, examining the potential of DTx as a driver of new knowledge management strategies in healthcare, ultimately reducing unnecessary costs. The article offers various implications for researchers and practitioners, contributing to the current academic debate on knowledge management and innovation management in healthcare and providing practitioners with several insights on applying a transdisciplinary approach in healthcare settings.

2 Theoretical Background

2.1 Transdisciplinarity in Healthcare

According to the literature (Barney, 1991; Ferreira, Coelho and Moutinho, 2020; Lado and Zhang, 1998) knowledge is a primary intangible resource that helps organizations and institutions to bring valuable innovations into society.

Knowledge management occurs through various mechanisms, including multidisciplinary collaboration, where different fields work alongside each other (Fong, 2003); interdisciplinary integration, which combines and transforms knowledge from multiple disciplines to address complex challenges (Disterer, 2002); and transdisciplinarity, which transcends individual disciplines to create new frameworks and approaches for solving real-world problems (Sasson and Douglas, 2006).

The term "transdisciplinary" refers to the *"higher stage of succeeding interdisciplinary relationships which would not only cover interactions or reciprocities between specialized research projects but would place the relationships within a total system without any firm boundaries between disciplines*" (Piaget and Development, 1972). Recently, interest in the transdisciplinary approach has increased as it enables collaborative research among individuals from different disciplines, generating new approaches and theories (Archibald et al., 2023).

Over the years, different industries increasingly implemented a transdisciplinary research approach to complex topics, as planetary and human health (Pineo et al., 2021; Wardani et al., 2022) contexts. This approach is crucial in healthcare research due to the systemic understanding required to solve the challenges emerging in it; these are grounded on complex and multiple dynamics characterising the interaction between humans and the environment, together with the context-specific factors determining it (Armitt et al., 2024; Van Bewer, 2017).

In particular, a transdisciplinary approach is highly required for non-pharmaceutical treatments, therapeutic interventions that do not involve drugs, such as music-therapy (Chin et al., 2021). These care pathways affect patients' emotional, behavioural, and cognitive behaviour, highlighting the need to integrate knowledge from fields such as medicine and the arts.

2.2 Digital and Transdisciplinary Healthcare: Digital Therapeutics

In the latest century, the implementation of new technologies in healthcare increased, which enable safer and higher-quality care (Marques and Ferreira, 2020). Such changes derive from a phenomenon defined as "Digital Transformation" (DT), representing "*the efficient integration and utilization of knowledge, information, and data through digital technologies*" (Long, Liu and Yang, 2024). Consequently, transdisciplinarity is the approach driving DT (Klerkx, Jakku and Labarthe, 2019) consistently with Gürdür Broo, Kaynak and Sait (2022) sentence: "*the connections between different disciplines are becoming the core of the new technologies, in a not multi-, not inter-, but in a transdisciplinary, seamless manner*". Thanks to the transdisciplinary nature of digital solutions, DT enhances the integration between different disciplines within industries. Thus, DT reshapes the logic and services of the healthcare ecosystem (Biancone et al., 2023), creating opportunities for change by fostering knowledge diffusion (Balta et al., 2021; Verhoef et al., 2021; Vial, 2021). Digital Health (DH) enhances intellectual capital within organizations through Industry 4.0 digital technologies (Pundziene et al., 2023).

Moreover, DH strengthens value co-creation processes (Swan, Peltier and Dahl, 2024), reducing inefficiencies and costs (Kraus et al., 2021). DH also enhances the effectiveness of non-pharmaceutical treatments (Toni, Mattia and Pratesi, 2024). DTx are one of the most recent DH solutions providing non-pharmaceutical treatment. Recently, practitioners and scholars paid increasing attention to DTx, as "digital-medical hybrids that had proven therapeutic value and could stand up to rigorous clinical testing and regulatory approval" (Geiger and Kjellberg, 2021). DTx adoption enhances cognitive and emotional well-being (Sestino and D'Angelo, 2024; Yang et al., 2025). Given their non-pharmaceutical and technological nature DTx development and management requires a transdisciplinary approach (Smits et al., 2022).

3 Methodology

3.1 Research Design

Due to the relative novelty of the phenomenon under study and the lack of comprehensive knowledge in the study area, the research design employs an exploratory approach. To address the RQ, we conducted an exploratory analysis employing a multiple case study (Eisenhardt, 1989; Yin, 2017), adopting an inductive approach (Thomas, 2006). We selected two DTx solutions aligned with the research goal (Eisenhardt, 1989). The

two selected cases are LUCID and MediMusic. Employing a multiple-case study approach enables us to improve both the reliability and the broader applicability of their analysis of social phenomena (Saunders, Lewis and Thornhill, 2009).

Specifically, the unit of analysis is the way through which DTx enhance the transdisciplinary approach to music therapy (Russo et al., 2023). Music-Based Interventions (MBIs) refer to planned therapeutic programs that utilize music as a tool to reach specific therapeutic outcomes (Thaut and Hömberg, 2025; Bruscia, 2014) and have been primarily developed within the practice of music therapy. Music-Based DTx are based on a music medicine approach, where music is treated as a self-applied therapeutic resource through carefully designed listening experiences provided via digital health technologies (Venkatesana, Demetrioua and Bowlingc, 2025).

Data were collected from various sources, including company reports, online documents, and public statements. We conducted a reflexive thematic analysis following the steps outlined by Braun and and Clarke (2006) to provide useful theoretical and practical insights.

3.2 Research Settings

3.2.1 A multiple-case study: LUCID and MediMusic

LUCID is a Canadian entrepreneurial venture founded in 2017 developing DTx based on music (LUCID, 2025).

The company personalizes musical experiences by leveraging Emotion AI to improve patient's mental health. Its solution, "Resonance Rx," is a Medicare-eligible mental health platform designed for older adults. MediMusic is a U.K based medtech company founded in 2016, developing a music prescription platform designed to reduce anxiety, stress, and pain, designed to be used within geriatric settings. It treats people with dementia (MediMusic, 2025). At the heart of the technology is MediBeat, a device that plays personalized therapeutic playlists. MediBeat is a DTx smart music player created by MediMusic that selects specific songs to induce desired physiological responses, such as relaxation or pain relief (MediMusic, 2025).

3.3 Data Collection and Data Analysis

To triangulate data, we relied on secondary sources (Yin, 2017). Particularly, data were gathered from: (1) public statements, (2) online documentation, and (3) official archival data. Data analysis followed an iterative and inductive approach (Bansal, Smith and Vaara, 2018; Miles and Huberman, 1984). Developing theorical insights inductively from qualitative data is considered suitable in empirical settings that are not well explored and where existing research is limited (Bansal, Smith and Vaara, 2018).

The data collection was carried out from September to December 2024 and refers to the period 2020-2025 because with the advent of the COVID-19 pandemic, there was a significant increase in DTx adoption (JuniperResearch, 2021). To strengthen the study's validity and reliability, we initially performed independent coding before comparing their results (Patton, 2014). To maintain analytical rigour and transparency, helping to identify and categorize themes that emerged from the data (Tisdell, Merriam and Stuckey-Peyrot, 2025) based on the authors' interpretation, the research adopted the six-phase framework outlined by Braun and and Clarke (2006). From the conducted thematic analysis, three main themes were selected: 1) *Digital as an active agent and not just a tool*; 2) *Treatment as a human and personalized experience;* 3) *Real-time mood state monitoring.*

4 Findings

4.1 Digital as an active agent and not just a tool

Both companies implemented a triadic transdisciplinary approach in designing and managing their DTx. Indeed, both LUCID and MediMusic integrate science, music, and tech knowledge. Differently from traditional music therapy treatment, which is usually based on medicine and music, LUCID and MediMusic merge technology competencies to formulate digital therapeutic pathways to increase patients' compliance.

MediMusic integrates the three disciplines to create, through AI and machine learning, "*audio fingerprints which mimic the human brain's response to music and then scientifically dispense it as an efficacy-driven medicine for the benefit of clinical pain and anxiety*". According to its CEO and co-founder, combining scientific and technological competencies makes it possible to create a musical experience with clinical benefits. He describes such a transdisciplinary approach as the ground for effectively treating multiple physical and psychological diseases: "*MediMusic's mission is to ethically leverage the power of technology, combining algorithms and artificial intelligence with music to clinically dispense music as medicine for the benefit of multiple physical and psychological conditions*".

LUCID's ResonanceRx is a geriatric mental health platform leveraging scientific knowledge derived from the neuroscience field, the musical one, and the technology skills, particularly related to implementing artificial intelligence algorithms enabling patients' emotions' codification (i.e., Emotion AI). According to data, transdisciplinarity is translated into different collaborations with experts, which is the basis for the DTx effectiveness. LUCID implements technology competencies by providing a recommendation system reinforced by learning mechanisms to cultivate affect-driven personalized music sequences, thus approaching music knowledge through a psychological perspective (Mallik and Russo, 2022). Indeed, LUCID's music experts as music directors/compositors work along with health professionals and algorithm developers. This triadic approach emerges in the company's statements on the website "*We're glad to be contributing at the forefront of research into the health benefits of music. [...] LUCID leverages people's natural enjoyment and use of music to enhance the digital bioavailability of DTx, and uses cutting-edge methods to optimize the active components of music for mental health outcomes".*

4.2 Treatment as a human and personalized experience

Both companies focus their offer on personalizing the music therapy treatment thanks to the digital tools they leverage. MediMusic considers the patient's age, gender, nationality, and ethnicity to create a personalized experience through a 20-minute playlist that influences multiple areas of the human brain to help reduce anxiety and pain. Its CEO, during a 2024 podcast interview, described the company's offer as follows: "W*e use personalised playlists to reduce stress*". Another company's statement presents personalization as a key factor of MediMusic offer. It explains how it is related to positive clinical outcomes "*We auto-create personalised, smart playlists that use predictive analysis to reduce heart rate and the stress hormone Cortisol, thereby promoting positive endocrine secretions – such as Dopamine, Immunoglobin-A and Oxytocin – as well as improving breathing and cognitive response*". This is consistent also with LUCID's intention to incorporate personalization within music-therapeutic interventions through quantitative measurement and machine learning techniques driving patient well-being, as in the case of ResonanceRx. ResonanceRx falls into LUCID's evidence-based digital therapeutics grounded on AI-personalized music. This is highlighted by the following sentences "*We are using personalized audio to help reduce neuropsychiatric symptoms such as anxiety and agitation*" and "*We develop AI that is personalized, adaptive, and enjoyable*". By analysing a patient's mood and facial expression, ResonanceRX provides personalized music for each therapeutic session. Furthermore, Emotion AI enables personalization: "*Our closed-loop Affective Music Recommendation System (AMRS) is an Emotion AI which enable a personalized, effective, and enjoyable digital music therapy experience".*

4.3 Real-time mood state monitoring

Both DTx companies design their solutions considering real-time monitoring driving DTx's improvement as a key factor to simultaneously achieve positive results in medical, musical and technological terms. As stated by MediMusic, this is possible by leveraging on tech skills to adapt the music recommended to improve patient's health "*Our Digital Drip component dynamically monitors a listener's response to the music and if the HRV is not as we predict subsequent tracks are swapped out to bring the heart rate down faster or in slower steps depending on use case*". The following sentences explains MediMusic's solution basis in this sense:*"MediMusic developed a dedicated hardware player for its music that works in concert with a wearable meant to track a patient's heart rate*". Indeed, a patient's heart rate response is monitored for playlist refinement purposes via Digital Drip® biofeedback loop, and this is also important for healthcare services since such techniques enable MediMusic to provide evidence-based ROI and multiple cost-saving KPIs. Consistently, LUCID affirms that along the therapeutic path, the digital solution "*measures the listener, their intentions and the context to understand the listener's starting cognitive mood state*", which helps patients move toward their target mood state. Monitoring an individual's mood and reaction to the musical stimuli helps the company drive the therapeutic path toward the predefined goal and improve the ongoing treatment. In the LUCID case, a music playlist is *"generated with the intent of effecting a controlled trajectory of the listener's affective state from the current state to the target state".*

5 Discussion

The findings illustrated above show how DTx technology represents a solid ground for boosting the interrelation between different knowledge fields in providing digital non-pharmaceutical treatments (Jeon, Yoon and Sohn, 2023; Yang et al., 2025). In particular, by analyzing the two cases selected, both companies implement a triadic transdisciplinary approach by integrating science, music, and technology. In particular, the first refers

to the medical and neuroscience competencies that have merged with the musical ones. This is typical of the traditional music therapy approach. According to several studies (Hole et al., 2015; Raglio, 2019), listening to music decreases drug consumption and, in some cases, reduces hospitalization time. For this reason, such therapeutic pathways are implemented to treat different types of diseases and health issues, as in the case of postoperative pain (Yang et al., 2025) and mental health issues. However, the particular characteristic of DTx is that they do not represent a digitalization of such treatments, but the digital technique is clinically validated to improve patients' conditions (Geiger and Kjellberg, 2021). This means that the science-music-tech transdisciplinary approach is the heart of the active agent of the non-pharmaceutical treatment. This is consistent with Gürdür Broo, Kaynak and Sait (2022). affirming the central role of transdisciplinarity in designing new technologies. Moreover, such transdisciplinarity leads to providing tailored treatment. Results reveal how both companies offer highly personalized treatment. This is widely recognized as one of the DTx strengths (Sestino and D'Angelo, 2024). Indeed, any type of treatment should be patient-centric, thus personalized, to be more effective (Chibuike, Grobbelaar and Botha, 2024). This is especially true for music therapy, which is highly connected to the patient's emotional and psychological traits, which are strictly intimate and unique for their intrinsic nature. Personalization, indeed, is fundamental for music-therapy success (Russo et al., 2023). The two DTx solutions described leverage on AI and other Industry 4.0 technology to find which music genre and rhythm produces a more effective response in the patient. This means adapting technology competence to "teach" the digital tool some neuroscience and music skills to be applied along the therapeutic journey. Moreover, according to Russo et al. (2023), a music-based DTx offers the level of personalization required for the best patient outcomes without the intervention of a music therapist. Our results reveal that DTx consider individuals as human beings, supporting the principles of Industry 5.0 (Leng et al., 2022). Indeed, transdisciplinarity helps to consider human needs by impacting a patient's entire life experience through personalized therapeutic pathways.

Findings illustrate how real-time data monitoring guarantees personalization, the third theme emerging from our analysis. The data collected are related to the three disciplines identified. This enhances the "iso principle", a specific music-therapy methodology that LUCID applies in ResonanceRx. Generally, this principle means identifying a patient's current emotional state and then changing the music played to transform that mood state into the one desired for therapeutic goals. Thanks to DTx, which leverages Emotion AI, sensors, and wearable devices, technology can better monitor the patient's mood and appropriately provide music stimuli that gradually lead to an individual's emotional state change by implementing the triadic transdisciplinary approach. Our results, thus, are consistent with Venkatesana, Demetrioua and Bowlingc (2025) describing music-based DTx as "*a key strategy for increasing the accessibility of music-based interventions*".

Thus, DTx's transdisciplinarity nature could be intended as a synonym for equity improvement, confirming how much such an approach to integrating disciplines is important for healthcare research and the system in general (Armitt et al., 2024).

6 Conclusions, Limitations and Future Research

This study contributes to understanding how DTx enhance a transdisciplinary approach to non-pharmaceutical treatments and opens new research avenues by deepening the scientific understanding of the role of DTx in healthcare. These considerations contribute to the knowledge and innovation management literature and support the emerging research stream on DTx.

Indeed, findings reveal three key theoretical insights. First, DTx are designed to treat digital technologies as active therapeutic agents, positioning software alongside clinical, psychological, and neuroscientific interventions. This epistemological shift legitimizes the digital domain as a core therapeutic discipline. Second, they provide and improve personalized treatment daily, considering the human needs over the patient's one.

DTx suggest a broader lens on how non-pharmaceutical treatment should be integrated into individuals' lives by adopting different disciplinary perspectives simultaneously. Indeed, the third consideration is related to DTx approach to real-time data monitoring. Data are collected to provide transdisciplinary insights allowing for adaptive management of care. From a managerial perspective, the findings underscore the importance of adopting a patient-centred and personalized approach to non-pharmaceutical treatment through leveraging the digital and data-driven nature of DTx. Since these last's relevance in reducing healthcare costs, transdisciplinary-grounded DTx development is thus strongly suggested. It underscores the need for collaboration between scientific communities, researchers, and practitioners in developing digital non-pharmaceutical therapeutic pathways. This study, however, has some limitations related to the limited number of cases analysed and the only consideration of secondary data; future research can focus on analysing primary data.

7 Ethical declaration

This research did not require ethical approval as it was based solely on the analysis of publicly available data and did not involve any direct interaction with human participants or the collection of personal or sensitive information. All sources used were openly accessible, and no identifiable personal data were processed.

8 AI declaration

We acknowledge the use of ChatGPT and Grammarly in helping us proofread the research article. On ChatGPT, we used the following prompt: *"Suggest ways to improve clarity and concision without changing the meaning of the text".* Then we reviewed the feedback generated critically and revised the writing.

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What if…? Narratives, Stakeholders and Alternate Endings in Value Creation

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Abstract

The research conceptually outlines the nodal importance of narration as a crucial tool supporting stakeholders' moral imagination in the conception of desirable alternatives to the critical existing status quo. This due to the fact that stories enable people to better understand reality decreasing, at the same time, the ethical pressure related to decisions and actions. Narrative is indeed a central and characterizing human activity orienting – through projections – moral choices, thanks to the evaluation of prospective effects. This is a pathway for value creation based on cooperative generation of knowledge to fully understand the big picture, thereby overcoming problems, crises and trade-offs.

Into this groove, Artificial Intelligence (AI) can play a valuable supporting function thanks to its computing and creative capacity becoming a convenient assistant for stakeholders during the genesis of alternate representations as possible "what if…". AI can in fact contribute to envision further scenarios, making moral imagination even more inventive. Taking into account the doubts and risks connected to AI, control and management of technological tools is needed by the involved stakeholders, to orient the solutions without, of course, limiting the innovative potential. This represents a royal road to overcome a well-known, diffused and increasing resistance and opposition to the cooperation between human and non-human agents.

The paper thus contributes to the concept of moral imagination by adding stakeholders' stories co-design as a creative form of moral imagination and investigating the ancillary role of AI.

The limit of the work is represented by the earlier stage of the still ongoing analysis.

Keywords: Moral imagination, narrative, Stakeholder Theory, Artificial Intelligence, value creation

Paper type: Academic Research Paper.

1 Background

The increasing uncertainty of recent and present times is due to the growing wide-ranging complexity originating from – and at the same time exacerbating – different and sometimes in appearance conflicting interests, needs, and claims from diverse stakeholders (Schiuma et al., 2021; Casalegno et al., 2020; Freeman, 2010; Harris and Freeman, 2008). The most dangerous associated threat is the rise of trade-offs, although it is manifest that the only path to prevent – or overcome – critical problems and crises is value creation (Freeman et al., 2007) based on the cooperative generation of knowledge to fully understand the big picture (Dumay, 2022; Valentinov, 2022). To pave the way for this orientation it is essential to put back at the center the human dimension by holistically enriching the managerial perspective with the humanistic dimension (de Colle et al., 2024; Cortese and Civera, 2022; Dion et al., 2022; Ciulla, 2020). That in fact allows to broaden the view by including all the stakeholders and their perceptions as well as sensitivity, making more complete, general, and adequate the adopted standpoint and the detected solution.

In this sense, this research theoretically outlines the importance of narration as a tool supporting moral imagination (Werhane, 2008) in the conception, ideation, and construction of alternatives to the critical existing status quo: in other words, a sort of imaginary "what-if…?" challenging the present and its potential inertia. This for the reason that "narratives or stories are said to enable us to better understand real lives because stories are concrete, dynamic, and highly contextual in a way that abstract moral theories are not" (Koehn, 2024: 765) and decrease, at the same time, the ethical pressure related to decisions (Mitchell, 2014). Into that groove, Artificial Intelligence (AI) can play a supporting role thanks to its computing and processing capacity becoming a useful assistant in merging acquired information and boosting understanding (and hence knowledge) emersion also showing unforeseen contingencies or obstacles. Consequently, AI may become nodal during the genesis of representations of possible attitudes or behaviors and so result in an effective aid when considering stories as moral forerunners.

The paper follows Koehn's position about narratives as an assistant in screening for ethical salience and identifying relevant possibility for actions and aims at bridging the proposed gap: "future research [..] on the power of narratives within the learning-process of agents who are on the road to virtue" (2024: 777) by including AI as stakeholder's facilitator and partner. In such a way, the article also contributes to the concept of moral

imagination by adding stakeholders' stories co-design as a creative form of moral imagination (La Forge, 2004; Ciulla, 1998; Johnson, 1985; De Mello, 1984).

2 Moral (A)Imagination

2.1 Moral imagination

"We tend to listen to a well-told story because its characters serve as role models. Their fates strongly imply what will befall us if we follow a similar path" (Sachs, 2012: 18). Narration is a central and characterizing human activity: it is crucial in proposing and disseminating archetypes and images, and therefore orienting – through projections – moral choices, thanks to the evaluation of prospective consequences. That indeed does not only concern the structure of the fairy tale – the story par excellence – of which a clearly recognizable and rebuildable morphological homogeneity is demonstrated (Propp, 1928), but – and this is the fundamental point for the fairy-tale context too – it applies to human behaviors and their exhibition in general. According to MacIntyre, in fact, stories and roles of those who animate them are closely interrelated: "man is in his actions and practice, as well as in his fictions, essentially a story-telling animal. [...] I can only answer the question 'What am I to do?' if I can answer the prior question 'Of what story or stories do I find myself a part?' We enter human […] with one or more imputed characters-roles into which we have been drafted-and we have to learn what they are in order to be able to understand how others respond to us and how our responses to them are apt to be construed" (MacIntyre, 2007: 216). As a result, storytelling becomes pivotal since it extends the ability to understand thanks to the imagination enriching "experiences by allowing us to see the world as (we imagine) others do, and […] by giving us a tool for exploring how the objects of our experience might be related to each other" (Hankins & McDavid 2023: 109).

The narration is therefore a primary mechanism of moral imagination, intended as "the ability to discover, evaluate and act upon possibilities not merely determined by a particular circumstance, or limited by a set of operating mental models, or merely framed by a set of rules'' (Werhane, 1999: 93). Moral imagination is conceived as a three-step process: the first one – reproductive imagination – is related to understanding factors influencing awareness of a moral question; the second one – the productive imagination – reformulates the problem in many ways; the third one – the creative imagination – develops solutions to the moral issues (Werhane, 1998). La Forge (2004), in line with Ciulla (1998) and De Mello (1984) suggests stories as a means for productive imagination because they accelerate comparisons and enable the growth of moral imagination. In line with the Kantian matrix of the concept, Johnson (1985: 273) says that "moral reasoning involves an act of imaginative envisionment of a non-existing world as a means for judging a proposed maxim". Werhane too refers to "Critique of Judgment" (Kant, 2004; 1790) to remind that the philosopher suggests to freely "play" with ideas, outside pre-established and recognized schemes, to allow creativity and therefore perception. According to Ciulla (1998: 106), "what distinguishes […] moral imagination from fantasy […] is the strand of truth that ties creativity to that which is known to be true by others". Thus, the narrative can be transformed into a projection of "morally acceptable alternatives to solve the ethical problem" (La Forge, 2004: 15): a new and inventive value creation path (Valentinov & Pérez Valls, 2021) based on "a morally imaginative systemic approach" (Werhane, 2008: 467). Accordingly, by contemplating the invention of narratives, we consider stakeholders' storytelling as a form of creative imagination – coming to the third stage of moral imagination –.

This experimental solution rooted on the knowledge of individual stakeholders who intervene in the elaboration of the story by sharing and pooling their own perceptions and interpretations is straightly exemplified by "real utopias" (Wright, 2020; 2011): disruptive projections of powerful images leading to hypothetically better and then desirable alternatives that reshape stakeholders' relationships and guide their future actions (Richard et al., 2024). The plot of an alternate future is co-shaped by participants, and this allows the possibility to forge a way towards a better state.

2.2 Artificial intelligence for creativity

Why, then, is it interesting, both from a theoretical point of view and in terms of managerial implications, to think about AI in this scenario? What are the opportunities and limitations – or risks – associated with technology?

A premise is necessary to frame the temporal and cultural depth of the underlying doubts affecting AI. In 1950, Alan Turing asked the fundamental question about the possible intelligence of machines. He did so by overcoming the most obvious question, namely "can machines think?" (Turing, 1950: 433), since that combining the concepts of "machine" and "thought" would have led to semantic diatribes resulting in insignificant points.

Instead, he directed the reasoning towards a game: the well-known "imitation game". In the simulation, two subjects – A and B –, respectively a man and a woman, are questioned by a third party – named C (of which gender is not relevant) – who has to determine, by communicating with A and B – in a mediated way, in order to ensure neutral answers that do not favor him –, which of the two other persons is the man and which is the woman. B has the role of supporting C in the investigation, while A must deceive to reach an incorrect verdict. That is where the well-known Turing's question came in: "'What will happen when a machine takes the role of A in this game?'. Will the questioner make a wrong decision as often when the game is played this way as when it is played between a man and a woman?". So, the author focused on the involvement of machines in the imitation game, but, of course, he looked at the wider concrete implications of the proposed gamification: is it likely that machines behave – by emulating human strategies – as if they were thinking? More than 70 years later, the possibility mentioned by Turing in the conclusion of his article is confirmed: the approximation of machines to human thought thanks to the ability to learn. However, the heart of the matter remains the same: the potential danger resulting from the substitution of AI to human, behind which we continue to see the doubt underlying the imitation game, that is the probability of deception by machines.

That being said, we believe it is interesting to think about the use of AI in the generation of narratives – including real utopias as plastic and clear representations of projection of solutions co-created by stakeholders – for two reasons. These obviously are opportunities, but they do not exclude risks that must be considered, monitored and possibly managed. The first reason is the AI ability to collect and aggregate information and therefore the conceivable incremental rise of knowledge to the benefit of stakeholders. In fact, as above-mentioned, value creation passes through knowledge (Valentinov, 2022) that is characterized *by* and suffers *from* distribution and dispersion. In this sense, the participation of stakeholders in the creation of knowledge-based solutions would be an opportunity for engagement and empowerment, overcoming the risk of trade-offs: this will be made even more solid and complete thanks to the AI incremental knowledge. Since we are in the field of ethics, the concept of paradox is an element easy to introduce and useful to reflect. In "Eat a rock a day, put glue on your pizza: how Google's AI is losing touch with reality" Toby Walsh (2024) exposes the necessary caution, not wanting to fall into surreal error. In fact, the risk related to the "knowledge" proposed by AI – in this specific case, the one developed by Google – that does not know the difference between true, false and popular and, above all, does not share the human perception of values, emerges. Sarkar (2025), on the contrary, highlights how the supposed "Artificial stupidity" arises from a cultural opposition – more functional to parlor games than to scientific discussions – that is substantiated in unintelligent questions, to create easy – bizarre – responses that follow the tone of the speech. In any case, a progressive – natural, in the field of machine learning – purposeful training is needed for the collection of information supporting the construction of shared understanding, based on an ever-increasing attention to the selection of authoritative sources, as the main body and solid basis of information.

The second reason is the creative potential of AI. It is proved *ad absurdum* – together with the latent negative consequences that confirm the presence of the prospective – not only by recent news stories about – to mention the best known – the prolonged strike of Hollywood screenwriters in the face of a risk of replacing their professionalism, but also by theoretical reflections on the ethical implications of the use of AI in artistic productions (Hagtvedt, 2025). It is indeed necessary to ponder the threats associated with the "post-human" condition as the loss of human nature and identity (Qerimi, 2019) when considering the creative chances of AI, as well as the "Baudrillard's (dis)trust in Artificial Intelligence" (Sommerer, 2025). In more detail, Baudrillard's reflection invites to cogitate on the idea of "hyperreal" that is a "real" without origin or authenticity: "the desert of the real" (Baudrillard, 1981) understood as the disappearance of genuine sense bringing with it the menace of lacking significant human interactions. Anyway, in our case, it is not about reasoning on the technical-ethical debated implications linked to AI (Román Almánzar et al., 2024; Undheim et al., 2023; Umbrello, 2020; LaChat, 1986) bearing in mind, in particular, the sentient one (Pauketat and Anthis, 2022) as possible "artificial moral advisors" or "moral observers" (Giubilini and Savulescu, 2017), but about the use of AI to support stakeholders' shared effort in the design of alternate ending(s). AI can increase and boost moral imagination, and it can do it even better if it is used as a help for stakeholders' shared effort in drawing "what if…". Training AI in "radical imagination", understood as a "deeply dialogical creative power that exists only through collective and critical encounters", according to Molotokienė (2019: 445), is a fundamental element for non-human intelligence to ethically serve human needs, enabling new forms of interaction between human and non-human. Actually, Pinka (2021: 123) states that "an artificially intelligent system could potentially perform ethical deliberation (or something similar) if it were imbued with a form of emulated imagination". This means overcoming the fear of Turing and Baudrillard by relocating the medium to its instrumental purpose discovering "its potential as a harbinger of narratives beyond human ideation" (Saddhono et al., 2024: 748) too.

Thanks to AI computing and processing capacity as well as creative potential, stakeholders can "harness local and dispersed pieces of knowledge that would not be available" (Valentinov, 2022: 536) and thereby combine all the sensitiveness and demands by creating altered – both narrative and viable – horizons. Shared comprehension co-generation is the basis to cover the distinctive facets of problems as well as the intersection of matters thanks to an all-embracing consciousness (González-Mohíno et al., 2024; Schiuma and Lerro, 2011). Concurrently, knowledge joint making rooted on the connection of stakeholders pooling their standpoints and know-how results in their empowerment, thanks to the augmented learning-based perception and in perspectives – projections and action plans – for value creation.

3 Conclusions, limitations and future research

The conceptual reasoning here briefly exposed – whose limit is represented by being offered in embryo, as the first sharing of a work in progress – revolves around the role of narration (Koehn, 2024) as a tool for stakeholders co-creation of alternative scenarios to the status quo and its complexity, in which often some actor is not represented or involved or even is in a marginal condition due to limited power (Richard et al., 2024; Schiuma and Lerro, 2011; Werhane, 1999). The creation of projections, of "what if…" – whether they are real utopias (Wright, 2020; 2011) or other forms of perspectives – is characterized by the chance of participation and involvement for stakeholders because, although it leads to realistic visions, it precedes the implementation phase of the solution and, therefore, makes the moral implications less heavy and pressing (Mitchell, 2014) stimulating, on the contrary, the moral imagination in its most creative shape (La Forge, 2004).

Since narratives are the result of individual stakeholders' knowledge and perceptions allowing to collect – and increase – fragmented knowledge (Valentinov, 2022), obviously the potential of AI can be expressed by a further growth of information or in its systematization. Additionally, AI creative learning can contribute to projecting broaden scenarios, making moral imagination even more inventive (Saddhono et al., 2024; Molotokienė, 2019).

It is however clear that the infancy stage of the tools available to the large audience and their progressive training require control and education by the interested stakeholders, in order to orient them, without, however, limiting their originative potential.

At the same time, theoretical contributions – and this is the first step of our attempt – are also needed from literature, with reference to the great and consolidated topic of moral imagination.

In conclusion, to create new stories – understood as new "pages" – of value creation it can be strategic to monitor and contribute to the evolution of AI as a support for the benefit of stakeholder, remembering that "we're only as good as the stories we can tell, we're only as good as we can live the lives that we can imagine. And imagination and creativity are muscles that atrophy if they're not used" (Freeman, 2013).

4 Ethics declaration

No ethical clearance for the research referred to in this paper is necessary.

5 AI declaration

No AI tools were used for the creation of the paper.

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Bibliometric Exploration of Impression Management and Emerging Technologies in Business Communication

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Abstract

This study offers a bibliometric analysis of impression management (IM) within the evolving landscape of individual and organizational communication, shaped by emerging digital technologies. By analyzing 262 peer-reviewed journal articles indexed in Scopus between 2000 and 2024, the research examines the thematic structure of this interdisciplinary domain.
Performance analysis and co-occurrence network mapping findings reveal a growing interest in IM, particularly over the past decade. The study identifies four core thematic clusters: IM for identity construction through social media; technological augmentation of communicative credibility and authenticity; branding, self-presentation, and user engagement through IM in the age of digital intermediation; socio-psychological dimensions of IM in digital contexts.
The research shows that while IM has been widely explored in psychology, communication, and information science, it remains underrepresented in management and business studies.
The present study contributes to the literature on IM by providing a systematized, multidisciplinary overview of the topic and proposing directions for future research. It advocates for a deeper integration of IM into knowledge management and digital transformation frameworks, emphasizing the need for new communication paradigms to address current challenges.

Keywords – Impression Management, Communication, Digitalization, Emerging Technologies, Stakeholder Engagement

Paper type: Academic Research Paper

1 Introduction

In the current context, characterized by uncertainty and high competitiveness, businesses need to reshape their communication models using accurate strategies (Iaia *et al.*, 2024).

Corporate communication is conceptualized as a dynamic network of individuals interacting both vertically and horizontally, within and outside organizational boundaries. Technological advancements have significantly reshaped the corporate and individual communication landscape, requiring professionals to possess robust digital and linguistic skills. Along with this, emerging technologies such as artificial intelligence (AI) are reshaping the way organizations communicate with their stakeholders, enabling the former to produce accurate reports or attractive posts on social media. Nevertheless, it is not simple to define how organizations could communicate to create stakeholder engagement in terms of the usage of digital and emerging technologies. Kujala et al. (2022) provide a comprehensive definition of stakeholder engagement, affirming that it "refers to the aims, activities, and impacts of stakeholder relations in a moral, strategic, and/or pragmatic manner.".

Impression management (IM) emerges as a fundamental point in shaping perceptions, especially in a highly fragmented digital communication context. The concept of IM was first introduced by Goffman (1959), who likened individuals to "actors" performing on a social stage. Nowadays, its application is demonstrating how the IM approach could contribute to defining innovative frames of communication models among individuals and organizations through two components (Leary *et al.*, 1986). The first deriving from *impression motivation*, involving the desire to control others' perceptions, the second associated with *impression construction*, referring to the efforts undertaken to shape perceptions. Besides, advancements in communication technologies have enabled companies to adopt IM tactics through various digital channels, including blogs and social networks (Keskin *et al.*, 2024). In organizational settings, IM is adopted for performance evaluations and the establishment of organizational legitimacy (Luo *et al.*, 2022). Organizations employ diverse tools to manage stakeholder perceptions, including social media (Benthaus *et al.*, 2016), visual elements and graphs (Kanbaty et al., 2024).

Growing academic interest in social media and impression management has been observed, as the IM may innovate the sharing of people and companies' information through a purposeful approach able to consolidate the competitive edge. Recent studies investigate the role of communication technologies in the enhancement of stakeholder engagement (Viglia et al., 2018; Iazzi et al., 2022). De Luca et al. (2022) evaluate different social media post characteristics, finding that the use of hashtags, links, number of characters in a post, industry type, and the country in which firms operate play a pivotal role in influencing stakeholder engagement rates.

However, the adoption of new technologies requires specialized skills to harness their potential and the establishment of previously non-existent paradigms (Iaia *et al.*, 2024). This shift moves toward a perspective that not only enhances traditional value but also integrates digital value, fostering a more comprehensive approach (Pironti and Iaia, 2022). In such a context, where technologies and paradigms need to evolve, and more knowledge is required to understand how to enhance skills, knowledge management (KM) is the way to promote collaboration among skilled professionals while maximizing employee potential and creating a competitive advantage (Grimsdottir and Edvardsson, 2018).

This research explores how emerging technologies and social practices could influence communication models through IM tactics. Due to the prevalence of contributions in social sciences, computer sciences, and psychology areas, and the complexity of representing the phenomenon from multiple viewpoints, our research proposes a systematic and interdisciplinary overview of the topic. So, our study aims to contribute to the debate on IM, providing managerial implications, focusing on new emerging technologies.

To this point, the present study performs a bibliometric analysis to evaluate academic production and investigate the research trends on IM tactics adopted by companies, considering the new information and emerging technologies paradigm. Moreover, to the best of our knowledge, literature about impression management in such a field does not present other bibliometric analyses.

It is meant to address the following research questions:

- *RQ1: How is scientific research on IM and communication technologies developing?*
- *RQ2: Which are the most important studies on the topic?*
- *RQ3: Which are the most cited countries?*
- *RQ4: Which research clusters can be identified on the topic?*
- *RQ5: What are the future research evolutions?*
- *RQ6: What are the managerial implications?*

Section 2 describes the selected sample of articles and the methodology; Section 3 presents the performance analysis; Section 4 illustrates the main clusters through a network analysis; Section 5 is dedicated to conclusions, including future research avenues and managerial implications.

2 Methodology

The study examines the literature on IM communication tactics employed by organizations in the context of digital transformation and the adoption of emerging technologies, utilizing a bibliometric analysis complemented by a systematic literature review.

A bibliometric analysis is conducted to identify critical insights within the existing body of literature. After that, a systematic review of the selected articles enabled a more in-depth exploration of the key research streams identified through the network analysis.

The bibliometric technique is useful for obtaining a comprehensive overview of the phenomenon in a specific scientific field (Mukherjee *et al.*, 2022) and synthesizing the results with clusters resulting from a network analysis from a multidisciplinary perspective. According to Cosma and Rimo (2024), it avoids the biases inherent in the sample selection process that often affect traditional systematic reviews, as utilizing bibliographic data provides a comprehensive overview of the scientific unexplored output. Quantitative metrics and analysis can be verified ex-post and corroborate research (Pizzi *et al.*, 2024).

The research has been carried out by initially determining the most suitable query string.

The analysis uses bibliographic data exported from the Scopus database as one of the two most widely used citation databases for bibliometric analysis (Martín-Martín *et al.*, 2018).

A screening is carried out through filters to extract a representative sample, limited to final-stage peer-reviewed articles published in English until the end of 2024. Articles in press, conference papers, and publications in other languages are excluded to achieve consistency during the steps.

This phase led to the final following query string, with the selection of a sample of 262 studies:

(TITLE-ABS-KEY ("IMPRESSION MANAGEMENT") AND TITLE-ABS-KEY ("COMMUNICATION TECHNOLOG*") OR TITLE-ABS-KEY ("SOCIAL MEDIA") OR TITLE-ABS-KEY ("EMERGING TECHNOLOG*") OR TITLE-ABS-KEY ("ARTIFICIAL INTELLIGENCE")) AND PUBYEAR > 1999 AND PUBYEAR < 2025 AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English"))

The bibliometric data are processed through the Bibliometrix R package (Dervis, 2019) and Vosviewer software. The Bibliometrix R package was used to conduct the performance analysis, and Vosviewer was used in the network analyses to find the main research clusters.

Performance analysis refers to the number of publications and citations and allows for answering three research questions (RQ1, RQ2, RQ3). Otherwise, the network analysis yields results through visualization depicting the relationship between different scientific items, illustrating connections between keywords and thematic areas to answer the fourth research question (RQ4). Finally, a systematic review and content analysis are performed to propose a future research agenda, possible managerial implications, and answers to RQ5 and RQ6.

3 Performance analysis

Fig.1 highlights the number of publications by year, showing an increasing interest in literature on the topic of IM tactics adoption through emerging and digital technologies, especially in the last decade.

Notable publication peaks have been reached in 2018, 2021, and 2024. The enforcement of the General Data Protection Regulation (GDPR) in 2018 marked a significant moment in corporate digital communication, compelling firms to reconceptualize their public-facing digital identities under heightened transparency and accountability requirements. Concurrently, the exponential growth of algorithmic visibility structures redefined the strategic choices of how firms managed their reputational capital in digital environments. These dynamics were further intensified after the COVID-19 pandemic. Firms migrated their reputational strategies to digital platforms, leveraging AI-driven analytics, social listening tools, and virtual engagement technologies to engineer perceptions of resilience and corporate responsibility.

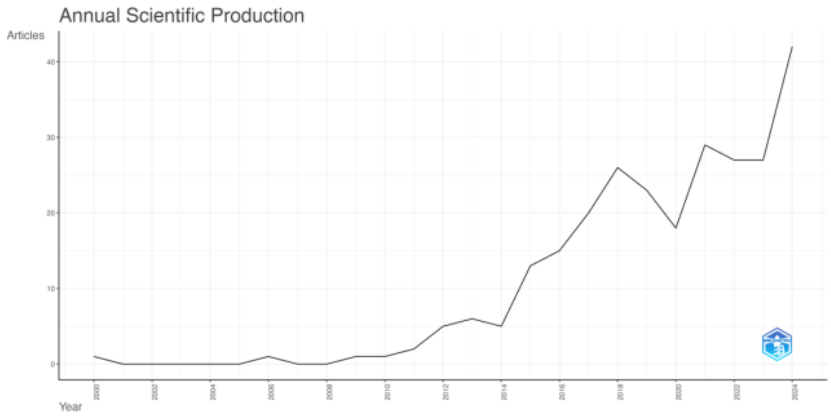


Figure 1 - Annual scientific production

The most cited article is “The effects of social media-based brand communities on brand community markers, value creation practices, brand trust and brand loyalty” (Laroche *et al.*, 2012) with 652 total citations (TC). Laroche et al. (2012) found that digital technologies facilitate and enhance impression management practices. IM tactics are influenced by community markers such as social obligations and shared rituals, and positively affect brand trust, reinforcing brand loyalty through digital communities. Therefore, according to the study, marketers should actively promote IM adoption in social media communities to strengthen trust and loyalty. The second most cited article, “Is Facebook creating “iDisorders”? The link between clinical symptoms of psychiatric disorders and technology use, attitudes and anxiety” (Rosen *et al.*, 2013), collects 342 TC and examines the role of IM as a predictor of clinical symptoms for several psychiatric disorders. Specifically, greater IM on Facebook predicted greater clinical symptoms of major depression, bipolar mania, narcissism, antisocial disorder, compulsive disorder, and histrionic disorder.

“Microblogging, Constituency Service and Impression Management: UK MPs and the Use of Twitter” (Jackson and Lilleker, 2020) is the third most cited article (249 TC) and reveals that Twitter is widely adopted as a tool for favourable self-presentation and an auto-promotional IM tactic. Specifically, Twitter is adopted by the members of the Parliament in the UK for managing their image through self-promotion, highlighting their abilities and hard work, and through building a more human and approachable image.

Within the top five most cited articles figure “What you don't know won't hurt me: Impression management functions of communication channels in relationships” (O’Sullivan, 2000) with 217 TC and “Facebook involvement, objectified body consciousness, body shame, and sexual assertiveness in college women and men” (Manago *et al.*, 2015) with 201 TC. According to O’Sullivan (2000), technologies help regulate the exchange of self-relevant information in managing their self-presentation, so that when an individual perceives that interactive episodes are potentially threatening or supportive of their self-presentation, they are likely to strive

to maximize rewards and minimize costs. It doesn't necessarily imply deception or the creation of a false personality, but it also includes efforts to regulate what information is known and what is not known by others. Manago et al. (2015) depict social networks as digital environments of visual IM where individuals create flattering images of themselves, post sexually provocative posts to garner attention, and observe friends' photographs. Image-mediated social interactions on social networking sites foster an external perspective and can lead to vehicular positive or negative messages, thus placing major emphasis on the physical aspect for self-esteem or determining body shaming consequences.

The prominence of citations of research from the USA, Canada, UK, China and Australia (Fig.2) can be attributed to the structural alignment between national innovation ecosystems, academic infrastructure, and digital platform economies, due to the globally influential research institutions these countries host (Prokop et al., 2021; Liang and Li, 2023).

Furthermore, advanced economies array foremost levels of digital penetration and platform adoption (Acs *et al.*, 2021), and emergent economies, such as China, sustain mounting investments in advanced technologies, including artificial intelligence, blockchain, and immersive media (Wu *et al.*, 2020).

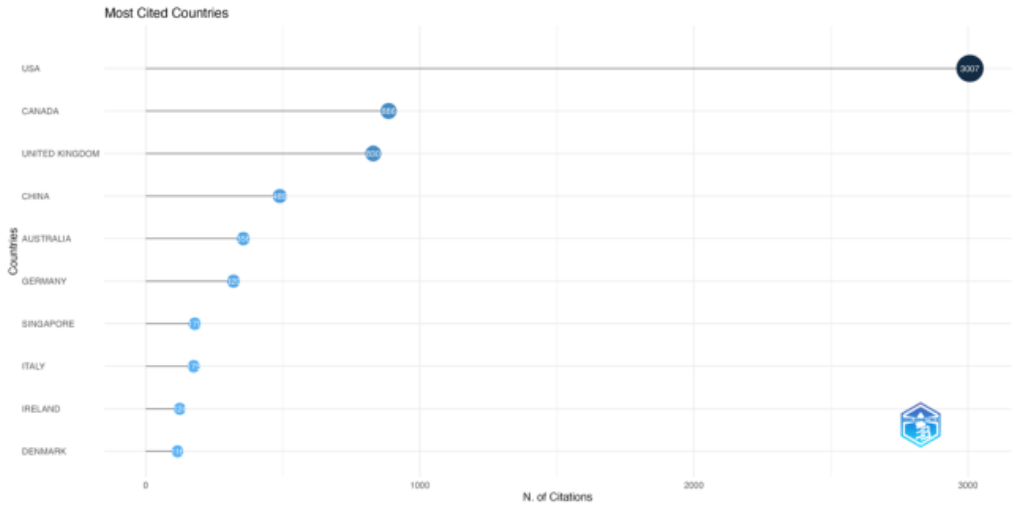


Figure 2 - Most cited countries

The most impactful sources are considered through the measure of total citations in Fig. 3 and underscore the interdisciplinary character of the academic production on digital IM, which predominantly spans the domains of psychology, behavioural science, communication studies, information science, and human-technology interaction. Leading journals such as *Computers in Human Behaviour*, *New Media and Society, Cyberpsychology, Behaviour, and Social Networking, Human Communication Research, New Media and Society*, and *Journal of Legislative Studies* signal a research orientation grounded in psychology and computer sciences. This distribution is consistent with the idea that IM, when mediated by emerging technologies, is frequently approached as a sociotechnical phenomenon rather than an economic or managerial function. The limited presence of business and management journals suggests that strategic management studies only marginally address the conceptual objective of IM as a data-intensive process embedded in digital affordances.

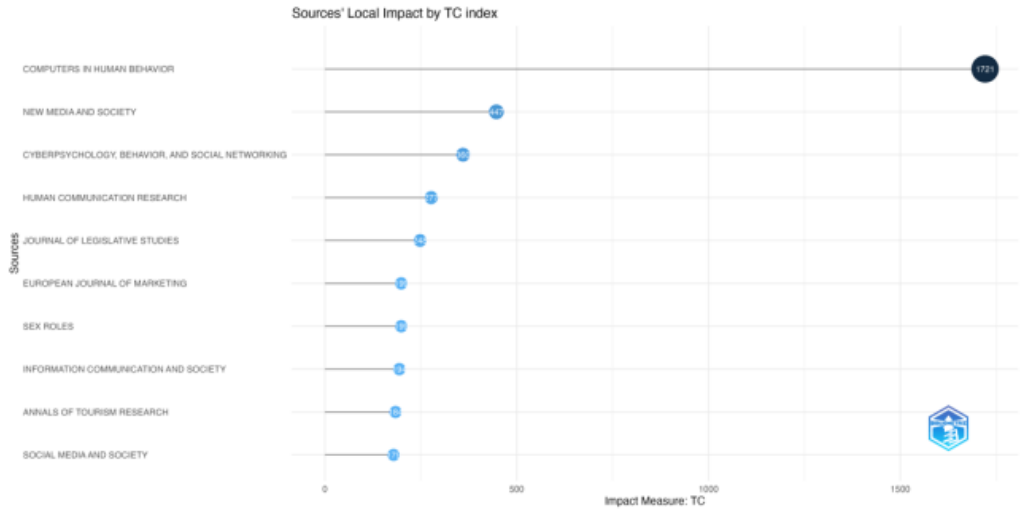


Figure 3 - Most cited sources

4 Network analysis

The network analysis was carried out through VOSViewer 1.6.20 software.

The most frequent authors' keywords are social media (145), impression management (134), self-presentation (54), social networks (27), and communication technologies (11).

Fig. 4 depicts the co-occurrence analysis of the authors' keywords, divided into four clusters:

- Red cluster: IM for identity construction through social media;
- Green cluster: technological augmentation of communicative credibility and authenticity;
- Blue cluster: branding, self-presentation, and user engagement through IM in the age of digital intermediation;
- Yellow cluster: socio-psychological dimensions of IM in digital contexts.

The red cluster involves studies aiming to capture how organizations and individuals leverage platforms such as social media to structure online self-presentation and identities.

From an organizational perspective, Suryani and Fernando (2023) and Schniederjans et al. (2013) examine how companies select the information they share with stakeholders through assertive tactics on social media and their impacts on organizational financial performance. From an individual perspective, Sukmayadi et al. (2024) analyse online identity construction mechanisms through impression management among TikTok influencers. Lo and McKercher (2015) focus on travel experience, which is increasingly shaped by visual content shared online, influencing expectations, engagement levels of tourists, and the symbolic value of destinations. IM strategies often encompass public perception orientation and political image building through self-promotion on social media to give stakeholders the desired image in professional contexts (Jackson and Lilleker, 2020).

The green cluster integrates research investigating the intersection between emergent technologies, particularly artificial intelligence and machine learning, and communicative performance. Technological attributes, anthropomorphism, attribution of human traits to technologies, and publicness are also considered as factors able to promote people's trust or as moderators (He et al., 2023; Suen and Hung, 2024). Gnewuch et al. (2023) and Li et al. (2024) investigated communication styles adopted by consumers when interacting with AI agents, demonstrating that individuals who perceive AI agents as judging entities are more inclined to adopt IM tactics to communicate.

The blue cluster underscores how impression management supports self-presentation and brand management through online professional networking, intending to promote consumer engagement and proactive positioning within competitive, influencer-driven contexts. Currently, IM is adopted in human branding in social media, where individuals apply strategic control, selection, and display of information to positively present themself to the audience, often through the creation of texts, photos, videos (Porto *et al.*, 2024). Similar online IM techniques are used for self-presentation to create an online professional identity to obtain social acceptance within the workplace (Nazzal, 2024). Companies utilize social network sites to interact with multiple online audiences (Marder et al., 2016). IM tactics are shaped by community elements like social norms, obligations, and shared rituals, which foster brand trust and reinforce customer loyalty within digital communities (Laroche *et al.*, 2012).

The yellow cluster includes studies evaluating the psychological consequences of technological communication on mental health and personality construction, especially among young people (Rosen *et al.*, 2013). It offers critical insights into the psychological pressures of excessive positivity (Salopek and Eastin, 2024), maintaining visibility and coherence across fragmented platforms and audiences (Fullwood *et al.*, 2020), and consequences that can lead to anxiety related to physical appearance needs and body shaming episodes (Manago *et al.*, 2015). Associated concerns of online IM are linked to privacy and self-esteem problems (Yang and Zhang, 2022).

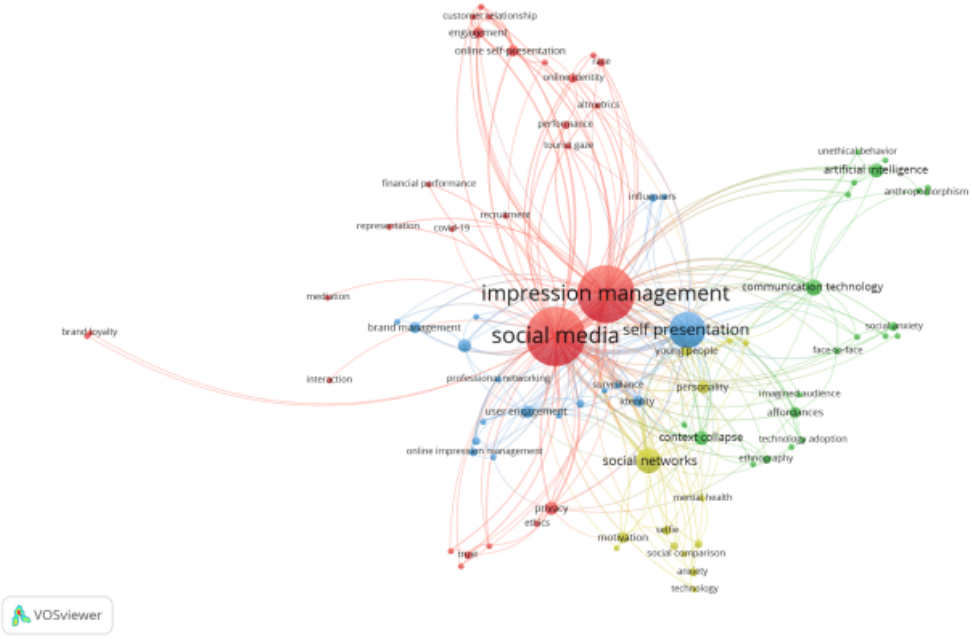


Figure 4 - Network visualization

5 Conclusion

5.1 Trend topics

A trend topic analysis has been performed through the Bibliometrix R package. The points in Fig. 5 represent the frequency of the terms, expressed as the median years in which the keywords most occur (Cosma and Rimo, 2024).

Early research in the field was predominantly tied up in platform-specific analyses as Facebook and Twitter, reflecting the early stage of social media's institutionalization as a site for strategic self-presentation. However, conceptual domains such as "self-presentation", "identity", "self-esteem", and "social media" gradually became prevalent, indicating that IM was no longer examined solely through the lens of platform affordances, but as a broader socio-economic and psychological phenomenon.

In the latter years, the emergence of terms such as "artificial intelligence" and "personal branding" denotes a critical point in the literature, whereby automated systems and intelligent technologies became agents and mediators of impression formation. Simultaneously, the continued prominence of "social networking" in recent years suggests a convergence between individual identity construction and platform-mediated visibility.

Therefore, a shift from a static consideration of IM towards more systemic perspectives occurs in the selected literature, integrating technology, behavioral, and social dimensions.

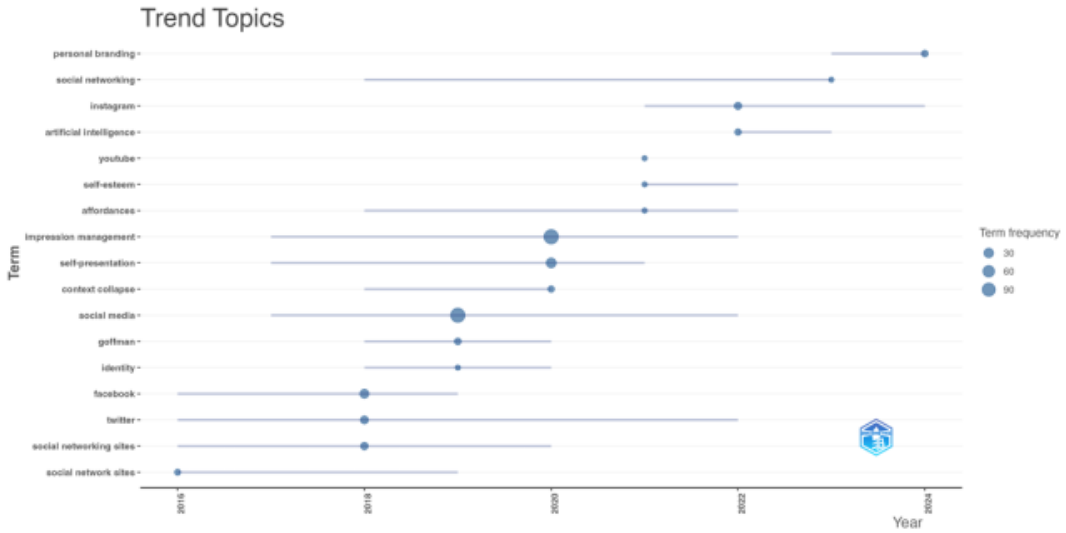


Figure 5 - Trend topics

5.2 Future research avenues and managerial implications

After depicting the actual trends in scientific production on the considered topic, a future research agenda is presented.

Table 1 illustrates possible research avenues by cluster.

Table 1 - Future research agenda

Clusters	Future research topics	Main references
Red cluster	• Provide solutions to use IM to promote multiple stakeholder engagement through social media; • Investigate the visual characteristics of videos/photos on social media which stakeholder engagement; • Further IM tactics, including indirect ones, should be considered in future studies, as they might be related to financial performance of organizations.	Jackson and Lilleker (2020); Suryani and Fernando (2023); Schniederjans et al. (2013)
Green cluster	• Explore unstructured online data as elements that can influence purchase decisions; • Analyze customer reviews for a deeper understanding of how impressions are managed and perceived during and after interactions; • Explore how the importance of online IM, including appearance, might vary depending on the market context; • Investigate AI methods to measure IM techniques in online content.	Yang et al. (2022); Korzynski et al. (2021)
Blue cluster	• Explore possible cultural factors affecting discursive practice in online IM practices; • Involve comparisons of the effects of IM tactics between different segments of human brands; • Identify indicators on human brands' earnings as a performance metric of IM tactics.	Sharifzadeh et al. (2021); Sun et al. (2023); Porto et al. (2024)
Yellow cluster	• Understand the range of perceptions users have toward social media content; • Consider the positive and negative impacts of perceived toxic positivity intentions resulting from social media consumption; • Explore the false self-presentation construct to include intent; • Determine what about IM usage in social media promotes mental health and what promotes psychiatric disorders; • Examine whether expressing oneself in sexualized ways in online spaces might be associated with less body shame and more sexual assertiveness.	Salopek and Eastin (2024); Rosen et al. (2013); Manago et al. (2015)

From a managerial perspective, the increasing centrality of AI-based tools, social media, and algorithmically mediated communication requires organizations to rethink their communication architectures. Additionally, the digitalization of stakeholder interactions introduces a new paradigm where credibility and authenticity must be engineered through hybrid communicative approaches as visual storytelling, interactive content, and automated personalized responses on multiple platforms, while maintaining message consistency and transparency. Furthermore, the study underlines the strategic value of IM for building brand communities, reinforcing customer loyalty, and facilitating stakeholder co-creation processes.

The present analysis provides current interdisciplinary perspectives and a future research agenda on the IM tactics usage in a context characterized by continuous technological mutation and digital communication evolution. However, some limitations emerge from the study. Firstly, the use of the Scopus database as a single source to extract articles limits the possibility of including other databases and the sample size. Moreover, the subjective inclusion of keywords and formulation of the query string contribute to restricting the generalizability of the results. Finally, the continuous evolution of the theme requires frequent refinement of considerations to reflect the state of the art and the constant change in communication practices and technological advancement.

6 Ethics declaration

Ethical clearance was not required for the research.

7 AI declaration

No AI tools were used to create or draft the scientific content of the manuscript.

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Integrating the Business Model Concept for the Development of Physicians' Dual Practice in Public Healthcare Delivery Systems

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Abstract

Background: Physicians' Dual Practice (PDP), defined as the concurrent provision of public and private healthcare services by the same physician, presents significant managerial challenges for public healthcare institutions. Its effective governance requires balancing public service obligations with private sector incentives.
Objective: This study aims to develop a comprehensive conceptual business model framework to support the development of PDP within public hospitals. The framework combines regulatory analysis, market evaluation, and the application of the Business Model Canvas (BMC) methodology.
Methods: An inductive approach was adopted, featuring a case study of Policlinico Tor Vergata (PTV), a major university hospital in Italy. The research integrates regulatory context analysis, K-means clustering for market segmentation, and the structured application of the BMC to assess and guide PDP management. Artificial Intelligence (AI) was examined as a strategic enabler to optimize operational processes.
Results: The findings underscore the centrality of regulatory frameworks, organizational governance models, and market dynamics in shaping PDP strategies. Clustering analysis revealed distinct strategic profiles among public healthcare organizations. Furthermore, the study highlights the pivotal role of AI technologies in optimizing waiting lists and balancing public-private service delivery.
Conclusion: By developing a structured and adaptable business model, this study provides actionable insights for policymakers and hospital administrators seeking to enhance the effectiveness of PDP initiatives. The integration of regulatory compliance, market responsiveness, and digital innovation emerges as essential for transforming PDP into a lever for strategic institutional development and improved healthcare delivery.

Keywords: Physicians' Dual Practice, Business Model Canvas, Public Hospital, Healthcare Management, Artificial Intelligence

Paper type: Academic Research Paper

1 Introduction

Physicians' Dual practice (PDP) is defined as the simultaneous engagement in both public and private healthcare services (WHO, 2024). This phenomenon is widespread across many health systems and can take several forms. Private services may be delivered externally, in independent facilities, or adjacent to public institutions, in physically connected but administratively separate spaces. Alternatively, they can be provided within public facilities, either outside regular operating hours or in an integrated manner, alongside public services—often in an informal or loosely regulated arrangement (McPake et al., 2016). PDP poses substantial challenges for public institutions, especially in reconciling public healthcare goals with physicians' financial interests. However, PDP is often considered a double-edged sword, as it also presents potential benefits (Ashmore and Gilson, 2015). Managing the contrasting impacts of PDP is a complex, multi-level challenge involving society, organizations, and individuals (Hipgrave and Hort, 2014). While policymakers set the general direction for healthcare strategies, hospital managers are tasked with adapting and implementing sustainable management tools (Jankelová, Joniaková and Mišún, 2024). Among these tools, business models have emerged as essential instruments, achieving global impact in driving companies' competitive success (Wirtz et al., 2016). All organizations, whether aware of it or not, operate within a business model; yet, public institutions often encounter greater challenges in its adoption (Lorenz et al., 2024). Among the various strategic management tools for business model design, the Business Model Canvas (BMC) (Osterwalder and Pigneur, 2010) has proven particularly valuable in the healthcare sector (Sibalija et al., 2021). Building on these insights, this paper aims to develop a comprehensive conceptual framework for a PDP business model. This framework integrates the BMC to systematically represent and analyse the organizational and strategic dimensions of PDP, with the goal of promoting robust management practices within healthcare institutions. The PDP business model considers the role of artificial intelligence (AI) as a lever to streamline waiting lists and strengthen the adaptability of PDP

management in complex settings (Almyranti et al., 2024). A single case study was conducted at Policlinico Tor Vergata (PTV), a university hospital located in central Italy, to validate the framework and assess its practical relevance.

This study is guided by the following research questions:

- RQ1: What are the key factors influencing PDP implementation in public healthcare?
- RQ2: How can a business model support the effective management of PDP in a public hospital?
- RQ3: How can AI address the challenges associated with PDP?

2 Method

This study adopts an inductive and exploratory method, aiming to develop new conceptual insights into the PDP management in public healthcare institutions. The research was conducted in three phases:

1. a comprehensive literature review on PDP and business models;
2. the development of a framework to design a PDP business model for a public organization;
3. the empirical validation of the framework through an empirical case study.

The first phase was conducted through a literature review on PDP and business models using the Scopus and Web of Science databases, which enabled the identification of key factors that are critical for the design of a PDP business model and informed the development of a conceptual framework (Barquet et al., 2013). In the second phase, the analysis revealed that effective PDP business model design requires an integrated framework that simultaneously addresses three core dimensions: regulatory conditions, market dynamics, and the business model configuration (Figure 1).

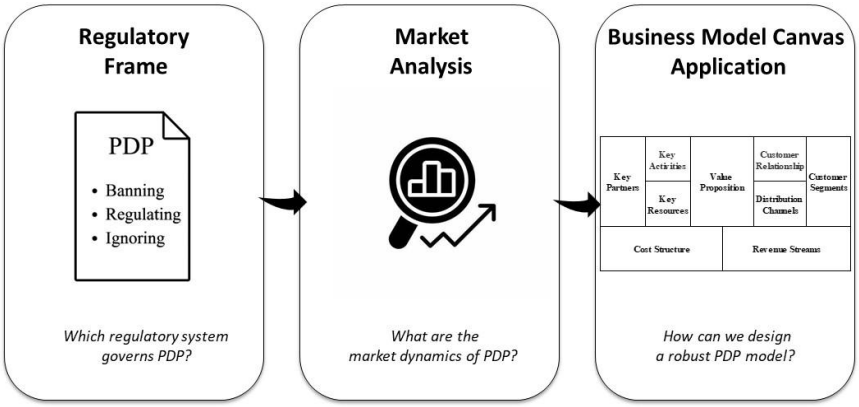


Figure 1: PDP business model framework

The first framework element is the study of the national law, which is crucial in shaping how PDP develops within specific country context (WHO, 2024). The second element focuses on understanding the dynamics of the PDP market, including institutional behaviours and regional variations.

The third element involves a structured business model design for PDP activities. Within the design of the PDP business model, the enabling role of AI is also considered, given its substantial potential to enhance healthcare management (Ali et al., 2022). The proposed framework lends itself to application across diverse regional settings.

In the third phase, following Yin (2018), the case study explores the phenomenon within its real-life context with unclear boundaries in which the PDP public and private activities intertwine within the same institution. The case study investigation was structured according to the three core components of the proposed framework. First, the institutional background was analysed through a review of PDP regulations in Italy. Second, the market environment was explored through an inferential statistical approach employing the K-means, a method for dividing a dataset into K non-overlapping clusters (James et al., 2013). Institutions were grouped based on similarity across three key variables: the total number of physicians (a proxy for structural size), the efficiency index (PDP revenue-to-cost coverage ratio), and the PDP revenue incidence (the share of total revenue generated through PDP). Prior to clustering, all numerical variables were standardized to ensure comparability. The objective of the K-means was to identify the most effective and efficient organizational models within the PDP services market in the case study region. The results of the K-means were related to the classification of organizational models. Structures were categorized into four types (A, B, C, D), depending on whether PDP activities fell under the responsibility of general management, administrative direction, medical direction, or human resources management, respectively. As a third step, the BMC was applied to PDP activities, with the

aim of mapping key organizational components, identifying strategic choices, and highlighting potential areas for improvement. Data collection during the case study involved both the consultation of publicly available 2022 datasets provided by the Italian Ministry of Health (Ragioneria Generale dello Stato, 2025) and direct interviews with key stakeholders. Although grounded in empirical evidence, the study maintains a conceptual orientation, consistent with Jaakkola's classification (2020), pursuing an explicating objective by defining PDP as a distinct managerial phenomenon and offering a structured model to guide its strategic management.

3 Application outcomes

This section is organized according to the three methodological phases: (1) Literature review; (2) Framework for designing a PDP business model; and (3) Empirical validation: PTV case study.

3.1 Phase 1: Literature review

Concerning PDP in public healthcare, most studies emphasise that the primary physicians' driver for PDP is financial, stemming from the significant disparity between public sector salaries and their expected earnings (Ferrinho et al., 2004). Non-pecuniary factors also play a critical role: limited career progression (Matiwane, Blaauw and Rispel, 2023), prestige increase (Bayat et al., 2018), greater autonomy (Barros and Olivella, 2005), and improved access to resources (Bayati et al., 2020). The literature reports that the negative effects of PDP generally outweigh the positive ones, although the overall balance remains unclear (Socha and Bech, 2011). Conflicts of interest can lead to absenteeism (Yu et al., 2020), misuse of public resources (Eggleston and Bir, 2006), and cream-skimming based on patients' income or case complexity (Moghri et al., 2017). Moreover, PDP often compromises the quality of public healthcare services (Ashmore and Gilson, 2015). Positive effects are also identified: an increase in physicians' overall labour supply and physicians' retention within public sector (Matiwane, Rispel and Blaauw, 2025).

Governments can adopt three main approaches to address PDP outcomes: they can choose to ignore it, attempt to manage it, or impose a ban (WHO, 2024). The complete prohibition of PDP is rare, and currently, it is only implemented in Canada (Flood and Bryan, 2018). Banning PDP risks pushing physicians toward the private sector or incentivizing their migration abroad, further aggravating shortages of skilled medical personnel in the public system. The existing literature on PDP management is fragmented and largely descriptive (García-Prado and González, 2011; WHO, 2024). Research concerning patients and hospital managers is particularly scarce despite these groups being significantly impacted by PDP (Huang et al., 2023). This gap highlights the need for a comprehensive business model framework to clarify managerial and organizational impacts of PDP and guide evidence-based strategies to reduce risks and enhance potential benefits in healthcare institutions.

Business models explain the logic behind how an organization generates, delivers, and captures value (Osterwalder and Pigneur, 2010). They are conceptual tools that enable organizations to comprehend their business configurations (Lorenz et al., 2024). Profit-oriented enterprises widely acknowledge that a clear articulation of their business model contributes to the enhancement of competitive advantage and the improvement of financial performance (Snihur and Eisenhardt, 2022). Public institutions must also strategically orient their activities and adopt specific business models but they face increasing challenges in utilizing them as managerial tools (Schedler, 2023). Business models have traditionally emerged within the domain of private enterprises; nevertheless, public management literature increasingly endeavours to adapt and apply these frameworks to the context of public sector organizations. One of the most prominent examples of this cross-sectoral adaptation is the BMC (Osterwalder and Pigneur, 2010). It consists of nine interrelated building blocks that outline how an organization creates, delivers, and captures value. Researchers and practitioners see its potential to improve transparency, align strategies, and foster innovation in public services, adapting its elements to focus on public value instead of profit and to meet the specific needs of public institutions (Lorenz et al., 2024). The BMC proves also particularly suitable for application in the healthcare sector, as it enables the design of patient-centred models by incorporating the perspectives of all key stakeholders (Sibalija et al., 2021).

3.2 Phase 2: Framework for designing a PDP business model

Building on the literature review, the objective is to develop a generic and adaptable business model suitable for PDP implementation within public sector organizations (RQ2). Following the steps outlined in Figure 1, the first task is to identify, based on the specific context, the regulatory framework governing dual practice and the market dynamics influencing physicians' behaviour. Physicians' decisions to engage in PDP are shaped by supply and demand factors, as well as by the degree of separation between public and private markets (Russo et al., 2014). Analysing these dynamics is crucial for designing PDP business models. Building on these analyses, the

final phase focuses on translating these insights into a structured business model. Using the BMC, this phase defines how the PDP initiative creates, delivers, and captures value for a public health institution. The nine BMC elements have been specifically adapted to reflect the distinctive features of dual practice within the public sector context, as following:

- *Value Proposition* centres on providing patients with timely and scheduled access to highly qualified medical specialists, while enabling them to exercise choice in selecting their preferred physician within the public healthcare facility.
- *Key Partners* include public healthcare institutions (e.g., research centres and the Ministry of Health), health insurance providers, private healthcare organizations affiliated with the NHS, private companies offering employee healthcare, and technology companies specializing in AI systems.
- *Key Activities* involve the provision of private medical services within public facilities and the optimization of patient scheduling through AI-based systems to reduce waiting lists and improve efficiency (RQ3).
- *Key Resources* include public-employed medical staff, retired physicians who continue offering consultancy services, AI technologies used for scheduling support, and public spaces dedicated to PDP.
- *Customer Relationships* are built through personalized care and continuity. They can be enhanced by digital platforms that tailor information and reminders to patient needs.
- *Distribution Channels:* In the PDP model, services are accessed through national booking systems, hospital-managed desks or telephone lines, web scheduling platforms, and AI-powered virtual assistants that facilitate appointments.
- *Customer Segments:* PDP primary customer segments include patients seeking faster access to specialized care, patients who prefer to choose their physician, and individuals covered by private insurance.
- *Revenue Streams* derive from direct out-of-pocket payments by patients, reimbursements from private insurance companies, and bilateral agreements with private companies for employee healthcare coverage.
- *Cost Structure* includes staff salaries and compensation for private activities, operational expenses for facility/equipment use, and investments in AI technologies.

The proposed framework identifies the key factors influencing the implementation of PDP in public healthcare, namely the regulatory context, the market environment, and the business model (RQ1). In particular, faster access to care and the integrated management of human resources, supported by AI-driven systems, emerge as highly strategic elements. In this regard, the integration of artificial intelligence into the design and delivery of public services represents a critical enabler for improving both operational efficiency and service quality across public sector domains (Fatima et al., 2022).

3.3 Phase 3 Empirical validation: PTV case study

The case study offers a detailed account of the results emerging from the application of the framework's three phases (Figure 1). The PTV is a multidisciplinary public hospital in Rome that serves a population of over 1.5 million inhabitants and operates in cooperation with the University Tor Vergata. As of 2022, the facility employed approximately 1,550 staff members, of whom 197 were physicians. It also reported 455 beds and gross annual revenues of 213.8 million euros, of which 6.3 million were generated through PDP activities (Policlinico Tor Vergata, 2022). The hospital is located in Italy, one of the G7, the seven most advanced economies in the world (United Nations, 2025). The Italian National Health Service (NHS) ensures universal healthcare coverage for all citizens and is characterized by a high degree of decentralization, with the twenty regions holding responsibility for the organization of healthcare (De Belvis et al., 2022). Between 2018 and 2022, government transfers funded about 74.5% of Italy's total health expenditure, while out-of-pocket and voluntary payments covered the remaining 25.5%, indicating persistent difficulties in ensuring timely access to public healthcare services (World Health Organization, 2025).

3.3.1 Regulatory Frame

In Italy, PDP public sector physicians are allowed to engage in private practice either within public facilities or externally. Physicians are entitled to receive the exclusivity allowance only if they perform private practice within the premises of their public healthcare institution or in a private facility formally affiliated with it. Healthcare entities are required to ensure that PDP does not interfere with institutional activities, maintaining a balance between the two and guaranteeing that the volume of services provided under private arrangements does not exceed that of ordinary public service delivery (Italian Republic, 1992). The regulation of PDP follows a

progressive and multi-level approach that starts with national legislation, continues through regional regulations, and is completed with specific institutional protocols. While the initial rationale for permitting PDP was also primarily to safeguard the patient's right to choose their physician (Italian Ministry of Health, 2025a), more recent policy orientations have progressively reinterpreted PDP as a strategic instrument for improving the management of waiting lists (Italian Ministry of Health, 2025b).

3.3.2 Market Analysis

The Italian healthcare system is organized on a regional basis, with each region independently regulating the provision of healthcare services (De Belvis et al., 2024). The market analysis focuses specifically on the Lazio region, where PTV is located. Given its central geographic position and demographic importance, Lazio offers a strategic context for examining the implementation and governance of PDP, serving as a representative foundation for subsequent nationwide analyses. Of the 18 public healthcare facilities in the region, 17 were analysed, excluding one outlier due to its atypical size and limited PDP activity. The K-means analysis was based on normalized values for structural size (number of physicians), economic efficiency (defined as the revenue-to-cost coverage ratio), and the incidence of PDP (the proportion of revenue generated from physicians' private practice within the public system). The analysis revealed two distinct clusters (Figure 2).

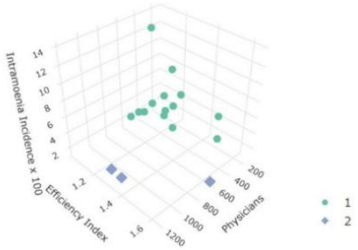


Figure 2: K-means clustering

Most facilities are grouped in Cluster 1, which includes small to medium-sized hospitals such as PTV (Table 1). These organizations vary in size, with the number of physicians ranging from 125 to 734. Their efficiency levels span from 1.04 to 1.51, suggesting a moderate capacity to cover PDP costs through revenue streams. The incidence of PDP ranges widely from 1.02% to 14.02%, indicating substantial variability in how facilities leverage PDP as a complementary revenue source. PTV is characterized by a low PDP revenue incidence (2.95%) and a reasonable efficiency index (1.18). These features suggest that there is untapped potential to further expand the PDP as a lever for economic optimization and strategic positioning. Cluster 2, in contrast, includes a limited number of large and economically high-performing facilities. These institutions have between 628 and 1200 physicians and demonstrate higher levels of efficiency, with indices ranging from 1.34 to 1.65, while keeping PDP incidence low (between 1.42% and 3.28%). Two of the three facilities in this cluster are governed under Model B (Administrative Direction), which appears particularly suited for complex, high-volume operations.

Table 1: Clustered Data

Facility	Physicians	Efficiency	Incidence	Organizational_Model	Cluster
I. Fisioterapici Ospitalieri	287	1,28	6,04	A - General Directorate	1
Policlinico U. I	558	1,13	3,79	B - Administrative Direction	1
Roma 4	254	1,51	5,5	B - Administrative Direction	1
Viterbo	473	1,18	14,02	B - Administrative Direction	1
PTV	197	1,18	2,95	C - Medical Direction	1
San Camillo-Forlanini	734	1,28	6,55	C - Medical Direction	1
S.Giovanni/Addolorata	485	1,28	5,15	C - Medical Direction	1
Sant`Andrea	303	1,17	4,89	C - Medical Direction	1
Spallanzani	125	1,46	1,02	C - Medical Direction	1
Rieti	330	1,24	9,08	C - Medical Direction	1
Roma 3	332	1,25	1,52	C - Medical Direction	1
Roma 5	518	1,04	1,92	C - Medical Direction	1
Frosinone	680	1,38	6,86	D - Human Resources Direction	1
Latina	590	1,25	6,42	D - Human Resources Direction	1
Roma 1	1133	1,36	1,91	B - Administrative Direction	2
Roma 2	1200	1,34	3,28	B - Administrative Direction	2
Roma 6	628	1,65	1,42	C - Medical Direction	2

PTV presents a distinctive profile within Cluster 1. With 197 physicians, it is among the smaller facilities in terms of staff size. Its efficiency index stands at 1.18, placing it near the lower end of the cluster's performance range. This suggests a limited ability to generate revenues sufficient to cover operating costs, which may reflect structural, managerial, or contextual constraints. Moreover, the incidence of PDP is relatively low at 2.95%, significantly below the cluster's upper values. This limited reliance on private practice revenues may indicate unexploited potential in terms of strategic development and resource optimization. Given its status as a university hospital with specialized services, PTV may be well-positioned to strengthen its PDP offering and explore governance models that enhance both efficiency and financial sustainability. We hypothesize that PTV could benefit from a strategic transition from its current Model C (Medical Direction) toward Model B (Administrative Direction), to support the expansion and integration of PDP activities within the hospital's broader governance structure. Adopting a governance model under the Administrative Direction offers a more strategic and integrated approach to managing PDP services, enabling improved resource allocation, financial oversight, and alignment with institutional objectives.

3.3.3 Strategic and Organizational Design of a PDP business model at PTV

The application of the BMC to the PDP at PTV outlines a model integrating private medical services within a public healthcare facility (Figure 3). The value proposition combines timely access to skilled physicians, patient choice, and care within a safe hospital setting, while enhancing physician retention and institutional loyalty. The interviews confirmed that physician retirement represents a critical factor, and the possibility of involving retired doctors in private practice through PDP could help mitigate the loss of institutional knowledge and clinical expertise. Key partnerships with the Lazio Regional Authority, Tor Vergata University, and insurance providers strengthen operational and financial sustainability. Key activities include personalized services delivery and could be integrated with AI-based scheduling systems to improve access and comply with national regulations, limiting private workload to 50% of a physician's total workload. Key resources involve active and retired public physicians, supported by dedicated support staff and medical equipment, alongside robust digital infrastructure. PTV addresses a broad patient base, including individuals from neighbouring regions, via digital and in-person channels. Revenue streams are diversified across patient payments, insurance reimbursements, institutional agreements, and corporate healthcare contracts, while the cost structure reflects investments in staff, facilities, technology, and training.

The developed model offers a viable path to balance public healthcare goals with private service delivery, in line with recent legislation promoting AI and a unified national booking system to reduce waiting times and improve service accessibility (Italian Republic, 2024). Given this complexity, a shift in PDP governance from the Medical Direction to the Administrative Direction would allow for a more strategic and financially integrated approach, supporting expansion into specialized services, such as high-end care for international clients based in Rome. The BMC, viewed within the regulatory and market context, underscores PTV's strong potential to expand PDP, especially given current gaps in efficiency and strategic positioning compared to regional competitors.



Figure 3: The PTV Business Model Canvas

4 Discussion

Business models are simplified representations of the relevant activities of a company (Wirtz et al., 2016), and at the same time, they embed strategies, operations, and relationships that define their business logic (Barquet et al., 2013). Following this approach, our study offers a structured lens to PDP business models and considers regulatory, market, and operational dimensions to define how value is created and distributed within public healthcare systems. The integration of the legislation within the framework allows for the contextualization of PDP within the national and regional environment, providing clarification of how the regulations can shape the final market landscape (WHO, 2024). Allowing PDP can enhance social welfare by attracting and retaining skilled physicians; however, concerns persist that it may harm public sector service quality (Eggleston and Bir, 2006). The issue of controlling the division of dual practitioners' activities between public and private services could be addressed through the implementation of AI-driven scheduling systems, as they optimize resource allocation, improve appointment management, and help ensure a balanced distribution of physicians' workloads (Knight et al., 2023).

The conceptualization and implementation of business models are the result of a complex interplay among institutional frameworks, organizational characteristics, and market conditions (Yadav, Singh and Prusty, 2025). In the field of healthcare services, strategic positioning depends on both internal configuration and external responsiveness (Purcarea, 2019). In this study, the market analysis proved to be a fundamental step in designing the PDP business model and in finding a more suitable organizational model. The strategic profiling resulting from the clustering analysis confirmed that organizational size, efficiency, and PDP incidence are interdependent variables that shape PDP's success within public hospitals. Shifting PDP governance from the Medical Direction to the Administrative Direction would provide a more strategic, integrated approach to scale PDP effectively.

Overall, our findings confirm that PDP can be effectively managed within public healthcare institutions through the adoption of tailored business models that balance regulatory compliance, market responsiveness, and operational innovation.

5 Conclusion and Future Directions

This study proposed a framework to support the development of PDP in public healthcare, combining regulatory analysis, market evaluation, and the BMC. The case study of PTV showed how a structured approach can enhance PDP management, retain skilled physicians, and improve financial sustainability. AI emerged as a key enabler to optimize scheduling and balance public and private service delivery. Future research should validate the framework in different contexts and explore the long-term effects of AI integration on service quality and institutional efficiency. Further policy studies could assess how new regulatory and technological innovations shape the scalability of PDP models within public healthcare systems.

6 Ethics declaration

Ethical clearance was not required for the research.

7 AI declaration

AI tools were employed solely for language refinement purposes.

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From Innovation to Integration: A Bibliometric-Systematic Review of Digital Therapeutics and Their Impact on Healthcare

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Abstract

Digital therapeutics (DTx) are an emerging class of evidence-based software interventions developed to prevent, manage, or treat medical conditions. Their increasing application across clinical settings reflects their potential to improve healthcare accessibility, enhance patient engagement, and support better treatment outcomes. When combined with artificial intelligence (AI), DTx can offer advanced capabilities such as real-time monitoring, personalised interventions, and predictive analytics, further strengthening its clinical impact. However, despite these technological advancements, widespread adoption remains limited due to persistent challenges in regulatory compliance, integration within clinical workflows, and the lack of standardised frameworks for evaluating effectiveness. This study presents a systematic literature review conducted according to PRISMA guidelines to explore the empirical landscape surrounding the implementation, ethical integration, and assessment of DTx within healthcare systems. From an initial pool of 1,951 records, 114 peer-reviewed studies met the inclusion criteria. The analysis identified three central research gaps: first, barriers to integration arising from limited acceptance by healthcare providers and patients; second, unresolved ethical and regulatory issues related to AI use, particularly concerning data privacy, algorithmic bias, and transparency; and third, the absence of consistent clinical benchmarks for evaluating DTx across different therapeutic areas. Bibliometric and thematic analyses reveal a rapidly expanding body of literature, with increasing attention to mental health and chronic disease management. AI integration stands out as a promising yet insufficiently validated DTx dimension. These findings highlight the need for unified regulatory approaches, robust ethical oversight, and interdisciplinary collaboration to support digital therapeutics' safe and effective integration into routine clinical care.

Keywords: Digital therapeutics, DTx, Digital transformation, Healthcare, Artificial Intelligence

Paper type: Academic Research Paper

1 Introduction

Digital therapeutics (DTx) represent an emerging category of evidence-based interventions using digital approaches to prevent, manage, or treat medical conditions (Fürstenau et al., 2023). These solutions provide structured, clinically validated therapies that can supplement or, in some cases, replace conventional medical treatments. Their ability to enhance healthcare accessibility, patient engagement, and clinical outcomes has fuelled growing interest across various medical fields (Jeon et al., 2023; Phan et al., 2023). However, the field continues to evolve, facing challenges related to regulatory frameworks, standardisation, and seamless integration into healthcare infrastructures. As DTx expands, regulatory frameworks adapt to ensure clinical efficacy and patient safety. In some countries, such as Germany, digital therapeutics are now prescribed similarly to pharmaceutical treatments, underscoring the importance of scientific validation and compliance with medical device regulations (Fürstenau et al., 2023). The effectiveness of these interventions depends not only on their technological sophistication but also on their acceptance by healthcare providers and patients (Carrera et al., 2024, 2023; Sestino and D'Angelo, 2023). One major hurdle remains their integration into existing clinical workflows, particularly ensuring interoperability with electronic health records and adherence to regulatory guidelines, which are crucial for widespread adoption.

In parallel, artificial intelligence (AI) is reshaping multiple sectors, including healthcare, driving advancements in diagnostics, precision medicine, and operational efficiency (Dal Mas et al., 2023; Meyer et al., 2024). AI also transforms digital health, facilitating more efficient and accessible healthcare delivery (Mauro et al., 2024). While AI is not inherently the foundation of digital therapeutics, its integration is increasingly enhancing these interventions by enabling data-driven personalisation and predictive analytics (Hong et al., 2021).

AI-powered digital biomarkers and real-time monitoring technologies introduce new opportunities for tailored DTx interventions, ensuring that treatments dynamically adapt to individual patient needs (Palanica et al., 2020). By leveraging AI, digital therapeutics can refine treatment pathways, optimise patient adherence, and provide more precise clinical recommendations. However, despite these promising developments, AI-enabled DTx still requires further validation regarding data quality, clinical efficacy, and implementation feasibility (Çetin,

2024; Mauro et al., 2024). Addressing these challenges will be critical to unlocking AI's full potential in enhancing digital therapeutics and driving their integration into mainstream healthcare.

This study aims to clarify the current state of the art about three key research gaps and key challenges affecting the development and adoption of DTx in real-world healthcare systems. First, despite the growing number of digital therapeutic applications, real-world implementation remains challenging, particularly regarding patient engagement and healthcare provider acceptance. Understanding the behavioural and institutional barriers that hinder adoption can inform strategies to improve integration into existing healthcare systems. Second, while AI integration holds promise for enhancing DTx personalisation, the ethical and regulatory challenges surrounding data privacy, bias mitigation, and transparency remain unresolved. Ensuring that AI-driven DTx aligns with medical guidelines and patient safety requirements is crucial for long-term sustainability. Third, there is a lack of standardised evaluation metrics for assessing the effectiveness of DTx interventions across different medical conditions. Although various digital therapeutic solutions have demonstrated positive outcomes, the absence of universally accepted clinical benchmarks limits comparability and broader adoption. In light of these challenges, this review seeks to address the following question:

- *What is the current empirical evidence on the key challenges affecting the implementation, ethical integration, and evaluation of digital therapeutics in real-world healthcare systems?*

2 Methodology

This study carried out a systematic literature review in alignment with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework (Moher et al., 2009). PRISMA's sequential architecture, i.e., identification, screening, eligibility, and inclusion, ensured that every procedural step was transparent and replicable. In the identification phase, a deliberately expansive research query was designed, capturing the widest feasible landscape of academic contributions (Marzi et al., 2025). Titles and abstracts were then examined during screening to cull extraneous records. The papers retrieved in this triage proceeded to full-text assessment, where eligibility was adjudicated against a priori criteria. Only studies satisfying all requirements were retained in the inclusion stage, thereby crystallising the final analytical corpus and safeguarding internal validity through rigorous inspection. The selected keywords' relevance lies in the study's conceptual pillars: digital therapeutics and healthcare. The research query used in this study is:

(dtx OR "digital therapeutic" OR "digital therapeutics" OR samd OR "software as a medical device") AND (healthcare OR "health care" OR "digital health")

The first component of the query, "dtx", "digital therapeutic", "digital therapeutics", "SaMD", and "software as a medical device", targets the core technological artefacts under investigation. These terms are not merely synonymous but reflect the pluralism of language across domains. "Digital therapeutics" has emerged as the dominant term within the academic literature and industry communications to refer to software-driven interventions that are evidence-based and intended to treat, manage, or prevent medical conditions. Its acronym, "DTx", is frequently used in scientific abstracts and grey literature, especially in the context of start-ups and technology evaluation. Similarly, "software as a medical device" (SaMD), introduced by the International Medical Device Regulators Forum (IMDRF) and adopted by regulatory bodies such as the FDA, anchors the technological artefact within a specific legal and governance framework. Including the abbreviation ("SaMD") and its complete form ensures sensitivity to terminological variance across policy, clinical, and technical domains. The second component, "healthcare", "health care", and "digital health", anchors the technological focus within its operational domain. While "healthcare" and "health care" are used interchangeably across databases and journals, their inclusion ensures that stylistic or typographic inconsistencies do not limit retrieval. More importantly, "digital health" captures the broader ecosystem in which digital therapeutics are developed and deployed. It reflects the ongoing digital transformation of healthcare systems and encompasses topics such as telemedicine, remote monitoring, and integrated data infrastructures, contexts that frequently intersect with or enable digital therapeutics.

The review was guided by the research question presented in Section 1 and the inclusion and exclusion criteria developed accordingly. The inclusion and exclusion criteria are inspired by the definition of digital therapeutics proposed by Füsternau et al. (2023), which frames DTx as regulated, evidence-based software interventions designed to treat, manage, or prevent medical conditions within clinical care pathways. Accordingly, studies were included if they presented empirical data, qualitative, quantitative, or mixed-methods on the implementation, ethical integration, or evaluation of DTx in real-world healthcare settings. Eligible studies addressed challenges such as regulatory compliance, clinical workflow integration, data governance, patient engagement, or ethical concerns like transparency and equity. On the other hand, studies were excluded if they focused solely on technical development (e.g., algorithm design) without healthcare system context or if they

addressed digital health tools that did not meet the criteria for DTx (e.g., general wellness apps). Evidence was drawn from Scopus, Web of Science and PubMed, repositories widely recognised for their multidisciplinary breadth and bibliometric robustness. Table 1 summarises the inclusion and exclusion criteria as well as the databases used in this study.

Table 1: Inclusion and Exclusion Criteria

Databases and Parameters	Inclusion Criteria	Exclusion Criteria
Scopus, Web of Science and PubMed **Search in: Title, Abstract and keywords** **Document type: Peer-reviewed Journals** **Language: English** **Last retrieval date: February 21st, 2025**	• Empirical studies examining the implementation, ethical integration, or evaluation of digital therapeutics (DTx) within real-world healthcare settings. • Research addressing system-level challenges, including organisational, regulatory, ethical, or clinical dimensions of DTx use. • Studies involving regulated or clinically oriented digital therapeutics, as opposed to general wellness or consumer health apps.	• Studies focused solely on technical development, algorithm design, or proof-of-concept trials without a healthcare system context. • Research on digital health tools not aligned with the definition of digital therapeutics. (REF)

3 Results

The PRISMA flow diagram outlines the structured selection process conducted in this study. A total of 1,951 records were identified across Scopus (n = 717), Web of Science (n = 498), and PubMed (n = 736). After removing 907 records due to duplication, language, or lack of peer review, 1,044 unique records remained. Following title and abstract screening, 695 records were retained, with 349 excluded for irrelevance. A second screening stage excluded another 368 records, leaving 327 full-text articles for eligibility assessment. Of these, 212 were excluded, primarily due to misalignment with the inclusion criteria. The review included 114 studies, representing a focused body of empirical research on the implementation, ethical integration, and evaluation of digital therapeutics in real-world healthcare systems. Figure 1 summarises the results for each phase of the review process.

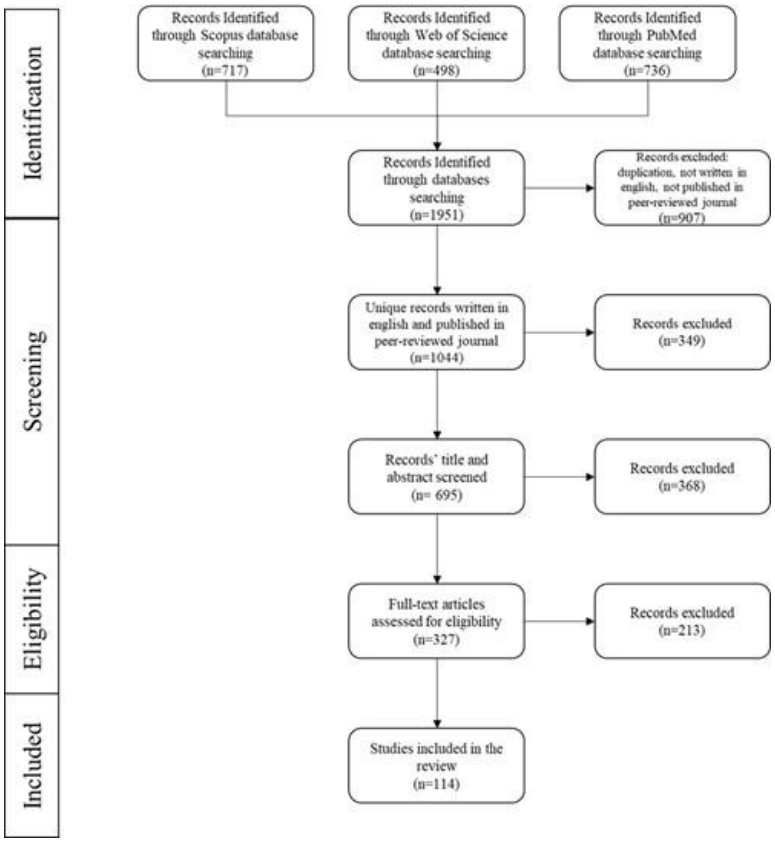


Figure 1: The PRISMA flow diagram

3.1 Bibliometric Analysis

Figure 2 presents the annual distribution of publications included in the final corpus, covering the period 2018 to early 2025. The data reveal a marked escalation in research output on digital therapeutics, particularly from 2021 onward. After a relatively modest presence between 2018 and 2020 (with annual outputs of 1, 3, and 5 publications, respectively), the volume increased substantially, peaking in 2024 with 36 contributions. The polynomial trendline suggests a non-linear, accelerating growth trajectory, indicative of a rapidly intensifying research agenda. This inflexion coincides with broader shifts in healthcare innovation policy, regulatory interest in software-based interventions, and the structural integration of digital modalities into clinical practice, especially after COVID-19. Although the figure for 2025 (n=12) appears lower, this is likely a function of the partial year of data collection rather than a genuine decline. These dynamics point to an emergent research field in accelerated consolidation, marked by increasing publication density and thematic diversification.

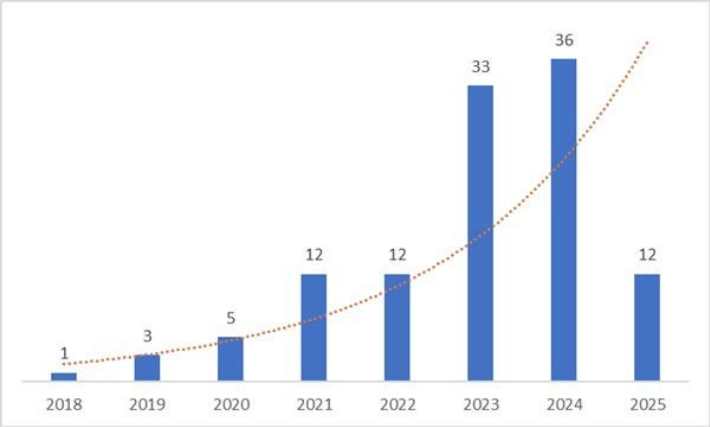


Figure 2: Papers distribution per year

Table 2 shows the distribution of articles across journals, revealing a concentration of scholarly output in a small number of specialised outlets, alongside broader dispersion across a wide array of secondary venues. The Journal of Medical Internet Research (JMIR) accounts for the largest share of included studies (n = 17), reaffirming its role as a leading platform for digital health scholarship. This is followed by Digital Health (n = 13) and JMIR mHealth and uHealth (n = 6), both of which are strongly positioned within the digital therapeutics and mobile health domains.

Several other journals make moderate contributions to the literature, including Frontiers in Digital Health (n = 5), BMC Health Services Research (n = 4), and Healthcare (n = 3), reflecting the interdisciplinary nature of the field and its linkages to health services, informatics, and public health. A number of journals—such as Clinical Pharmacology and Therapeutics, Technological Forecasting and Social Change, and Psychiatry Research—are represented by two papers each, suggesting the field's gradual diffusion into adjacent disciplinary spaces, including pharmacology, technology management, and mental health.

Table 2: distribution of articles across journals

Journal	**# Papers**
Journal of Medical Internet Research	17
Digital Health	13
Jmir Mhealth and Uhealth	6
Frontiers in Digital Health	5
BMC Health Services Research	4
Healthcare	3
Clinical Pharmacology and Therapeutics	2
Clinicoeconomics and Outcomes Research	2
Healthcare Informatics Research	2
Jmir Formative Research	2
Jmir Human Factors	2
Psychiatry Research	2
Technological Forecasting and Social Change	2
Other	52

3.1.1 Keywords Co-occurrence analysis

Figure 3 illustrates a keyword co-occurrence network (Aria and Cuccurullo, 2017). Using author-assigned keywords from the final corpus, the map visualises the frequency and co-occurrence relationships between key terms, with node size reflecting relative frequency and edge thickness denoting the strength of association. Colour-coded clusters were generated through modularity-based clustering to identify thematic domains within the broader research landscape.

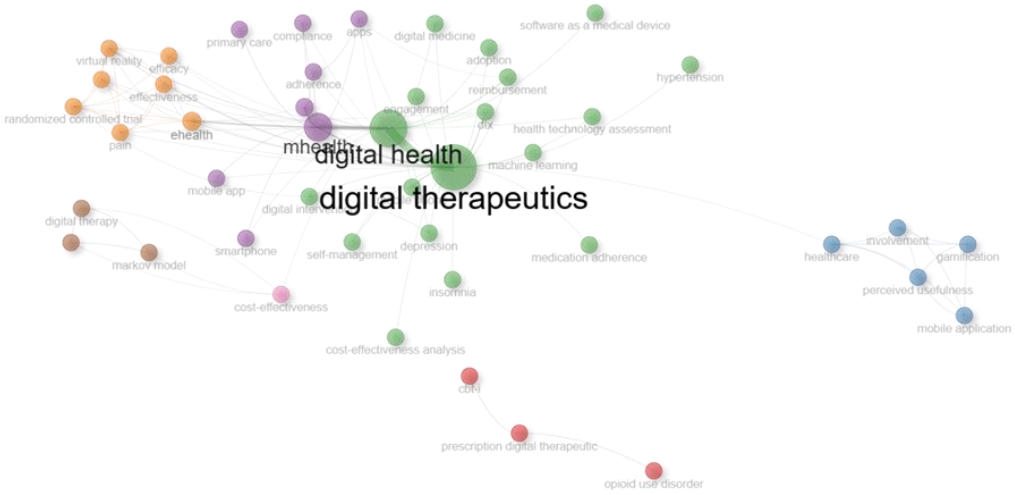


Figure 3: Co-occurrence analysis

At the core of the network, digital therapeutics and digital health emerge as dominant, highly interconnected terms, underscoring their integrative role in structuring discourse across clinical, technological, and institutional contexts. Surrounding this conceptual centre are several densely populated and thematically coherent clusters, reflecting the most developed areas of the field. The green cluster focuses on implementation and policy, featuring terms such as reimbursement, health technology assessment, adoption, and software as a medical device. This indicates a well-established concern with the system-level integration of DTx, regulatory frameworks, and pathways to market access. The orange cluster centres on clinical validation, with keywords including randomised controlled trial, efficacy, and virtual reality, signalling a strong empirical emphasis on outcome measurement and trial-based evaluation. In purple, a third major node group reflects technological delivery platforms and user adherence mechanisms, clustered around terms such as apps, mobile app, smartphone, and compliance. In contrast, less developed or emerging areas are positioned at the periphery of the network. The blue cluster, comprising terms like gamification, perceived usefulness, and involvement, represents growing but still marginal attention to behavioural design and user experience. Similarly, the red cluster highlights niche clinical applications, such as opioid use disorder, that, while promising, remain relatively underrepresented in the broader discourse. Other peripheral terms, including Markov model, cost-effectiveness, and medication adherence, suggest underexplored intersections with health economics and longitudinal outcome tracking.

3.1.2 Thematic map

Figure 4 presents a thematic map derived from a keyword co-occurrence analysis of the final set of studies included in the systematic review. The map was generated using Biblioshiny based on a co-occurrence network of author keywords (Aria and Cuccurullo, 2017). It applies centrality and density metrics to visualise thematic clusters' structural relevance and developmental maturity within the literature on digital therapeutics.

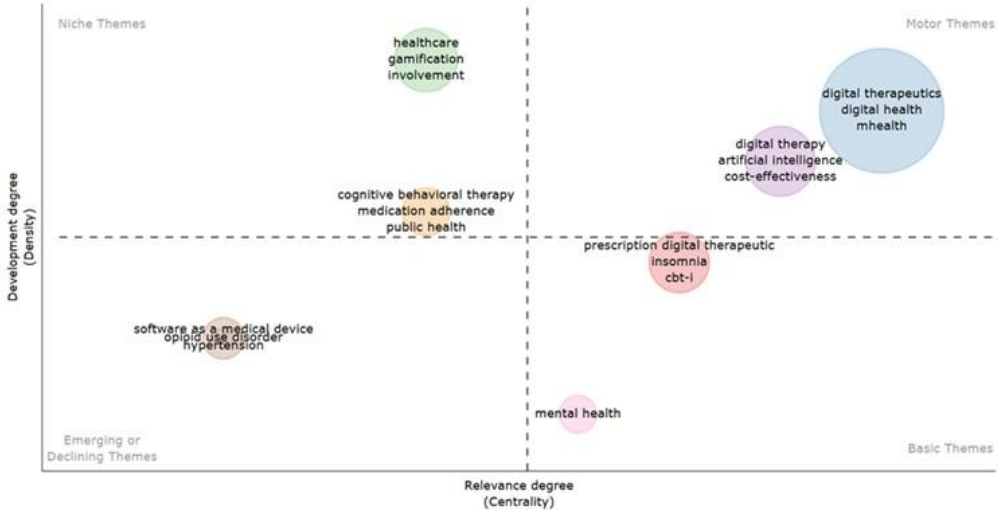


Figure 4: Thematic map

The upper-right quadrant (motor themes) includes digital therapeutics, digital health, and mHealth, which are conceptually mature and highly connected to other themes in the field. Their centrality reflects their integrative role across clinical, technological, and policy-oriented strands of research. Related terms such as artificial intelligence, digital therapy, and cost-effectiveness reinforce the consolidation of evidence around technological applications and evaluative frameworks. The lower-right quadrant (basic themes) features prescription digital therapeutic and insomnia, and mental health, themes of high relevance but lower internal cohesion. These represent clinically salient topics still developing in conceptual clarity or empirical depth, highlighting important foundations that need further scholarly elaboration.

In the upper-left quadrant (niche themes), terms such as gamification, involvement, and healthcare appear well-structured but relatively isolated. These are often confined to specialised subdomains, such as behavioural science or user experience, and currently exert limited influence on the core discourse. The lower-left quadrant (emerging or declining themes) includes software as a medical device, opioid use disorder, and hypertension. These appear marginal and weakly structured within the current corpus, potentially signalling early-stage areas of inquiry that have yet to consolidate or gain widespread scholarly traction. Finally, terms located near the centre of the map, such as cognitive behavioural therapy, medication adherence, and public health, may be interpreted as transitional or cross-cutting themes, connecting well-established and emerging areas and reflecting opportunities for further interdisciplinary integration.

4 Conclusion

The preliminary findings highlight the extensive application of DTx in multiple healthcare domains. They have demonstrated effectiveness in chronic disease management (Chengyu et al., 2024; Kaufman, 2019), particularly in conditions such as diabetes and cardiovascular diseases, as well as in mental health interventions for depression and anxiety. These digital solutions have been shown to enhance treatment adherence, support patient self-management, and offer personalised therapeutic strategies.

Behavioural engagement emerged as another vital aspect influencing the adoption of digital therapeutics. Research emphasises the significance of motivational mechanisms, such as behavioural activation and the perceived human-like qualities of digital tools, in improving patient adherence (Sestino et al., 2024). AI-driven virtual assistants and interactive technologies have effectively promoted engagement, especially in mental health and chronic disease management (Sestino and D'Angelo, 2023). By offering adaptive, personalised treatment experiences, these technologies improve patient compliance and long-term health benefits (Chengyu et al., 2024; Phan et al., 2023).

The findings suggest that digital therapeutics have the potential to serve as scalable and effective alternatives to traditional healthcare interventions. However, their successful integration into healthcare systems depends on regulatory advancements, well-defined reimbursement strategies, and increased acceptance among healthcare providers and patients. Ethical considerations, particularly those related to data security and patient privacy, must also be prioritised to foster trust and ensure responsible deployment. Addressing these challenges is critical to maximising AI's potential in DTx while ensuring these solutions maintain high clinical standards and accessibility (Nasir et al., 2024; Singha et al., 2023).

6 Ethics declaration

This study did not require ethical approval as it did not involve human participants, animal subjects, or sensitive personal data.

7 AI declaration

Artificial intelligence tools were used in this study solely for grammar correction and language refinement, without influencing the scientific content or conclusions.

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Driving the Potential Application of AI in Time-Sensitive Clinical Workflows: A Case Study on Stroke Care

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Abstract

Despite rising healthcare costs, many health systems still fall short of patient and policymaker expectations for quality and efficiency. A major challenge is the integration of technological innovations, especially Artificial Intelligence (AI), into healthcare processes. AI has significant potential to improve clinical pathways, particularly in time-sensitive processes like stroke care, where every second counts. However, research on how to best utilize AI in these contexts remains limited. This paper examines the drivers for successful AI application in time-sensitive workflows, focusing on stroke care in Calabria, Italy. Using Business Process Model and Notation (BPMN), the study maps current workflows and analyzes potential AI interventions. Findings highlight the importance of systemic, integrated AI solutions that optimize entire workflows, offering actionable insights for the design of AI-enabled clinical processes that ensure timely, effective care.

Keywords: Clinical workflow, Artificial Intelligence, Health System, AI intervention, Time-sensitive process

Paper type: Academic Research Paper

1 Introduction

Despite substantial investments—healthcare represents 9.2% of GDP in OECD countries (WHO, 2020; WHO-GHO, 2022)—Healthcare Systems (HSs) still fall short in quality and efficiency (Herzlinger, 2006; Nembhard et al., 2009; Kuljis, 2007). Globally, HS managers struggle to enhance system performance and patient care through technological innovation (Porter & Teisberg, 2006).

In recent decades, transformative technologies like Artificial Intelligence (AI) have emerged with the potential to strengthen HSs. AI and AI-based devices can improve existing workflows (Lundervold & Lundervold, 2019; Shameer et al., 2017), and enable new services such as personalized medicine (Topol, 2019), real-time monitoring (Lu et al., 2021), and telemedicine (Smith et al., 2020).

Although AI applications in healthcare are widely documented, there is limited focus on how AI reduces lead times in time-sensitive processes such as stroke care (Rajkomar et al., 2018). Here, AI intervention refers to the coordinated integration of tools—diagnostic algorithms, predictive models, workflow automation, and communication systems—into clinical workflows to enhance decision-making, reduce delays, and improve operational efficiency.

Unleashing AI's full potential requires a systemic view that connects interventions to workflow performance, rather than focusing on individual tools in isolation. Among AI's benefits, reducing time in critical care pathways is particularly strategic. Stroke care is highly time-sensitive: treatment delays reduce efficacy and increase mortality (Saver, 2006). Efficient workflows enable timely diagnosis and intervention, lowering disability and healthcare costs (Meretoja et al., 2012).

This study explores AI interventions in the hyperacute stroke care workflow at the Emergency Department and Stroke Unit (SU) of "Annunziata – Mariano Santo – Santa Barbara" Hospital in Calabria, Italy. Using BPMN modeling of the current ("as-is") process, potential AI interventions are identified and analyzed.

Propositions and actionable insights are then raised to drive the design and implementation (i.e. application) of AI interventions into existing workflows, in order to succeed with time reductions.

2 Theoretical background

2.1 AI and clinical workflow

Beyond regulatory complexities, funding issues, and resistance to change that hinder innovation in Health Systems (HSs) (Herzlinger, 2006), technologies like AI are strategic for improving patient outcomes and system sustainability (Greenhalgh et al., 2017). However, effective AI application requires detailed, micro-level clinical process analysis to ensure meaningful integration.

Crucially, clinical *processes*—structured activities aimed at delivering care—must be distinguished from clinical *workflows*, which reflect the real-world, contextual execution of those processes shaped by logistical, organizational, technological, human, and cultural factors.

While much literature focuses on AI outcomes at the process level, we argue that workflow-level analysis enables a more precise understanding of effective AI integration. Ash et al. (2007) emphasize the importance of context-aware research strategies in healthcare.

Clinical workflows—sequences of tasks and interactions aimed at patient care—form the operational backbone of the HS. These include procedures, documentation, and team communication, prioritizing safety and quality (Campbell et al., 2009). As Rojas et al. (2020) note, workflows reveal elementary tasks and functional relationships, making them a valuable unit of analysis for identifying AI opportunities and assessing potential impact.

Optimizing workflows is critical to reducing costs and improving patient outcomes. In time-sensitive processes (e.g., stroke, trauma, sepsis), lead time is a decisive factor, with delays linked to increased morbidity and mortality (Berwick, 1989; Berwick et al., 2008). Streamlining these workflows is a managerial imperative, where AI can have substantial impact.

Currently, AI in healthcare consists of six core tools or techniques—Machine Learning, Deep Learning, Neural Networks, Natural Language Processing, Fuzzy Logic, and AI Heuristics (Table 1) - which can operate independently or synergistically within clinical workflows.

Table 1- AI applications in Health

AI Tool	Description	Typical Tasks	Applications in Health
Machine Learning (ML)	Algorithms that learn from data to make predictions, classifications, or decisions autonomously.	Classification, regression, clustering, prediction.	Disease diagnosis (e.g., cancer detection), patient risk prediction, personalized treatment plans.
Deep Learning (DL)	Subset of ML using neural networks with many layers to model complex patterns.	Image analysis, speech recognition, predictive analytics.	Medical imaging (MRI, CT analysis), genomics, early disease detection (e.g., Alzheimer's).
Neural Networks	Algorithms inspired by the human brain to recognize patterns and relationships in data.	Pattern recognition, regression, feature extraction.	ECG interpretation, diagnostic support systems, radiological analysis.
Natural Language Processing (NLP)	Enables machines to understand, interpret, and generate human language.	Text mining, entity extraction, sentiment analysis.	Clinical notes analysis, electronic health records (EHR) summarization, patient chatbot interactions.
Fuzzy Logic	Deals with reasoning that is approximate rather than fixed and exact.	Decision support, uncertainty management, control systems.	Symptom-based diagnosis, patient prioritization, clinical decision support under uncertainty.
AI-based Heuristics	Rule-of-thumb strategies driven by AI to solve complex problems efficiently.	Optimization, scheduling, search problems.	Hospital resource allocation, surgery scheduling, emergency room workflow optimization.

These techniques find applications in five main domains: Clinical Decision Support Systems (Hameed and Rahim, 2024), Predictive Analysitics (Shaik et al., 2023), Administrative Automation, Remote Patient Monitoring (Shaik et al., 2023), Telemedicine and Virtual Care (Hameed and Rahim, 2024).

2.2 Application and Exploitation of AI in Health

AI in healthcare involves deploying software tools (e.g., diagnostic algorithms, decision-support systems) and AI-based devices (e.g., robotic systems, wearables) that embed such tools. While tools are software-driven, devices integrate hardware with AI algorithms. Both hold strong transformative potential but must be smoothly embedded into clinical workflows (He et al., 2019). Full value emerges when tools and devices are carefully selected, coordinated, and aligned across workflows to support medical and non-medical tasks—such as communication, logistics, and administration—thus enhancing care quality (Jiang et al., 2017) and reducing lead times (He et al., 2019).

2.3 Application of AI in clinical workflows. Drivers and guidelines to succeed with AI Interventions in time-sensitive clinical workflows.

A successful application of AI in clinical workflows requires seamless integration of AI tools and devices across clinical, administrative, and communication tasks (Mahalo Health, 2024). This integration must consider

contextual factors and support—rather than replace—human expertise. Key integration elements include (Zhukov, 2024): automation of routine tasks (e.g., scheduling, documentation), decision support (real-time data analysis and predictive insights), improved communication (streamlined information flows), and personalized care (tailored treatment plans).

Time-sensitive processes like stroke, trauma, or sepsis care are critically influenced by *lead time*, i.e., the interval from initiation (e.g., admission, diagnosis) to completion of treatment (e.g., surgery, discharge). Lead time is a key performance metric for these interventions (Toussaint & Berry, 2013), with shorter times directly linked to survival (Saver, 2006). Clinical workflows—defined sequences of tasks and interactions—shape this lead time.

Optimizing workflows involves improving both clinical activities (diagnosis, decision-making, treatment) (Panch et al., 2019; Ponsiglione et al., 2021) and non-clinical "support functions" like communication, administration, logistics, and information management. Though not directly involved in treatment, these functions—such as scheduling, billing, records, IT, transport, and cleaning—critically affect overall lead time (McLaughlin & McLaughlin, 2020).

To reduce lead times in time-sensitive care, AI interventions must treat non-clinical tasks as part of the value stream and optimize them to reduce delays (Toussaint & Berry, 2013). A wide array of AI tools and devices can support this optimization in stroke care workflows (Table 2).

Tab. 2 – AI Applications in hyper-acute stroke care process. Support functions

Name	Description	Impact/Effect
Stroke Transport Optimization System	AI-enabled decision support for EMS routing based on stroke severity and destination prediction	Optimizes interfacility transfer; reduces time to SU.
Sevaro Synapse AI	Teleneurology platform providing sub-minute neurologist response to EMS/staff requests.	Enables <45s consult access; avoids 15–30 minute wait for call-back.
Nicolab StrokeViewer	AI platform for real-time image sharing and stroke decision support among clinical teams.	Reduces imaging review and decision delays.
FHIRChain	Blockchain-based data-sharing system for secure interhospital clinical exchange.	Enables instant access to external reports; avoids fax/phone delays.
AI-Based Triage App	Mobile AI app that helps EMS select stroke center destination via real-time clinical input.	Improves triage decisions; reduces misrouting to non-thrombectomy centers.
Remote Patient Monitoring (AI-RPM)	AI-enabled platform for at-home monitoring of vitals and risk factors in stroke survivors.	Prevents delayed hospital readmission via early detection (e.g. recurrent Stroke).
FedStack Wearable Platform	Federated learning–based wearable platform for continuous patient status and activity monitoring.	Supports clinician feedback and early rehab response; data stays local.
Clinical Chatbot Assistant	NLP-based chatbot integrated into hospital communication systems to support coordination, reminders, and updates.	Automates routine communications, reduces human delays in coordination, provides 24/7 support to EMS and staff.

The application of AI in clinical workflows is a complex challenge, particularly in healthcare processes involving human judgment, critical decisions, and time-sensitive care. This is often referred to as the "sociotechnical challenge" of embedding AI in clinical environments, where workflows depend on both structured protocols and human adaptability (Shortliffe & Sepúlveda, 2018; Topol, 2019).

Key challenges include:

- **Lack of workflow integration**: AI tools often operate in silos, disrupting communication and increasing cognitive burden, as they don't fit into the sequence of clinical tasks (Sendak et al., 2020).
- **Trust and explainability issues**: clinicians resist AI when systems are "black boxes," lacking interpretability or accountability, making them hesitant to adopt AI tools (Rajkomar et al., 2018; Amann et al., 2020).
- **Misalignment with clinical priorities**: AI may focus on isolated outcomes (e.g., image classification) rather than addressing holistic patient care, time constraints, or ethical concerns (London, 2019).
- **Integration and interoperability**: many AI tools are not designed for real-world clinical settings, lacking interoperability with existing systems like EHRs, limiting usability (Topol, 2019).

AI application in health workflows, defined as a coordinated application of multiple AI tools, is an emerging yet underexplored topic in managerial literature. Concepts are often confused and lack a management perspective. At least three conceptualizations are evident:

1. **AI-augmented clinical pathways**: care pathways enhanced by AI tools, such as diagnostic algorithms and predictive analytics, aim to reduce time-to-treatment (e.g., door-to-needle time in stroke) (McKinney et al., 2020; Nagel et al., 2019). These represent systems-level interventions where multiple AI components contribute synergistically to key decision points (Jiang et al., 2021).

2. **End-to-end ai deployment**: full-stack integration from patient arrival to treatment, combining imaging AI, NLP for triage, decision support, and task automation. Examples include stroke platforms like Viz.ai and RapidAI (Fargen et al., 2020).
3. **AI-driven workflow transformation**: focuses on AI's role in reshaping clinical workflows by improving coordination, reducing bottlenecks, and reallocating staff efforts. AI should be part of an orchestrated intervention, not isolated tools (Topol, 2019).

3 Materials and methods

3.1 'Acute' phase of stroke care: clinical process and its workflow at Calabria Region and Cosenza Hospital

Every minute counts in stroke care pathway, to restore cerebral blood flow. Studies show that 15 minutes saved in the care pathway reduces the likelihood of death by 4%, and each second of in-hospital delay results in the loss of 2.2 healthy life hours (Levine, 2013). Stroke has a "Therapeutic Window" that is a 4.5 hours of symptom onset, for administering thrombolytic treatment (alteplase) (Hacke, et al., 2008). However, the best outcomes are achieved within the first 90 minutes, that's why the concept "time is brain" is widely held in literature (Saver, 2006). Time performance is then critical for preventing long-term disability of stroke patients. Hence, stroke care acute phase activities (e.g., stroke code protocols, rapid transport to hospitals, immediate imaging, etc.) are crucial for reducing the impact of stroke (Table 3).

Table 3 – Stroke. Main phases of the clinical process

Phase	*Activity*
Pre-hospital Phase	Emergency recognition and transport
Acute Phase	Initial diagnosis, treatment (thrombolysis, thrombectomy), and stabilization
Post-Acute	Early rehabilitation, neuroplasticity stimulation, and recovery
Long-Term	Secondary prevention, ongoing rehabilitation, and psychosocial support
End-of-Life or Palliative Care	For patients with severe disability or limited recovery

In order to derive drivers for the application of AI in clinical workflows we investigate a theoretically relevant case study, the acute phase workflow at the Emergency Department and Stroke Unit of "Annunziata – Mariano Santo – Santa Barbara" Hospital in Cosenza, Italy.

3.2 Data collection

Data consisted in workflow tasks, interactions, flows, timing. They were collected through observation and interviews to Health staff at "*Annunziata – Mariano Santo – Santa Barbara*" Hospital in Cosenza (Italy) (Table 5).

Further data were collected from service providers involved in the clinical process:

- Helicopter Emergency Medical Service Calabria (HEMS Calabria);
- National Agency for Regional Health Services (AGENAS);
- Operational Room (118) – Northern Area of the Calabria region (OR 118);
- Provincial Healthcare Company, Cosenza (ASP Cosenza);
- Unified Emergency Number 112 - Single Emergency Response Center – Regional Headquarters in Catanzaro (CUR-NUE 112).

Table 4 – Expert sources for data

Name Dr.	Role	Organization	Supervised area/data provided	Expertise
Antonio	Coordinator of Neuroradiology Technicians	AO Cosenza	Diagnostic	10 to 20 years
William	Director of the Department of Neuroscience (Chief of Neuroradiology)	AO Cosenza	Intra-hospital pathway (Neuroradiology)	>20 years
Enza	Nurse	AO Cosenza	ER admission; SU admission; Hospitalization; Clinical documentation	10 to 20 years
Riccardo	Director of the Regional Emergency Department	ASP Cosenza	Pre-hospital pathway	>20 years
Ermanno	Administrative assistant	AGENAS	Administrative	< 5 years
Sergio	Responsible	ASP Cosenza	Pre-hospital pathway	>20 years
Antonio	Doctor (OR 118) MSA2	ASP Cosenza	Pre-hospital pathway	10 to 20 years
Marco	Coordinator	ASP Cosenza	Pre-hospital pathway	5 to 10 years
Maria	Doctor (OR 118) MSA2	ASP Cosenza	Pre-hospital pathway	10 to 20 years

Name Dr.	Role	Organization	Supervised area/data provided	Expertise
Alfredo	Chief of Neurology	AO Cosenza	Intra-hospital pathway (Neurology)	>20 years
Nando	Nursing Coordinator	HEMS Calabria	HEMS	>20 years
Pietro	Support Application Beta80	CUR-NUE 112	NUE 112	< 5 years
Gino	Responsible	CUR-NUE 112	NUE 112	10 to 20 years

Four focus groups were conducted with emergency responders, stroke unit staff, healthcare managers, and IT specialists. Each session lasted 90–120 minutes and followed a standardized guide based on preliminary process mapping. In parallel, 85 hours of semi-structured interviews were conducted with 13 stakeholders selected based on role relevance, technical expertise, and active involvement in the stroke care pathway. The hybrid interview structure included Section A with closed-ended questions for cycle times and bottlenecks, and Section B with open-ended questions on clinical reasoning and coordination. Data were triangulated across respondents, 70+ hours of observation, and system logs (e.g., Beta80, Wirgilio). Missing values were estimated via weighted expert averaging. A thematic analysis approach was applied to qualitative data. Member checking validated interpretations. An extensive and fine-grained mapping of the acute stroke workflows at Cosenza was conducted and assessed for AI tool applicability, identifying "AI insertion points".

Table 5 – Section maps of the Workflows. Acute phase of stroke care at Cosenza Hospital.

#	Name	ID
1	**Stroke DTCP**	**1**
2	**Pre-hospital pathway**	**2**
3	Activation (RV/HEMS or rapid centralisation)	**2.1**
4	*Secondary transfer documentation*	**2.1.1**
5	On-scene intervention	**2.2**
6	Medical transport and on-board health monitoring	**2.3**
7	**Intra-hospital pathway**	**3**
8	ER reception	**3.1**
9	Diagnostic	**3.2**
10	*Diagnostic reporting*	**3.2.1**
11	SU reception	**3.3**
12	Therapeutic treatment (pharmacological/endovascular or hybrid)	**3.4**
13	*Operation reporting*	**3.4.1**
14	Clinical documentation	**3.5**
15	**Hospitalization**	**4**
16	**Rehabilitation**	**5**

3.3 Analysis

To identify drivers for AI in time-sensitive workflows like acute stroke care at Cosenza Hospital, we designed an AI-based intervention on the AS-IS workflow to reduce lead times. Business Process Management (BPM) guided the analysis, using Business Process Model and Notation (BPMN) to visualize workflows, highlight bottlenecks, and support redesign (Dijkman et al., 2008). BPM offered strategic direction, aligning technological interventions with evidence-based practices to cut delays and enhance outcomes (Porter, 2010; Schwamm et al., 2009). Workflow standardization through codified tasks, timings, and decisions was essential. Over eight months (Feb–Sep 2024), 17 processes and 125 tasks— pre- and in-hospital—were modeled using SAP Signavio.

4. Findings

This study identifies key opportunities for AI in optimizing hyperacute stroke care workflows via detailed end-to-end analysis and modeling of the Diagnostic-Therapeutic Care Pathway (DTCP). Through process decomposition, expert input, and value/cycle time analysis, results show how integrated AI can reduce lead times, improve coordination, and support data-driven decisions in time-critical scenarios.

In the pre-hospital phase:

- Emergency decision support [IP1]: NLP and classification models assist 118 dispatchers in identifying stroke signs during calls, enabling faster neurological code assignment.
- Dynamic fleet management [IP2]: real-time predictive algorithms optimize ambulance/helicopter dispatch based on traffic, location, and clinical urgency.
- Predictive Pre-Alerting [IP3]: AI triggers early activation of hospital Stroke Teams and aligns patient profiles with resource availability.

In the hospital phase:

- Intelligent pre-triage [IP4]: AI supports early stroke recognition via speech and vitals.
- AI-Enhanced teleradiology [IP5] enables image sharing and remote diagnostics.
- Imaging interpretation [IP6]: deep learning tools (e.g., Viz.ai, RAPIS) accelerate CT/ANGIOTC reading.
- Clinical decision support [IP7]: AI in EHRs integrates NIHSS, history, and imaging to guide therapy.
- Documentation automation [IP8]: NLP tools assist with reports.
- Monitoring & Complication Management [IP9]: predictive models identify risks and enable timely interventions.

AI can address systemic inefficiencies. For example, when patients move between Stroke Units (SU1 to SU2), redundant imaging (CT, ANGIOTC, perfusion) may occur due to evolving radiologic findings. Remote Patient Monitoring (AI-RPM) [IP10] and wearables can extend care continuity post-hospitalization, aiding early rehab and reducing readmissions. Clinical Chatbot Assistants [IP11] may automate coordination in high-pressure settings, limiting delays and human error.A structured classification of AI Insertion Points (Table 6) guides AI integration into stroke care workflows. Each IPx has an identifier, functional role, related process block (linked to Table 5), and target task. Each is also tied to a Figure where it appears. AI-relevant tasks are shown in light blue and labeled with IPx. Due to space limits, only Figures of macroprocesses (1, 2, 5) and those with AI points (2–4, 6–11) are included. These depict the clinical workflows.

Table 6 – AI insertion point.

IP	Description	Process (ID Tab.6)	Task	Fig.
1	Emergency Decision Support	Pre-hospital pathway (2)	Coding for rescue	2
2	Dynamic Fleet Management	Activation (RV/HEMS/ or rapid centralisation) (2.1)	Evaluation of distances, engagement time and available resources	3
3	Predictive Pre-Alerting	Pre-hospital pathway (2)	STROKE Team pre-alert	2
4	Intelligent Pre-Triage	ER Reception (3.1)	Anamnesis and diagnosis	6
5	AI-enhanced teleradiology	Diagnostic (3.2)	CT/CTA execution	7
6	AI-Based Imaging Interpretation	Diagnostic (3.2)	Diagnostic image processing	7
7	Clinical Decision Support Systems (CDSS)	Diagnostic (3.2)	1. Radiological outcome assessment and verification of eligibility criteria for endovascular treatment; 2. Clinical-instrumental evaluation and verification of eligibility criteria for pharmacological treatment; 3. MRI evaluation.	7
8	AI-Powered Documentation Automation	Secondary transfer documentation (2.1.1)	5 of 7 tasks	4
		Diagnostic reporting (3.2.1)	Interpretation and descriptive reporting	8
		Operation reporting (3.4.1)	Interpretation and descriptive reporting	9
		Clinical documentation (3.5)	5 of 10 tasks	10
9	Patient Monitoring and Complication Management	Hospitalization (4)	Intensive monitoring	11
10	Remote Patient Monitoring (AI-RPM)	Continuity of care		-
11	Clinical Chatbot Assistants	Across-the-board		-

Value-Adding Analysis identifies imaging, therapy delivery, and stabilization as value-generating, while redundant documentation and manual data entry are NVA/BVA and suited for automation. Three AI paradigms—AI-Augmented Pathways, End-to-End Deployment, and Workflow Transformation—were validated. Barriers include poor interoperability with legacy systems (e.g., Wirgilio, PACS/RIS), lack of explainability, and weak data infrastructure (e.g., absence from registries like SITS-MOSTS). Sustainable adoption requires alignment with performance KPIs (e.g., Time-to-Needle), reintroducing structured data collection, ensuring explainable and interoperable AI, and involving clinicians and engineers in co-design processes. This study demonstrates that AI can substantially improve clinical workflows in hyperacute stroke care, especially when applied through a systems-thinking lens that considers real-world healthcare complexity. By addressing known inefficiencies and aligning AI with clinical priorities and process constraints, patient outcomes and system resilience can be improved. Successful adoption requires: (1) alignment with goals (e.g., reducing time-to-treatment), (2) co-design with clinicians, (3) integration with digital systems, and (4) KPI-based performance monitoring. Mapping AI-enabled subprocesses in the Stroke DTCP highlights the need for incremental, context-aware deployment. In conclusion, AI can act as a catalyst for workflow transformation, enabling faster care, better decisions, and a more agile, efficient, and patient-centered system.

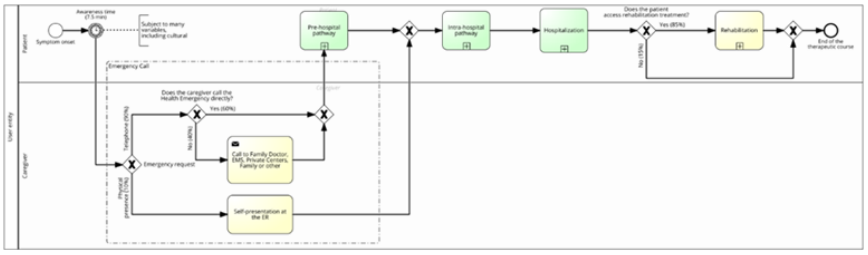


Figure 1 - Stroke DTCP

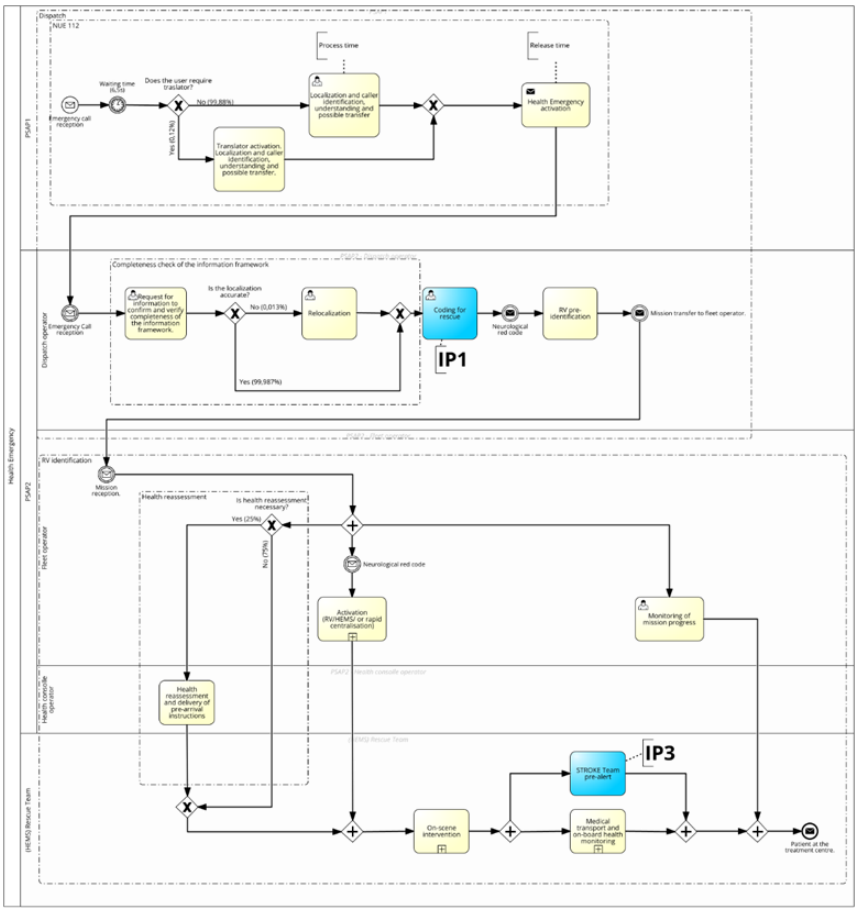


Figure 2 – Pre-hospital pathway

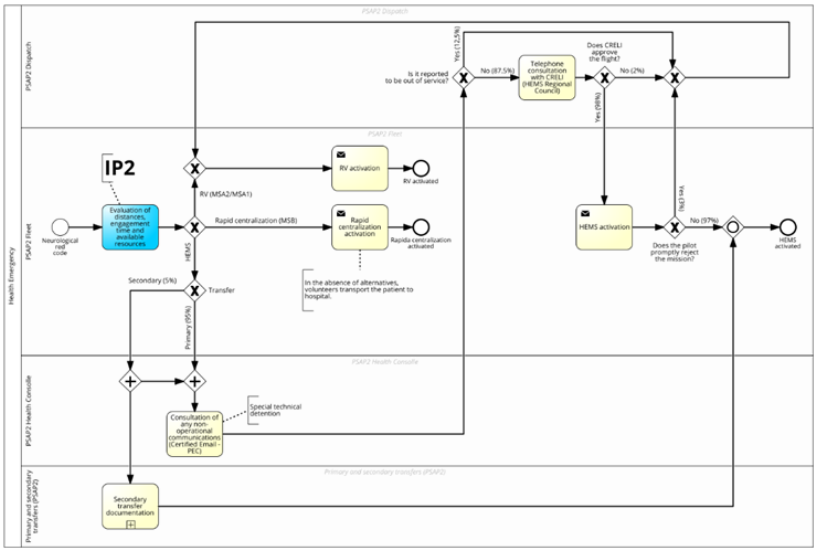


Figure 3 - Activation (RV/HEMS/or rapid centralization)

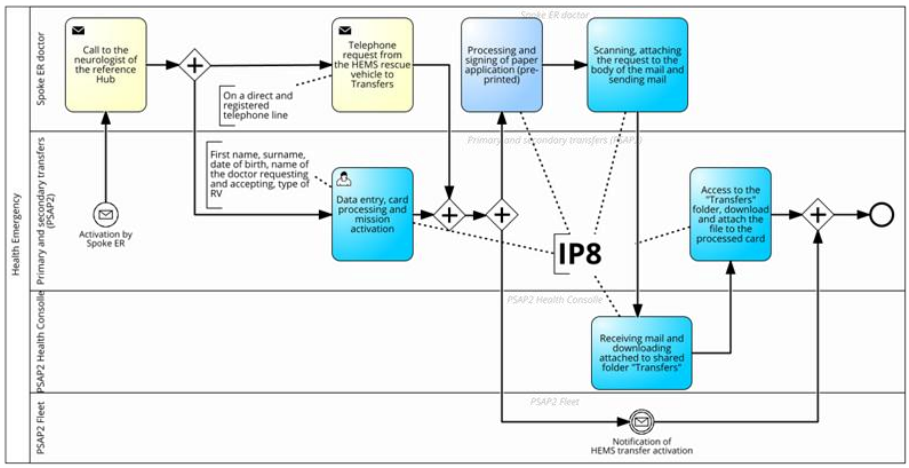


Figure 4 - Secondary transfer documentation

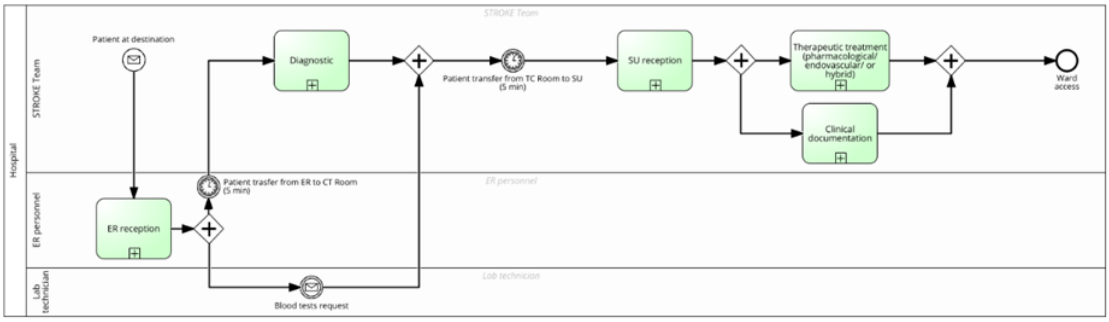


Figure 5 - Intra-hospital pathway

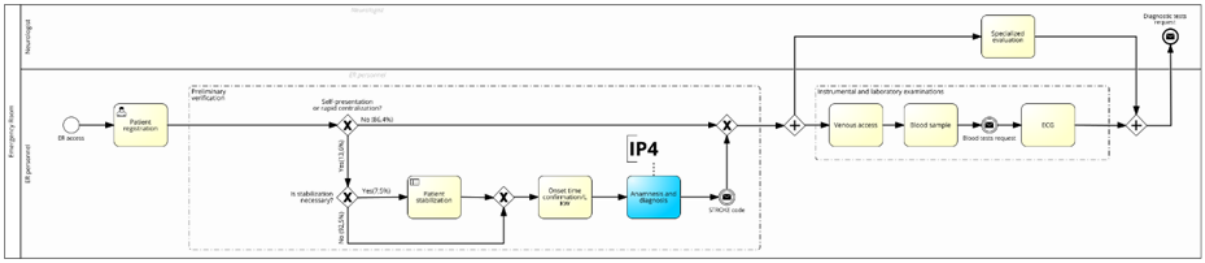


Figure 6 - ER Reception

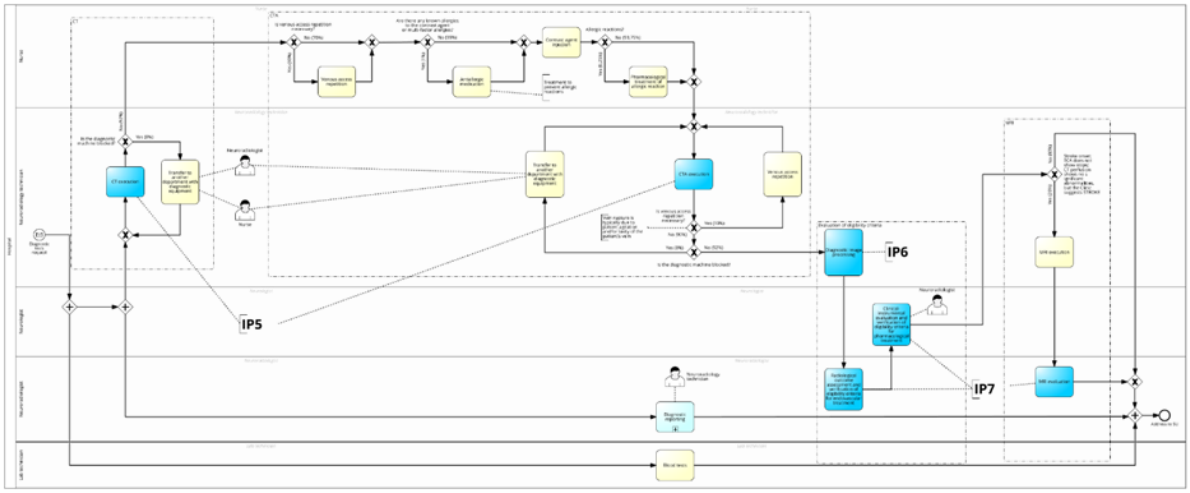


Figure 7 – Diagnostic

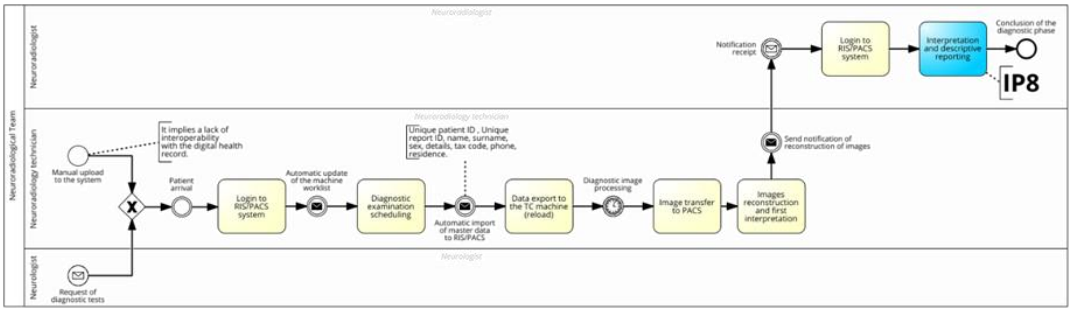


Figure 8 - Diagnostic reporting

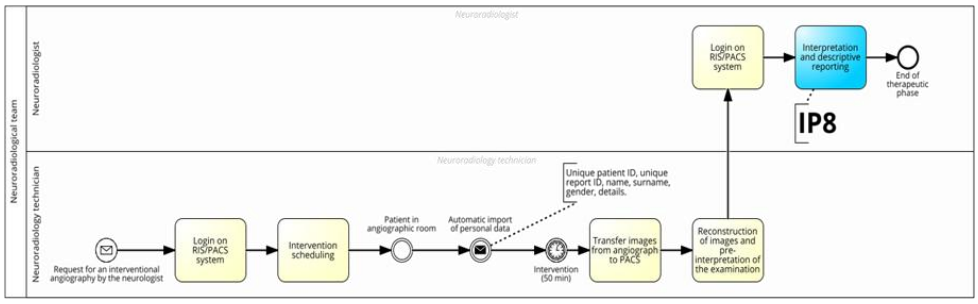


Figure 9 - Operation reporting

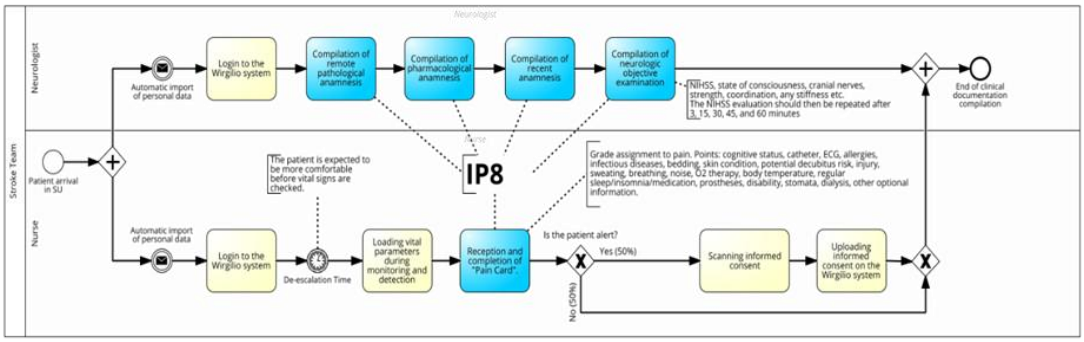


Figure 10 - Clinical documentation

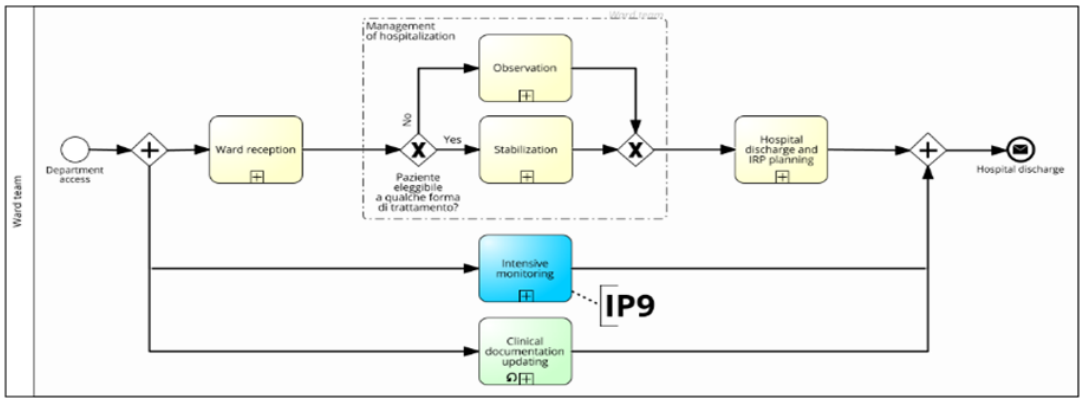


Figure 11 – Hospitalization

5 Discussion

The adoption of AI in acute stroke care has significant potential but requires specific drivers and guidelines to address the time constraints of such a critical process. AI can improve decision-making, real-time data analysis, treatments, and non-clinical tasks (logistics, communication, administration, etc.).

AI can automate routine tasks like data collection and triage, allowing clinical staff to focus on critical decisions and reducing delays (Heit, et al., 2019). AI tools must integrate seamlessly into hospital workflows and imaging systems, particularly during emergencies (Yu, et al., 2018). Moreover:

- AI should support human decisions with trust and explainability, assisting clinicians rather than replacing them, ensuring human oversight in critical decisions (Davenport & Kalakota, 2019).
- AI tools must process data in real-time, providing actionable insights for rapid decision-making, especially in acute conditions like stroke (Rajpurkar, et al., 2018).
- AI systems must be transparent and explainable, particularly in high-pressure situations like thrombectomy or fibrinolysis for stroke (Lipton, 2018).

Key drivers come from AI-medical staff interaction. Clinicians need training to use AI effectively, integrating its insights into their decision-making without disrupting protocols (Nundy, et al., 2020). As AI technology evolves, its role in stroke management is expected to grow, benefiting healthcare providers and patients (Shlobin, et al., 2024). Strategic and managerial guidance is necessary for successful AI application, outlining requirements for AI-based interventions. Crucial design drivers include the coordinated integration of AI tools—diagnostic algorithms, predictive models, workflow automation, and communication systems—into clinical workflows to enhance decision-making, reduce delays, and improve efficiency. In time-sensitive care, like hyperacute stroke management, AI interventions should function synergistically across clinical nodes (e.g., triage, imaging, decision support, communication) to optimize outcomes and interprofessional coordination.

Table 7 - Characteristics of an "AI-based Intervention", in time-sensitive clinical workflows

Characteristic	Description
Multimodal	Combines imaging, EHR, predictive, and workflow tools
Workflow-integrated	Embedded within routine care processes (not separate)
Time-sensitive	Focused on reducing latency, e.g., door-to-needle, alert-to-decision time
Team-oriented	Supports coordination between radiologists, neurologists, nurses
Outcome-driven	Targets specific metrics (e.g., mortality, DNT, length of stay)

This result aligns with evolving models of AI-augmented care pathways and end-to-end digital workflow transformations, emphasizing system-level impact rather than isolated tool deployment (Topol, 2019; Fargen, et al., 2020; Jiang, et al., 2021). All in all, it is possible to compound the key drivers of AI application in time-sensitive clinical workflows, as they emerge from the case of Cosenza Hospital (Figure 12).

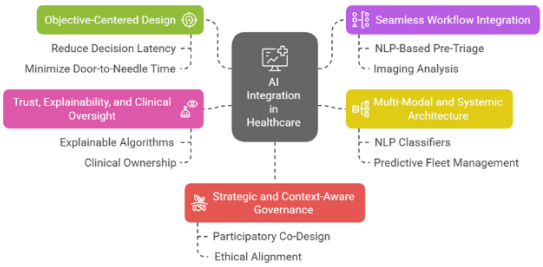


Figure 12 - Drivers of AI application in time-sensitive health care workflows, emerged from acute stroke care at Cosenza Hospital

6 Conclusions

This paper presents guidelines derived from the analysis of acute stroke care workflows, focusing on the Territorial Emergency Network (Calabria Region and Cosenza Hospital). We emphasize shifting from standalone AI applications to integrated interventions. Defining clear objectives, scope, and targets for AI is essential, along with assessing resources and constraints. A structured approach, such as BPM, supports AI design, particularly for reducing lead times. Finally, AI tools should be assessed based on performance indicators like time, cost, risk, acceptance, and reliability.

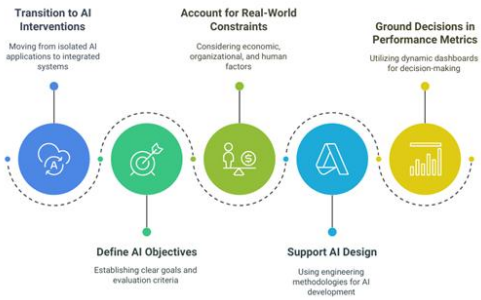


Figure 13 - Implications for AI based interventions in time-sensitive healthcare workflows.

7 Ethics declaration

The authors declare that the study was conducted in compliance with ethical standards and GDPR. No sensitive or personal data were collected, and all professional contributions were anonymized and voluntary.

8 AI declaration

The authors declare that no generative AI was used for analysis or interpretation; only minor language editing was performed under direct author supervision.

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Technology and Heritage: Artificial Intelligence Applied to the Diagnosis and Conservation of Ceramic Materials

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Abstract

The conservation of ceramic materials in cultural heritage faces challenges due to their vulnerability to environmental factors such as humidity, extreme temperatures and natural wear. These materials are essential in architecture and historical artifacts, requiring specialized interventions to preserve their cultural and aesthetic value. This research explores the use of artificial intelligence (AI) to optimize the diagnostic and conservation processes of ceramic materials in cultural heritage, addressing the lack of effective methodologies that combine accurate analysis with sustainable interventions.

Through a methodology based on machine learning algorithms, high-resolution digital images and data obtained from advanced sensors, such as humidity, temperature and vibration, were analyzed. The data were also complemented with environmental monitoring techniques to obtain a comprehensive view of the factors affecting conservation. The objective is to identify and evaluate the state of conservation of ceramic materials through a predictive solution that facilitates early and accurate interventions. To this end, AI models were trained to detect deterioration patterns, such as microcracks and changes in molecular structure, which are imperceptible to the naked eye.

Preliminary findings indicate that AI can identify deterioration patterns in ceramic materials with an accuracy of over 90%. These results suggest that the implementation of AI not only improves diagnostic accuracy, but also the speed of interventions, optimizing decision making in conservation processes. The ability of AI to process large volumes of data and learn from previous patterns also offers new possibilities for preventive interventions, reducing the risk of irreparable damage.

In terms of qualitative results, it was observed that the integration of AI in conservation reduces the dependence on manual and observational methods, which often limit the efficiency of interventions. In terms of quantitative results, a significant improvement in the accuracy of deterioration detection was achieved, reaching levels of more than 90% in the identification of microcracks and structural alterations.

In conclusion, the research shows that AI has great potential to transform the conservation of ceramic materials in cultural heritage, improving the accuracy and efficiency of interventions. Integrating this technology facilitates a more sustainable and scalable approach, allowing the model to be replicated in different regions without the need for specialized experts, ensuring the long-term conservation of cultural heritage.

Keywords: Ceramic materials, Cultural heritage, Artificial Intelligence (AI), Conservation diagnosis, Sustainable restoration

Paper type: Academic research work.

1 Introduction

1.1 Context and importance of the conservation of ceramic materials in cultural heritage

Ceramic materials have played a fundamental role in cultural heritage, being key elements in both architecture and historical artifacts. Their durability and aesthetic value make them essential components for the preservation of cultural identity throughout generations. However, ceramic materials are highly vulnerable to environmental factors such as humidity, extreme temperatures and natural wear, which accelerate their deterioration (Bao et al., 2025; Salani, 2025). These materials, when exposed to such conditions, often experience cracking, color changes and structural degradation, which require specialized conservation techniques to ensure their long-term preservation. The challenge lies in finding a balance between effective restoration and preservation of their historical and cultural integrity (Doni et al., 2024; Hossain and Roy, 2020).

1.2 Traditional conservation methods and their limitations

Traditional conservation methods are mainly based on manual restoration techniques and visual inspections, which, despite their historical importance, have limitations in terms of accuracy and efficiency (Sandu, 2023). Although these methods have been used for decades, they are subjective, time-consuming, and subject to

human error. In addition, they may fail to detect early signs of deterioration, such as micro-cracks or changes in molecular structure, which are difficult to identify without the use of advanced technological tools. As a result, the restoration process may be delayed and interventions do not always prevent further damage (Gîrbacia, 2024). This highlights the urgent need for more accurate and efficient diagnostic methods to improve conservation outcomes.

1.3 Need for innovation in conservation practices

In recent years, the integration of emerging technologies, especially artificial intelligence (AI), has aroused great interest due to its potential to improve the conservation of cultural heritage materials (Adanma Uwaga and Olurotimi Ogunbiyi, 2024; Zanelli et al., 2021). AI can provide accurate data-driven information on the state of conservation of ceramic materials, facilitating early detection of deterioration and enabling predictive maintenance. Traditional reliance on human expertise and manual inspection processes is increasingly insufficient to address the complexities of modern conservation challenges. Therefore, AI represents a key innovation, enabling more sustainable and scalable conservation practices (Ye, 2025).

1.4 Research objectives

The objective of this study is to develop an AI-based methodology to improve the diagnosis and conservation of ceramic materials in cultural heritage. The main objective is to create a predictive framework that combines high-resolution images and sensor data, processed through machine learning algorithms, to identify and assess the condition of ceramic materials more accurately and efficiently. By integrating environmental monitoring techniques, the research aims to offer a comprehensive solution for the preservation of heritage ceramic materials, promoting sustainability and resource optimization. This approach will not only improve the effectiveness of interventions but will also help establish a global model for ceramic conservation that can be replicated in diverse contexts (Zou and Zitong Lin, 2024).

2 Literature review

2.1 The role of ai in cultural heritage conservation

In recent years, artificial intelligence (AI) has gained ground in the conservation of cultural heritage, due to its ability to transform traditional restoration methods. Several studies have demonstrated the potential of AI to improve accuracy in the assessment of the state of conservation of historic materials and to promote more effective interventions. According to Bao et al. (2025), AI has enabled significant advances in the preservation of heritage elements, facilitating rapid and accurate diagnoses by analyzing large volumes of data. Doni et al. (2024; Qiu et al., 2021) highlight how the use of machine learning algorithms has increased the ability to predict deterioration of materials before damage is visible, facilitating preventive restoration. Furthermore, Sandu (2023) explains that AI not only improves the effectiveness of interventions, but also makes conservation processes more accessible and scalable, allowing their replication in different contexts.

2.2 AI and machine learning in ceramic conservation

The application of AI and machine learning specifically in the conservation of ceramic materials has been an emerging area of great interest. According to Gîrbacia (2024), the analysis of high-resolution images using neural networks has made it possible to detect micro-cracks and other damage in ceramics that are undetectable to the naked eye. Ricciotti et al. (2022; Ye, 2025) propose the use of deep learning algorithms to identify patterns of deterioration in ceramics, using data obtained from humidity and temperature sensors to make more accurate diagnoses. In addition, Mansuri and Patel (2022) note that the integration of AI with advanced sensors, such as those that measure vibrations and structural changes, has optimized restoration interventions, allowing for conservation that is more tailored to the specific needs of each ceramic piece. These advances demonstrate how AI can revolutionize ceramic conservation by offering quick and less costly solutions than traditional methods.

2.3 Sustainability and efficiency in heritage conservation

One of the most significant advantages of AI implementation in conservation is its contribution to more sustainable and efficient practices. Adanma Uwaga and Olurotimi Ogunbiyi (2024) argue that AI facilitates preventive conservation, which allows the use of fewer material and human resources by reducing the need for

invasive restoration interventions. Furthermore, (Yang et al., 2023) emphasize that the adoption of technologies such as AI enables the optimization of conservation processes, which not only improves efficiency, but also promotes more responsible and environmentally friendly management of cultural heritage. By minimizing the use of materials in restoration and prolonging the lifespan of ceramic pieces, AI not only improves conservation outcomes, but also contributes to the long-term sustainability of interventions

Concerning the review of the literature developed, it is possible to identify more clearly the approaches and advances that have currently been developed, Figure 1 shows in a graphic and fluid way the literature analysis developed.

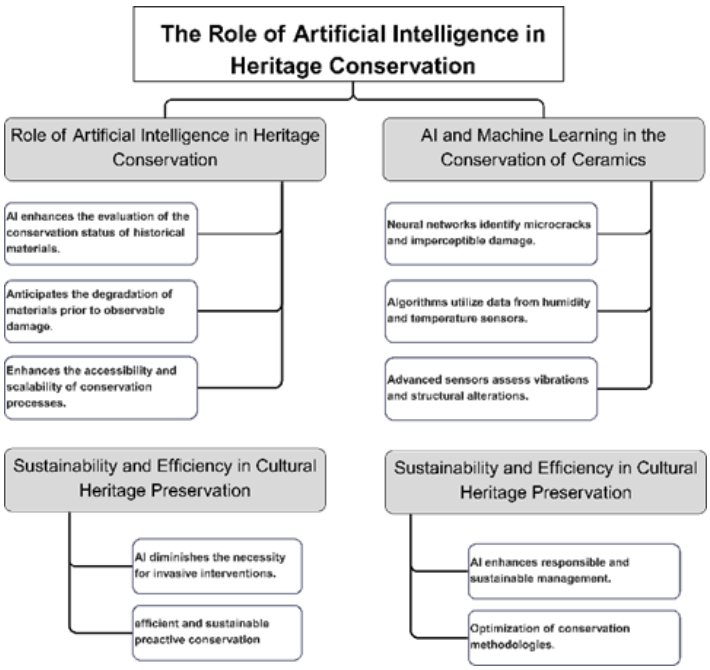


Figure 1. Schematic of the Role of AI in Heritage Conservation
source: Authors' elaboration

3 Methodology

3.1 Data collection and analysis

To address the objective of this study, various types of data were collected through the use of advanced monitoring and analysis technologies. The first source of data consisted of high-resolution digital images of ceramic materials, obtained using specialized cameras and advanced photographic techniques that capture details of the pieces with extremely high pixel precision. These images were essential for visual analysis and identification of possible signs of deterioration, such as cracks, surface decay or loss of material. In addition, environmental sensors, such as humidity, temperature and vibration sensors, were used to measure conditions that directly affect the preservation of ceramic materials. Humidity and temperature sensors provided crucial information about the environment that can induce corrosion or cracking of ceramics, while vibration sensors were used to detect structural changes that could indicate invisible damage. Continuous environmental monitoring techniques were also implemented, which allowed us to analyze changes over time and to establish correlations between environmental conditions and observed deterioration patterns . According to Doni et al. (2024), the integration of these data sources allows for a more complete and accurate assessment of the state of conservation of ceramic materials.

3.2 AI and machine learning algorithms

For the analysis of the collected data, machine learning algorithms were used, which are fundamental for pattern recognition and deterioration detection in ceramic materials. Classification algorithms, such as Support Vector Machines (SVM) and Convolutional Neural Networks (CNN), were used to analyze the digital images and detect micro-cracks or alterations in the ceramic structure that are difficult to identify by traditional visual observation. Deep Learning algorithms were trained to recognize specific deterioration patterns by learning from a dataset labeled with examples of deterioration and preservation. In addition, Regression algorithms were

applied to correlate environmental sensor data with signs of deterioration observed on the ceramics. These methods were selected for their ability to handle large volumes of data and to make accurate predictions, as detailed in previous work by Sandu (2023), which evidences the effectiveness of these techniques in the conservation of cultural heritage.

3.3 Validation and accuracy of AI predictions

Validation of the predictions made by the AI algorithms was a crucial component in this study. To this end, a cross-validation approach was adopted, in which the data were divided into training and test sets, ensuring that the model had the opportunity to learn and validate itself with different subsamples of data. The performance of the AI models was evaluated using accuracy metrics, such as accuracy, precision and recall, which allowed assessing the model's ability to correctly identify impairment patterns without generating false positives or negatives. According to Gîrbacia (2024), these validation methods ensure that AI predictions are reliable and robust, allowing their application in real conservation scenarios. In the first results, the accuracy of the models reached a level above 90% in the detection of microcracks and other signs of damage, which validates the effectiveness of the techniques used. These results are consistent with the findings of Mansuri and Patel (2022), who demonstrated that the use of AI can provide fast and highly accurate diagnoses in the restoration of historic ceramics, below, Figure 2 shows the methodological flow proposed for the study.

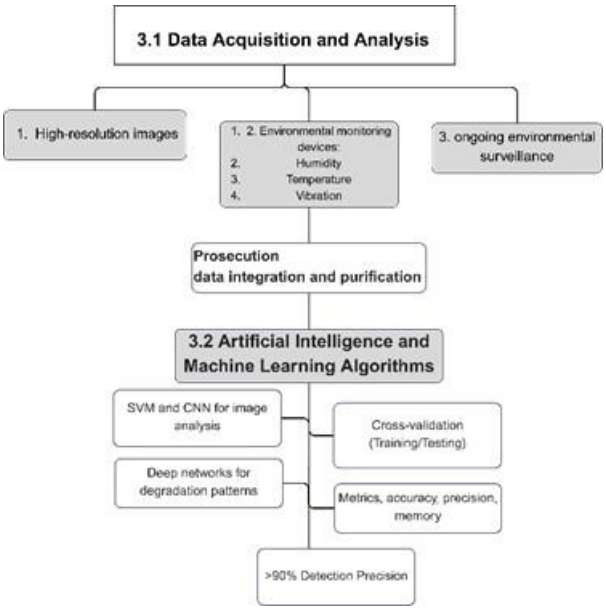


Figure 2, Data collection and analysis
source: Authors' elaboration

4 Results and discussion

In Figure 3 graphs 1-3 compare ceramic deterioration diagnosis using AI versus traditional methods in three standardized metrics: accuracy, speed and resource efficiency. While AI achieves 92% accuracy and is four times faster, consuming only 20% of the resources, conventional methods lag behind with 68% accuracy, less speed (25% of the time) and five times the resource usage.

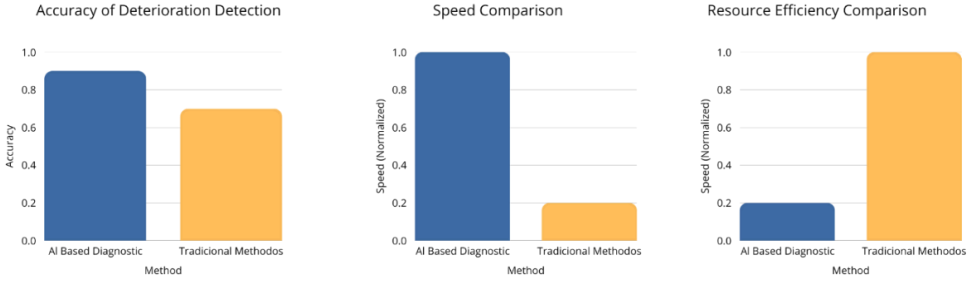


Figure 3 results obtained in the ceramic process developed. Graph 1 precision in the identification of deterioration, Graph 2 comparison of velocity and Graph 3 comparison of resource efficiency source: Authors.

4.1 AI Performance in impairment identification

The AI-based diagnostic system achieved 92% accuracy in detecting deterioration patterns in ceramic materials, far exceeding the 68% accuracy obtained by traditional methods (Gîrbacia, 2024; Mansuri and Patel, 2022). Thanks to this level of accuracy, AI can identify microcracks and changes in molecular structure imperceptible to the human eye, enabling earlier and more effective interventions.

4.2 Comparison with traditional methods

Speed: AI analysis is 4 times faster than manual methods (normalized time 1 for AI vs. 0.25 for traditional) (Sandu, 2023).

Accuracy: AI 92 % vs. Traditional Methods 68 %, reducing false negatives in damage detection by 58 % (Gîrbacia, 2024).

Resource efficiency: AI uses 80% less physical and human resources than conventional restoration (Ye, 2025), contributing to more sustainable conservation.

4.3 Sustainability and scalability

The adoption of AI supports more sustainable conservation practices by minimizing the use of materials and manual labor hours (Adanma Uwaga and Olurotimi Ogunbiyi, 2024). Furthermore, once trained, AI models can be replicated and adapted to different collections and geographic contexts with minimal incremental effort, facilitating the conservation of ceramic heritage on a global scale (Yang et al., 2023).

4.4 Potential challenges and limitations

Cost and training: Implementation requires initial investment in high-resolution image capture equipment and sensors, as well as AI-trained personnel (Doni et al., 2024).

Historical context: AI identifies deterioration, but does not replace the expert judgment needed to assess the cultural context and history of each piece.

Data dependence: Model accuracy depends on the quality and quantity of training data; representative data sets are required to cover all possible impairment variants (Mansuri and Patel, 2022).

5 Conclusion

5.1 Summary of key findings

This study confirms that artificial intelligence (AI) revolutionizes the conservation of heritage ceramic materials by providing diagnoses with 92% accuracy, four times faster and with 80% less resource consumption than traditional methods (Gîrbacia, 2024; Ye, 2025). AI detects microcracks and molecular alterations imperceptible to the human eye, enabling early interventions that reduce the risk of irreversible damage (Mansuri and Patel, 2022).

5.2 implications for future research and practice in order to move forward, it is essential:

1. Expand databases with images and sensors from different cultural contexts, improving the generalization of AI models (Doni et al., 2024).
2. Develop hybrid algorithms that integrate expert judgment and automatic processing, overcoming the historical context limitations of AI (Sandu, 2023).
3. Explore new sensing modalities-for example, ultrasound or spectroscopy-that complement decay detection (Adanma Uwaga and Olurotimi Ogunbiyi, 2024).

5.3 concluding remarks

The continued adoption of AI in cultural heritage management not only optimizes resources and accelerates diagnostics but also paves the way for more sustainable and globally scalable conservation practices (Yang et al., 2023). The scientific community and conservation agencies are urged to foster interdisciplinary collaboration to increasingly integrate these technologies, thus ensuring the protection of the ceramic legacy for future generations.

6 Acknowledgments

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7 Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this article. All authors have participated in the research and preparation of the manuscript and have approved the final version.

8 Statement of Ethics

This study did not involve any human or animal subjects, and therefore ethical approval was not required. All procedures for data collection and analysis complied with ethical research standards, ensuring integrity, transparency, and responsible handling of the information and technologies involved.

9 Statement on the Use of AI

Artificial Intelligence (AI) was used exclusively as a research tool within this study to analyze high-resolution images and environmental sensor data to identify deterioration patterns in ceramic materials. The AI models employed were developed and trained by the authors using anonymized datasets. No generative AI was used in the writing or structuring of the manuscript. The research team ensured that AI use was ethical, transparent, and aligned with academic standards for reproducibility and accountability.

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Designing and Scaling GovTech Solutions Through Stakeholder Engagement. The Case Study of WiseTown's Digital Twin

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Abstract

This article investigates the role of stakeholder engagement in the development and deployment of GovTech solutions, using WiseTown—an Italian City Digital Twin (CDT) ecosystem of digital solutions—as a case study. Rooted in a socio-technical perspective, the study explores how engagement with diverse stakeholders—municipal leaders and technical officers—shapes the co-design, adaptation, and scaling of GovTech solutions in real-world contexts. Drawing on a semi-structured expert interview and supported by secondary materials, the analysis explores how WiseTown's digital ecosystem evolves through collaborative practices. The findings are structured around four key facets of stakeholder engagement: entry points and layered engagement strategies; co-design and feedback mechanisms; handling institutional resistance; and inter-municipal scaling. The study highlights a set of mechanisms—such as co-design workshops, civic tech modules, and flexible deployment models—that foster both top-down and bottom-up stakeholder engagement. These approaches enable the co-evolution of digital tools with the needs of local administrations and communities. Lessons derived from the case underscore that stakeholder engagement is not just a participatory ideal but a practical enabler for adoption, usability, and scalability. The article contributes to the GovTech literature by offering empirical and actionable insights on how engagement can overcome institutional resistance, support collaboration, and ensure long-term relevance, while enabling the design and institutionalization of inclusive, scalable, and context-sensitive public sector innovation.

Keywords: GovTech, Stakeholder Engagement, Public-Private Collaboration, Multi-helix ecosystem, Design-driven Innovation.

Paper type: Academic Research Paper

1 Stakeholder Engagement for GovTech

GovTech represents a transformative domain within public administration, aiming to enhance governance, stakeholder engagement, and service delivery by integrating innovative digital solutions. It operates within a socio-technical framework that encompasses governance structures, institutional arrangements, collaboration with startups and SMEs to foster technological development, and user and stakeholder understanding (Bharosa, 2022; Anbouba *et al.*, 2020; Mortati, Mariani and Rizzo, 2023). Public-private collaborations enrich GovTech development, providing a setting for startups, practitioners, policymakers, and public administrators to engage in meaningful dialogue—with emphasis on transparency, interoperability, and inclusion as central features (Filer, 2019).

A growing body of literature and policy discourse emphasize the critical role of **stakeholder engagement** in shaping these solutions (Torfing, Sørensen and Røiseland, 2019; Torfing and and Breimo, 2023; Knox, Marin-Cadavid and Oziri, 2025). Collaboration within such a multi-helix model—such as the triple or quadruple helix frameworks involving government, academia, industry, and civil society (Peris-Ortiz *et al.*, 2016; Galvao *et al.*, 2019)—is widely recognized as essential for the co-creation of meaningful, impactful GovTech solutions, bringing together diverse perspectives and expertise. In this context, stakeholder engagement goes beyond consultation, being a set of *practices* that underpin the co-creation of public sector innovation—including procedural, material, relational, and cognitive engagement practices enacted by public sector teams (Knox, Marin-Cadavid and Oziri, 2025). These practices support collaboration across internal stakeholders (such as decision-makers and technical officers) and external actors (such as citizens, private providers, and civic tech communities). The engagement process spans top-down and bottom-up innovation dynamics and reflects the shift from stakeholder *management* to stakeholder *co-production* (Voorberg, Bekkers and Tummers, 2015; Chen, Walker and Sawhney, 2020). However, it also comes with inherent challenges, particularly in aligning the varying goals, languages, and operational logics of the involved actors. Recent work has also highlighted how engagement strategies are not uniform but vary depending on the innovation's origin (top-down vs. bottom-up) and the degree to which stakeholders are empowered in the process (Knox, Marin-Cadavid and Oziri, 2025).

In GovTech, these dynamics are particularly visible in ecosystems structured around Business-to-Government (B2G) and Business-to-Government-to-Citizen (B2G2C) models. While public administrations remain the primary users and gatekeepers of these technologies, citizens are increasingly involved as co-

producers of public value. This dual-user model presents both design challenges and opportunities, requiring GovTech developers to navigate divergent goals, expectations, and institutional logics (Best and and McAdam, 2019; Boon, Wynen and Callens, 2023). Rooted in leveraging public-private partnerships, GovTech emphasizes principles of citizen-centricity, co-creation, and the development of scalable solutions to address societal challenges (Mortati, Mariani and Rizzo, 2023). However, despite its potential, GovTech often struggles to fully operationalize such principles. Challenges such as an overemphasis on technology that neglects critical socio-political dimensions, rigid procurement systems conflicting with the agility required for innovation, and skill gaps in advanced technologies—such as AI, blockchain, and data analytics—hinders digital transformation (Dener *et al.*, 2021; Hoekstra, Van Veenstra and Bharosa, 2023; Nose, 2023). Moreover, the contextual specificity of many GovTech solutions limits their scalability (Anbouba *et al.*, 2020; Zapata, 2020). These challenges often result in isolated innovations that fail to create systemic impact. As highlighted by the JRC report *Scoping GovTech dynamics in the EU* (Mergel *et al.*, 2022) one of the main drivers for governments engaging with GovTech is the opportunity to shape innovation directly through participatory procurement and solution development. This positions governments not just as buyers but as strategic co-creators of digital public infrastructure. In this light, stakeholder engagement becomes essential to inform need-driven design, strengthen institutional capacity, and improve implementation outcomes. However, realizing meaningful co-creation requires enabling conditions. These include institutional willingness to collaborate, procedural openness, and the creation of spaces and mechanisms for stakeholders to contribute insight and shape outcomes (Lindsay *et al.*, 2021; Knox and Marin-Cadavid, 2023).

Based on these challenges and the discourse in the literature, a relevant question is how stakeholder engagement can enter the loop to drive the successful development and scaling of GovTech solutions. To answer this point, this paper investigates stakeholder engagement as a core mechanism in the development and deployment of GovTech solutions, and examines WiseTown's digital twin **as a GovTech case study**. By developing a tailored solution that bridges virtual and physical city spaces through advanced data integration, WiseTown puts in place a balanced approach to technological innovation and contextual adaptability. The platform aggregates data from IoT devices, public records, and citizen inputs, supporting urban planners, policymakers, and administrators in visualizing, simulating, and optimizing city functions. Central to this approach is the strategic role that stakeholder engagement plays: rather than being an ancillary component, it serves as a foundational mechanism for shaping, refining, and implementing GovTech solutions. WiseTown's experience serves as a primary example for demonstrating how multi-stakeholder collaboration—across government officials, public administration technicians, technology providers, and citizens—can be strategically orchestrated to co-create digital solutions that are context-sensitive, scalable, and impactful.

2 Methodology: An In-depth Qualitative Analysis of WiseTown as Case Study

This study undertakes a qualitative case analysis of WiseTown (https://wise.town/en), a digital twin solution developed by the Italian company TeamDev (https://teamdevecosystem.it/en). WiseTown offers a comprehensive suite of modular applications designed to support urban management and enhance civic engagement. WiseTown was chosen as the subject of this case study due to its recognized leadership in deploying smart cities solutions. It has received notable recognition, including being named Best Civic Tech Startup by the South Europe Startup Awards (2019), and being awarded by Unicamere with the prestigious national Top of the Pid 2023 award. In addition, WiseTown has participated in European Commission initiatives, including GovTech Connect's BootCamps, reinforcing its standing as a relevant and forward-looking player in the European GovTech landscape. Its socio-technical and user-centric approach to smart city innovation made it a prominent candidate for investigating the role of stakeholder engagement in the design and implementation of GovTech solutions.

In line with the objective of gaining rich, contextualized insights into a real-world application of GovTech solutions (Yin, 2011), we adopted a case study methodology based on multiple data sources. Primary data was collected through a 2.5-hour semi-structured interview conducted in January 2025 with Irene Provvidenza, Business Developer at TeamDev for WiseTown. This interview captured first-hand knowledge on WiseTown's stakeholder engagement strategy and its impact on technological design and implementation process. A set of targeted questions were posed to uncover how WiseTown integrates diverse stakeholder perspectives across governance, institutional, user, and technological dimensions, the questions explored: (i) Engagement with different stakeholders throughout the development of WiseTown solutions; (ii) Mechanisms to ensure adaptivity to evolving needs; (iii) Diversity of priorities among stakeholders, their management and how they impacted the solution development; (iv) Citizen engagement possibilities and integration into WiseTown. The interview was analyzed using MAXQDA to code, organize, and interpret the data. The authors first annotated

the transcript individually, then cross-checked and merged their findings. Emerging themes were identified through a three-step process: clustering similar annotations, developing themes, and refining them into insights. These themes structure the Results section. Secondary data—such as publicly available reports, project descriptions, and articles published by TeamDev—were used to triangulate and enrich the analysis.

3 The Case Study of WiseTown as an Integrated Solution

WiseTown's digital twin is an integrated suite of digital solutions designed to enhance urban management and foster citizen engagement by supporting public administrators in developing inclusive and participatory forms of urban governance (Sartoretti and Minascurta, 2024). It supports data-driven policy making by offering tailored solutions for human-centered urban planning, transforming data into actionable insights and supporting more effective, informed, and sustainable decision-making. The suite (Figure 1) operates as a modular digital ecosystem, allowing cities to assemble customized configurations that respond to their unique challenges and strategic goals. It is not a one-size-fits-all platform, but rather an adaptive framework that evolves alongside the priorities of local administrations.

SOLUTIONS	AIM	USERS	USER'S NEEDS	FEATURES	IMPLEMENTATION LOGIC
CitiVerse (CDT)	Simulate, monitor, and plan urban dynamics	Decision-makers, planners, administrators	Integrated decision-support based on data	3D city model, scenario simulation, machine learning for data forecasting.	Collects 3D and sensor data for scenarios and informed decisions
Urban Dashboards	Visualize and analyze geo-referenced urban data	City planners, administrators, data analysts	Insights into phenomena for planning	Customizable views, real-time satellite and statistical data integration, thematic filters.	Combines spatial and statistical data for visual exploration
Situation Room	Monitor real-time events and emergencies	City officials, emergency managers	Timely responses to critical citywide events	Centralized control dashboard, data aggregation from various sources, rapid decision-making.	Visualizes urban data in real-time to support operations and decisions
Issue Manager	Facilitate communication between citizens and municipalities	Citizens, municipal staff	Efficient issue tracking and service responsiveness	Mobile app for reporting, automated task creation and assignment, multilingual support.	Transforms reports into actionable tasks with automated workflows
Crowd Planning	Support participatory urban planning and co-creation	Citizens, public administrators, urban planners	Inclusion of citizen input in planning decisions	Publishing urban plans, collecting citizen feedback, facilitating co-creation.	Publishes projects, collects feedback, include insights into plans
Custom Solutions	Customize and integrate WiseTown features to local contexts	Municipalities with urban development needs	Adaptability to specific municipal needs and constraints	Modular architecture, FIWARE compatibility, integration with third-party and existing municipal systems.	Integrates with existing infrastructure and third-party systems

Figure 1: WiseTown integrated solution

These tools are currently deployed across various Italian cities, demonstrating WiseTown's adaptability and scalability. The most complete and advanced implementation is in Perugia, where the full CDT has been adopted to support integrated urban governance since 2022. In Perugia, the CDT aggregates data from a wide range of sources to build integrated tools that support public administrators. These sources include the city's Geographic Information System, IoT sensors, citywide monitoring systems, Open Data repositories, historical records, and datasets retrieved from both internal municipal applications and external providers, thus providing departments with continuously updated information across various domains. Thematic Dashboards are used to visualize geospatial data and highlight spatial-temporal relationships, informing urban planning, green space management, public welfare services, and mobility analysis, by enabling city administrators to make data-informed decisions and deliver more effective, citizen-centered services. In other municipalities, specific components have been configured to meet targeted needs, creating fit-for-purpose solutions. Notable examples include Narni, Parma, San Fermo della Battaglia, Calcinato, and Todi—cities where WiseTown has been applied to address challenges such as social policy monitoring, urban planning, infrastructure management, and community engagement.

4 WiseTown's Stakeholder Engagement

WiseTown's approach to stakeholder engagement is a central pillar of its socio-technical strategy and is deeply integrated into the design, implementation, and evolution of its GovTech solution as a modular digital ecosystem. Stakeholder engagement for WiseTown is both a methodological and operational commitment, aimed at ensuring that digital tools meet the diverse, real-world needs of public administrations, technical personnel, and citizens.

4.1 Initiating engagement in a multi-stakeholders ecosystem

WiseTown's stakeholder engagement strategy spans a wide spectrum of actors across different layers of governance, technical operations, and civil society. The process is structured and layered, with a tailored approach that responds to the specific roles, expectations, and responsibilities of each stakeholder group. This strategy ensures that engagement adapts to the institutional context of each city, helping solutions evolve organically within existing ecosystems. The case study reveals that engagement can have two entry points. At the **strategic level**, TeamDev often initiates contact with municipal decision-makers, especially when they have an appreciation for data and digital technologies. Typically these are political or high-level administrative figures within decision making roles, such as councillors, mayors, or department heads—with the authority to initiate or endorse digital transformation agendas. This engagement ranges from securing buy-in from senior municipal decision-makers through business cases, consultations, and alignment with policy goals, and is facilitated through presentations, consultations, and participation in planning sessions in which TeamDev demonstrates the value of its solution by showcasing its alignment with policy objectives, such as sustainability, efficiency, and citizen engagement. As noted in the case of Perugia, a high-level institutional buy-in was instrumental in the city's decision to deploy the full WiseTown CDT ecosystem. This top-down engagement establishes initial legitimacy and creates a governance anchor for wider adoption across departments.

However, engagement more frequently starts at the **operational level**, with technical officers and public employees who oversee the day-to-day functioning of city systems and have technical expertise. These stakeholders are critical in translating strategic goals into practical action and are often the first to recognize the platform's potential. They have specific needs and requirements that the platform needs to address and can inform decisions at the administrative and political levels. These stakeholders are considered the primary users and gatekeepers of data and operational workflows as they can drive the administrative and political decision-making. As emphasized by the interview, "the technical offices that have needs, sometimes even very practical, of calculations, of mappings, of creation, of report—in short, a whole series of requests—that then direct the more administrative and political parts and how they make decisions". As such, these actors serve as both early adopters and internal advocates who validate the relevance of the tools through direct application. Through workshops, training, and iterative feedback cycles, the company co-produces digital tools that respond directly to institutional constraints and operational needs. The engagement with technical officers involves **diagnosing immediate operational needs**—such as spatial data analysis, infrastructure mapping, incident reporting, or workflow optimization—and configuring tailored functionalities like geospatial dashboards and automated task management tools. From the earliest stages, these stakeholders are not just consulted, but actively involved in shaping the tools to ensure usability and institutional compatibility. Co-design occurs through workshops, training sessions, and continuous support, enabling a **feedback loop** that ensures the solution evolves with its users.

This **bottom-up approach** builds trust incrementally, allowing WiseTown to demonstrate value before scaling implementation. It reflects an understanding that stakeholder engagement is not a one-off event but a continuous process of mutual learning and tool refinement. The platform's modular architecture supports this evolution by allowing individual departments to integrate the tools at their own pace, expanding functionality as organizational readiness grows. Beyond continuous training, these stakeholders are indeed engaged to provide direct feedback to inform support and collaborative customization efforts that help ensure the solutions are relevant and valuable from day one. This approach, based on continuous exchanges builds familiarity with the municipality, proving effective in building trust over time and enabling follow-ups and larger projects.

The interaction with technical units allows TeamDev to demonstrate their capabilities to propose solutions responsive to actual operational challenges. Over time, this engagement evolves into a strategic collaboration, often reaching higher administrative and political levels. This **co-evolutionary nature of engagement** means that WiseTown is not a static product, but rather an adaptive solution shaped through sustained dialogue. As stakeholder needs change—due to regulatory shifts, funding availability, or technological advancement—the platform is reconfigured accordingly. For example, when new reporting requirements or data sources emerge, WiseTown collaborates with city staff to develop compatible dashboards or integration pathways. This adaptive capacity ensures that the CDT remains relevant over time and avoids obsolescence.

Engagement may be triggered by a technically-minded officer or a politically progressive municipal leader. Either way, the approach scales to engage broader departments and eventually fosters institutional alignment. WiseTown's dual-entry engagement model—bottom-up from operational staff and top-down from strategic leadership—ensures both functional legitimacy and strategic support. Over time, this results in a shared digital vision, where the platform supports not just isolated tasks but citywide coordination and governance innovation. As a result, the stakeholder engagement here represented takes the shape of a **co-evolutionary practice**, where

digital solutions are not merely implemented but shaped in collaboration with stakeholders. By embedding engagement throughout design and deployment, the platform grows with its users—improving usability, increasing institutional buy-in, and ensuring that solutions stay relevant to the evolving realities of urban governance.

4.2 Mechanisms of engagement

WiseTown's stakeholder engagement strategy exemplifies a **multi-helix approach** (Peris-Ortiz *et al.*, 2016; Galvao *et al.*, 2019), engaging multiple actors—government, industry, and citizens—in the development and continuous refinement of its solutions. It leverages targeted mechanisms to engage stakeholders at different levels of governance—from strategic decision-making to operational use and citizen participation—ensuring that its solutions remain context-aware, inclusive, and technically robust.

The engagement adopts **layered and role-specific** mechanisms for targeting different stakeholders across governance, operations, and community participation. **Government stakeholders**—from municipal decision-makers to technical staff—are engaged through a flexible and iterative process that aligns digital solutions with administrative goals and operational realities. Nevertheless, engagement often begins with **technical officers** who manage existing workflows and hold key operational knowledge, helping translate high-level administrative and political goals into specific technical requirements. These actors become key enablers for adoption and internal change. Nevertheless, the interview highlights that these stakeholders are often protective about their own skills and knowledge, making it strategic to first establish trust through responsiveness to their practical challenges. To this end, TeamDev organizes **technical workshops, hands-on training sessions, and other collaborative activities** that enable public sector staff—spanning architects and IT administrators—to understand and use the platform. These sessions go beyond onboarding: they serve as moments to align expectations, demonstrate the platform's immediate value, and **surface critical feedback** that informs iterative improvements. In many cities, municipal staff proactively request additional training once they recognize how the tools address real bottlenecks. Importantly, these workshops serve as **entry points for co-design**. They allow TeamDev to gather operational insights directly from users and adapt the platform's functionalities accordingly. This provides knowledge to make the solution not merely "fit" the current context but to enable its co-evolution with changing administrative structures, political agendas, and technological standards. As the interviewee noted, "it's not about selling a product, but about accompanying the city through a transformation process".

After building relationships at the technical level, TeamDev works to **scale engagement vertically**, involving higher-level administrators and political actors. This step is often facilitated by the technical officers themselves, who advocate internally for broader platform adoption.

The engagement process is **tailored to the specific context and priorities of each city**. WiseTown may start with technical staff or political leaders depending on who is more open to innovation. The goal is to create trust and buy-in across the different levels of the administration. The overall approach involves a gradual, collaborative process of engaging technical experts, managers, and political leaders to collectively understand requirements, build trust, and implement the digital platform across the city administration.

Additionally, WiseTown steadily invests in methodological inclusivity through **Civic Tech tools** (Gilman, 2017; Rajabiun, 2020) that enable communities to contribute local insights and actively participate in decision-making. Citizens engage through dedicated modules: Issue Manager for reporting local problems via smartphone—automatically routed to relevant departments and tracked internally—and Crowd Planning, which supports participatory planning by allowing comments and suggestions on proposed projects. These Civic Tech tools play a dual role. First, they serve as channels for institutionalizing citizen feedback, turning informal observations into structured data that informs city planning. Second, they democratize participation by making governance more transparent and interactive. The interview points out that these tools have proven especially useful in smaller municipalities where traditional mechanisms for citizen consultation—such as public meetings, structured feedback sessions, or participatory budgeting—are often **limited due to lack of institutional capacity, resources, or administrative experience**. As these municipalities may not have established processes to systematically gather or manage citizen input, civic Tech tools **fill the gap** by offering a digital, ready-to-use platform that facilitates two-way communication between citizens and the administration. "Crowd Planning helps bring voices into the room that otherwise wouldn't be heard. Even just a few citizen inputs can shift how a plan is structured". In parallel, the simplicity and accessibility of tools like the **Issue Manager** encourages citizens who might not attend a town hall or write formal complaints to submit issues from their phone, quickly and intuitively. This helps surface local knowledge and concerns that would otherwise remain unheard. "Even just a few citizen inputs can shift how a plan is structured", showing how these tools can have meaningful impact even when participation volumes are modest.

The participatory approach is supported by a **dedicated technical support team** within WiseTown, responsible for maintaining feedback loops between citizens, municipalities, and developers. In larger municipalities like Perugia, feedback is collected by Smart City Offices and forwarded to TeamDev, where it informs future platform refinements. This continuous feedback mechanism enables the co-evolution of tools alongside changing community needs, ensuring relevance over time.

4.3 Tackling institutional diversity and resistance

WiseTown's stakeholder engagement strategy is highly **adaptive to the institutional diversity** that characterizes different municipalities. The company recognizes that cities vary significantly in terms of administrative readiness, digital literacy, and openness to innovation. As said before, for this reason, the entry point for engagement is carefully tailored to local contexts. In some cases, the process is initiated through a digitally forward political leader or a younger councillor with a mandate for modernization. In other situations, engagement begins from within technical personnel driving change from the bottom up.

A recurrent challenge lies in institutional resistance, particularly within departments that tend to retain data and expertise within their own units, often displaying reluctance toward sharing and overlooking the broader value of interdepartmental collaboration. WiseTown addresses this reluctance by demonstrating the concrete value of data integration. The approach to change this logic is grounded in exposing the inefficiencies of maintaining siloed systems—especially the duplication of effort, resources, and time when data is collected and processed separately by different departments. TeamDev uses this argument to promote a unified data-sharing model where layered datasets—such as traffic flows and public health statistics—are combined to support predictive and targeted policymaking. As highlighted in the interview, demonstrating real use cases that merge diverse data types has been instrumental in overcoming resistance. For instance, one example shared was the ability to "combine the traffic data with the health data to understand the quality of an area", allowing municipalities to optimize interventions and enhance urban wellbeing. These kinds of scenarios illustrate the strategic value of WiseTown's approach and help to shift stakeholder perception from one of territoriality to one of mutual benefit. The **platform's modular architecture** supports this process by enabling municipalities to gradually integrate datasets from different departments (e.g., infrastructure, health, environmental services) without needing a complete systems overhaul. This incremental approach allows public administrations to scale their adoption based on internal capacity and readiness, while still building toward a shared digital infrastructure that supports cross-departmental collaboration and informed decision-making.

A key finding from the interviews is that the WiseTown **collaborative infrastructure-building process** is inherently dynamic and adaptive. As trust deepens, competencies develop, and new needs surface, the platform evolves accordingly—ranging from refinements to user interfaces and the expansion of indicator sets, to the integration of additional datasets and, in some cases, the co-development of entirely new functionalities or modules. These elements, built from stakeholder needs, once validated, are often incorporated into the WiseTown ecosystem, thus enhancing its capacity to respond to the evolving demands of urban governance. Dashboards are an essential component of this evolution. Designed around indicators selected by each municipality, they support constant monitoring of strategic issues—from green space management to social welfare trends and mobility dynamics. These tools allow administrators to assess phenomena in real time, track trends over time, and inform policy in a data-driven manner. As the interviewee emphasized, the real value lies not only in data collection but in making data visible, understandable, and actionable across departments.

4.4 Engagement beyond the municipality

WiseTown's stakeholder engagement strategy extends beyond the confines of individual municipal administrations. A distinctive feature of its model is its ability to catalyze **inter-municipal collaboration and scaling**, creating broader ecosystems of innovation, particularly among smaller cities that benefit from shared knowledge, technical resources, and strategic alignment. A key approach is supporting coalition-building where one "lead" municipality champions the adoption of WiseTown's solutions and encourages neighboring administrations to follow suit. This has proven particularly effective in contexts where individual municipalities may lack the critical capacity or influence to initiate large-scale digital transformation independently. Furthermore, WiseTown solutions tackle needs that the company and its municipal clients recognize as common ground. This fosters a proactive partnership in implementing these solutions. Often, a leading municipality champions the adoption of a particular solution by others, aiming for comprehensive territorial monitoring and management across the board. The case of **Perugia**—described in the interview as a **"pioneer" municipality**—illustrates this dynamic. WiseTown's comprehensive implementation in Perugia, which includes the full CDT ecosystem, serves as a **demonstration case** to show how data integration, participatory tools, and real-time

monitoring can be successfully deployed. This flagship implementation has had a **spillover effect**, encouraging other cities—such as Narni, Todi, and San Fermo della Battaglia—to adopt components of the platform based on their localized needs. The interview highlights how "the pioneering city helps to bring others along", demonstrating how trust and relevance grow through proximity and peer-to-peer influence.

The **networked approach** comes with possibilities and challenges. While it supports incremental scaling—allowing cities to learn from each other and tailor implementations—it also requires coordination to adapt the solution based on feedback and ensure interoperability across municipalities. This fosters co-evolution, as lessons from one city inform refinements that benefit the wider user network. WiseTown's developers stay closely connected with municipal partners to align the platform accordingly. Beyond individual municipalities, WiseTown actively positions itself within the **broader GovTech and civic innovation ecosystem**. It participates in international GovTech initiatives, and collaborates with academic institutions to explore experimental applications of its technology. These partnerships represent WiseTown's multi-helix engagement model applied to the co-development of research-driven innovations with societal relevance.

5 Discussion and Conclusions

Overall, the case offers insights on how engaging stakeholders throughout the design and implementation processes enables solutions to co-evolve and remain relevant. Participation fosters innovation by incorporating local insights while ensuring expanded access for multiple user groups. From the analysis conducted, several key lessons emerge that are highly instructive for addressing common challenges in future GovTech projects. They reflect both the successes and tensions of co-creating digital solutions with public sector institutions and civic actors, offering valuable insights for practitioners and policymakers aiming to scale meaningful digital transformation in urban governance.

1. Start where the motivation is: flexible entry points enable progress. WiseTown's stakeholder engagement reflects a dynamic, multi-strategy approach that adapts to contextual conditions rather than following a rigid, top-down model. Engagement often began with either technically competent municipal officers or politically progressive councillors who championed the platform internally. This flexible entry strategy echoes findings from Mergel et al. (2022) on adaptive procurement and from Knox and Marin-Cadavid (2023), who highlight that engagement should be situated and responsive to organizational context. Tailoring the engagement strategy to each municipality's internal dynamics is a way to tackle the fragmented landscape of local governance. Future GovTech efforts should recognize that there is no one-size-fits-all engagement model, instead organizational readiness should be assessed to identify the best anchor points. **Lesson:** Engagement can begin either at the strategic level with political champions or at the operational level with technical staff—but the key is to identify and leverage the most motivated entry point.

2. Technical offices are critical enablers, not just end-users. WiseTown's iterative engagement and co-creation with technical offices were central in aligning the CDT's capabilities with real-world administrative needs and workflows, enabling the contextualization of the CDT features. This group helped refine use cases and ensured the system met local needs (e.g., spatial analysis, workflow automation), while also serving as internal advocates who helped raise support from senior management. Future GovTech efforts should formalize this translational role by empowering technical staff through co-design workshops and participatory implementation strategies. This mirrors the translational role of "middle actors" in public innovation, described by Knox and Marin-Cadavid (2023), and supports Mortati et al. (Mortati, Mariani and Rizzo, 2023), who emphasize the importance of collaborative prototyping between users and developers. **Lesson:** Technical officers often act as "translators" between high-level political goals and the operational realities of city administration, and should be treated as strategic partners in the innovation process.

3. Co-creation requires capacity building and iterative support. WiseTown's ability to build trust and scale its implementation across departments depended on early and sustained support. Workshops, technical onboarding, and responsive consultancy services created a learning environment that demystified digital tools and helped overcome resistance. This commitment was particularly important in municipalities with limited digital literacy or experience with smart city technologies. This aligns with Bharosa (2022), who stresses that GovTech requires continuous engagement and iterative development, while echoing design-led approaches to public innovation advocated by Mortati et al. (2023), which emphasize that learning-by-doing is essential to co-evolution. In light of this, future projects should budget and plan for this support as a core part of the implementation—not as an afterthought. **Lesson:** Stakeholder engagement is not a one-time consultation but a continuous process that requires investment in education, training, and ongoing technical support.

4. Citizen participation must be institutionalized, not just piloted. WiseTown's civic tech tools strengthened the relationship between residents and public administrators, creating a feedback loop that improves service

delivery and governance transparency. However, the true impact depended on whether municipalities institutionalized the use of these tools—e.g., by assigning personnel, incorporating insights into policy, and maintaining transparency. This supports Gilman (2017) and Rajabiun (2020), who argue for formal structures to turn participation into co-governance. This highlights the need for GovTech providers to not only develop civic tools but also support local governments in embedding them into their internal procedures and decision-making frameworks. **Lesson:** Participatory mechanisms are most effective when integrated into institutional routines and not treated as temporary experiments.

5. Demonstrating tangible benefits builds legitimacy across departments. WiseTown overcame siloed resistance to data integration by highlighting concrete gains, like cost and time savings or predictive analytics. This approach made abstract digital transformation goals tangible and actionable. This aligns with Dener et al. (2021), who note that operational wins are essential to overcome organizational inertia, and Mergel et al. (2019), who call for use cases that show clear public value. For future GovTech efforts it is relevant to contextualise abstract values like "innovation" or "efficiency" against what users can gain, and how quickly. **Lesson:** Data integration is more likely to gain traction when it is framed in terms of concrete, immediate benefits—such as time savings, better coordination, or cost reductions.

6. Multi-level and multi-stakeholder coordination is difficult but necessary. The ability to integrate different voices and priorities—from institutional actors to citizens—is essential for building trust, ensuring adoption and contextual alignment. WiseTown's efforts to engage regional consortia or clusters of municipalities shows the value—and difficulty—of inter-municipal coordination. This reflects the findings of van Veenstra and Kotterink (2017) on the need for shared standards and governance frameworks in cross-jurisdictional digital projects. Future projects should consider the value of "lead municipalities" to champion adoption, but also invest in coordination mechanisms such as shared standards, joint funding models, and regional data governance frameworks. **Lesson:** A successful GovTech deployment often requires coordinating actors across multiple governance levels and sectors—from citizens to service providers to inter-municipal unions.

7. Engagement needs to align with governance structures and capabilities. WiseTown's engagement strategy succeeded because it adapted to the administrative capabilities of different cities, offering more support where capacity was lacking and leveraging internal champions where they existed. This corresponds with Ubaldi et al. (2019), who call for capacity-sensitive innovation strategies in digital government. Differentiation also reflects the adaptive approach emphasized in Carvalho (2015) and Bharosa (2022), where engagement success hinges on understanding local capability constraints. Insights for future projects concern the need to assess institutional maturity and develop differentiated engagement pathways, especially for under-resourced or smaller municipalities. **Lesson:** Successful stakeholder engagement requires an understanding of—and alignment with—the administrative and governance capacity of each context.

WiseTown's experience shows that stakeholder engagement is not only an ethical or democratic requirement—it is also a practical necessity for GovTech success. While the implementation of such an approach is not without challenges—including institutional resistance, limited resources, and coordination across departments—WiseTown's strategy highlights how these can be addressed through targeted actions. These include stakeholder workshops, the use of modular and phased deployments, technical consultancy, and the development of civic technologies that enable two-way interaction between municipalities and residents. Such mechanisms have proven essential to building internal support, ensuring usability, and embedding digital tools within everyday public administration practices. Beyond the municipal level, the study has examined how WiseTown's engagement approach supports scalability by enabling cross-city learning and replication. The role of lead municipalities, such as Perugia, is particularly relevant in catalyzing adoption within wider networks. This reveals how stakeholder engagement also operates as a strategy for scaling and sustainability, facilitating both knowledge transfer and the institutionalization of innovation.

At its core, WiseTown's approach provides insights on how systemic barriers—such as siloed data practices or fragmented governance structures—were overcome through co-creation and adaptive solution development, thus confirming how stakeholder engagement, when embedded throughout the design and implementation process, can enables GovTech solutions to evolve in step with changing needs and conditions. As a consequence, this study contributes to the growing field of research on GovTech by offering empirical insights into how stakeholder engagement can support more effective, inclusive, and resilient public sector innovation. While not all contexts are the same, the lessons from WiseTown offer a useful reference point for future projects aiming to align digital transformation with institutional realities and citizen expectations.

6 Ethics Declaration

No ethical clearance was required for the research presented in this paper.

7 AI Declaration

The analysis of the interview data was supported using MAXQDA, which includes an AI Assistant tool that can be asked to suggest potentially relevant passages by highlighting sections of the transcript related to specific topics. In this study, the AI tool was used to assist the authors in the initial identification of passages based on the coding provided by the authors for subsequent review; however, all coding, thematic clustering, and interpretation were carried out independently by the authors, who retained full responsibility for the analysis and the final findings.

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Artificial Intelligence and the Future of Copyright Law

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Abstract

The advent of generative Artificial Intelligence (AI) represents a significant challenge for contemporary copyright law. As the capacity of machines to generate content autonomously has increased, the distinction between human creation and automated production has become increasingly indistinct. This raises fundamental questions concerning the attribution of authorship and the ownership of rights. The prevailing legal framework, which is primarily anchored to the "human author" concept, is ill-equipped to resolve these issues uniformly and coherently. The intensity of the international debate has increased in recent years. Legislatively speaking, the adoption of EU Regulation 2024/1689 (AI Act) represented a significant turning point in the governance of AI. Although it does not directly regulate copyright, it introduces transparency for providers of general-purpose AI models, imposing, among other things, the obligation to document the content used for training algorithms and to comply with European copyright law, with particular reference to EU Directive 2019/790. Concurrently, the Italian legislator recently approved DDL no. 1146/2024, which proposes to extend copyright protection to works created with the help of AI, provided they are the result of human intellectual work.

Keywords: Artificial Intelligence, Copyright, AI-Generated Works, EU Regulation 2024/1689 (AI Act), Author

Paper type: The paper is an Academic Research Paper

1 Introduction

Technological advancement has engendered legal uncertainties in the digital age, particularly with the intersection of human artists and artificial intelligence (AI). The question of who should be recognised as the author of an AI-generated work has become a complex copyright debate. This issue has been identified as a contributing factor to international legal disputes. The crux of the issue pertains to the attribution of authorship for these creations, namely, whether it should be ascribed to those who develop the algorithm, those who provide the input to train the AI, or those who give the final input. Another salient question pertains to the legal protection of works created by artificial intelligence and whether such works can be considered original creations. There is a paucity of clarity about the ownership of rights and the legal ramifications of such works. The future of generative AI remains uncertain as courts continue to clash over interpretations of the law, and the definition of "human authorship" remains unclear.

Nevertheless, this challenges the very nature of human creativity and paves the way for new possibilities in the digital age. The emergence of AI-generated platforms has underscored the necessity for a novel regulatory framework. The European legislator has acknowledged the significance of this issue, leading to the introduction of Regulation (EU) 1689/2024, also referred to as the AI Act. This legislative development signified a substantial landmark in global AI governance, constituting the inaugural international endeavor to regulate AI applications.

2 Methodology

This article adopts a doctrinal approach that examines the impact of artificial intelligence (AI) on the concepts of authorship, protection, and invention in copyright law, complemented by a comparative analysis and a review of case law. A literature review was conducted in specialised databases such as Normattiva, DeJure, and EUR-Lex to identify the main theoretical strands and normative orientations. The selection of case law was based on three main criteria: legal relevance, novelty of the normative intervention, and interpretative impact on the concept of authorship. The results identify several gaps in copyright law and significant challenges arising from the production and use of works created by AI. The study aims to comprehensively understand copyright issues related to intelligent systems by analysing existing legislation, case studies, and literature. The main areas of interest include studying Regulation (EU) 1689/2024, its implementing provisions, and their potential impact in Italy. To understand and assess how the courts and the different jurisdictions have dealt and are dealing with the complex balance between IA and copyright, the paper presents a space-time catalog of the individual legal cases that have arisen in the different jurisdictions, from which it emerges that the consequences and legal positions vary depending on the country considered. In light of regulatory and jurisprudential developments, the paper aims to critically examine the concept of "author" in the context of works created by intelligent systems, with particular reference to the notions of creativity, originality, and human contribution. Through a

comparative and doctrinal analysis, the aim is to outline a possible interpretive and regulatory path that would allow the protection of creativity to be reconciled with technological development, in a context in which the figure of the author tend to change from that of the exclusive creator to that of the artificial creator.

3 Discussion: Artificial intelligence and the concept of human authorship

John McCarthy coined the term "Artificial Intelligence" in 1956 at the conference "The Dartmouth Research Project on Artificial Intelligence" (Lakshminath & Sarda, 2012). Ahuja states that the term AI refers to the ability of machines to perform cognitive tasks such as thinking, perceiving, learning, solving problems, and making decisions (2020). AI is "activities we associate with human thinking, such as decision making, problem solving, learning, creating, and playing" (Bellman, 1978). In this case, intelligence refers to the ability of a machine to imitate the cognitive functions associated with the human brain, namely the ability to learn and solve problems. This may involve thinking or acting by imitating human behavior - cognitive approach - or rationality - computational approach - (Russell; Norvig, 2016). According to Adaka (2022), it can also be defined as the ability of a digitally controlled robot to perform tasks commonly associated with intelligent beings (Oriakhogba & Olubiyi, 2021). The World Intellectual Property Organization (WIPO) (2020) defines AI-generated creations as AIs that generate "output without human intervention" capable of modifying their behavior during operations to respond to unexpected information and events.

The Berne Convention for the Protection of Literary and Artistic Works (also known as the Universal Copyright Convention), adopted in Berne in 1886, is an international agreement establishing the mutual recognition of copyright between the member nations for the first time. The Convention is still in force, and international divergences on copyright have been resolved. According to Article 2,1, as stated by Oriakhogba & Olubiyi, the primary purpose of copyright is to encourage and maximize creativity (2021).

The general principle of copyright concerns the human authorship of literary, artistic, sound, musical, and cinematographic works, provided that they are original. Although the Berne Convention does not give a precise definition of authorship, according to Article 2,6, it can be deduced that protection operates for the benefit of the author and their heirs. According to Chapon, the author's definition is left to the contracting parties, but it can be deduced that paternity refers to the human creator or a natural person (2014).

3.1 Jurisprudence: Comparative survey

Two contrasting orientations have emerged on the problem of copyright protection for AI-generated works at a national and international jurisprudential level.

On the one hand, some States, for example, the United States and Italy, deny copyright protection without the human contribution and intervention for the work created by generative AI tools. Other systems, such as Spain and Japan, on the other hand, are favorable and open to a new definition of copyright for the protection and regulation of works created with the use of AI. To understand and evaluate how the various Courts have addressed and are addressing the complex interaction between AI and copyright, we start from the main decisions adopted by the national and international Jurisdictions.

At the national level, the Civil Court of Cassation, Section I, with Order no. 1107 of 16.01.2023, addressed the issue of recognizing works generated by AI as creative works and deserving of legal protection.

The Court established that reproducing an image, even if created with software, may violate the creator's copyright. The Supreme Court was keen to underline that the use of digital technology to create a work does not automatically exclude the recognition of the work as the fruit of the human intellect, provided that the artist's creative elaboration has not been absorbed by technology.

The legal protection of the work depends on the importance of the human creative contribution in the creation process.

Opening up to an international panorama, the United States, with Article 12 of the Federal Law on Copyright, defines the author of a work as the natural person who created it. Aware of the issue's centrality, the US Copyright Office has emphasized that, although copyright protects works born from human creativity, technological tools can be part of the creative process. Still, this statement requires an in-depth evaluation of their contribution.

The Copyright Office had also refused to register the individual images in the comic «Zarya of the Dawn», as they were generated through a generative Artificial Intelligence system, known as MidJourney. The Copyright Office formally determined that the images created using Midjourney could not benefit from copyright protection, as the necessary human creative contribution was missing (https://www.copyright.gov/docs/zarya-of-the-dawn.pdf?utm_source=chatgpt.com). It also examines how AI, while dependent on human input, can generate content, raising questions about the copyright ownership of such creations.

The legal systems of Spain, Germany, and Brazil also exclude copyright protection for works created without human intervention.

In Spain, the Spanish Ministry of Culture, led by Ernest Urtasun, following a long protest by Spanish artists against the massive use of artificial intelligence (AI) in the creative field, published a guide in February 2024 containing recommendations and instructions on the use of artificial intelligence in the creative sector (https://www.cultura.gob.es/dam/jcr:469163cc-0fdf-4fe2-964f-d4815cde40b1/240219-nota-informativa-ia.pdf). The note on the guidelines issued by the Spanish Ministry of Culture established that national prizes will no longer be awarded to works created entirely by AI, but will favor human creations that use AI as a support tool, giving preference instead to "works protected by intellectual property rights that are created by people, who may use artificial intelligence systems in terms of supporting the creative process, but not as a substitute for human performance".

There is also an express clause in which the supplier who intends to use artificial intelligence for creative activities, "must provide information, indicating in detail the level of intervention and, where appropriate, the role of the natural person in reviewing the project". With the introduction of these new guidelines, the Association of Professionals of Illustration of Madrid (APIM) has accused the authorities of normalizing the improper use of AI and endorsing the violation of artists' rights.

Hong Kong intends to liberalize copyright law to adapt it to new technologies. The primary intent is to "liberate" online content protected by copyright to allow its processing for training and the training of generative technology to adapt to new technologies. Recently, also in China, the Beijing Internet Court (BIC), a Chinese court, ruled in the Case Li vs. Liu Beijing Internet, Court Civil Judgment (2023) Jing 0491 Min Chu No 11279 (https://english.bjinternetcourt.gov.cn/pdf/BeijingInternetCourtCivilJudgment112792023.pdf), regarding the infringement of copyright regarding images generated through the use of Stable Diffusion, a generative AI system, recognizing the originality and creativity of the work, as well as the ownership of the AI user who had selected it from the various outputs produced.

In this case, AI software was used to create images starting from textual descriptions and subsequently published on Xiaohongshu, a Chinese social network; in turn, the images were reused in an article by a blogger.

The Court, following the summons, established that the plaintiff had provided a significant intellectual contribution in the creation of the image, including the choice of the AI software, the formulation of the prompts and finally the choice of the generated image, in fact the plaintiff claimed that the work he generated with artificial intelligence was worthy of protection under copyright.

This creative process was considered sufficient to qualify the work as an expression of an intellectual and creative activity, distinguishing it from the simple result of a mechanical process. As for the authorship of the images, the Court rejected the idea that software or the owner of the AI platform can be considered the author of an image generated by it, since it is not a human being. The decision is interesting and has a significant impact on European legal systems. The Beijing Court seems to consider generative AI only as an "assisting tool" in the hands of man rather than an autonomous creator, placing itself as a precedent to be considered for further developments on the need to adapt copyright laws to a rapidly evolving laboratory.

The main decisions have been collected and catalogued in Table 1, and offer a national and international overview, summarizing the case studies and solutions that the various Courts have proposed. The consequences and legal positions vary based on the country considered.

Table 1: Jurisprudence: Comparative survey

Country	**Legal position**	**Legal case**	**AI GENERATIVE**	**LEGISLATIVE REFERENCES**
Italy	Reproducing an image, even with the aid of software, may constitute a violation of the creator's copyright.	Cass. Civ., Sez. I, Ordinanza n. 1107 16/01/2023	*Not specified*	Legge sul Diritto d'autore, Law 22 April 1941, no. 633
USA	Although Copyright protects works born from human creativity, technological tools can be part of the creative process. Images created with the AI tool are not protected by Copyright, considering only human text protected.	Copyright Office, Comic book "Zarya of the Dawn" 21/02/2023	*MidJourney*	Federal Law on Copyright, art. 12

Country	Legal position	Legal case	AI GENERATIVE	LEGISLATIVE REFERENCES
China	Copyright infringement regarding images generated through the use of a generative artificial intelligence system, recognizes the originality and creativity of the work, as well as the ownership of the AI user who had selected it from the various outputs produced.	Beijing Internet Court (BIC) - 2023	*Stable Diffusion*	Copyright Law of the People's Republic of China (中华人民共和国著作权法)
Hong Kong	Intends to liberalize Copyright law to adapt it to new technologies. The intention is to "liberate" online content protected by Copyright to allow its processing for the purposes of training and training of generative technology to adapt it to new technologies.	Authorities have initiated a consultation.	*Not specified*	Trade Marks Registry, 1873 Trade Mark Ordinance, 2003
Spain	The guidelines require the declaration of the human role in the creative process and prohibit awards for fully automated works.	Guidelines of the Ministry of Culture	*Not specified*	

3.2 Regulation (EU) 2024/1689

European Regulation 1689/2024 of 13/06/2024 establishes harmonized rules on artificial intelligence and amends Regulations (EC) no. 300/2008, (EU) no. 167/2013, (EU) no. 168/2013, (EU) 2018/858, (EU) 2018/1139 and (EU) 2019/2144 and Directives 2014/90/EU, (EU) 2016/797 and (EU) 2020/1828 (Artificial Intelligence Regulation (https://eur-lex.europa.eu/legal-content/IT/TXT/PDF/?uri=OJ:L_202401689).

The Regulation marked a significant regulatory progress at the European level, establishing common standards and introducing specific provisions for works created through AI systems. The transposition of this Regulation will have given rise to a vast doctrinal and practical debate, especially regarding the protection of works that use AI to produce creative content.

The European Legislator has recognized the importance of this issue. On 13 March 2024, the European Parliament approved with 523 votes in favour of the European Regulation n.1689/2024, known as the "AI Act", which concluded the lengthy legislative process to regulate (for the first time) artificial intelligence applications. This is the first international attempt to regulate artificial intelligence applications through legislation. The AI Act is a flagship legislative initiative in the Global Governance of AI, whose main objective is to promote the development and adoption of safe and trustworthy AI throughout the EU single market. The measure has created a uniform legal framework for the development, placing on the market, commissioning, and using AI systems, promoting the spread of human-centric and trustworthy AI that can guarantee high protection of the European Union's health, safety, and fundamental rights.

The AI Act does not directly regulate copyright protection but introduces rules for the responsible use of artificial intelligence. The obligation of transparency for AI systems and the security of data used in model training play an essential role in preventing copyright infringements through improper use of artificial intelligence.

In particular, Article 53 relating to the "Obligations for providers of general-purpose AI models" provides for:

Lett. c) "Put in place a policy to comply with Union law on copyright and related rights, and in particular to identify and comply with, including through state-of-the-art technologies, a reservation of rights expressed according to Article 4(3) of Directive (EU) 2019/790". Letter *c* refers to Directive (EU) 2019/790 (https://eur-lex.europa.eu/legal-content/IT/TXT/?uri=CELEX%3A32019L0790), the Directive on Copyright and Related Rights in the Digital Single Market, with particular reference to reservations of rights (Article 4). Therefore, the conditions established for reproducing and extracting works for text and data mining purposes (using data and texts) also apply in Artificial Intelligence. This results in recognizing the right holders' right to limit text and data extraction, except in specific situations outlined by the Directive, such as use for scientific research purposes. The reference to Article 4 of the Copyright Directive is intended to clarify the controversies regarding the applicability of these rules to the creation and training of AI models. AI system providers must obtain permission from rights holders for any use of copyrighted content unless exceptions and limitations provided by law apply.

The issue of copyright protection is also addressed in the introductory "Whereas" of the AI Act. In particular, "whereas" no. 105 describes how generative AI models can be developed and trained using the technique of text and data mining, which allows access to large volumes of texts, images, videos, and other information.

The main objective of the Regulation is to create a single regulatory framework, with particular attention to the protection of copyright, by imposing specific obligations on providers of AI models, regardless of the jurisdiction in which the training takes place. In this way, the legislator intends to avoid disparities in the protection of rights between the various countries. The Regulation also includes specific transparency obligations, aimed at imposing on providers the responsibility to make available to the public a detailed summary of the contents used for training generative AI, including those protected by copyright, so that the latter's owners can exercise and enforce their rights. The objective is to analyse how the Italian regulatory system addresses the creation, protection, and management of works created by AI.

4 Results: DDL 1146/2024 and the Italian legislator

The issue of Copyright in the context of Artificial Intelligence (AI) applications demonstrates the inadequacy of this regulation. Regarding the AI Act, there is a lack of adequate regulation and implementation data regarding copyright (Hristov, 2016).

Despite the lack of a comprehensive and adequate regulation on copyright in AI, the AI Act is the most recent legislation addressing this field. In Italy, the AI bill approved by the Council of Ministers, DDL Butti, suggests several amendments to Law No. 633/1941 on copyright, where it will be specified, if this bill becomes law, that intellectual works could be protected even if created with the aid of AI tools, provided that they are the result of the intellectual work of the author. From this perspective, the focus of the issue could shift not so much on the creativity of the work or its originality, but on the aspects related to the economic exploitation of such work. Therefore, the question is not whether the work is protectable, but who owns the related economic exploitation rights. In light of the new EU Regulation 1689/2024, the Italian legislator, ahead of all other European countries, presented in 2023 the DDL no. 1146/2024 «Provisions and delegations to the Government on artificial intelligence», also called DDL Butti, as it takes its name from Alessio Butti, Undersecretary of State to the Presidency of the Council of Ministers. The DDL is part of the national initiatives to regulate the impact of artificial intelligence based on what has been defined at a Community level.

Chapter IV is dedicated to the protection of copyright: through an amendment to Article 1 of the Copyright Law, works generated with the aid of artificial intelligence would also be protected, provided that the human contribution is creative, relevant, demonstrable, and that an intellectual contribution from the author remains. The DDL was approved on 20 March 2025 by the Senate with the new title "Provisions and delegations to the Government on artificial intelligence" and passed the Chamber with 85 "yes" votes and only 42 "no".

The current text suggests several changes and will focus on national strategy, authorities, promotional actions, protection of copyright, and criminal sanctions. One of the laws that would be affected by these changes is Law No. 633/1941 on copyright, which will specify, if this bill becomes law, that works of the mind could also be protected if created with the aid of artificial intelligence tools, provided that they constitute the result of the author's intellectual work.

The protection of copyright is the subject of Chapter IV of DDL 1146/2024, which contains provisions for the protection of users according to Article 23, entitled "Identification of textual, photographic, audiovisual and radiophonic content produced by artificial intelligence systems" and in matters of copyright according to Article 24, entitled "Protection of copyright of works generated with the aid of artificial intelligence", thus protecting, on the one hand, users and, on the other hand, the copyright of works generated with the aid of AI. As underlined by the explanatory report of the bill, "in consideration of the growing use of artificial intelligence systems in sectors involving the recognition by the user of textual, photographic, audiovisual and radio content produced by artificial intelligence systems, Chapter IV introduces procedures to allow users to recognize content generated by AI -Article 23, as well as establishing specific rules on copyright - Article 24".

Article 24 regulates copyright protection for works generated with artificial intelligence. In particular, through amendments to Law no. 633 of 1941, it is first specified that the "works of the mind" protected under the law above must be of "human" origin. The expression "works of the mind" refers to those intangible assets that consist of creations of the human intellect that present the following characteristics: creativity, concreteness of expression, and belonging to one of the sectors of intellectual production expressly considered by the law (musical works, cinematographic works, software, ...). Works of the mind are protected by copyright, regulated at a national level mainly by Law no. 633 of 22 April 1941. Secondly, it is specified that even works created with the aid of artificial intelligence tools are protected by copyright, provided that their creation derives from the intellectual work of the author. Furthermore, reproduction and extraction, carried out through the use

of artificial intelligence models and systems, including generative ones, of works or other materials, is permitted, in compliance with specific provisions of the same law no. 633 of 1941.

As specified in the Dossier (https://www.senato.it/leg/19/BGT/Schede/Ddliter/dossier/58262_dossier.htm) to the DDL, specifically, Article 24 "Copyright protection of works generated with the aid of artificial intelligence", consists of a single paragraph, and is divided into two letters *a*) and *b*). Letter b) inserts the new Article 70-septies into Law no. 633 of 1941, which provides, in its sole paragraph, that the reproduction and extraction of works or other materials through models and systems of artificial intelligence, including generative intelligence, are permitted by the provisions of Articles 70-ter and 70-quater of the same law.

The introduction of this provision allows the use of protected works by AI systems by research organizations and cultural heritage protection institutes for scientific research purposes. According to letter a), article 1, first paragraph, of law no. 633 of 1941 is amended, specifying that the mind that creates the works protected by the law above is "human". Furthermore, with a further integration to the same article 1, first paragraph, it is provided that works of the mind are also protected when created with the aid of artificial intelligence tools, provided that they constitute the result of the intellectual work of the author. Article 2 entitled "Definitions" of DDL 1146/2024 defines in letter a) the artificial intelligence system, but does not explicitly define the "generative" artificial intelligence system. This term refers to an automated system designed to operate with variable levels of autonomy and which can present adaptability after dissemination and which, for explicit or implicit objectives, deduces from the input it receives how to generate outputs such as predictions, content, recommendations, or decisions that can influence physical or virtual environments. As also recalled in the explanatory report, this definition is identical to that in art. 3, par. 1, no. 1) of the AI Act Reg. EU 1689/2024 (finally approved by the EU Council on 21 May 2024).

The article in question provides specific rules for works created with AI systems, ensuring the identification of works and other materials whose use is not expressly reserved by the copyright holders. But in this perspective, is it possible to identify the "protection of copyright for works generated with artificial intelligence"?

To the current wording of Article 1, first paragraph of the Copyright Law which states "Creative intellectual works belonging to literature, music, figurative arts, architecture, theatre and cinematography are protected under this law, whatever their mode or form of expression", provides for the addition that works of human ingenuity are protected in any mode and form of expression, "even when created with the aid of artificial intelligence tools, provided that they constitute the result of the intellectual work of the author". In the initial draft of the bill in question, before the stamping of the General Accounting Office of the State, the amendment to Article 1, first paragraph of Law 633/1942 included the addition of the phrase "even when created with the aid of artificial intelligence tools, provided that the human contribution is creative, relevant and demonstrable", amended with "provided that they constitute the result of the intellectual work of the author", a formula that had immediately raised more than one doubt. Therefore, it is clear that the Legislator is excluding copyright protection about those works generated with AI and this emerges from the amendments that they intend to make to Article 1 of Law no. 633/1941, as previously seen, the USA and other EU countries have also expressed themselves in this sense, or are oriented towards excluding copyright protection about works generated with artificial intelligence. Among these, those created with the aid of AI tools will also be considered, provided that they constitute the result of the intellectual work of the author, but works created exclusively with artificial intelligence systems are excluded.

The economic repercussions are not the only ones that authors and publishers fear suffering. Their creative identities and the specificity of their roles are also at risk. The primary concern is generative AI, which is capable of producing works similar to human ones, which the Legislator excludes in the current DDL. In this scenario, there are many questions about the compatibility between new creation methods and the protection offered by copyright. The main issue concerns the legal status of works generated by AI, whether they can be protected by copyright independently or, if not, how their nature should be configured. The European regulation resulting from the AI Act and the EU Directive 2019/790, implemented in Italy with Legislative Decree 177/2021, recognizes copyright holders the right to prevent their protected works and materials from being used by AI software, except for scientific research. This means that suppliers of AI models for general purposes must obtain authorization from the rights holders if they intend to perform text and data extraction on their works.

5 Conclusions

The advent of AI has accelerated many advances in the technological domain, thus challenging existing intellectual property legislation. Establishing authorship and invention in the context of AI is crucial to ascertain the appropriate designation of the inventor, be it the programmer, the AI owner, the data provider, the

operator, or the trainer. This article posits the need for explicit legislative amendments that outline the eligibility criteria for authorship and protection of works created by AI. Regulation (EU) 1689/2024 represents a fundamental progression in regulating AI-generated works. The main challenge the sector faces is to balance copyright protection and the promotion of technological innovation.

6 Ethics declaration

Ethical clearance was not required for the research.

7 AI Declaration

AI tools were used only to rephrase a few sentences for clarity, enhancing clarity, and summarizing content. The paper's content, structure, and conclusions remain the result of the authors' original work. All AI outputs were reviewed and edited by the authors to maintain the originality and rigor of the paper.

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Platform Capitalism and the State: Between a New Balance of Power and Geopolitical Competition

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Abstract

The advent of digitization has significantly changed how we live and work, and information society services - especially intermediate services - have become crucial components of our everyday lives. Platform capitalism, which is characterized by the dominance of major digital platforms that have substantial influence across different sectors, has emerged as a result of this digital transition. The widespread impact of these platforms raises serious concerns about their societal ramifications, especially in relation to individual rights, democratic governance, and geopolitical competition. This phenomenon has given rise to the term "state platform capitalism", where governments increasingly leverage dominant digital platforms for their own political and economic agendas.

Aspects of this phenomenon have been examined in the literature to date, but there are still significant gaps in the extant research. Specifically, further research is required to fully comprehend how platform capitalism impacts public speech, accountability, and participation as well as how the power of digital platforms interacts with democratic processes. A small number of dominant digital platforms strongly affects international politics, data sovereignty, and technological competition. Additionally, given the growing competition between China and the United States in the digital sphere and the regulatory role of European Union, the geopolitical implications of platform capitalism demand further scholarly attention.

The purpose of this paper is to fill the literature gaps by carefully examining the complex interactions between platform capitalism and the State. With this aim, and applying a qualitative methodology, this work: first, analyzes the state of the art; second, proposes a definition and identifies the challenges of the platform infrastructural power; third, discusses the main models of the relationship between dominant platforms and the State. Eventually, further research paths are suggested.

Keywords: State Platform Capitalism; Digitization; Geopolitical Competition; Dominant platforms; Infrastructural Power.

Paper type: Academic Research Paper

1 Introduction

The rise of digitization has radically transformed the way we live and work, making information society services, and in particular intermediary services, essential elements of our everyday lives (Regulation (EU) 2022/2065). The evolution of information technologies, including big data, AI, cloud computing, and machine learning, is rapidly transforming how we access and utilize information across social, political, and cultural domains (Qi and Wang, 2021). Platform capitalism is a term coined to describe this emerging digital economy, which is marked by the dominant digital platforms. The widespread impact of dominant digital platforms prompts serious concerns about their wider societal ramifications, especially regarding the fundamentals of democratic governance, the protection of individual rights, and the geopolitical competition (Barile et al., 2022; Rolf and Schindler, 2023).

Even though the current academic literature has started to analyze several aspects of this phenomenon, there are still relevant gaps. Among these, a significant gap concerns the investigation of how digital platform power influences democratic procedures. Despite research on misinformation and algorithmic bias, there is a lack of deep knowledge of how platform capitalism affects public speech, accountability, and democratic participation.

Moreover, the geopolitical dimensions of platform capitalism are highlighted by the competitive dynamics between China and the United States in the technological and digital domains. However, this theme is neglected by scholarly attention too.

This work aims to fill the aforementioned gaps and to contribute to a deeper understanding of the implications of platform capitalism for democracy, individual rights, and geopolitical competition.

The paper is structured as follows: Sec. 2 describes the methodology; Sec. 3 proposes a literature review on digital platforms and the rising of "State Platform Capitalism"; Sec. 4 defines the infrastructural power of digital platforms and analyzes its risks and challenges; Sec. 5 critically discusses the increasing power of the dominant digital platforms (GAMAM and BATX) and their geopolitical ramifications and describes the main different

regulatory and geopolitical approaches; finally, Sec. 6 suggests future research paths about the geopolitics of platforms and discusses the implications for scholars, practitioners and policymakers.

2 Methodology

The work is developed according to a qualitative methodology that can be outlined as follows:

- Definition of the objective of the literature review;
- Determination of the keywords and criteria for selecting sources - scientific and "grey" - consistent with the purpose;
- Search for and selection of relevant documents;
- Analysis of the information gathered;
- Identification of the literature gap.

The scientific and grey literature was searched in the EBSCO database (restricted access) and the Google Scholar database (open access) due to their broader literature coverage compared to other databases and inclusion of publications that might not indexed in other directories.

The search query was constructed using two primary sets of terms to identify relevant scholarly work:

- The first set focused on the key concepts of digitization in relation to governance influence: digital platforms ecosystems (e.g. structural elements of digital platform, digital infrastructure power, platform data governance, digital algorithms), platform economy, digital business platform, and state platform capitalism;
- The second set covered the associated dynamics and geopolitical implications of the rising digital landscape, including terms such as: information warfare (e.g. information propaganda, misinformation), geopolitical competition (including platform geopolitical relevant actors, "GAMAM" and "BATX", technological rivalry, platforms-military nexus), virtual sovereignty, cybersecurity, platform antitrust and internet regulation (e.g. Digital Markets Act, Digital Services Act, Great Firewall).

To be included in the analysis, documents, encompassing both scientific and grey literature, were required to contain the search terms from one of the sets within their titles. The documents were also required to be published in Italian, English, or French during the period of 2010-2025.

According to an analysis based on titles, abstracts, keywords, and executive summaries (the latter where available, e.g., for grey literature reports), over 50 documents were selected – both scientific and "grey" literature deemed eligible and relevant for the purpose of drafting the present work and the overall project objectives.

3 Dominant digital platforms and State Platform Capitalism: state of the art

Digitization is the driving force behind the development and growth of market economy in the 21st century (Liang et al., 2022). Dominant digital business platforms have played a crucial role in shaping this landscape. In relatively brief periods of time, during the last three decades, dominant digital platforms have attained market shares of at least seventy percent (Cusumano et al., 2019).

Digital business platforms are complex systems that have to accommodate enormous user networks with a wide range of roles and interactions (Parker et al., 2016). Digital business platforms are defined by scholars as intermediaries that connect independent groups via the internet for mutual advantage, establishing connections across customer segments (Faber et al., 2016; Srnicek, 2017; Büchel and Rusche, 2020; De Falco, Simone et al., 2024). Economics and managerial literature enlightens that the success of the digital business platforms depends by the capability to foster network effects, in other words their utility to the customer grows exponentially with the number of users interacting in the ecosystem they provide (Tiwana, 2013; Gawer and Cusumano, 2015; Rahman, 2018; Gawer, 2022).

In terms of structural design, the ecosystems create by the digital business platforms are characterized by structural elements, such as demand and supply-side users, architecture, digital algorithms and APIs, apps, and the key mechanisms of value creation. The platform sponsor is the platform owner and provides the general organizational framework, achieved through governance, regulations, and ecosystem support (Parker and Van Alstyne, 2012).

The architecture of the digital platform dictates how information, goods and services are exchanged. Sharing information is an intrinsic and vital element of digital platforms (Parker et al., 2016).

The digital business platforms create value through three main mechanisms: datafication, commodification, and selection. Datafication lets a platform collect real-time user data through digital algorithms and share it with ecosystem players; commodification transforms data into marketable goods; selection is the choice of which

services/content users access (Van Dijck et al., 2019). The underlying technology of those mechanisms are the digital algorithms of the platform that create so-called "filtering bubbles" (Berman and Katona, 2020; Leysen et al., 2022; Fabiano, 2023). The digital business platform determines the content shown to the consumer, keeping them unaware of how it works and reducing their decision-making power. This involves a sort of black box (Pasquale, 2016; Armano et al., 2022) for the users, both demand and supply-side.

By virtue of this architecture, the digital platform ecosystem makes it possible to collect data on human behaviors, goals, and representations in a way that has never been possible before (Boyer, 2022).

Data extraction is growing in popularity. Indeed, digital business platforms like Google, Facebook, and Amazon are expanding their data gathering activities (Srnicek, 2017). Although data and profit are not the same thing, however, their reasoning is comparable. We should expect data-driven approaches, just as we expect profit-driven ones. In short, the need to gather data is driving new approaches to governance and business practices (Sadowski, 2019).

The growing acknowledgment of data as a crucial strategic asset is comparable to financial capital. The data imperative impacts many aspects of organizational behavior, from developing innovative business models to strategic decision-making and operational efficiency.

As dominant digital platforms become more and more pivotal mediators of economic, political and cultural relationships, they increasingly concentrate a huge infrastructural power on users widely meant (individual, businesses, institutions, public administrations etc.). This new landscape configures veritable "platform capitalism" (Barile et al., 2022) that affects, among others, the role of the State. In fact, the rise of platform capitalism reflects broader social and political changes as well as economic ones (Liang et al., 2022; Coveri et al., 2024). Furthermore, the rise of platform capitalism has led to intense competition among monopolistic platforms (Srnicek, 2017) – the two principal blocks are GAMAM (Google, Amazon, Meta Facebook, Apple and Microsoft) in US and BATX (Baidu, Alibaba, Tencent and Xiaomi) in China.

Platform capitalism relies on complex ecosystems involving digital algorithms, submarine cables, and satellites that enable online interactions (Zhang et al., 2024). Up to 99% of all transoceanic digital communications, such as phone calls, emails, and financial transactions, are carried by submarine cables. They are fastest, most effective, and cheapest way to transmit global digital data (Bueger and Liebetrau, 2021). Thus, these elements have a symbiotic relationship that fosters a dynamic environment, underscoring the foundations of platform capitalism.

About 70% of submarine cables are not state-owned or maintained. Global business conglomerates own and maintain them, and ownership can be complex. Indeed, Google, Amazon, Meta and Microsoft are the main investors (Bueger and Liebetrau, 2021; Wired Italia, 2025).

The powerful and deep expansion of dominant digital platforms makes them crucial infrastructures capable of decisively affecting the institutionalized social order (Cuppini, 2023). They often become transparent and undetectable due to their deep integration into existing social and technical settings (Shen and He, 2022).

In this scenario, the symbiotic relationship between States and dominant digital platforms has led to the emergence of "State Platform Capitalism" (SPC) (Rolf and Schindler, 2023), where governments increasingly leverage dominant digital platforms for their own political and economic agendas.

Indeed, States increasingly rely on dominant platforms when they are unable to implement their own functions. This is a significant novelty because these platforms are mostly run by private companies (Frapporti, 2023).

Because of all those reasons - in particular their impressive technology, their wide control over data and their huge infrastructural power - dominant digital business platforms configure new political agents whose owners often act as unelected politicians (Ergen et al., 2024).

US and Chinese digital business platforms increasingly collaborate with their respective governments in surveillance and policing, creating tension with states (Rolf and Schindler, 2023). TikTok, owned by Bytedance, exemplifies this, raising US concerns about data sharing with China (Gray, 2021; Muratore, 2025).

Serious concerns regarding privacy, security, and democratic values arise from those scenarios. Dominant business platforms implies challenges to national security by shaping information flows and influencing public discourse (Van Dijck et al., 2019).

Two regulative approaches are emerging: the first deal with a progressive counter-narrative critiques prevailing firms and calls for regulations to constrain their power; conversely, the second deals with a neoliberal standpoint values these dominant firms and opposes their regulation, placing the interests of current consumers above those of other actors. This opposing perspective emphasizes how governmental action is required to prevent monopolistic domination (Pasquale, 2016).

In this regard, the European Union (EU) is endeavoring to maintain a certain degree of competitiveness within the digital markets, currently dominated by GAMAM and BATX (Manzini, 2021). For example, the recent

Digital Markets Act (DMA) and Digital Services Act (DSA) (dated 2022) configure a divergence in the position of the EU with respect to the Chinese market capitalism and the US neoliberal approach (Mansell, 2021).

4 The digital platforms infrastructural power: definition, challenges and risks

In the contemporary socio-economic landscape, digital business platforms have become indispensable infrastructure of daily life. They wield a huge power in terms of shaping and governing not only the digital landscape, but also affecting the daily socio-economic interactions. Even if there are several kinds of power wielded by the dominant business platform - infrastructural power, algorithmic power, economic power, and regulatory power (Crawford, 2016; Plantin et al., 2018; Poell et al., 2019; Busch, 2021; Busch et al., 2021), this study will primarily concentrate on the infrastructural power of these actors. The infrastructural power is quite neglected by the extant economic literature, even if it deals with a crucial source of power. It stems from the inherent capacity of the dominant platforms to orchestrate and regulate the flow of information, as well as social and economic interactions (Busch et al., 2021). This power is manifested in their centrality to the aggregation and flow of data, thereby becoming crucial nodes through which an ever-increasing amount of information transits.

Both online and offline activities are significantly impacted by the infrastructural power of digital platforms, which is derived from the management of data, algorithms, and technical standards. Targeted advertising, customized services, and user behavior manipulation are some ways that this impact is exhibited (Busch, 2021).

Through the mechanisms of value creation - datafication and commodification - digital platforms collect and analyze data from real-world human interactions – such as rating, paying, searching, talking, driving. Then, these data are made accessible to a broad range of external parties (Poell et al., 2019; Van Dijck et al., 2019; Boyer, 2022). The algorithms rank search results, curate information, and customize user experiences (Simone et al., 2020; Frapporti et al., 2024). Furthermore, the control over technological standards - guidelines or protocols for connecting various components and products together - enables the digital platforms to create interoperable technological and economic standards and to exploit network effects. These requisites are indispensable for the consolidation of power (Cusumano, 2010; Van Dijck et al., 2019).

However, this landscape has evidenced social, economic and political issues.

Through the inherent capability of digital platforms to profile users, information warfare, propaganda, and disinformation, the States are increasingly leveraging dominant digital platforms for their own economic and political aims, such as citizens surveillance and control. Indeed, with the increasing capabilities of Information and Communication Technologies (ICT), mass surveillance is now a realistic prospect (Boyer, 2022; Fabiano, 2023). Furthermore, algorithms can improve efficiency but also influence public opinion in ways that are not always clear or accountable. Fairness, bias, and the possibility of manipulation come up in this context (Crawford, 2016; Busch et al., 2021).

A further challenge emerges in achieving balance between innovation and control. Different services can be integrated within an ecosystem if they are interoperable, like Apple products and services. However, this integration concurrently establishes a barrier between the ecosystem and the external environment. Customers have no incentive to leave this "walled garden" since it offers an increasing number of products and services (Busch, 2021). Thus, the ability to set standards can encourage innovation by creating a framework for developers. Conversely, this control can impede innovation by constraining interoperability and fostering vendor lock-in.

The increasing infrastructural power and influence of digital platforms are also being subjected to close regulatory analysis and antitrust investigations. The emergence of a small number of platforms that have accumulated significant market power has prompted investigations into potential anti-competitive conduct. The rationale behind this examination stems from the acknowledgment that digital platforms may engage in practices that hinder competitive markets, including the restriction of interoperability and the utilization of their predominant market position to favor their own services. Indeed, increasing evidence suggests that platforms may possess capabilities that extend beyond conventional market power. This more comprehensive viewpoint acknowledges that platforms exert influence over numerous domains, including control over data, algorithms, and the digital infrastructure itself. Consequently, contemporary legal and economic frameworks are confronted with the intricacies inherent in platform structures (Plantin et al., 2018; Van Dijck et al., 2019; Busch et al., 2021; Busch, 2021).

5 The role of dominant digital platforms in the geopolitical competition: macro areas and main models

The two dominant digital blocks GAMAM (US) and BATX (China) have achieved higher and higher market shares, involving a concentration of power that goes beyond simple economic domination (Cusumano et al., 2019; Thibout, 2020; Liang et al., 2022). These dominant business platforms, acting as pivotal intermediaries in economic, political, and cultural exchanges (Barile et al., 2022), are effectively wielding a new form of infrastructural power.



Figure 1: Software & Web Companies headquarters (2018-2021), p.7 (Area Studi MedioBanca, 2021)

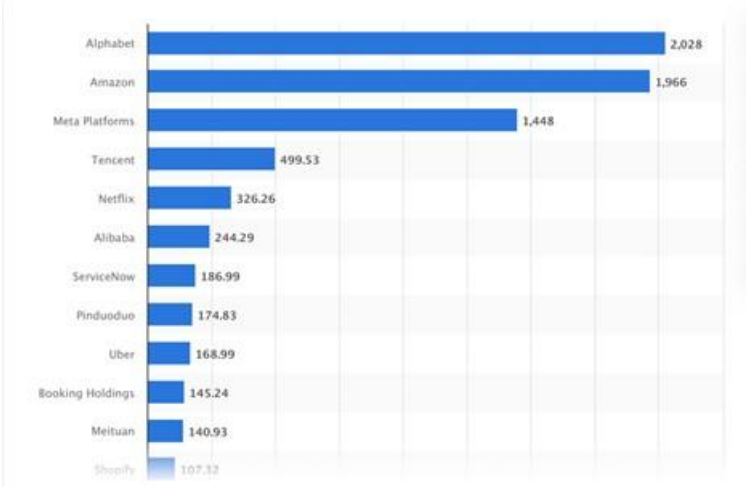


Figure 2: The largest internet companies worldwide by market capitalization 2024 (Statista Reaserch Department, 2025)

Figure 1 shows that the main headquarters of digital platforms are in China and the US, leaving the EU on the periphery. Figure 2 shows that the largest internet companies by market capitalization are American and Chinese, except for Booking (European).

Particularly, US and Chinese platforms put these states at the forefront of the digital economy, giving them significant influence over international standards, norms, and technology. The dominant platforms have a strategic advantage because they can gather and analyze large datasets. This affects consumer behaviors, market trends, political discourse, and state security (Kokas, 2018; Sadowski, 2019; Boyer, 2022; Wang, 2022). The GAMAM block wields significant influence over state decisions through financial support and political pressure. The US state often supports their interests and mobilizes them for geopolitical purposes. A similar phenomenon can be observed in China, where organizations such as the China Association for Science and Technology seek to enhance the political influence of prominent domestic technology enterprises (Mirrlees, 2024).

The digital arena is now a crucial arena for geopolitical competition. Private and governmental organizations are converging, potentially establishing them as agents of an emerging international political order (Wang, 2022; Cuppini, 2023; Ergen et al., 2024). For instance, Google owned a significant stake in roughly 8.5% of the global

network of submarine cables in 2021 (Kelton et al., 2022). SpaceX, owned by Elon Musk, has provided the Ukrainian army with a private satellite system, while Alphabet strengthened security measures for user access in Ukraine and prohibited access to Russian state media distribution and advertising (Abels, 2024; Coveri et al., 2024).

China and the United States are currently the two most powerful states in the world in terms of economy, military strength, and media-technological powers (Mirrlees, 2024). However, the growing competition between them is a key link between geopolitics and state platform capitalism.

As previously stated, both US and Chinese digital platforms collaborate with their respective governments in surveillance and policing, creating tension with states (Rolf and Schindler, 2023; Coveri et al., 2024; Mirrlees, 2024). Indeed, the GAMAM and BATX blocks both dominate information and communication technologies (Thibout, 2020). For instance, Microsoft, Facebook, Twitter (now X), and other US-based platforms have actively cooperated with the US government by exchanging threat intelligence and obstructing disinformation by removing compromised networks (Coveri et al., 2024). Nevertheless, Facebook was also considered as the hub of misinformation spreading – particularly during Covid19 crisis and political elections – due to its algorithms that tend to increase the shares of mostly views contents, without controlling the reality of the information (Boulianne and Hoffmann, 2024).

Furthermore, dual-use technologies, like facial recognition, that are controlled in security and defense-sensitive fields turn digital platforms into tools of governmental monitoring, making them key players in the technological rivalry between the US and China. Chinese digital platforms pose a threat to US techno-military dominance. China deliberately blocks US-based platforms and encourages the growth of its own dominant platforms (like Alibaba or Tencent) as essential elements of the military-industrial complex. The "Great Firewall" regulates the flow of information on the Internet and makes it easier to monitor online activity (Brown, 2024; Coveri et al., 2024).

Compounding the vulnerabilities inherent in the digital infrastructure, despite the recognized necessity for digital platforms to possess submarine cables for global connectivity (Kelton et al., 2022), their fragility has become increasingly apparent. Sometimes accidental, sometimes suspicious, damaging instances have shown how their disruption can have serious consequences. As a result, China claims to have created a device to cut complex cables, but there is a chance of instability because states might use these advanced tools to deliberately target infrastructures (Genco, 2025).

The use of different regulatory approaches and geopolitical strategies concerning digital markets further highlights the complexity of the landscape. The United States prioritizes limited involvement and the expansion of its tech giants, primarily following a neoliberal strategy. China, on the other hand, follows a market capitalist model that is marked by stringent control over its digital domain, as demonstrated by the "Great Firewall" and data localization regulations, as well as substantial governmental support for its national digital platforms. China forces US tech companies to give Chinese regulators access to personal user and corporate data. The Chinese government describes its authority over its digital areas, including outside access to them, as "Cybersovereignty" (Kokas, 2018; Mirrlees, 2024).

The EU has taken a different approach. It has implemented the DMA and the DSA to establish a regulatory framework for the digital markets and ecosystems. The DMA (Regulation (EU) 2022/1925) is a regulatory tool designed to ensure the proper functioning of the digital market by establishing rules for "gatekeeper" businesses.

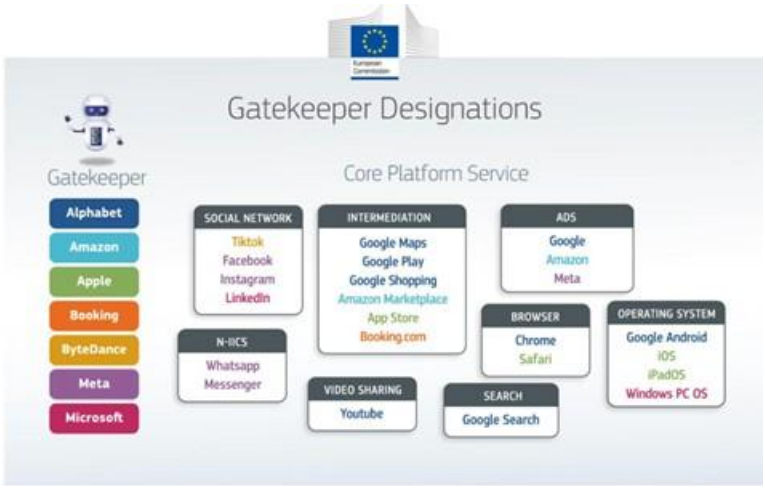


Figure 3: Designated gatekeepers by the European Commission (European Commission, 2025)

Currently, figure 3 shows that the European Commission has designated 7 gatekeepers – ByteDance is a Chinese platforms; Alphabet, Amazon, Apple, Meta and Microsoft are US platforms; Booking is a European platforms (European Commission, 2025).

Conversely, the DSA (Regulation (EU) 2022/2065), aims for greater online platform accountability. It promotes transparency and user safety through rules on transparency, due diligence, and third-party content liability (Erixon et al., 2022).

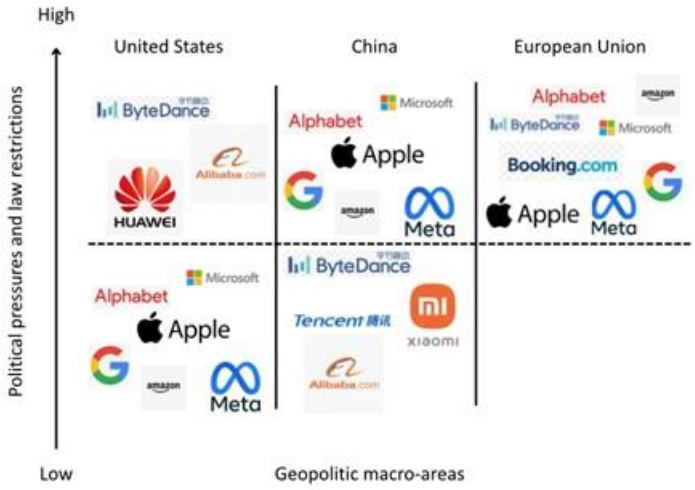


Figure 4: Different levels of political pressures and law restrictions of dominant digital platforms, based on the distinction between US, China and EU
(source: our elaboration)

Figure 4 shows that the EU exerts pressure on dominant digital platforms within a clearly delineated regulatory framework, the DMA. The US imposes significant pressure on Chinese digital platforms, and China does the same on American ones. This suggests a competition that extends beyond mere regulation.

The EU seeks to leverage the "Brussels effect" because of its technological marginality. This process involves the externalization of its norms and values in digital policy (Bendiek and Stuerzer, 2023). This move makes the EU an important player in global digital platform governance, showing differences in how they handle legislation that reflect different geopolitical interests.

6 Conclusion

This work focuses on the infrastructural power of dominant digital platforms and enlightens the relative geopolitical implications. First, a resulting shift of power from public institutions to private companies such as the dominant digital business platforms has been discussed; second, the influence on competition among different geopolitical macro-areas (i.e., the United States and China) has been analyzed.

The provided analysis suggests several implications for scholars, practitioners and policymakers.

For practitioners understanding the ramifications of data collecting and their use for surveillance or political influence is necessary to define effective corporate strategies governance.

For policymakers, regulating digital platforms is a challenging issue. Gaining a solid knowledge of platform power dynamics, including how they affect information flows, market competition, and public speech, provide relevant benefits. Promoting economic growth, international cooperation, and the protection of democratic values through effective policy design are some examples of this.

Scholars analyze the complex interrelationships of technology, power, governance, and geopolitics. The knowledge of the evolving dynamics of "State Platform Capitalism" and its extensive ramifications improves the capacity of scholars to contribute to the discourse, guide future research, and offer important perspectives on the dynamics of the digital era.

Further research paths in geopolitical studies should aim to operationalize variables such as "political pressures" and "legislative restrictions" and to provide more comprehensive frameworks about the emerging different approach in the geopolitical of digital platforms.

Ethics declaration

Ethical clearance is not required for the research.

AI declaration

AI tools were not used for the creation of the paper.

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Cybersecurity in the Legal Context: State of Art and Next Challenges

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Abstract

In recent years, the issue concerning digital security has become increasingly important. Academics within an interdisciplinary approach are debating the topic and how to ensure and implement digital information security from the perspective of both companies and consumer users. The issue affects both the public and private sectors and requires coordinated and effective policy action.
The risks associated with such attacks are closely linked to identity theft, cyber fraud, and money laundering.
In order to address the security-related emergency, the European legislator has enacted several legislative acts. The purpose of this paper is to explain, through a legal analysis, the current regulatory framework examining the new developments and identifying any remaining gaps.
From this analysis, it appears that the topic has recently been the subject of several legislative actions. In this scenario, the NIS 2 Directive (Directive EU 2022/2555) represents a crucial update in the European Union's legislation for network and information security. This work points out the lack of remedies for individuals in the case where the parties addressed by all regulatory interventions fail to respect their obligations.
At the same time, there is no doubt that cyber incidents have a significant impact on the profits of companies. In this regard, the Corporate Sustainability Reporting Directive (CSRD 2022/2464) introduced the inclusion of cybersecurity information in the annual report as non-financial information. For this reason, it is useful to investigate how the cybersecurity obligations contribute to the quality of sustainability reporting.
To address the application problems of these regulations, in the final part of the paper, it could be proposed to use blockchain tools to implement the certainty of digital identity and the integrity of the entered information.

Keywords: Cybersecurity; Data Protection; sustainability; compliance; blockchain

Paper type: Academic Research Paper

1 Introduction

Nowadays, digital security represents one of the main areas of research among scholars, who adopt an interdisciplinary approach to analyze how it can be implemented and ensured, both from the perspective of businesses and that of end users. (Porcedda, 2023). The issue affects both the public and private sectors and requires coordinated and effective policy action (Odermatt, 2018; Brandão and Camisão, 2022; Carrapico and Barrinha, 2017).

The organization of the digital sphere around the platform system has also impacted public administration—including education, healthcare, culture, and justice (Chiara, 2024) —as well as the administrative activities and responsibilities related to the promotion of social welfare entrusted to public authorities (e.g., PagoPA, digital identity systems for accessing services, among others).

The strategy adopted by the European Union through the Digital Compass for 2030 aims to bring about a paradigm shift in the way citizens, public administrations, and democratic institutions interact (EU Commission, 2021; Brandão and Camisão, 2022).

Nowadays, most of the digital services these platforms offer are limited to basic services. Digitalisation also plays a key role in the development of “Smart villages”, i.e. communities in rural areas that use innovative solutions to improve their resilience, building on local strengths and opportunities (EU Commission, 2021; Bygrave, 2022; Dunn Cavelty et al., 2023).

Platforms in rural and urban communities will be powered by digital technologies and will offer services such as multi-modal intelligent transport systems, rapid emergency assistance in case of accidents, more targeted waste management solutions, traffic management, urban planning, smart energy and lighting solutions. Using Green Public Procurement criteria (EU Commission, 2020) can boost demand for a green digital transformation.

The digital transformation should also enable modern and efficient justice systems, protection of consumer rights and increased effectiveness of public action including law application and investigation capacities and law enforcement must be best equipped to deal with more and more sophisticated digital crimes.

The pressing relevance of the issue is also evident from the analysis of data concerning the number of recorded cyberattacks. According to the Clusit 2023 report, the number of attacks registered globally has

increased by 60%, with a deterioration in the social and economic consequences of incidents caused by cyberattacks.

In the first six months of 2024, the number of cyberattacks recorded by Clusit experts increased by 23% compared to the previous semester. On average, there were 9 major attacks per day worldwide; in Italy, 7.6% of the incidents occurred (Clusit, 2024). Between July 2022 and June 2023, approximately 2,580 incidents were registered in the European Union (Enisa, 2023).

Counteracting cyber-attacks represents one of the key challenges for operators. The risks associated with such attacks are closely linked to identity theft, cyber fraud, and money laundering (Fuster, 2016; Van der Sloot, 2017).

In order to address the security-related emergency, the European legislator has enacted several legislative acts (Barrinha and Christou, 2022).

The purpose of this paper is to explain, through a legal analysis (Chiara, 2024; Fuster and Jasmontaite, 2020), the current regulatory framework investigating what the new cases are and what the remaining gaps are. The research question aims to evaluate whether the regulatory framework is exhaustive or fragmented (par. 2,3,4).

At the same time, the objective of the research is to analyse whether the obligations imposed by the regulatory framework can contribute to the implementation of corporate sustainability-related information (par. 5). The final part of the study examines the benefits that blockchain technology may offer in the subject (par. 6).

We investigated the research question through comparative analysis of the existing legal framework between the European Union and the Italian legal system, identifying similarities and differences, in addition to a literature review (Bygrave, 2022).

2 Cybersecurity law in EU e in Italian law

Recently, both the European and Italian legislators have enacted various regulatory measures. Within this scenario, the European Union has consolidated its policy-making role in the sector (Fuster and Jasmontaite, 2020). The legal basis for the European Union's action is established in Article 114 TFEU, which serves the objective of ensuring the proper functioning of the internal market through the harmonisation of national provisions (Odermatt 2018; Brandão and Camisão, 2022; Carrapico and Barrinha, 2017).

2.1 Italian Cybersecurity law no. 90/2024

The Italian legislator has first enacted the "Cybersecurity Law", No. 90 of 28 June 2024. This law contains provisions aimed at strengthening national cybersecurity and addressing cybercrimes. The legislative update pursues two main objectives: on the one hand, to enhance the security measures of public information systems, and on the other, to update criminal policy by revising the management of cybercrimes in Italy.

The subjective scope of the law is derived from Article 1, titled "*Incident Notification Obligations*," and primarily concerns public administration actors. These entities are subject to a mandatory reporting and notification obligation regarding specific types of incidents that impact networks, information systems, and IT services. Such incidents must be reported without delay and, in any case, within 24 hours of their detection via the designated procedures on the website of the National Cybersecurity Agency (ACN) (Renzi, 2021; Cusenza, 2023).

Within 72 hours of the initial report, a complete notification must be submitted, containing all available information, again through the Agency's online procedures.

Article 8 outlines measures for "*Strengthening the Resilience of Public Administrations and Appointing a Cybersecurity Officer*." Entities subject to this law are required to establish a dedicated cybersecurity unit responsible for developing cybersecurity policies, managing IT risk, and continuously updating security procedures. Core obligations include drafting and maintaining a document defining the roles and organization of the administration's information security system; developing a risk management plan that includes preliminary analysis and regular updates of security measures; and conducting ongoing threat and vulnerability assessments, with prompt updates of security protocols based on emerging evidence. Consequently, all staff must be prepared to respond effectively in the event of an incident.

Periodic evaluations of cybersecurity risks must be conducted to identify threats and vulnerabilities. Based on the outcomes of these assessments, organizations are expected to implement appropriate security controls, including preventive, detective, and corrective measures.

The law also mandates continuous and adequate training for all staff involved in cybersecurity. It establishes an operational coordination framework between intelligence services and the National Cybersecurity Agency to ensure an effective response to cyber incidents.

This legal framework must be harmonized with the provisions of the GDPR Regulation (Bygrave, 2022) designates specific responsibilities for the protection and processing of personal data, as defined by European law. The GDPR also mandates notification of any security breach that results in the destruction, loss, alteration, unauthorized disclosure of, or access to personal data transmitted, stored, or otherwise processed (so-called data breach).

The key differences between the two regulatory frameworks are as follows: the GDPR is designed to protect natural persons with regard to the processing of their personal data, safeguarding fundamental rights and freedoms, particularly the right to data protection. In contrast, Law No. 90/2024 aims to protect IT infrastructures—such as networks, information systems, and digital services—which are critical to the essential functioning of the public sector. Moreover, while the GDPR applies to both public and private entities, Law No. 90/2024 applies exclusively to public entities.

Another distinction lies in the notification responsibilities and timelines: under the GDPR, the data controller must notify the Data Protection Authority without undue delay and, where feasible, within 72 hours of becoming aware of the breach. In contrast, the timeline under Law No. 90/2024 is stricter: a report must be submitted to the ACN within 24 hours, and a full notification must follow within 72 hours.

2.2 Italian Legislative Decree No. 138/2024, implementing Directive (EU) 2022/2555 (NIS 2 Directive) into the Italian legal framework.

At the European level, Directive (EU) 2022/2555 (known as NIS 2) plays a crucial role. It has been transposed into Italian law through Legislative Decree No. 138 of 4 September 2024. The regulation imposes stringent requirements for governance, risk management, and incident reporting.

Legislative Decree No. 138/2024 establishes measures aimed at ensuring a high level of cybersecurity across the entire Italian territory.

Among the key innovations introduced by Directive NIS2 is the implementation of the sectors concerned. The entities involved are required to comply with specific requirements, covering from governance to cybersecurity, the adoption of measures for risk management (including supply chain security), as well as the management of operational continuity and incident reporting (Novelli et al., 2024).

The analysis synthetically casts light on i) the wider scope of the NIS2; ii) revised cybersecurity risk-management measures and reporting obligations for NIS2 entities; iii) rules on cybersecurity information sharing and vulnerability disclosure; and iv) supervisory and enforcement framework (Chiara, 2024).

The Directive introduces severe requirements in terms of governance, risk management, and incident reporting. Legislative Decree No. 138/2024 sets out measures designed to ensure a high level of cybersecurity across Italy, thereby contributing to the overall improvement of cybersecurity in the European Union. In addition to mandating a national cybersecurity strategy, the Decree integrates crisis management protocols and confirms the National Cybersecurity Agency as the competent NIS authority, the single point of contact, and the national CSIRT for handling incidents at the national level (Novelli et al. 2024).

The decree also includes obligations related to cooperation and information sharing to tackle cyber fraud.

One of the most significant innovations introduced by the NIS 2 Directive is the expanded scope of affected sectors. Replacing the former distinction between Operators of Essential Services (OES) and Digital Service Providers (DSPs), the Directive now refers to “Essential Entities” and “Important Entities” (Chiara, 2024). These include all entities operating in the sectors classified as Highly Critical and Other Critical Sectors, as listed in Annexes I and II of the Directive, provided they meet specific size criteria.

The NIS 2 Directive applies to all large enterprises operating in the identified sectors—those with more than 250 employees, or an annual turnover exceeding €50 million, or an annual balance sheet total above €43 million. It also covers medium-sized enterprises (50–250 employees, with an annual turnover or balance sheet total between €10 and €50 million), provided they operate in the listed sectors.

The identification of the relevant public administrations is left to the discretion of the Member States. The Directive also includes specific categories of entities, including certain small enterprises.

As regards risk management, entities are required to assess cybersecurity risks and implement appropriate technical and organizational measures. Article 21 of the Directive outlines a set of high-level requirements, such as multi-factor authentication, encryption, basic cyber hygiene practices, and human resources security measures. The NIS2 sets out a list of minimum cybersecurity measures that both EEs and IEs must adopt, following a risk-based approach (Chiara, 2024). Risk management measures include data backups, disaster recovery, and crisis response planning, all aimed at minimizing service disruption.

In addition to ensuring resilience and disaster recovery capabilities (Dupont, 2019; Rothrock, 2017; Bjorck et al., 2015), both essential and important entities are required to notify their respective CSIRTs or the national

competent authority of any incident having a significant impact on the provision of their services—without undue delay and by issuing an early warning within 24 hours of becoming aware of the incident.

NIS2 strengthens national competent authorities' powers and tasks (Chiara, 2024). Supervisory and enforcement measures are now more detailed (e.g., on-site inspections, targeted security audits, security scans, requests for information and to access data, etc.) but are differentiated depending on whether the authority enforces them against an EE or an IE, the latter being subjected to ex-post supervisory measures.

The distinction between essential and important entities also affects supervisory measures and penalties: essential entities are subject to more stringent controls and potentially higher sanctions. The imposition of fines is determined either by a fixed minimum amount or by a percentage of the organisation's total annual turnover, depending on which of the two is higher.

2.3 Analogies and Differences between Law No. 90 of 2024 and Legislative Decree No. 138 of 2024

Both regulations establish a general obligation to notify cybersecurity incidents, detailing the related timelines. However, there are some differences between the two.

As far as the definition and scope of a cybersecurity accidents is concerned, Law No. 90 of 2024 refers to the taxonomy of incidents established through a reference to the National Cybersecurity Perimeter regulations. Differently, NIS 2 Directive defines a cybersecurity incident as "a*n event that compromises the availability, authenticity, integrity, or confidentiality of data stored, transmitted, or processed, or the services offered by information systems and networks or accessible through them*.". In accordance with Law No. 90 of 2024, the ACN has already published important guidelines on the procedure to follow for reporting and notifying incidents covered by the cited legislation (ACN, 2024).

It would be appropriate, in order to avoid duplication and complications for the affected entities, to extend similar procedures for reporting and notifying incidents covered by the decree transposing the NIS 2 Directive.

Both legislative measures introduce, for entities falling within their scope, obligations related to cybersecurity governance and risk management.

As previously mentioned, Law No. 90/2024 mandates the establishment of a structure that plans, adopts, and monitors the cybersecurity risk management system, and within this structure, a designated cybersecurity officer.

NIS 2 requires the identification of at least one point of contact between the entity and the ACN, which acts as the link between the NIS entity and the institution responsible for overseeing the correct implementation of governance measures and management of cybersecurity incident risk.

The legislative technique chosen is inspired by the so-called "*by design*" principle, aiming to implement management systems characterized by planning that follows the criteria of adequacy and proportionality depending on the size and type of the public entity applying it, rather than by introducing a mere list of minimum-security measures.

From the analysis, it is clear that part of the legislation is common to both regulations. It would be desirable to have a common and systematic compliance model, so that the public administration entities covered by Law No. 90 of 2024 can comply with both regulations.

3 CER Decree

On 23 September 2024, Legislative Decree No. 134/2024 ("CER Decree") was published in the Official Gazette, through which the CER Directive was transposed.

In particular, the CER Decree will apply to all public and private entities that, by no later than 17 August 2026, will receive notification of their inclusion among the so-called critical entities. The entities involved are those that (i) operate and have a critical infrastructure (even partially) on national territory, (ii) provide at least one essential service for society, and (iii) could experience significant negative effects in the event of an incident, also impacting other essential services that depend on it.

The provisions of the CER Directive, therefore, apply only in a residual manner in cases where the NIS2 Directive does not apply.

In other words, the CER Decree also safeguards the physical protection and operational security of infrastructures, which translates into the obligation, for example, to develop and update a resilience plan, covering various aspects such as risk management, disaster risk reduction, and adaptation to climate change.

4 Other relevant legislative instruments

From this analysis, it appears that the topic has recently been the subject of several legislative actions (Bygrave, 2017; Schmitz, 2022; Kamara, 2024). In this scenario, the NIS 2 Directive represents a crucial update in the European Union's legislation for network and information security (Schmitz-Berndt 2023; Vandezande 2024). On the same days, the European Union enacted the CER Directive, Regulation Dora (Regulation EU n. 2022/2554) as well as regulations related to cybersecurity in the financial services sector.

All of these regulations are in addition to the General Data Protection Regulation, (Fondrieschi 2019), the Digital Market Act (DMA, Regulation EU 2022/1925), the Digital Service Act (DSA, Regulation EU 2022/2065), and Electronic Identification Authentication and Signature (eIDAS 2, Regulation EU 2024/1183) (Bush 2022).

Notwithstanding, security remains a recurring topic addressed by all these Directives and Regulations (Porcedda, 2023).

The regulatory framework lacks coherence. The legal instruments interact in complex, confusing, and at times uncoordinated ways. EU cybersecurity law appears as a tangle of rules without an overarching structure; although the various instruments share significant commonalities in terms of approach and mechanisms, an excessive degree of overlap — combined with conceptual uncertainty — prevents them from forming a cohesive whole. The absence of judicial rulings further highlights the practical difficulties in applying the provisions examined (Bygrave, 2025; Carrapico and Barrinha 2017).

5 Cybersecurity and sustainability

At the same time, there is no doubt that cyber incidents have a significant impact on the profits of companies.

This has led private entities to increasingly focus on the issue, acknowledging its growing relevance within the broader framework of digital governance and risk management.

Until the CSRD came into effect, the disclosure of cybersecurity-related information in annual reports was not subject to binding obligations.

In this regard, the CSRD introduced the inclusion of cybersecurity information in the annual report as non-financial information. For this reason, it is useful to investigate how cybersecurity obligations contribute to the quality of sustainability reporting (Boggini, 2024).

Furthermore, according to Article 29b of the Accounting Directive, as introduced by the CSRD, the sustainability report should be drafted following the European Sustainability Reporting Standards (ESRS).

It has been previously observed how Article 21 of NIS 2 imposes a series of measures that must be adopted by the obligated entities. Similarly, Article 32 of the GDPR requires the data controller and processor to implement appropriate technical and organizational measures to ensure a level of security that is appropriate to the risk, considering the nature, scope, context, and purposes of the processing, as well as the specific risks to the rights and freedoms of individuals. Some of these measures can be disclosed in the annual reports to meet the disclosure requirements of ESRS S4. Indeed, the purpose of ESRS S4 is to disclose how the company manages the material impact of its activities on consumers and end users. The growing number of cybersecurity obligations in EU legislation, coupled with the increased adoption of cybersecurity controls by companies, enhances the content of sustainability reporting under the CSRD. The disclosure of the adopted security controls will provide stakeholders with an understanding of how the company addresses cybersecurity risks.

6 The potential use of blockchain as a tool for enhancing cybersecurity

The examined regulations primarily address the procedures to be used for preventing cyberattacks and for responding promptly if they occur. However, scholars' attention must also be directed toward the use of tools that can reduce the number of cyberattacks. In the final part of this contribution, we aim to examine the role that blockchain can play in implementing digital certainty and the security of the information entered.

Blockchains are part of Distributed Ledger Technologies (DLTs), referred to as "nodes," characterised by decentralization and accessibility to all users (Riet, 2020). They are structured in blocks that allow that the data is simultaneously present on each participant's device and linked by a peer-to-peer network that ensures simultaneous updates (Cucurru, 2017). This aspect guarantees the transparency of the process. Moreover, any modification on a single node does not compromise the system's effectiveness, meaning the information can be recovered from the data of other nodes in the DLT (Davola, 2020). This leads to the immutability of the data.

Specifically, the blockchain is a DLT characterised by chronological block arrangement in a chain, placed in chronological order. Unauthorized modification of a transaction results in the alteration of the block's hash containing the transaction and the subsequent blocks downstream, which is immediately verifiable and visible by the nodes.

The digital information blocks in the distributed ledger are cryptographically linked to each other, and they also include a timestamp system known as time-stamping (Natale, 2020).

The EU Regulation of 30 May 2022, No. 858 establishes requirements related to DLT market infrastructures and their operators concerning specific regulatory obligations.

The use of blockchain technologies has seen significant implementation with the rise of cryptocurrency and NFT markets (Nava, 2022; Carriere, 2021; Finzer, 2020).

These tools are also contained within smart contracts that circulate through DLT and blockchain via marketplaces. Beyond issues related to property rights, usage licenses, and intellectual property, NFTs, like cryptocurrencies, are seen by users as means of generating profit.

In particular, the use of NFTs creates a mechanism that allows digital assets to be uniquely identified, have a nearly immutable provenance, and be available for trade, largely without requiring large amounts of money (Vallabhaneni, 2021).

In the case of creating an official registration and identification system, the user, after providing personal information and after identity verification with public security systems, would be enabled to access and equipped with a personal digital badge through digital encryption technology.

7 Conclusions

This analysis has examined the state of the art concerning cybersecurity in Italian and EU law. The research highlighted the existence of a non-uniform and fragmented regulatory framework. It emerged that cybersecurity is a fundamental right, the protection of which is essential to promote social and economic development. The regulatory measures aimed at establishing cybersecurity offices and procedures to follow in the event of cybersecurity incidents are certainly commendable. Public administration is deeply involved in this issue, providing essential services to citizens and managing numerous personal, including sensitive, data.

Similarly, the importance of the adoption of measures that companies must implement has been demonstrated, as well as how they are required to include information related to cybersecurity in the sustainability report, which is also impacted by the existing regulations.

In order to enhance the security of digital data, we suggest implementing the adoption of blockchain technologies, which ensure greater certainty of identity and the integrity of the data entered. It would also be desirable to establish legal remedies for individuals in the event of non-compliance by obligated parties with the duties imposed by existing legislation. In fact, the primary objectives of these legal acts lie in the 'functioning of the internal market' and not the protection of natural and/or legal persons per se.

8 Ethics Declaration

Ethical clearance was not required for the research presented in this paper.

9 AI Declaration

No AI tools were used in the preparation of this paper.

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Human-Machine Interaction and Robotics in Healthcare: A Research Programme as a Starting Point

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Abstract

The increasing adoption of artificial intelligence (AI) and robotics is leading to a profound transformation of the healthcare sector (Raimo et al., 2022), affecting diagnostic accuracy, optimising clinical processes and redefining care practices (Comite, 2022). Collaboration between healthcare professionals and intelligent machines is a key element in the evolution of care, redefining roles and changing traditional organisational structures (Çetin, 2024).

However, large-scale implementation is hampered by acceptance barriers, behavioural resistance and ethical and regulatory issues. This integration presents an opportunity to increase efficiency and reduce the margin of error (Babashahi, 2024), yet questions remain about safety, reliability and the impact on professional skills (Nivethithitha et al., 2014). Adoption depends largely on the trust healthcare professionals place in these technologies, transparency in algorithmic decision-making, and the availability of resources and adequate training.

The study asks: "How does human-computer interaction affect the acceptance of digital technologies by healthcare professionals and what strategies can be implemented to improve their adoption?"

To answer this, the authors conducted a systematic literature review (Massaro et al., 2016), analysing articles from Web of Science (WoS) and Scopus. The selection process combined automated and manual searches, identifying 11 relevant studies. Inclusion criteria focused on works addressing acceptance factors, barriers, and implementation strategies of AI and robotics in healthcare. Technical studies without a human-computer interaction perspective were excluded. Recent literature also highlights the growing role of AI-powered assistants, where human-chatbot interactions redefine service delivery (Akpan et al., 2025).

The aim is to create a strategic agenda for adopting AI and robotics in healthcare, identifying strategies and methods, including empirical ones, to facilitate integration and improve perception among professionals.

Findings show that acceptance depends on trust, perceived usefulness, ease of use and training adequacy. Resistance stems from fear of a diminished human role, regulatory uncertainty and ethical concerns linked to automation. Effective strategies include transparency in decisions, involving healthcare workers in development, and specific training programmes.

Human-computer interaction is redefining healthcare, promoting a collaborative model between professionals and AI. For this transition to succeed, organisational, ethical and training challenges must be addressed. Institutions must invest in training and policies for responsible and sustainable integration (Murugan et al., 2024). Recent studies also emphasize AI-driven assistants as tools to enhance collaboration and bridge gaps in professional-patient interactions (Liu et al., 2024). The adoption of AI and robotics (Kaur, 2024) offers a unique chance to improve care, but requires a strategic, interdisciplinary approach. This contribution offers a foundation for future research and for defining effective, sustainable implementation models.

Keywords: Artificial intelligence, Robotics, Healthcare, Human-machine collaboration

Paper type: Academic research paper

1 Introduction

This study highlighted the integration of artificial intelligence (AI) and robotics in the healthcare sector as a growing phenomenon with a significant impact on clinical efficiency, quality of care and the work dynamics of healthcare professionals. The degree of adoption of these technologies depends on several factors, including practitioners' confidence in automated systems, the perception of their usefulness, ease of use and the adequacy of training received.

The literature review revealed that human-computer interaction plays a significant role in facilitating or hindering the acceptance of digital technologies in healthcare, and the main resistances identified relate to the fear of a progressive reduction of the human role, regulatory uncertainties and ethical implications related to the automation of clinical processes. In this context, strategies such as transparency in algorithmic decision-making processes, the active inclusion of healthcare professionals in technology development and the implementation of targeted training paths prove to be crucial in order to facilitate the adoption of AI in the sector.

The results show that artificial intelligence technologies, including AI assistants (concierge AI), are playing a significant role in optimising interactions between patients and healthcare professionals, and such tools can

improve human-machine collaboration, bridge communication gaps and contribute to a more efficient delivery of healthcare services.

The research question that prompted this contribution is: How does human-computer interaction affect the acceptance of digital technologies by healthcare professionals and what strategies can be implemented to improve their adoption?

The results can contribute to the construction of a strategic agenda for the effective adoption of AI and robotics in the healthcare sector, providing useful insights for researchers, policy makers and practitioners considering that overcoming existing barriers requires a joint effort between technology development, training and regulation, in order to ensure a sustainable and responsible integration of new technologies.

2 Methodology

To conduct this literature review, the following queries were made on Scopus.

TITLE-ABS-KEY (('Artificial Intelligence' OR 'AI') AND ('Robotics' OR 'Robot') AND ('Healthcare' OR 'Medical care' OR 'Health sector') AND ('Human-Machine Collaboration' OR 'Human-Computer Interaction' OR 'HCI')) AND (LIMIT-TO (SUBJAREA , "BUSI") OR LIMIT-TO (SUBJAREA , "ECON") OR LIMIT-TO (SUBJAREA , "DECI")).*

The literature review shows that the integration of artificial intelligence (AI) and robotics in the healthcare sector is a topic of increasing relevance, with a focus on human-computer interaction, and this is clearly evident from the visualizations.



Figure 1: Words Cloud

The word cloud offers an insight into the dominant themes in the literature where the term 'healthcare' is central, followed by key words such as 'AI', 'concierges', 'customer', 'research' and 'collaboration'. which implies that the focus is not only on the technological aspect, but also on how these innovations impact the patient's journey (customer journey) and teamwork between humans and machines. The concept of 'concierge AI' is particularly interesting, as it indicates that artificial intelligence is increasingly seen as an interactive support, similar to a virtual assistant, capable of improving the patient experience and the efficiency of healthcare services.

Then there are terms such as "vocal", "devices" and "digital" that confirm the importance of integrating intuitive interfaces, probably via voice commands or connected devices while terms such as "challenges" and "implications" also suggest that scholars are analysing both the benefits and barriers to the adoption of AI in healthcare. (see Figure 1).



Figure 2: Cluster

With the help of R study, an attempt was made to conduct a cluster analysis, but only one cluster emerged. which relates two fundamental concepts: health care and human computer interaction indicative of the fact that research is focusing on the influence of the interaction between humans and intelligent machines in the health sector. The use of AI not only provides technical support but also redefines professional roles and care processes, and the fact that these two concepts are closely linked indicates that strategies for implementing AI in healthcare must consider efficiency, acceptance and adaptation by healthcare professionals. (see Figure 2).

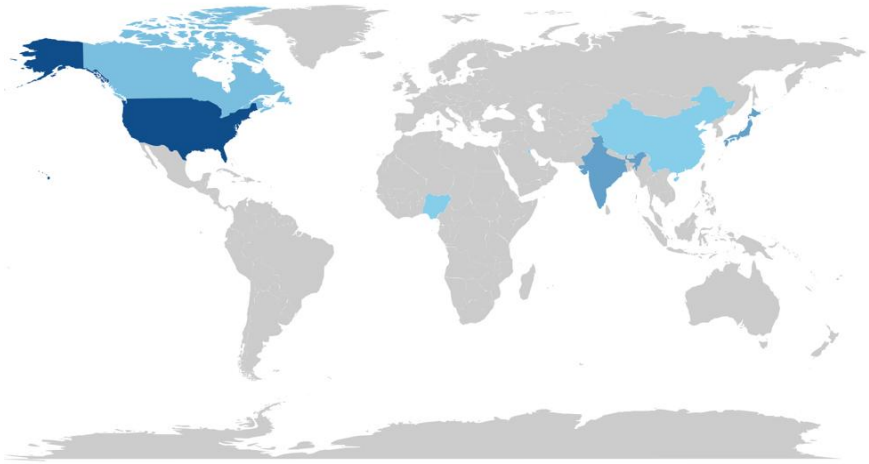


Figure 3: Geographic distribution of publications

In Figure 3, the geographic distribution of publications or studies related to the topic is shown, and it can be seen that the United States emerges as the main hub for research and innovation in this field, followed by Canada, Europe (with emphasis on certain nations) and Asian economies such as China, India and Japan. This map reflects the global technological reality: countries with a strong push in digital innovation and AI adoption are driving the transformation of the healthcare sector, and the low intensity in some geographic areas is indicative of the fact that there are still countries where AI adoption in healthcare is limited, probably due to regulatory, infrastructural or economic barriers.

3 Results

The increasing adoption of artificial intelligence (AI) and robotics is leading to a profound transformation of the healthcare sector (Raimo et. al, 2022), influencing diagnostic accuracy, optimising clinical processes and redefining care practices (Comite, 2022)

Collaboration between healthcare professionals and intelligent machines is a major element in the evolution of care, redefining professional roles and changing traditional organisational structures (Çetin , 2024). The implementation of these technologies is hindered by barriers of acceptance, behavioural resistance and ethical and regulatory issues, and such integration represents an unprecedented opportunity to increase operational efficiency and reduce the margin of error (Babashahi, 2024), but questions remain about safety, reliability and the impact such innovations may have on professional competence (Nivethithithitha et. al 2014). Their adoption largely depends on the degree of trust that healthcare professionals place in these technologies, the transparency of algorithmic decision-making processes and the availability of resources as well as appropriate training paths.

To answer the research question, a literature review was conducted (Massaro et al., 2016), analysing articles from Web of Science (WoS) and Scopus. Recent literature also highlights the growing role of AI-based assistants in healthcare and other sectors, where AI concierges and human-chatbot interactions redefine service delivery and operational efficiency (Akpan et al., 2025).

The aim of the research is to create a strategic agenda for the effective adoption of AI and robotics technologies in healthcare, identifying strategies and methods, including empirical ones, to facilitate their integration and improve their perception among healthcare professionals. The results show that the acceptance of AI and robotics depends on variables such as trust in the technology, the perception of its usefulness, ease of use and the adequacy of the training received. The main resistances can be traced back to the fear of a reduced human role, regulatory uncertainties and ethical implications of the progressive automation of clinical processes. Effective strategies to promote adoption include transparency in decision-making processes, the active inclusion of healthcare professionals in the development of the technology, and the implementation of specific training programmes.

Human-computer interaction is progressively redefining the healthcare paradigm, favouring a collaborative model in which professionals and artificial intelligence work in synergy, and for this transition to be effective, organisational, ethical and training obstacles must be overcome. Healthcare institutions need to invest in staff training and develop policies that ensure responsible and sustainable integration of new technologies (Murugan et al. 2024), and in this regard, many studies have emphasised the importance of AI-based assistants in

improving human-computer collaboration and suggest that AI-based concierge models can help bridge gaps in interactions between professionals and patients (Liu et al., 2024).

The adoption of artificial intelligence and robotics in healthcare (Kaur, 2024) represents an unprecedented opportunity to improve both the effectiveness and quality of care, and to ensure optimal integration, a strategic and interdisciplinary approach is crucial. Overcoming existing barriers requires a joint effort of researchers, clinicians, policy makers and technology developers to ensure that innovation is geared towards equity, safety and sustainability

4 Implications

The adoption of artificial intelligence and robotics in healthcare is profoundly transforming the organisation of care and the role of healthcare professionals. In particular, the implementation of these technologies offers numerous benefits, including greater operational efficiency, a reduction in the margin of error and an improvement in the quality of care; their deployment depends on multiple factors, including the confidence of healthcare professionals in automated systems, the perception of their usefulness and the adequacy of the training received.

One of the key aspects that emerged from the research is the crucial role of human-computer interaction in facilitating or hindering the adoption of these innovations. Indeed, while AI can support clinical decisions and automate repetitive processes, there is a fear that an excessive reliance on machines may reduce the decision-making autonomy of physicians and threaten the centrality of the human relationship in medical practice. Moreover, barriers to acceptance are often linked to ethical and regulatory issues, which raise questions about the transparency of algorithms and the protection of sensitive patient data, and for this reason, it becomes essential to adopt targeted strategies that promote trust in the technology and ensure its safe and responsible use.

A key element in fostering the integration of AI in healthcare is training in fact, healthcare professionals should be adequately trained in the use of these technologies, understanding not only how they work but also their ethical and practical implications. Research has shown that greater involvement of medical staff in the development and implementation of AI solutions can improve the level of acceptance and reduce resistance to change, and transparency in algorithmic decision-making processes and the introduction of intuitive interfaces could facilitate the adoption of these tools, making them more accessible and reliable.

In addition to training and trust aspects, another emerging trend is the increasing use of AI assistants in the healthcare sector where tools such as AI concierges are redefining how patients and caregivers interact, simplifying the management of clinical information and improving the accessibility of healthcare services. These systems can be a valuable support for medical staff, reducing their workload and improving the overall efficiency of healthcare facilities, but for these tools to be truly effective, it is necessary to develop human-machine interaction models that always put the patient and the quality of care at the centre.

The literature review also revealed a strong geographical disparity in the research and implementation of AI in healthcare. Countries such as the United States , Canada, China and India appear to be among the main promoters of these technologies, while other regions still show a limited level of adoption, hence the need for global policies that foster a more equitable access to technological innovation, reducing the gap between different healthcare realities and promoting the adoption of AI even in contexts with fewer resources.

5 Conclusions

The integration of artificial intelligence and robotics in healthcare represents an extraordinary opportunity to improve the effectiveness and quality of care, but it requires a strategic approach where the key to success can be found not only in technological development, but in the ability to adapt these innovations to the needs of the healthcare sector, guaranteeing transparency, safety and sustainability. To achieve this, a joint effort between researchers, developers, healthcare professionals and policy makers is essential, so that the introduction of new technologies is done in an ethical and responsible manner.

The future of healthcare will not be characterised by the replacement of human work by machines, but by an increasingly close collaboration between artificial intelligence and healthcare professionals, and the main goal should be to harness the potential of AI to improve the work of physicians, optimise the use of resources and ensure that patients have access to increasingly personalised and effective care. To realise this vision, current barriers need to be overcome through investment in training, appropriate regulation and technology design that takes into account the real needs of professionals and patients, only in this way will it be possible to build a more efficient, inclusive and future-oriented healthcare system.

6 Ethics declaration

This study did not involve the collection of sensitive or personal data, nor did it include experiments involving human or animal subjects. Therefore, ethical approval was not required.

7 AI declaration

An artificial intelligence tool was occasionally used for minor linguistic suggestions. The authors reviewed and integrated the content, taking full responsibility for the final text.

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Specific Learning Disabilities (SLD) and Artificial Intelligence (AI): A Bibliometric Analysis

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Abstract

This study conducts a bibliometric analysis of the scientific literature addressing the intersection between Specific Learning Disabilities (SLDs) and Artificial Intelligence (AI), a field that has been gaining increasing relevance due to the transformative potential of AI-based interventions in education. SLDs, including dyslexia, dysgraphia, and dyscalculia, significantly impact learning processes and academic outcomes, making it crucial to explore innovative approaches for their early identification and personalized support. AI technologies, such as machine learning, natural language processing, and adaptive systems, offer promising tools to enhance educational inclusion and tailor interventions to individual learning needs. By leveraging data-driven methodologies, AI can provide dynamic and responsive learning environments, improving both engagement and outcomes for students with diverse cognitive profiles.

Using data retrieved exclusively from the Scopus database and analysed through the Bibliometrix R package, this research examines publication trends, citation patterns, international collaboration networks, and thematic evolutions within this interdisciplinary domain. The analysis reveals a substantial increase in research output since 2020, highlighting a growing academic and technological interest in leveraging AI to address SLD challenges. Countries such as the United States, Spain, Italy, and India emerge as key contributors, fostering an expanding global collaboration network. These international partnerships reflect a shared commitment to addressing the complex and multifaceted nature of learning disabilities through cross-disciplinary research efforts.

Thematic mapping identifies core topics like dyslexia, machine learning, and personalized learning systems, alongside emerging themes such as contrastive and adversarial machine learning approaches, which represent innovative frontiers for future exploration. In particular, these advanced AI techniques show potential in enhancing diagnostic precision and developing more adaptive educational tools. Despite this promising landscape, the study underscores the need for broader empirical validation and interdisciplinary cooperation involving educators, AI researchers, and healthcare professionals. Meta-analytic evidence also suggests the importance of integrating cross-disciplinary insights when developing AI tools tailored to the needs of students with disabilities (Zhang, Carter Jr., Liu, & Peng, 2024).

The findings emphasize the strategic role of AI in promoting educational equity and suggest future research directions to consolidate and expand this field, ultimately contributing to more inclusive and effective learning environments for individuals with SLDs. Such efforts are essential to bridge existing gaps in access to tailored educational resources, ensuring that technological innovation translates into tangible benefits for learners worldwide.

Keywords: Specific Learning Disabilities (SLD); Personalized Learning; Inclusive Education; Artificial Intelligence (AI); Bibliometric Analysis.

Paper type: Academic Research Paper

1 Introduction

Specific Learning Disabilities (SLDs) are neurodevelopmental disorders that significantly impair a person's ability to process language, whether spoken or written, resulting in difficulties in reading (dyslexia), writing (dysgraphia), spelling, and mathematics (dyscalculia) (Grigorenko et al., 2020; Chieffo et al., 2023). These disorders affect approximately 5% to 15% of the school-age population and represent a heterogeneous group of conditions that hinder the development of academic proficiency. Beyond academic struggles, individuals with SLDs often experience poorer long-term professional outcomes and face social, emotional, and behavioural challenges.

In recent years, Artificial Intelligence (AI) has emerged as a transformative force within educational and healthcare contexts, offering promising avenues to support individuals with SLDs. AI-driven technologies—including machine learning algorithms, adaptive learning systems, and assistive tools like speech recognition and text-to-speech applications—provide personalized educational interventions that address individual strengths, weaknesses, and learning preferences (Askarova et al., 2024; Hadinezhad, Garg & Lindgren, 2024; Jadán-Guerrero et al., 2024). Recent contributions also emphasize the potential of AI to empower individuals with cognitive impairments by promoting autonomy and inclusivity in educational and healthcare settings (Di Nuovo, 2023).

The integration of AI into educational practices not only enhances individualized learning but also enables early identification of learning disorders through data analysis and predictive modelling (Yap, Aruthanan, & Chin, 2025; Basnayaka et al., 2023). These applications can lead to more timely and effective interventions, potentially improving academic outcomes and promoting greater inclusivity in education.

Given the profound impact of SLDs on individuals and society, and the transformative potential of AI technologies, a comprehensive understanding of current research trends is essential. A bibliometric approach enables the systematic analysis and visualization of the scientific literature on this intersection, revealing collaboration networks, citation patterns, influential works, and underexplored areas (Zhang, Fan, & Zhang, 2021; Bosse, Nussbaumer, & Hövel, 2024). A recent systematic review highlights how AI-based interventions for students with learning disabilities remain fragmented and require more robust evidence across diverse educational settings (Panjwani-Charani & Zhai, 2024).

The present study aims to conduct a detailed bibliometric analysis with the following specific objectives:

- to investigate the overall trend of publications and citations over time, providing insights into the growing relevance of the topic;
- to analyse the main patterns of international collaborations among countries contributing to this field;
- to identify thematic clusters and emerging specializations within the research, highlighting key subtopics and knowledge domains.

By achieving these objectives, the paper seeks to offer a structured and comprehensive overview of the scholarly landscape concerning the application of AI in supporting individuals with SLDs.

2 Methodology

The bibliometric analysis presented in this study is based exclusively on data retrieved from the Scopus database, which offers comprehensive coverage of peer-reviewed scientific publications across a wide range of disciplines. Scopus was selected as the sole source of bibliographic data to ensure uniformity in metadata structure, reliability of citation indexes, and the overall quality of the retrieved documents.

The literature search was carried out using a combination of keywords related to Specific Learning Disabilities (SLDs) and Artificial Intelligence (AI). Terms such as "Specific Learning Disabilities," "SLD," "Artificial Intelligence," "Machine Learning," and "Assistive Technologies" were combined using Boolean operators to maximize the retrieval of relevant documents. The search was restricted to articles, reviews, books, book chapters, conference papers or reviews, editorials, notes, short survey, published between January 1986 and December 2024. A manual screening phase was conducted to exclude papers that, although related to either SLDs or AI individually, did not establish a direct connection between the two fields. Duplicate entries and incomplete records were also removed.

The final dataset, including bibliographic information such as authors, affiliations, abstracts, keywords, references, and citation data, was extracted in a structured format suitable for bibliometric analysis. An overview of the dataset's composition, including the number of records and relevant bibliographic attributes, is presented in Table 1.

Table 1: Number of records and relevant bibliographic attributes

Statistics	**Number**
Documents	218
Sources	143
Authors	710
Authors of single-authored docs	22
International co-authorship	21.1%
Co-authors per document	3.72
Document average age	5.73

A total of 218 documents published across 143 different sources were included. The dataset comprises contributions from 710 distinct authors, with 22 documents being single-authored. The degree of international collaboration is notable, with 21.1% of the documents involving authors from multiple countries. On average, each document is co-authored by approximately 3.72 individuals, highlighting a moderate level of collaborative authorship. The average age of the documents in the dataset is 5.73 years, indicating that the sample primarily consists of relatively recent publications.

All analyses were conducted using Bibliometrix, an open-source R package specifically designed for comprehensive science mapping (Aria & Cuccurullo, 2017). Bibliometrix provides a wide range of bibliometric

tools for quantitative research in bibliometrics and scientometrics and allows for both descriptive statistics and advanced network analysis through its integrated web-interface Biblioshiny.

The bibliometric investigation was designed to address three specific analytical objectives. First, the study examines the trend of scientific production and citation patterns over time, offering insights into the growth and evolution of research at the intersection of AI and SLDs. Second, it explores international collaboration networks by analyzing patterns of co-authorship across countries, highlighting the most active contributors and major hubs of scientific cooperation. Third, it identifies thematic clusters and emerging areas of specialization through co-word analysis and clustering algorithms, uncovering the main conceptual structures that characterize the field.

This methodological framework enables a comprehensive and systematic exploration of the intellectual, social, and conceptual dimensions of the research concerning the application of Artificial Intelligence to Specific Learning Disabilities

3 Analysis and results

The bibliometric analysis of the scientific production related to Specific Learning Disabilities (SLDs) and Artificial Intelligence (AI) reveals a dynamic and rapidly evolving research landscape. The study focuses on three key dimensions: the evolution of publication and citation trends, patterns of international collaboration, and the thematic structure of the field.

The trend in annual scientific production reveals a steady increase in interest over time, with an annual growth rate of 7.57%. As illustrated in Figure 1, the number of publications remained extremely limited and sporadic until approximately 2010, with fewer than five articles per year. A first notable acceleration occurred around 2015, although still with moderate output. From 2020 onward, the field has experienced a dramatic growth, culminating in over 60 articles published in 2024 alone. This sharp rise indicates a growing awareness of the potential role of AI technologies in addressing the needs of students with SLDs and a broader expansion of interdisciplinary research combining education, cognitive science, and technological innovation.

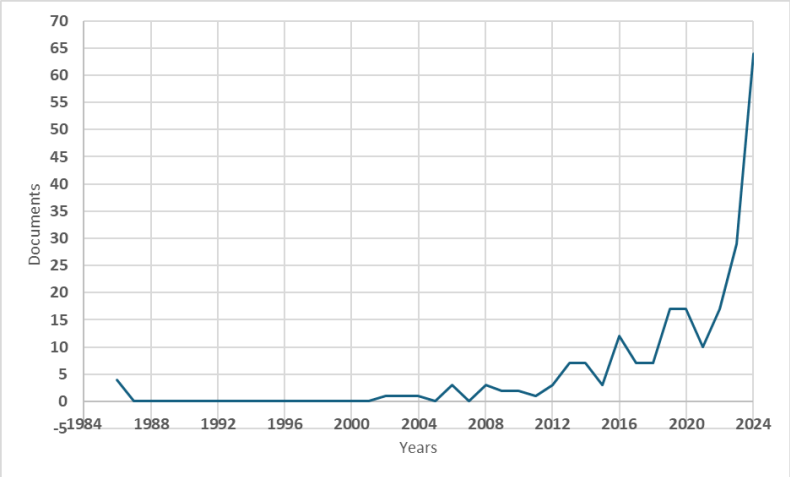


Figure 1: Annual scientific production

Similarly, the trend in citations offers important insights into the academic impact of this field. Figure 2 shows the average number of citations per article by year, with an overall average of 11.22 citations per document across the dataset. Although there are significant fluctuations — likely due to the small initial volume of publications — the overall trend suggests an increasing recognition of the relevance of this research topic. The sharp peak around 2003 reflects the influence of a seminal paper, after which the field matured with a more stable citation pattern. In recent years, particularly from 2015 onwards, average citations have remained consistently higher compared to earlier periods, confirming the growing importance and influence of studies situated at the intersection of AI and SLD research.

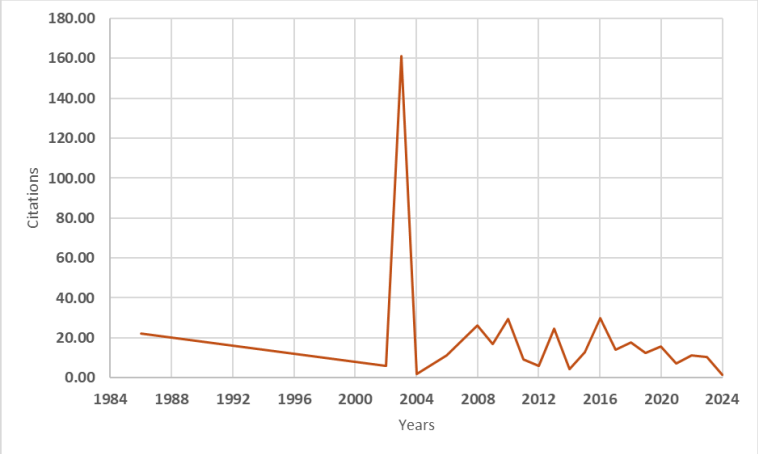


Figure 2: Average number of citations per article by year

International collaboration emerges as a fundamental factor in advancing this interdisciplinary area. The Country Collaboration Map (Figure 3) highlights the global distribution of scientific activity and the main cooperation networks. The United States leads the field both in terms of the volume of publications and international partnerships. Europe presents a dense network of collaborations, particularly involving Spain, Italy, and the United Kingdom, which act as major hubs for research development. Notably, India and China also show increasing contributions, indicating a growing global interest that transcends traditional Western-centric research patterns. These networks suggest that addressing SLDs with AI technologies is a universally recognized challenge that benefits from diverse cultural and scientific perspectives.

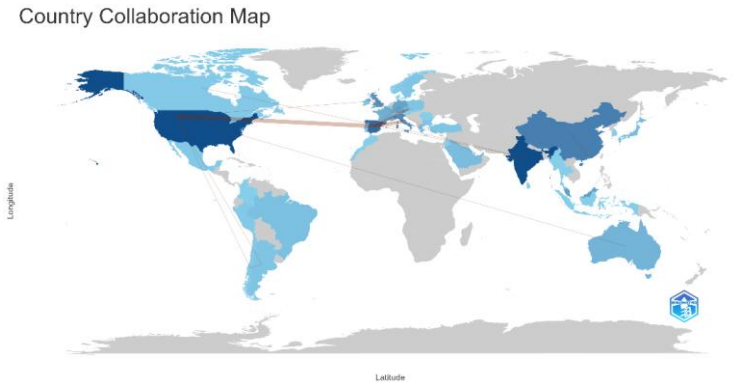


Figure 3: Country collaboration map

The thematic mapping of the field, presented in Figure 4, provides a more granular view of the conceptual structure of the research.

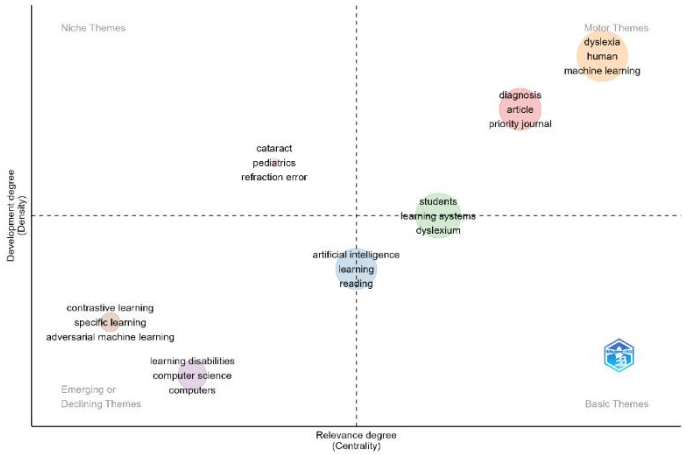


Figure 4: Thematic map

The thematic mapping of the field, presented in Figure 4, offers a comprehensive visualization of the conceptual structure of research at the intersection of Specific Learning Disabilities (SLDs) and Artificial Intelligence (AI). By plotting the themes across two axes—centrality (indicating the relevance of a theme within the overall network) and density (reflecting the internal development and cohesion of a theme)—the map provides a strategic overview of the maturity and importance of different research areas. This approach is instrumental in identifying established domains, emerging topics, and areas that may require further exploration or consolidation.

The map is divided into four quadrants, each representing distinct types of thematic clusters:

1. *Motor Themes (top-right quadrant):* these are the core drivers of research in the field, characterized by both high centrality and high density. Themes such as dyslexia, human, and machine learning fall into this category. Their placement suggests that they are not only highly relevant across multiple research domains but also exhibit a well-developed internal structure. For instance, numerous studies apply machine learning algorithms—such as support vector machines, neural networks, or decision trees—to the early detection of dyslexia, using features derived from reading patterns, eye-tracking data, or phonological processing assessments. This mature integration of AI techniques with dyslexia research reflects robust interdisciplinary collaboration between AI developers, educational psychologists, and neuroscientists, enabling effective diagnostic tools and intervention strategies. Early research already explored dynamic instructional adaptation using AI to tailor learning paths in computer science education, laying the groundwork for more personalized and responsive systems (Jurado et al., 2008).
2. *Basic Themes (bottom-right quadrant):* this quadrant includes topics like artificial intelligence, learning, and reading, which are highly central but less internally cohesive. These themes provide the foundational knowledge base for more specialized research, offering broad theoretical frameworks and methodologies. However, their lower density suggests that while these areas are widely discussed, further specialization and refinement in the context of SLDs may be needed. For example, although reading is a critical component of dyslexia research, it is often studied in general terms without sufficient integration of personalized AI-driven learning models that adapt to individual cognitive profiles.
3. *Niche Themes (top-left quadrant):* topics such as paediatrics, cataract, and refraction error are categorized as niche themes, characterized by high density but low centrality. These areas are well-developed internally but remain peripheral to the main research discourse on SLDs and AI. Their presence likely reflects specific subfields, such as the use of AI in paediatric ophthalmology, where vision-related conditions like cataracts or refractive errors are assessed using AI technologies. While these studies may intersect with learning disorders—given the impact of visual impairments on academic performance—they remain isolated from the central discussions around AI applications for cognitive or learning disabilities. For instance, AI models developed to detect visual anomalies in children might indirectly support better learning outcomes but are not explicitly integrated into broader SLD research.
4. *Emerging or Declining Themes (bottom-left quadrant):* themes like contrastive learning, specific learning, and adversarial machine learning are positioned here, indicating low centrality and density. These topics either represent nascent areas with high potential or declining interests. The presence of contrastive learning—a technique used to enhance the quality of learned representations by comparing similar and dissimilar data points—signals the early stages of applying advanced AI methodologies to the SLD context. Potential applications might include improving adaptive learning systems by distinguishing between different types of learning difficulties, thus offering more nuanced interventions. Similarly, adversarial machine learning could be employed to test the robustness and fairness of AI-based diagnostic tools, ensuring that models are not biased against certain populations or cognitive profiles. Although currently underexplored, these areas hold promise for redefining how learning disabilities are modelled and addressed through AI.

Although contrastive learning and adversarial machine learning are still emerging topics within the context of SLDs and AI, related studies in adjacent domains suggest their potential applicability. For instance, a study published in Science applied contrastive learning techniques to identify neuroanatomical variations specific to individuals with Autism Spectrum Disorder (ASD), distinguishing them from control groups. This methodology enabled the isolation of distinctive brain features associated with ASD, offering insights that could be adapted to detect neural patterns in SLDs, such as dyslexia or dyscalculia. Similarly, research published in Frontiers in Neuro-informatics explored the use of self-supervised contrastive learning to differentiate among various neurodegenerative disorders. Although these studies do not directly address learning disabilities, they illustrate the capability of contrastive learning to discriminate between different cognitive dysfunctions, indicating a promising avenue for future SLD research.

In parallel, the field of adversarial machine learning, while not yet directly applied to SLD research, has demonstrated significant potential in enhancing model robustness across various domains. A comprehensive taxonomy published by the National Institute of Standards and Technology (NIST) outlines adversarial attack techniques and mitigation strategies, emphasizing the need for resilient AI models. Applying such approaches to educational tools and diagnostic systems in SLDs could ensure that these systems remain reliable and unbiased, even in the presence of noisy or adversarial inputs. This is particularly relevant in educational contexts where data variability is common, and ensuring fairness and accuracy is critical.

These examples underscore the innovative potential of integrating advanced AI methodologies into SLD research, offering new directions for diagnostic precision and adaptive educational tools.

In summary, the thematic map not only captures the current intellectual landscape but also highlights strategic opportunities for advancing the field. For instance, integrating contrastive learning into adaptive educational platforms could enable real-time personalization, distinguishing between students with dyslexia and those with attention-deficit disorders based on nuanced behavioural patterns. Meanwhile, adversarial machine learning could be utilized to simulate challenging scenarios—such as noisy or incomplete data environments—to enhance the resilience of AI systems used in SLD diagnostics.

Furthermore, the thematic analysis suggests the need for greater convergence between niche and core themes, such as exploring how paediatric AI applications for vision impairments could be integrated with learning disability interventions, providing a holistic approach to student well-being. The thematic map thus serves as a strategic guide for researchers, offering a clear indication of where efforts should be concentrated to foster innovation, ensure ethical AI deployment, and enhance educational inclusivity.

4 Conclusions

This study provides a comprehensive bibliometric analysis of scientific literature at the intersection of Specific Learning Disabilities (SLDs) and Artificial Intelligence (AI), highlighting key trends, collaboration patterns, and thematic evolutions within the field. By analysing data exclusively retrieved from the Scopus database and employing the Bibliometrix R package (Aria & Cuccurullo, 2017), the study systematically mapped the intellectual and social structure of research activity in this emerging area.

The results reveal an exponential increase in scientific production over the past five years, reflecting a growing academic and technological interest in leveraging AI to support individuals with SLDs. Similarly, the average citation trends, despite some fluctuations, show an overall upward trajectory, suggesting that the relevance and influence of studies in this domain are steadily rising. The analysis of international collaborations highlights the pivotal role of countries such as the United States, Spain, Italy, and India, emphasizing the global scope of the research efforts and the importance of cross-border scientific cooperation.

The thematic analysis further uncovers a dynamic and diversified research landscape. While some areas, such as the application of machine learning to the diagnosis and support of dyslexia, have emerged as motor themes, other innovative approaches, including contrastive learning and adversarial machine learning, are beginning to gain attention as promising new directions for future exploration. These advanced AI methodologies, although still peripheral within the current research network, demonstrate significant potential to redefine diagnostic and intervention strategies. In particular, contrastive learning could enable more refined differentiation between various learning disorders, while adversarial machine learning offers tools for enhancing the robustness and fairness of diagnostic systems, ensuring reliable performance across diverse educational contexts.

Despite the notable progress observed, the bibliometric findings also highlight important gaps that merit further investigation. In particular, the emerging subfields require more empirical validation, and there is a need for broader interdisciplinary collaborations involving education experts, AI researchers, cognitive scientists, and policy makers. Greater efforts should also be directed toward integrating cutting-edge AI techniques with practical educational tools, ensuring that innovations translate into tangible benefits for learners with SLDs. This includes developing adaptive learning platforms that leverage advanced algorithms to personalize educational pathways, and diagnostic systems that are resilient to data variability and potential biases.

Moreover, the inclusion of insights from related fields—such as neurodevelopmental disorders and paediatric healthcare—could foster a more holistic understanding of the challenges faced by students with SLDs, promoting interventions that address both cognitive and environmental factors. Ensuring that AI-driven solutions are accessible and effective across different socio-economic and cultural contexts remains a critical challenge that future research should address.

In conclusion, the application of Artificial Intelligence to Specific Learning Disabilities represents a fertile and rapidly evolving research frontier. Continued investment in interdisciplinary research, combined with careful

empirical evaluation, will be essential to fully unlock the potential of AI in fostering more inclusive, personalized, and effective educational environments for all learners.

By bridging methodological innovation with practical application, researchers and practitioners can contribute to a more equitable and supportive learning ecosystem, where every student—regardless of cognitive differences—can thrive.

5 Ethics declaration

The authors declare they did not need ethical clearance for the research referred to in this paper.

6 AI declaration

The authors declare they did not use AI tools in developing the paper.

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Governance for Transition: Regulatory Incentives and Stakeholder Engagement in the New European Bauhaus

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Abstract

This paper investigates how regulatory frameworks and financial incentives influence stakeholder engagement and the institutionalisation of grassroots innovations within the New European Bauhaus (NEB) initiative. Launched by the European Commission as a creative and interdisciplinary extension of the European Green Deal, the NEB aims to foster more inclusive, sustainable, and aesthetically engaging urban environments. Despite its transformative ambitions, limited empirical evidence exists on how NEB projects evolve from local experimental niches into institutionalised practices embedded within mainstream governance systems.

Building on Transition Theory and the Multi-Level Perspective (MLP), this study conceptualises NEB projects as niche innovations operating within broader socio-technical regimes. It explores how policy instruments shape the dynamics of stakeholder engagement, knowledge diffusion, and adaptive governance. By integrating governance studies into the MLP framework, the paper addresses a critical gap in the sustainability transitions literature: the institutional conditions necessary to scale bottom-up initiatives. Methodologically, the study adopts a qualitative embedded case study design. Data were collected through an online self-assessment form distributed to all NEB prize finalists, complemented by secondary document analysis and semi-structured interviews with project leaders across diverse socio-political contexts. The findings reveal that regulatory incentives are key enablers of stakeholder engagement, particularly when supported by strong institutional backing, clearly defined roles, and mechanisms for continuous co-creation. However, the effectiveness of these incentives is uneven. Ambiguities in policy implementation and disparities in resource accessibility limit participation for smaller or less institutionally connected actors. Some projects succeed in aligning local stakeholders around shared goals, facilitated by municipal support and EU funding, while others struggle with bureaucratic barriers and limited access to technical expertise.

Theoretically, the study extends the MLP by embedding stakeholder co-creation and adaptive governance mechanisms into transition analysis. Empirically, it provides one of the first grounded assessments of how NEB projects scale and institutionalise within multi-level governance structures. Practically, the research offers policy recommendations aimed at strengthening long-term engagement mechanisms, improving the accessibility of funding tools, and fostering cross-sectoral collaboration between local authorities, civil society, and industry.

Ultimately, this study contributes to a more comprehensive understanding of how participatory governance and regulatory design intersect in shaping urban sustainability transitions. It underscores the need for flexible, iterative governance models that allow experimental initiatives to influence policy landscapes and highlights the importance of inclusive and sustained stakeholder engagement for the institutional success of visionary policy agendas such as the NEB.

Keywords: New European Bauhaus, Stakeholder, Policy, Governance, Collaboration

Paper Type: Academic Research Paper

1 Introduction

The New European Bauhaus (NEB) initiative represents a novel policy framework that seeks to bridge the European Green Deal with participatory urban transformation by integrating sustainability, inclusivity, and aesthetics into the fabric of European communities (EU NEB Compass, 2023; EU NEB Website, 2024). Through its multi-level and interdisciplinary structure (Kuenkel, 2019), NEB aims to accelerate sustainability transitions through bottom-up innovation (Anderson et al., 2014; Baldwin et al., 2024) and enabling systemic change through policy alignment (Lee and Koski, 2015).

Despite its transformative ambitions, the long-term impact of NEB projects depends on their ability to scale beyond isolated experiments and become embedded within formal governance structures (Emerson et al., 2012; Freeman and David, 1983; Lee and Koski, 2015). Drawing on Transition Theory, NEB projects can be conceptualised as *niche innovations operating within an existing socio-technical regime* (Geels, 2002). These initiatives often promote participatory models, design-led urban solutions, and sustainability-oriented practices (Alizadeh et al., 2019; Haesevoets et al., 2024). However, their success hinges on supportive regulatory frameworks, effective knowledge diffusion mechanisms, and policy incentives that facilitate integration into mainstream urban governance (European Union, 2023; Leiringer, 2006).

While the Multi-Level Perspective (MLP) highlights the importance of interactions between landscape-level pressures (e.g., EU climate policy), socio-technical regimes (urban governance systems), and grassroots niches (local NEB projects) (Schot and Geels, 2011), the specific role of regulatory incentives in shaping these dynamics remains underexplored. In particular, the literature offers limited empirical insight into how grants, subsidies, and tax benefits influence stakeholder engagement, knowledge co-creation, and the institutionalisation of experimental projects (Heinelt and Niederhafner, 2008; Pee and Pan, 2022).

This study addresses this gap by examining *how policy mechanisms facilitate—or hinder—the transition of NEB projects from experimental niches to institutionalised urban practices.* By analysing how regulatory frameworks influence stakeholder engagement, the study contributes to a more nuanced understanding of *how participatory initiatives can move beyond compliance to foster enduring collaboration, interdisciplinary knowledge exchange, and adaptive governance.* While NEB has been conceptually praised, little is known about its institutionalisation pathways at the grassroots level—a gap this study addresses.

Theoretically, the paper extends the MLP by incorporating insights from governance and policy studies to better account for the institutional conditions that support sustainability transitions. Empirically, it provides original data from prize-winning NEB projects, offering grounded insights into the role of financial incentives and institutional support in shaping multi-actor engagement. Practically, the research delivers evidence-based recommendations for policymakers and local authorities to enhance the effectiveness of regulatory instruments in scaling grassroots innovations and embedding NEB values into long-term urban governance.

This paper offers the first empirical analysis of *how EU-level regulatory incentives shape stakeholder engagement and institutionalisation of NEB grassroots projects*, advancing both transition theory and participatory governance research.

2 Methodology

To address the research question—how policy mechanisms facilitate or hinder the transition of New European Bauhaus (NEB) projects from experimental niches to institutionalised urban practices—this study employs a qualitative research design grounded in Transition Theory and the Multi-Level Perspective (MLP) (Geels, 2002). The embedded case study approach (Yin, 2009) is particularly suited for analysing complex phenomena in real-world settings, especially those involving dynamic stakeholder interactions and institutional diversity. In this study, the NEB initiative serves as the primary unit of analysis, while prize-winning projects selected through the NEB Awards serve as sub-units. This structure enables an in-depth examination of how grassroots innovations interact with governance frameworks and respond to policy mechanisms under varying conditions of institutional support (Esposito et al., 2024; Kemp et al., 1998; Schot and Geels, 2011).

The NEB Awards, established as an annual competition, celebrate exemplary projects and concepts that embody the initiative's core values of sustainability, aesthetics, and inclusion. These awards recognise local efforts to foster innovation through multi-level, multidisciplinary, and participatory approaches. Between 2021 and 2023, the NEB Awards identified 52 winning projects from over 4,500 applications, reflecting a broad spectrum of practices across the European Union. The selected finalists include projects from Spain, Italy, Greece, Denmark, Belgium, Austria, France, Germany, and numerous other EU member states, providing a rich empirical base for comparative analysis.

The data collection process began in September 2023 by distributing an online self-assessment form to all NEB prize finalists. The survey was created via Google Forms and included Likert-scale and multiple-choice questions designed to capture background information, alignment with NEB values, and stakeholder engagement practices. This instrument provided a preliminary mapping of how projects adhere to NEB principles in practice. The responses were triangulated with secondary data sourced from project websites, social media, and official NEB project fiches to refine our understanding of project scope and implementation contexts.

Semi-structured interviews were conducted with project owners between December 2023 and March 2024 to deepen the qualitative analysis. This method was chosen to elicit rich, context-specific insights into the governance processes, institutional enablers and barriers, and stakeholder dynamics experienced by NEB participants (Rowley, 2012). Interviewee selection followed a purposive sampling strategy based on two criteria: (1) inclusion across the five NEB prize categories—Mobilisation of Culture, Arts & Communities; Regaining a Sense of Belonging; Buildings Renovated in a Spirit of Circularity; Prioritising the Places and People That Need It the Most; and Reconnecting with Nature—and (2) geographic diversity to account for varied socio-economic and governance contexts. While the sample includes NEB award-winning projects, future studies should also consider less visible initiatives to capture the full spectrum of grassroots experimentation.

This multi-method, multi-scalar approach ensures analytical depth and methodological triangulation (Creswell, 2009; Mills, 2019). The resulting dataset is analysed through thematic coding to identify governance

barriers, policy leverage points, and transition pathways that enable or constrain the institutionalisation of NEB projects. In doing so, the study seeks to contribute to both the theoretical advancement of transition studies and the practical refinement of participatory governance frameworks in the context of EU policy implementation (Bianchi and Nasi, 2021; European Union, 2023; Haesevoets et al., 2024).

3 Findings

The initial findings suggest that regulatory incentives such as grants and tax benefits are key *enablers of stakeholder participation* (Dentoni et al., 2018; Kuenkel, 2019). However, their effectiveness varies significantly across different project types and stakeholder groups. Projects that benefit from strong institutional support, clearly defined stakeholder roles, and embedded co-creation mechanisms appear better positioned to leverage these incentives. These cases demonstrate how financial support and well-structured governance arrangements can foster interdisciplinary collaboration, knowledge diffusion, and participatory urban governance. Nevertheless, implementation challenges persist. Ambiguities in policy interpretation and administrative complexity contribute to inconsistent stakeholder engagement practices across NEB projects. Moreover, disparities in access to financial and technical resources disproportionately affect grassroots organisations and smaller enterprises, limiting their full participation in NEB initiatives.

The findings underscore the importance of *adaptive governance structures* that respond to the dynamic nature of multi-stakeholder collaborations (Ansell and Gash, 2008; Freeman and David, 1983). Specifically, the institutionalisation of NEB projects requires regulatory support and flexible, multi-actor governance mechanisms that enable scaling niche innovations into mainstream urban policy frameworks.

For instance, a project from Italy operating in the "Regaining a Sense of Belonging" category successfully mobilised local artists, public institutions, and SMEs around a shared urban regeneration goal, facilitated by municipal backing and EU funding. In contrast, a finalist from Eastern Europe noted limited access to local institutional support and procedural complexities in applying for EU grants, which constrained long-term engagement. Contrary to expectations, even highly recognised projects reported difficulty sustaining stakeholder engagement beyond the funding cycle, pointing to a lack of long-term mechanisms.

Theoretically, this study contributes to sustainability transitions literature by extending the Multi-Level Perspective (MLP) to incorporate governance mechanisms and stakeholder engagement dynamics more explicitly. It offers empirical insights into *how regulatory incentives influence the trajectory of grassroots innovations, how socio-technical regimes respond to participatory processes, and how governance barriers and enablers shape knowledge diffusion.*

This research thus bridges transition theory and governance studies, advancing a more integrated framework for analysing the institutional embedding of experimental projects. The evidence suggests that the long-term success of initiatives like NEB depends on top-down policy alignment, bottom-up capacity building and collaborative governance models that can adapt to evolving urban and socio-political contexts.

4 Discussion

By positioning the NEB's participatory and design-driven ethos within transition studies, this research advances a novel analytical framework for understanding *how policy interventions and stakeholder co-creation processes influence sustainability transitions*. It expands the application of the MLP by integrating governance mechanisms—particularly those tied to regulatory incentives and institutional embedding—into the analysis of niche innovations.

Empirically, the research sheds light on the uneven effects of regulatory incentives across contexts, revealing how institutional backing, stakeholder role clarity, and access to resources shape project success. Combining qualitative interviews and comparative analysis of NEB-awarded projects, the embedded case study approach offers grounded insights into the mechanisms that facilitate or hinder stakeholder engagement and knowledge diffusion (Bryson et al., 2006). On a practical level, the study offers policy recommendations to enhance the effectiveness of regulatory frameworks in supporting participatory governance. It suggests shifting from short-term, compliance-driven incentives to mechanisms promoting sustained engagement and institutional integration. It also calls for fostering cross-sectoral collaboration between local authorities, industry, and civil society to support mainstreaming NEB-inspired solutions. Furthermore, it advocates for multi-level governance models that are flexible, co-creative, and iterative, allowing bottom-up initiatives to influence and reshape policy landscapes (Ambrose and Siddiki, 2024; Maher and Buhmann, 2019; Njøs and Fosse, 2019).

Theoretically, the study contributes to transition theory by illustrating how grassroots innovations interact with socio-technical regimes under varying governance conditions. It highlights the critical role of adaptive, multi-actor governance in enabling the institutionalisation of experimental projects such as those supported by

the NEB (Raj et al., 2022; Seyfang and Haxeltine, 2012; Seyfang and Smith, 2007). Moreover, his study refines the MLP by integrating multi-actor governance dynamics, while practically, it offers actionable pathways for embedding NEB projects into municipal policy cycles. Rather than treating regulatory incentives as static enablers, this study conceptualises them as dynamic relational tools that can evolve through actor interaction and feedback. Ultimately, this research contributes to developing more resilient and inclusive governance frameworks, helping to ensure that NEB principles become embedded in the long-term evolution of sustainable urban policies and practices (Hospers, 2014).

5 Limitations and Future Research Directions

While offering in-depth insights into the governance dynamics of NEB initiatives, this study is subject to several limitations. A primary restriction concerns the representativeness of the interview sample. Although efforts were made to ensure diversity across NEB prize categories and geographical contexts, selecting semi-structured interview participants may not fully capture the breadth of grassroots initiatives involved in the NEB ecosystem. This potential sampling bias may affect the generalisability of the findings (Creswell, 2009). Future research should broaden its empirical scope to include a more representative range of projects and stakeholder types, particularly underrepresented voices such as local community members, end-users, and external evaluators. Including these perspectives would provide a more holistic understanding of how NEB values are interpreted, negotiated, and implemented on the ground.

From a methodological standpoint, while the study triangulated data through interviews, document analysis, and secondary sources, the qualitative nature of the research remains inherently interpretive and context-dependent (Tranfield et al., 2003; Yin, 2009). Despite internal validation efforts through iterative discussion and coding comparison, the potential for researcher bias cannot be eliminated. Future studies could enhance robustness by adopting mixed-methods approaches that combine qualitative insights with quantitative data, such as large-scale stakeholder surveys or analysis of funding and impact metrics. Moreover, this research offers a snapshot of project implementation at a specific point in time. Longitudinal studies are recommended to capture how stakeholder engagement and value integration evolve. Following NEB initiatives over time would enable researchers to track adaptive processes, institutional learning, and the long-term embedding of NEB values into governance structures. Additionally, incorporating real-time methods such as participant observation in project meetings or workshops could offer deeper insights into decision-making dynamics and multi-actor collaboration in practice(Escolar et al., 2019; Gerlak et al., 2023).

6 Ethics declaration

This research involved human participants through semi-structured interviews and an online self-assessment form. Before data collection, participants were informed of the research objectives, and their voluntary consent was obtained in line with the principles of research ethics and confidentiality. Ethical principles of anonymity, informed consent, and data protection were rigorously followed throughout the research process.

7 AI declaration

Artificial Intelligence tools were not used to generate content or conduct analysis in the development of this paper. However, language support tools such as Grammarly and ChatGPT by OpenAI were used to proofread, clarify sentence structure, and improve linguistic coherence during the revision phase. All substantive content, interpretations, and analytical contributions remain the author's original work. The AI tools were used strictly for editorial assistance and did not influence the intellectual or methodological substance of the paper.

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Crowdfunding Failures: An Opportunity for Stakeholder Collaboration?

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Abstract

The crowdfunding phenomenon has grown exponentially over the years; however this type of financing mechanism does not only include successful initiatives, but there are also numerous cases of failed campaigns in which the proponents do not receive any funding. While most of the studies focused on the post-campaign phases of successful initiatives, a very limited number of scholars have explored the case of unsuccessful initiatives. This study is one of the first to focus on the latter and try to shed some light on the dynamics of the initiatives that have faced such a failure. We conducted qualitative and inductive research based on interviews with proponents of failed CF campaigns in the Italian context and secondary data (in particular from websites, social media, updates). The preliminary findings highlight that significant differences exist between the initiatives failed in the reward-based CF context and the equity-based CF context, as well as the stage of development of the business. Most of the interviewees highlighted the significant learning opportunity for them and the importance of creating collaborations with different stakeholders; at the same time, they faced different emotional challenges in such a scenario. This study could have useful implications for theory and practice. Among the main stakeholders involved are entrepreneurs, CF platforms, investors, policy-makers, governments, incubators/accelerators.

Keywords: crowdfunding, entrepreneurs, stakeholders, failures, startups

Paper type: Academic Research Paper

1 Introduction

Over the years, the crowdfunding (CF) phenomenon has seen exponential growth in numbers across the world, becoming a crucial source of financing for entrepreneurs in many countries (Mollick, 2014; Li et al., 2016; Wang et al., 2018; Testa et al., 2024; Troise et al., 2024a, 2024b, 2025). At the same time, there has been growing academic interest in CF (Block et al., 2018; Estrin et al., 2022; Polzin et al., 2018; Troise et al., 2023, 2024b).

Among the main CF models that management have explored are the equity-based crowdfunding (ECF) model (Vismara 2018, 2019; Troise et al., 2021) and the reward-based crowdfunding (RCF) model (Chan et al., 2017; Parhankangas and Renko, 2017; Oo et al., 2019; Shneor and Munim, 2019). The first model is a specific financing method that allows entrepreneurs to sell predetermined amounts of equity-shares in a company to a crowd of investors (Ahlers et al., 2015; Vismara, 2016), while the second model allows proponents of initiatives to provide a pre-sell of new or future (sometimes unfinished/unproven) products or services (Belleflamme et al., 2014; Davis et al., 2017).

Scholars who have studied crowdfunding have found that not all CF campaigns are successful and there are many initiatives that have failed because they did not reach their pre-established target amounts (Troise et al., 2021, 2022).

While many studies have explored the factors influencing the success or failure of CF campaigns – i.e. the drivers that can lead to reach or not the funding goals – there is a paucity of studies that have focused on the post-campaign phase and, in particular, on what happened after an unsuccessful CF campaign (Rossi et al., 2022). This research tries to shed some lights on the dynamics of failed initiatives by exploring the view of entrepreneurs that adopted the CF system, although without success. Very limited attention, in fact, has been paid to the post-campaign lives of these initiatives and if, and to what extent, they have learned from such a failure and triggered new behaviors or collaborations with other stakeholders. Given these gaps, our research aims to improve our collective understanding of the phenomenon.

In doing this, we leveraged an inductive qualitative research design and explored the Italian context, given its importance in the field of CF at the European level (Troise et al., 2023).

2 Background

The literature on crowdfunding has advanced significantly over the years (Troise et al., 2024b). Most scholars have studied the dynamics of campaigns to understand the success factors, such as human, social and intellectual capital, that lead backers or investors to commit financial resources to support initiatives (Mollick, 2014; Lukkarinen et al., 2016; Vismara, 2016; Troise et al., 2020, 2022). These studies shed lights on the drivers able to mitigate the existing presence of information asymmetries between backers/investors and entrepreneurs.

Recently a limited number of studies started to focus also on the pre-campaign (Brown et al., 2018; Troise and Tani, 2021; Stevenson et al., 2022) and the post-campaign (Hornuf et al., 2018; Signori and Vismara, 2018; Di Pietro et al., 2018; Troise et al., 2021, 2023) phases. About the first, scholars tried to increase current knowledge on the elements that lead entrepreneurs to use CF and their underlying motivations such as the non-monetary returns they expect (Brown et al., 2018; Troise and Tani, 2021; Stevenson et al., 2022; Troise et al., 2023). While regarding the second, scholars have mainly explored the cases of initiatives that had been successful during CF campaigns, i.e. the post-offering lives of initiatives (Signori and Vismara, 2018). However, studies that have explored what happens after unsuccessful CF campaigns remain extremely limited with only a few of exceptions (Walthoff-Borm et al., 2018a, 2018b; Rossi et al., 2023). For example, the research conducted by Walthoff-Borm et al. (2018a) showed a significant failure rate of initiatives after an unsuccessful campaign of ECF. Similarly, the study of Rossi et al. (2023) explored the family business start-ups that have experienced an unsuccessful ECF campaign and highlighted their high probability to offer shares with voting rights after such a negative event; they also have found that these companies have more probabilities to collect equity financing than the same companies that have no a family-business nature.

Given the limited knowledge in this emerging field, this study aims to shed some light on the dynamics post-campaign of unsuccessful initiatives. Our research will explore what happens to entrepreneurs that have experienced the failure of a CF campaign and, more importantly, how and to what extent this could represent an opportunity for them to start new collaborations with different types of stakeholders.

In this vein, our research responds to recent calls for more research, such as the study of Rossi et al. (2023, p. 1348) that reported that “Our analysis suggests that future research should consider crowdfunding learning outcomes…”

3 Methodology

Given the recent phenomenon explored and, in particular, its limited knowledge of the failed initiatives, a qualitative research design is useful to achieve a better understanding of it (Eisenhardt & Graebner, 2007). In fact, recent studies (see among others Estrin et al., 2018; Troise et al., 2023) and reviews of the literature (see among others Mochkabadi & Volkmann, 2018) highlighted that CF is still characterized by novelty and, especially, its literature is very sparse.

In our case, a multiple-case study approach is particularly suitable to understand the views of the involve players and enhance the external validation of the findings (Eisenhardt, 1989; Eisenhardt & Graebner, 2007; Gioia et al., 2013). We conducted an inductive research utilizing and integrating interviews with entrepreneurs that experienced an unsuccessful CF campaign and several secondary data, (including updates from CF platforms, companies’ websites and social media, dedicated press/blogs).

We specifically focused on Italy for several reasons. First, this country is particularly vibrant and developed in relation to the the CF phenomenon; in fact, it was the first country in Europe to introduce and adopt an “ad hoc” regulation for the ECF model (i.e. the Decreto Legge n. 179/2012 or better known as “Decreto Crescita Bis”) and the authority “Consob” (Commissione Nazionale per le Società e la Borsa introduced a specific registry for ECF platforms and operators (Troise and Tani, 2021). Second, this country is characterized by the presence of small businesses – who made most of the production base of the country – and, in fact, the government tried to support these companies through the establishment of ECF system.

As this is a work in progress, we are still conducting the interviews and simultaneously collecting secondary data. At this stage we have finalized the interviews with some of the proponents of the failed CF initiatives in the Italian context related to both the equity-based crowdfunding (ECF) and reward-based crowdfunding (RCF) models. Based on these initial interviews, we provided some initial preliminary findings.

Once the data collection has been fully completed and the remaining interviews finalized, we will be able to review and examine in-depth the interviews’ transcripts and integrate them with secondary data to provide a final model or framework.

4 Preliminary findings

As a result of these interviews, the proponents of failed initiatives, i.e. those who experienced an unsuccessful CF campaign, underlined several elements of interest in terms of strategies and dynamics post-campaigns.

First, most of the interviewees highlighted that such a failure represented a significant learning opportunity for them. In fact, learning from this specific type of failure is recognized by them as a crucial step in the future development of their idea or business and thus - hopefully - paves the way for future success through improvements being undertaken. Among them, the proponents of initiatives reported that after the failure they started new collaborations with different types of stakeholders; it was triggered above all by the realization that external help could be decisive and an extra push towards the development of the initiative, since "going it alone" would not have been the best choice. The possibility of collaborating helps in some way to mitigate the uncertainty that has been created around the initiative and which, after the campaign, has increased.

The interviewees highlighted that significant differences exist between failed initiatives in the ECF and RCF contexts and that such failures have different effects on the proponents depending on the stage the business is at. For example, initiatives that are still in an embryonal stage of idea development have more opportunities to refine their products/services and implement new changes after having unsuccessfully tested a crowd of consumers with the RCF. The ECF, being targeted to established companies, especially small and new ones, represented an opportunity to establish new partnerships and – in some limited circumstances – to evaluate the potential transfer of an idea or innovation, not being able or having the resources to fully pursue it. While SMEs are in general more equipped to face such a failure, startups have more difficulties in changing their trajectory and in trying to further develop the failed initiatives, especially given the limited resources they possess; in fact, another failure could represent too high a risk for them and could undermine their survival in extreme cases.

The interviewees reported the emotional challenges they faced. In general, a failure generates negative emotions (such as helplessness, rejection, pain and shame in individuals), but the negative effects are more evident for proponents of initiatives that failed by a large margin – i.e. they achieved a very low percentage of the set goal – and that had been rejected - that is, not funded - by professional investors. In some cases, the projects were abandoned after failed CF campaigns. In other cases, proponents have tried to adopt more cautious strategies aimed at containing any waste of resources or energy and negative image effects.

5 Conclusion

The study tried to provide an interesting contribution to advance current literature in the field of CF characterized by a paucity of research focused on the failures.

Recently, in fact, there has been a relevant call for more research in this field to improve collective knowledge about the lives of companies/entrepreneurs after such a failure and, eventually, whether they learn from this negative CF experience and can engage investors and other stakeholders (Rossi et al., 2023).

This study could have useful implications for theory and practice. Among the main stakeholders involved are entrepreneurs, CF platforms, investors, policy-makers, governments, incubators/accelerators.

In particular, entrepreneurs, CEO and managers of start ups or SMEs adopting CF systems should acknowledge the importance of learn in a systematic way from failures in this specific contexts; they, in fact, could be a crucial opportunity to learn and strengthen their businesses thanks to such experiences. Hopefully, they can translate negative experiences into new business opportunities and – eventually – successful initiatives.

Similarly, the other relevant players of the innovation or entrepreneurial ecosystem should support the companies through learning processes from failures and invest specific financial and non-financial resources in this sense.

6 Ethics declaration

Ethical clearance is not required for the research

7 AI declaration

No AI tools were used for the creation of the paper

8 Other declarations

Declarations of interest: none.

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The Role of Technology in Advancing Sustainability: Insights from the Textile Industry

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Abstract

The textile industry faces increasing scrutiny for its environmental pollution, waste of water and energy resources, labor issues, and inefficiencies throughout the value chain (Pedersen and Gwozdz, 2014). As global agendas, such as the United Nations Sustainable Development Goals (SDGs) and the European Green Deal, call for urgent transformation, technology emerges as both a potential enabler of sustainability and a tool to mitigate the textile industry impacts. However, existing literature remains fragmented, often analyzing technologies in specific operational conditions or focusing on a singular dimension of sustainability. By conducting a systematic literature review of recent academic contributions, this study examines how technologies support the environmental, economic, and social pillars of sustainability in the textile industry. The review identifies and categorizes 88 articles from the Scopus database, revealing a diverse yet disconnected research landscape. From the content analysis, technologies are grouped into three clusters: emerging, established, and process-oriented. To offer an integrative perspective, the paper introduces a multi-level taxonomy that links technologies to specific sustainability-related weaknesses across the textile value chain. Findings show that while some technologies, especially Blockchain and data-driven systems, demonstrate convergent sustainability benefits, most generate partial or domain-specific improvements, such as Artificial Intelligence (AI) which raises concerns related to equity and digital exclusion (Park et al., 2020). The social dimension remains the least addressed, emphasizing the need for comprehensive strategies and governance frameworks to guide equitable technological adoption. This research offers a structured framework to help vertically integrated textile companies understand how technology adoption can address their sustainability challenges and provides practical insights for aligning business practices with innovation and SDGs objectives.

Keywords: Technology management; Innovation; Textile Industry; Sustainability.

Paper type: Academic Research Paper

1 Introduction

The textile industry has long been under analysis for its unsustainable practices, including excessive resource consumption, unsafe labor conditions, and chronic overproduction, which contribute to inefficiencies across global supply chains (Pedersen and Gwozdz, 2014). These challenges are becoming even more critical under increasing regulatory pressure, such as the United Nations' Sustainable Development Goals (SDGs) and the European Green Deal, which call for a fundamental shift toward more sustainable industrial practices. In this context, technologies, especially those related to Industry 4.0 and industry 5.0, are increasingly recognized as key enablers of sustainable transformation. The intersection between technological innovation and sustainability has thus become a central topic in academic debate, with a growing body of literature exploring how technological adoption can reshape the textile industry (Ejsmont, Gladysz and Kluczek, 2020). However, existing research tends to be fragmented: most studies focus on single technologies or sustainability aspects, offering limited insight into how these technologies address the broader sustainability challenges across the textile value chain. This reveals a key gap: the absence of an integrated framework linking technologies to sustainability and supply chain phases.

To address this gap, the present study adopts the Triple Bottom Line framework (Elkington, 1997) and proposes a multi-level taxonomy that links technologies to sustainability-related weaknesses along the textile value chain. This approach captures both synergies and tensions observed in literature. Considering these limitations, the study addresses the following research questions:

1. What is the state of art regarding the relationship between technologies and sustainability in the textile industry?
2. How do technologies contribute to environmental, economic, and social sustainability in the textile industry?

To answer these questions, a systematic literature review was conducted, aimed to map technological applications in the textile industry and their sustainability implications.

2 Methods

Following the guidelines proposed by Tranfield, Denyer and Smart (2003), this study adopts a systematic literature review methodology. The aim of this approach is to provide a comprehensive, transparent, and replicable process for identifying, evaluating, and synthesizing existing knowledge on the role of technologies in supporting sustainability within the textile industry. In this study, articles were collected employing Scopus database, recognized as one of the most extensive bibliographic resources. The search query was designed to capture articles that explicitly investigate the intersection between technological innovation and sustainability, be it environmental, economic, or social, within the textile and apparel sectors. The decision to focus on English journal articles and reviews from the last four years (2020–2024) was driven by the intent to better capture both the most disruptive and recent technologies as well as the current focal points of academic research. This time-bounded scope ensures that the analysis reflects the latest advancements and policy dynamics influencing sustainable innovation in the industry. To ensure data consistency and accuracy, specific inclusion criteria referred to subject area and keywords were established to guide the selection process and enhance the quality of the sample:

Table 1: Research criteria

Query	((textile OR fashion OR apparel OR clothing) AND (sector OR industr*)) AND (technolog* OR digital* OR "Industry 4.0" OR "Industry 5.0") AND (sustainab* OR ((environmental OR social OR economic) AND impact))
Result	287

During the screening phase, abstracts were carefully reviewed, and many contributions were excluded because they lacked a clear technological focus. Others were highly specialized studies on chemical or enzymatic processes, often limited to laboratory experiments with restricted applicability:

Table 2: Sample variance during the screening phase

Key steps	Sample variation	Final number of the paper
Database query	+287	/
Reading abstracts	-144	143
Not accessible articles	-42	102
Reading articles	-14	96
Final sample	/	88

This careful refinement process was essential to ensure that the final dataset included only those studies that meaningfully explored the role of technology in advancing sustainability in textile industry, reaching a sample of 88 papers.

3 Results

As a first step in addressing the research question about the stat of the art in the literature, the descriptive analysis reveals a predominance of qualitative studies, including literature review (Munir et al., 2022), semi-structured interviews (Kaur, Azmi and Majid, 2022), and case studies (Singh, 2024). Nonetheless, a substantial share of contributions adopts quantitative methods, such as Structural Equation Modeling (Bibi et al., 2024) and Multi Criteria Decision Approach (Agarwal and Singh, 2022), indicating a relative balance across approaches. Mixed-method designs are less frequent but increasingly valued for their ability to combine analytical rigor with contextual depth, such as text mining and coding analysis (Tolentino-Zondervan and DiVito, 2024), and fuzzy set Qualitative and Comparative Analysis (Cao et al., 2022), which are particularly suited to capturing the complexity of technology–sustainability interactions.

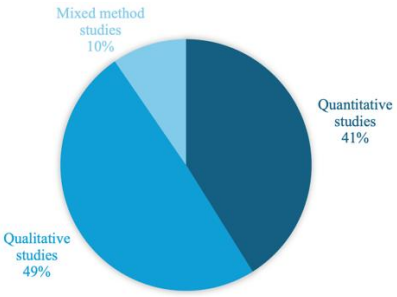


Figure 1: Percentages of methodologies applied in the research sample

Theoretically, the Triple Bottom Line framework remains the most widely employed (Munir et al., 2022). Complementary frameworks such as those related to Sustainable Supply Chain (Hauschild and Coll, 2023) and the Resource-Based View (RBV), (Irfan et al., 2020), highlight the strategic value of technology in enhancing organizational resilience and competitiveness. Contributions grounded in the Circular Economy (Ribul et al., 2021) and Dynamic Capabilities views (Saha, Belal and Talapatra, 2024) perspectives emphasize the importance of adaptability, regeneration, and innovation in navigating sustainability transitions. Notably, several studies adopt integrative models combining technology, organization, and environment elements, reflecting a growing recognition of the systemic nature of sustainable innovation and the need to align technological change with organizational and institutional contexts (Kutschera and Crowell, 2024).

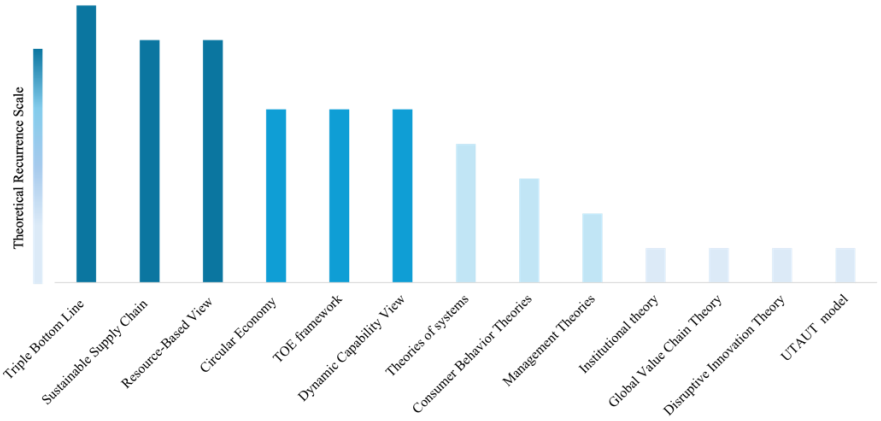


Figure 2: Theoretical framework applied in the research sample

Building on the content analysis, the authors identified three main technological clusters that currently dominate academic attention in the context of the textile industry. While their specific sustainability impacts will be discussed in the following section, this overview outlines the key technological domains shaping the current research landscape.

Emerging technologies: technologies that are relatively new to the textile industry but are increasingly recognized for their transformative potential, such as Artificial Intelligence (AI), (Jin and Shin, 2020), and Blockchain (Jain et al., 2022). Another emerging tool, the Digital Product Passports (DPP), is gaining relevance in response to evolving regulatory frameworks. However, the academic literature tends to examine DPP within broader technological ecosystems.

Established technologies: technologies that are already integrated into business and industrial processes, such as data-driven technologies (Irfan et al., 2020) as Internet of Things (IoT), Big Data, Cloud Computing, and Product Lifecycle Management (PLM) platform. It also comprises traceability technologies (Tolentino-Zondervan and DiVito, 2024) namely QR codes, Radio Frequency Identification (RFID), and DPP. Furthermore, literature reveals an interest also in immersive and visualization technologies, as Augmented Reality (AR), Virtual Reality (VR), and 3D simulation tools (Choi, 2022). Lastly, smart and connected technologies for Industry 4.0 encompasses configurations that integrate Cyber-Physical Systems (CPS), Digital Twin models, Additive Manufacturing (AM), autonomous systems, advanced manufacturing technologies, and real-time environmental data acquisition. These technologies are often adopted in combination to support comprehensive digitalization and sustainability across the value chain (Jin and Shin, 2020).

Process and treatment technologies: technologies that act directly on materials, production processes, or end-of-life stages to reduce environmental impacts, such as enzyme-based biotechnologies, ecological wastewater treatment solutions (Rahman et al., 2020), including Membrane Bioreactors (MBR), Electrocoagulation (EC), Moving Bed Biofilm Reactors (MBBR), Rotating Biological Contactors (RBC), and the Activated Sludge Process (ASP), and recycling technologies (Ribul et al., 2021).

Table 3: Technologies discussed in literature and classified by authors

Technological clusters identified in literature	**Technologies analised in textile industry**
Emerging Technologies	Blockchain Artificial Intelligence
Established Technologies	Information technologies (IoT, Big Data Computing, PLM platform) Track technologies (DPP, QR Code and RFID) Immersive and visualization technologies (AR, VR, 3D software simulation) Smart and connected technologies for the industry (Cyber Physical Systems; IoT + AI + Big Data; IoT + Big Data + Cloud Computing; Digital Twin + Smart Analysis Model; Additive Manufacturing + Automated production + Digital twin; Cyber Physical Systems + IoT + Artificial Intelligence + Big Data; IoT + Big Data + Blockchain + AI + Cloud Computing + Cyber Physical Systems + Additive Manufacturing)
Process and Treatment Technologies	Biotechnology based on enzymes (amylase, cellulase, pectinase, lipase, laccase, and peroxidase) Ecological technologies (MBR, EC, MBBR, RBC, ASP) Recycling technologies (mechanical and chemical recycling, enzymatic and biological processes)

Many studies focus on individual technologies or specific dimensions of sustainability, without offering an integrated or systemic perspective. This fragmentation partially reflects the structural characteristics of the textile sector, which is currently one of the most complex industrial domains in terms of sustainability, as it faces a range of systemic challenges, from overproduction to greenwashing and labor precarity in producing countries, to post-consumer waste management. Moreover, most contributions emphasize sustainability issues related to production and logistics, while neglecting other critical phases of the product lifecycle, such as early-stage design and end-of-life management.

This narrow focus limits the understanding of how the impacts of technologies may vary across different stages of the value chain. It is therefore necessary to identify all the operational stages of the textile value chain to pinpoint those that are underexplored and to clarify which types of technologies are currently applied to address specific sustainability-related vulnerabilities.

In response to these limitations, this study introduces a novel taxonomy aimed at integrating fragmented evidence, revealing research blind spots, and offering a structured framework for evaluating technological interventions across the textile value chain.

The structure is built upon the following levels: (1) the stage of the textile value chain in which the technology operates; (2) the sustainability-related challenges identified in the literature, mapped across the three dimensions of sustainability (environmental, economic, and social); (3) the technologies that are applied to mitigate these challenges within their respective phases of the value chain.

Specifically, the value chain level considers the main operational stages of the textile value chain:

1. Design and product development
2. Raw material sourcing and procurement
3. Production

4. Distribution and retail
5. End of life.

The definition of the five operational phases emerges from an inductive approach grounded in the literature review. It reflects the actual points of technological intervention identified across the analyzed studies, allowing for a technology-driven reading of the textile value chain. The model adopted in this study is primarily based on Gereffi and Frederick (2010) who provide a robust structural framework of the global apparel industry up to the retail phase. The structure proposed is also aligned with the lifecycle-based model proposed by United Nation Environment Program (2020), to incorporate sustainability related responsibilities beyond the point of sale, particularly those linked to environmental impacts and waste management. Hence, a proxy phase, end-of-life, was added. This extension reflects the growing relevance of the Extended Producer Responsibility (EPR) policy, which requires companies to take accountability for the environmental impacts of their products throughout the entire lifecycle, including collection, reuse, and recycling after consumer use.

The Triple Bottom Line (TBL) level of the taxonomy identifies, for each stage, the main sustainability related needs or vulnerabilities, where possible, according to the triple bottom line framework (Elkington, 1997). The weakness found in the literature review sample, are listed in Table 4:

Table 4: Main weakness identified in the literature sample

TBL framework	CODE	Weakness	Occurrences in literature
Environmental weakness	ENW1	Strong non-linearity and seasonality	4
	ENW2	Packaging	1
	ENW3	Textile waste and landfill	5
	ENW4	High Carbon footprint	8
	ENW5	High Water footprint	6
	ENW6	High Chemical footprint	6
	ENW7	High Energy consumption	6
	ENW8	Intensive use of land and raw materials	2
	ENW9	Use of unsafe materials/processes	1
	ENW10	High Green House Gases (GHG) emissions	1
	ENW11	Lack of reliable data	1
	ENW12	Incomplete/non-standardised ESG data	2
	ENW13	Lack of transparency and traceability	4
	ENW14	Waste of paper due to lack of digitalization	1
	ENW15	Waste of materials	1
Social weakness	SW1	Child labor	1
	SW2	Worker exploitation	3
	SW3	Under wage payments	2
	SW4	Health and safety issue	3
	SW5	Employment risks	1
	SW6	Fair Labour	3
	SW7	Long working hours	1
	SW8	Limited access to training	2
	SW9	Lack of transparency and traceability	7
	SW10	Information asymmetry	3
	SW11	Counterfeiting and forgery	1
	SW12	Lack of reliable data	2
	SW13	Incomplete/non-standardised ESG data	1
	SW14	Difficulty in accessing technology	1
	SW15	Dynamic market behavior	1
	SW16	Cultural and institutional resistance	2
	SW17	Lack of consumer awareness	5
Economic weakness	ECW1	Excess inventory	1
	ECW2	Missed Sales	1
	ECW3	Overproduction	9
	ECW4	Stock-outs	1
	ECW5	Environmental penalties	1
	ECW6	Product obsolescence	1
	ECW7	Price competition	1
	ECW8	High staff recruitment and training costs	1
	ECW9	High turnover and low performance	1
	ECW10	Waste of human and financial resources	1

TBL framework	CODE	Weakness	Occurrences in literature
	ECW11	Lack of transparency and traceability	6
	ECW12	Counterfeiting and forgery	1
	ECW13	Incomplete/non-standardised ESG data	2
	ECW14	High cost and time in physical prototyping	1
	ECW15	High operational and treatment costs	4
	ECW16	Lack of reliable data	4
	ECW17	Offshore production	1

The technological level synthesizes the positive impact of technologies on the three dimensions of sustainability through a visual code, answering the second research question of the study: triangle for positive contributions for the social dimension, square for positive economic impacts, and circle for environmental benefits. To ensure greater interpretive reliability and to reduce individual bias (Patton, 1999), the classifications were validated through a process of researcher triangulation. Two researchers independently reviewed the relevant studies and assigned the presence of technologies' sustainability positive impact, while a third researcher examined the coherence, facilitating their alignment.

In particular, the taxonomy is primarily intended for manufacturing firms and vertically integrated companies within the textile sector. It offers a structured dashboard to guide the adoption of technologies in response to sustainability-related vulnerabilities, enabling more targeted interventions and supporting strategic alignment with SDGs goals and regulatory compliance. By mapping the sustainability-related weaknesses identified in the literature according to the Triple Bottom Line framework, it becomes evident that these vulnerabilities are evenly distributed across the environmental, economic, and social dimensions. This widespread distribution signals not only an urgent need for greater awareness within the industry, but also a clear call for intervention by external actors, including policymakers and sustainability-focused institutions.

Among all stages of the textile value chain, the production phase emerges as the most critical, concentrating a high number of weaknesses across all three sustainability dimensions. This phase encompasses several energies- and resource-intensive subprocesses such as dyeing, printing, finishing, and cutting, which are frequently associated especially with high chemical, water, and energy consumption, greenhouse gas emissions (ENW5, ENW6, ENW7) and unsafe material use, worker health and safety concerns (SW4), high operational costs and efficiency losses (ECW15). These issues illustrate how sustainability challenges are often deeply interconnected. For instance, the excessive use of chemicals and water during the dyeing process (ENW5, ENW6) not only exacerbates environmental degradation but also creates hazardous working conditions (SW4), increases operational expenses (ECW15), and undermines long-term profitability due to regulatory penalties (ECW5). Following production, the logistics and sourcing phases also exhibit numerous weaknesses, primarily on the environmental and economic dimension, respectively. Logistics is frequently associated with excessive emissions, inefficient packaging, and waste of materials (ENW1, ENW2, ENW15), while sourcing is marked by overproduction, resource intensity, and offshore-related inefficiencies (ECW3, ENW8, ECW17).

These findings demonstrate how technological solutions must be tailored not only to specific sustainability goals, but also to the operational realities of each stage in the textile value chain.

Through the content analysis, the third level of the taxonomy was developed; the key results are then outlined.

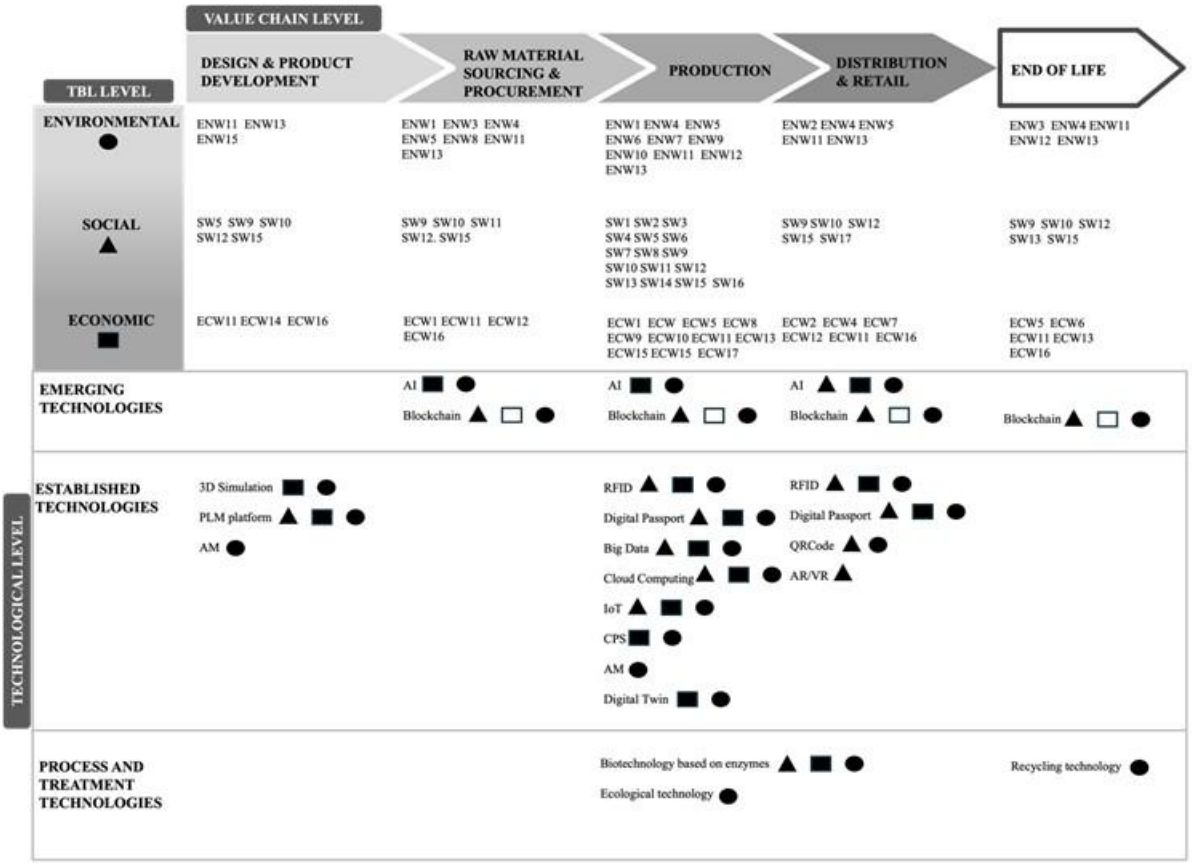


Figure 3: Multi-level taxonomy scheme proposed by the authors

Emerging technologies: AI shows a strong impact on economic and environmental sustainability. It is widely used for production planning and demand forecasting, reducing costs and eliminating overproduction and material waste (Jin and Shin, 2020; Singh, 2024). In the retail phase, it supports personalized services based on user preferences and contributes to distribution optimization and sustainable material selection (Singh, 2024). However, the social dimension remains underexplored or problematic, due to concerns over job displacement, privacy, and digital inequality (Sharma, Yadav and Chopra, 2020).

Blockchain demonstrates a more convergent impact across all three dimensions. It is employed in supplier selection for verifying sustainability certifications (Jain et al., 2022), in production for monitoring working conditions and environmental data (Munir et al., 2022), and in distribution and retail to ensure product authenticity and reduce counterfeiting costs (Jain et al., 2022). Moreover, it supports recycling facilitation and automated, transparent transactions, enhancing social equity and trust in the supply chain. Literature debates about blockchain interoperability and scalability (Chen, 2023); the empty square assigned to this technology represents the economic potential of blockchain despite its implementation costs, commonly recognized in literature.

Established technologies: IoT, Big Data, and Cloud Computing present a strongly convergent impact across all three dimensions of sustainability, with most contributions in the literature focusing on their integrated use during the production phase. From an environmental perspective, IoT and Big Data enable real-time monitoring of energy and water consumption, supporting more efficient and eco-friendly manufacturing (Park et al., 2020). Economically, these technologies contribute to process optimization, predictive maintenance, and supply chain integration, reducing operational costs and improving responsiveness (Alam and Islam, 2021). On the social dimension, they enhance transparency and traceability across the value chain and contribute to improved worker safety through advanced environmental monitoring and control systems (Irfan et al., 2020). PLM platforms support sustainability in the product development phase by enabling design, reducing waste, and ensuring environmental traceability. They enhance collaboration and transparency across teams, while economically contributing to shorter development cycles, lower costs, and faster time-to-market.

In the production and distribution phase RFID and DPP technologies show a convergent impact on sustainability by reducing waste and overproduction, optimizing inventory and logistics, improving traceability,

and supporting material-specific recycling. They also enhance transparency, prevent counterfeiting and labor exploitation, and contribute to energy savings and consumer awareness (Tolentino-Zondervan and DiVito, 2024). QR codes, primarily applied in the retail phase, support environmental and social sustainability by promoting paperless communication, enabling product traceability, and enhancing consumer awareness on sustainability aspects such as material origin and recycling options (Kutschera and Crowell, 2024).

AR/VR technologies are primarily applied in the retail phase, enhancing the shopping experience through personalization, interactivity, and emotional engagement (Hardabkhadze, 2023), so their impact is mainly social. However, their contribution to environmental or economic goals remains limited, as the creation of high-quality digital content is often resource-intensive and costly, (Choi, 2022). Conversely, 3D simulation tools, particularly employed in product design and virtual prototyping, have a strong environmental and economic relevance. They enable more sustainable product development, reducing the need for physical samples and lowering material waste, energy use, and time-to-market. In the textile sector, CPS, implemented in the production phase, are employed particularly in dyeing and finishing operations, where they enhance efficiency, resource optimization, and waste reduction (Park et al., 2020). Additive manufacturing, commonly referred to as 3D printing in the textile industry, is primarily applied in the product development stages of the textile value chain. It allows for savings, minimizing waste, and reducing the use of raw materials (Bibi et al., 2024). However, current literature highlights limitations in scalability and cost-efficiency for mass production, and social implications are underexplored. Therefore, the impact of additive manufacturing is primarily focused on the environmental dimension.

Process and treatment technologies: Bio-based enzyme technologies are applied exclusively in the production phase, offering a sustainable alternative to chemical treatments. They reduce water and energy use, limit pollution and improve product quality and production efficiency (Rahman et al., 2020; Eid and Ibrahim, 2021). Moreover, they contribute to workplace safety and public health, resulting in positive impacts across all three sustainability dimensions (Asada et al., 2020).

Electrocoagulation (EC), Moving Bed Biofilm Reactor (MBBR), and Rotating Biological Contactor (RBC), are applied in the production phase, particularly in wastewater treatment. Their environmental impact is well documented: they reduce pollution, improve water quality, enable water reuse, and lower carbon and greenhouse gas emissions (Agarwal and Singh, 2022). However, their economic and social impacts are more nuanced. From a social perspective, MBR and RBC are more widely accepted in the industry, while MBBR and EC face resistance due to limited technical awareness. Economically, MBBR is cost-effective, but EC involves high operational costs linked to energy and chemical use. These findings suggest strong environmental benefits and potential trade-offs in the economic and social dimensions.

Recycling technologies are applied in the end-of life phase, and offer clear environmental benefits, including reduced resource use, lower emissions, and improved wastewater management. However, trade-offs emerge in the economic and social dimensions. Mechanical recycling is cost-effective and labor-intensive but may involve informal work and quality issues. Chemical recycling supports skilled employment but raises safety and investment concerns. Energy recycling valorizes waste but depends on subsidies and may face social resistance (Ribul et al., 2021). Overall, these technologies show strong environmental impact with partial and contested effects on the economic and social fronts.

4 Conclusion

The review highlights a rapidly evolving yet fragmented landscape, where the interplay between technology and sustainability is explored in siloed ways. While a wide range of technologies has been identified, their contribution to the triple bottom line, encompassing environmental, economic, and social dimensions, reveals highly differentiated patterns. Only a limited number of technologies demonstrate a convergent impact across all three dimensions. Notably, Blockchain and integrated data-driven technologies exhibit the strongest alignment. Overall, the findings suggest that technological convergence across the three pillars of sustainability remains the exception rather than the norm. This reinforces the idea that technology alone is not a sufficient condition for sustainable transformation. Its effectiveness depends on the presence of enabling conditions, including governance frameworks, regulatory environments, inter-organizational collaboration, and capacity-building mechanisms that can support equitable and systemic adoption.

5 Limitation and Future Development

As with all systematic literature reviews, this study is subject to several methodological limitations. First, the review may suffer from selection bias, both in terms of the literature sample and the coding of sustainability impacts associated with each technology. Despite efforts to ensure triangulation, the classification of impacts

reflects a degree of interpretative subjectivity. Second, the fragmentation of the literature, combined with the increasing complexity of integrated technological systems, makes it difficult to isolate the effects of individual technologies, particularly when they are adopted in bundles. This reduces the generalizability of findings and complicates cross-comparative analysis. Moreover, the textile value chain model adopted to map the industry's weaknesses may not fully encompass all the critical stages and could therefore be further extended. Future research should consider the development of a structured weakness–technology matrix, to map technologies contribution to each dimension of sustainability and what kind of weakness they mitigate. Such a tool would improve comparability for evaluating technologies. Furthermore, more attention should be devoted to emerging technologies, which are rapidly gaining traction in both research and practice, yet their social sustainability impacts remain highly ambiguous due to the lack of standardized metrics (Singh, 2024). Quantitative approaches should be employed to evaluate the economic and reputational benefits associated with the adoption of emerging technologies (Sharma, Yadav and Chopra, 2020; Chen, 2023) and longitudinal studies could provide deeper insight about organizational resilience and sustainability in the long term. Lastly, while most studies focus on the central stages of the value chain, such as production, sourcing, and logistics, the end-of-life phase and circular design practices remain underexplored. This highlights the need to investigate how technologies can support recyclability, product modularity, and lifecycle extension.

6 Ethics declaration

This research is based on secondary data from published sources.

7 AI declaration

AI tool was used for minor linguistic refinement.

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Big Data Technology Maturity Model: Exploring User Perceptions

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Abstract

Big data technologies are fundamental in managing large volumes of data and transforming data into information. However, the mere availability of technological resources is not sufficient to extract meaningful insights. The maturity of these technologies and users' perceptions of their use play a crucial role in determining their potential for value creation. This study proposes a maturity model that integrates both the technological maturity perceived by users and users' own maturity in utilizing these tools. Focusing on three major cloud-based services for big data, namely Google Cloud Platform, Amazon Web Services, and Microsoft Azure, the research explores user perceptions regarding the capabilities and usability of these platforms in supporting big data initiatives. The research methodology involved the design of a structured questionnaire aimed at investigating two main constructs: “Technological Maturity”, referring to the extent to which the technology meets user needs; “User Maturity”, concerning users' competence, awareness, and confidence in utilizing the investigated platforms. The questionnaire was administered to big data professionals, who were asked to evaluate one or more technologies based on their own experience. The analysis revealed significant trends, including a general increase in perceived technological maturity with growing user experience, and a non-linear relationship between experience and user maturity. The high number of "Don't know" responses among less experienced participants, and their decrease among more experienced users, highlights a progressive increase in self-awareness and knowledge acquisition over time. Notably, evidence of the “Dunning-Kruger” effect emerged, indicating that less experienced users tend to overestimate their abilities. This research proposes an innovative framework for assessing technological maturity in the big data context. The model not only enhances academic understanding but also offers practical guidance for organizations in the selection, adoption, and integration of cloud technologies, while supporting effective strategies for internal skills development. The findings underscore the importance of considering, alongside technological characteristics, human factors related to perception and usability of the adopted technologies.

Keywords: big data, data analytics, cloud services, maturity model

Paper type: Academic Research Paper

1 Introduction

In the context of big data initiatives, the technologies adopted represent a critical factor for the effective implementation and scalability of projects. Big data technologies, indeed, form the backbone of the entire information ecosystem (Cavanillas, et al., 2016). Numerous studies have focused on identifying the technologies employed at the various stages of the data value chain, as well as analysing their evolution over time (Hu, et al., 2014).

However, the mere availability of advanced technologies is not sufficient to ensure the successful implementation of big data initiatives. It is essential that these technologies reach an adequate level of maturity to truly support organisational initiatives. In fact, technological immaturity has been recognised as one of the main barriers to the adoption of big data (Ylijoki & Porras, 2019).

In this context, for instance, monolithic architectures such as information silos have proven to be inadequate for the management and preservation of data within modern big data ecosystems (Ylijoki & Porras, 2019) (Bärenfänger, et al., 2014) (Fast, et al., 2021).

The relevance of awareness regarding limitations of a technology and their potential impact on organisations also enables the identification of objectives within big data initiatives that remain out of reach due to technologies that are insufficiently mature or appropriate (Huang, et al., 2015). Consequently, alongside internal resources and capabilities, organisations are required to make informed decisions concerning the infrastructure or big data platforms they adopt for analytics purposes. While new organisations may design or adopt platforms specifically tailored to their needs, established organisations with legacy IT systems are often compelled to integrate their existing infrastructures with modern big data platforms available on the market. Such integration can introduce challenges related to compatibility and coexistence between heterogeneous infrastructures, as well as adoption, integration, and maintenance costs. These challenges are commonly recognised as technological barriers in the context of big data initiatives (Alharthi, et al., 2017).

Technological maturity thus emerges as a strategic and independent factor within the decision-making process accompanying the implementation of big data solutions. A technology that is insufficiently mature may hinder value creation, just as a technically ready technology that is poorly perceived or insufficiently understood by users may fail to be fully exploited.

This research aims to develop a maturity model grounded in the analysis of responses from a questionnaire submitted to domain experts, focusing on three cloud service technologies within the big data context. The model aims to explore two key macro-dimensions:

- Perceived technological maturity: the ability of the investigated cloud service to effectively support value creation processes from big data, considering reliability, scalability, and performance relative to project objectives.
- User awareness and maturity: the level of user expertise, awareness, and ability to interact with these technologies in big data-related activities.

The research seeks to address the following research questions (RQs):

- *RQ1: What is the perceived level of technological maturity of cloud service in supporting big data-driven processes?*
- *RQ2: To what extent are users aware of, and prepared to leverage, these technologies to maximize their potential value?*

This study aims to bridge a gap in the existing literature by providing a model that examines both technological maturity and the cognitive biases of respondents in evaluating and self-assessing these technologies. The findings will offer valuable insights for both academics and practitioners, guiding strategies for technological improvement and skill development while enhancing organizations' awareness of their own resources and human capital.

2 Theoretical Background

Maturity models are strategic tools that organisations adopt to plan the continuous development of their capabilities (Ahern, et al., 2004), to study their own business, or to benchmark it against other organisations with similar characteristics (Mettler, et al., 2010). The primary objective of maturity models is to identify the level of maturity of a given situation, highlighting specific gaps within a particular focus area and determining how these may be addressed. The term maturity implies a change in capabilities and/or objectives from an as-is state to a to-be state (Corallo, et al., 2023).

The concept of technological maturity has been addressed across various domains. However, in the context of big data, structured and context-independent analyses remain relatively underdeveloped. Literature often tends to place greater emphasis on organisational maturity or on the development of organisational competencies, whereas the intrinsic maturity of technologies has received less systematic attention. Outside the big data domain, Till (Till, 2016) offers a comprehensive and structured analysis of technological maturity, highlighting three key aspects:

1. Timing represents a critical factor in technological investments, as adopting a technology either too early or too late may undermine competitive advantage.
2. The assessment of technological maturity is not a straightforward process: although experts often possess in-depth knowledge of individual technologies, a comparative and systemic perspective is frequently lacking.
3. Many evaluations rely on theoretical descriptions or subjective perceptions, highlighting the absence of an objective, standardised, and efficient measurement system.

Within the big data domain, one of the models explicitly oriented towards the evaluation of technologies is the *Maturity Model for Big Data Solutions* (Boncea, et al., 2017). This model investigates both *technical maturity* (development status, support libraries, guidelines and documentation, cross-platform support, professional certification) and *business maturity* (market usage, cloud computing support, licensing policy, enterprise support). The model was applied to assess the maturity of five different technologies associated with the big data context. The objective of the analysis was to support organisations in identifying the solutions most suited to their needs by developing a concept of maturity articulated across multiple dimensions. Relevant factors include: the current development status of the technology, the frequency of major and minor version releases, the average time to resolve issues, the availability of support libraries, the presence of comprehensive guidelines and installation documentation, and compatibility with major operating systems. Despite its descriptive completeness, the model appears limited in integrating the direct experience of users and the perceptions of experts, elements that are crucial for understanding the actual readiness of a technology. General characteristics such as *scalability, flexibility,* or *cloud compatibility* are necessary but not sufficient conditions for value

generation (Vitari & Raguseo, 2020). The way in which these features are perceived and utilised can vary significantly.

An equally significant contribution in the literature is the *Big Data Maturity Model (BDMM)* (Comuzzi & Patel, 2016), which aims to support organisations in realising the value generated by big data.

The BDMM is structured as a hierarchical framework articulated across six maturity levels (from 0 to 5) and five main domains: *Strategic Alignment, Organisation, Governance, Data, and Information Technology*. Each domain is further subdivided into sub-dimensions (such as *Strategy, Processes, People, Culture*), making the model comprehensive and multidimensional. The assignment of maturity levels is performed directly based on qualitative descriptions associated with each level, without the use of separate numerical rating scales. This approach differs from that adopted in other maturity models, where assessments are sometimes collected through broader numerical scales (e.g., from 0 to 9) and subsequently aggregated into a smaller number of synthesised maturity levels (e.g., from "not ready" to "leader") (Paulk, et al., 1991). Developed through a qualitative approach, the BDMM was evaluated through a domain expert evaluation and a practical settings evaluation, by implementing the model in three real-world organisations.

Further investigations are required to pave the way for the development of models that go beyond the assessment of technical and market-related characteristics, integrating instead the subjective perceptions of experts and users. A new model should be capable of distinguishing between actual technological maturity and maturity potentially influenced by the cognitive or interpretative peculiarities of the evaluators. The model should also be applicable in a transversal and context-independent manner, in order to produce assessments that are as objective and generalisable as possible. Another critical element concerns the distinction between the immaturity of the technology itself and the immaturity of the evaluator. Expert-based assessments can indeed be influenced by biases, personal experiences, or partial knowledge. Therefore, an effective technological maturity model should ideally be able to address both aspects, accounting for the cognitive and perceptual factors associated with the actors involved in the evaluation processes. Building on these considerations, this research proposes a new technological maturity model that integrates the assessment of big data technology maturity with the corresponding perceptions and maturity in use by both users and experts.

3 Methodology

The proposed maturity model, the *Technology and User Maturity Model* (TUMM), was designed to assess technological maturity across two fundamental constructs: the capability of the technology to fulfil its intended functions and meet user needs; the users' perception and competence in effectively adopting and utilizing the technology. To measure both constructs, a structured survey instrument was developed in the form of a questionnaire, organized into two main sections: *Technological Maturity* and *User Maturity*.

The *Technological Maturity* section aims to assess the perceived level of maturity regarding various characteristics of the examined technologies. This section consists of 28 items, grouped into thematic subsections covering six specific domains: functionality, user experience, security, flexibility, interoperability, and costs. The objective is to obtain a multi-level evaluation capable of providing a comprehensive and comparable overview across different technological solutions.

The *User Maturity* section, on the other hand, focuses on analysing users' awareness, preparedness, and autonomy in interacting with the technologies under study, within the context of big data initiatives. This section comprises 9 items focusing on three main aspects: training received, previous experience, and confidence level in using the technologies.

The questionnaire items were designed to explore the dimensions of analysis from multiple perspectives, ensuring broad conceptual coverage consistent with the research objectives. The preliminary version of the instrument was reviewed by a focus group of industry experts, whose feedback contributed to refining the question formulations, improving clarity, relevance, and content validity. Each question uses a five-point Likert scale to collect qualitative judgments suitable for quantitative analysis. Additionally, a "*Don't know*" response option was included, allowing respondents to abstain when they lacked sufficient knowledge or direct experience on the topic. This methodological choice acknowledges the importance of self-awareness regarding one’s knowledge level, as it constitutes a relevant element of the investigation and is related to both research questions.

The technologies analysed in the questionnaire include three of the most widely used cloud service platforms (Chauhan, 2020): *Google Cloud Platform* (GCP), *Amazon Web Services* (AWS), and *Microsoft Azure*. Accordingly, the investigation was focused on the cloud services ecosystem, considering these platforms as benchmarks for assessing technological maturity. Furthermore, to broaden the comparative scope of the analysis, respondents

were offered the opportunity to indicate a fourth technology of their choice, enabling a more comprehensive benchmark. The questionnaire was administered to a representative sample of professionals working in organizations varying in size and industry sector. Participant selection was based on relevance criteria, prioritizing profiles with technical or managerial roles and ensuring sample diversity to achieve high representativeness of the results.

At the beginning of the questionnaire, participants were asked to indicate the technologies for which they intended to provide evaluations, based on their direct experience and familiarity. This approach ensured the collection of relevant and reliable data, as each respondent provided assessments only for technologies they had interacted with directly. Consequently, not all participants completed all sections related to each technology. Rather, they answered only for those technologies with which they had sufficient knowledge, in line with the informed self-selection approach adopted in the study's methodological design.

4 Results

The results and analyses presented in this section are based on the responses collected from an initial sample of 100 participants who completed the questionnaire. The survey is currently still being administered and remains available online for further completion. The distribution of responses is reported in the table below.

Table 1: Summary of questionnaire responses

Respondent breakdown by technology	
Number of responses for Azure	35
Number of responses for GCP	50
Number of responses for AWS	44
Number of responses for other technologies	72
Number of responses indicating no specific technology	43
Total number of responses	202
Total number of respondents	100

To conduct the analyses, the collected responses were aggregated and analysed by calculating the mean scores, categorized by professional seniority classes. The objective was to examine both the perception of technological maturity and users' perceived maturity regarding their own competencies. This approach allows for the observation of potential evolutionary trends over time, by relating work experience to the evaluation of technologies. In parallel, the frequency of "Don't know" (DK) responses provided in the questionnaires was also analysed, similarly categorized by years of experience, in order to investigate the level of declared awareness and its variation as a function of professional seniority. The results of these analyses are summarized in Table 2 and Table 3.

Table 2: Average scores of responses divided by years of experience

Cloud Platform	**Maturity**	**EXP < 1**	**1≤EXP<2**	**2≤EXP<3**	**3≤EXP<4**	**4≤EXP<5**	**EXP≥5**	**EXP NA**	**TOT**
GCP	TM	3,11	3,52	3,63	3,23	4,19	3,84	3,28	3,53
	UM	2,42	2,96	3,31	2,31	3,14	2,98	1,62	2,67
AWS	TM	3,02	3,32	2,90	3,43	4,19	3,94	2,39	3,42
	UM	2,67	3,19	3,23	1,69	3,41	2,96	1,87	2,86
Azure	TM	3,04	3,62	2,59	3,71	4,14	3,79	2,49	3,44
	UM	2,22	2,84	3,25	2,71	3,19	2,48	1,47	2,44
Other Cloud Platform	TM	3,36	3,63	2,77	3,55	3,02	3,56	3,06	3,31
	UM	2,42	3,41	3,13	2,42	3,50	3,07	2,97	2,90

The variable *EXP* represents the number of years of professional experience declared by the respondent. Segmentation was performed on an annual basis for the first five years, while participants with longer professional experience were grouped into a single category labelled "more than 5 years". The label *EXP NA* (Not Available) refers to responses where the participant chose not to disclose their seniority in the field. *TM* (Technological Maturity) refers to the average evaluation of the technology in fulfilling the functions for which it was designed, as assessed by the respondents. *UM* (User Maturity) indicates the respondent's average evaluation in using the technology in question.

The analysis of the mean scores for technological maturity and user maturity, divided by experience classes, reveals several interesting trends. Regarding TM, a progressive increase in the average score is observed across rising experience levels, with notable peaks in the "4≤EXP<5" category for all major platforms (e.g., 4,19 for GCP and AWS, 4,14 for Azure). This trend suggests that professional experience may enhance positive perceptions of the technologies' ability to fulfil their intended functions. However, this growth stabilizes or slightly declines in the "EXP≥5" category, possibly indicating a more critical and perhaps more informed perspective among more experienced users.

As for UM, a less linear trend is observed. Although in some cases there is an increase in perceived user maturity up to the third year of experience, the scores become more variable in the subsequent categories. In particular, perceived user maturity tends to decrease among groups with greater seniority (e.g., Azure: UM=2,48 for EXP≥5), suggesting a possible discrepancy between initial confidence and awareness developed over time. Moreover, the significantly lower UM scores among respondents who did not indicate their experience (EXP NA) may reflect uncertainty or lower familiarity with the technologies.

Table 3: Number of “Don't know” responses divided by years of experience

Cloud Platform	**EXP < 1**	**1≤EXP<2**	**2≤EXP<3**	**3≤EXP<4**	**4≤EXP<5**	**EXP≥5**	**EXP NA**	**TOT**
GCP	127/392	32/280	15/112	0/56	19/140	19/252	41/168	253/1400
AWS	88/336	15/280	7/56	0/56	7/112	41/308	13/84	171/1232
Azure	69/308	57/252	1/28	0/28	0/56	24/252	13/56	164/980
Other Cloud Platform	167/588	24/224	0/112	0/84	0/84	32/364	154/560	377/2016

Table 3 highlights the distribution of "Don't know" (DK) responses in the questionnaires, calculated as the ratio between the number of DK responses and the total number of items. Once again, a clear relationship with the level of experience emerges. In the lower experience groups (EXP<1 and 1≤EXP<2), the proportion of DK responses is significantly higher across all platforms, reaching extreme values such as 167/588 for “Other Cloud Platforms”, indicating lower familiarity and confidence in evaluating technological maturity. Conversely, in groups with greater professional experience (3≤EXP<4, 4≤EXP<5, EXP≥5), DK responses tend to disappear or decrease drastically, suggesting a greater mastery and confidence in the evaluated topics.

However, a notable exception is represented by the EXP NA category, which shows high percentages of DK responses, particularly for “Other Cloud Platforms” (154/560), suggesting that uncertainty in declaring professional experience is also reflected in the ability to evaluate the technologies. This supports the hypothesis that the omission of experience information may serve as an indirect indicator of lower perceived maturity.

The combined results from the two tables suggest the possible presence of the *Dunning-Kruger effect* (Kruger & Dunning, 1999), a psychological phenomenon whereby individuals with limited competence tend to overestimate their abilities. Specifically, within the lower experience groups (especially EXP<1 and 1≤EXP<2), relatively high UM values are observed alongside a high number of DK responses and a moderate perception of TM. This pattern may indicate an initial overconfidence among less experienced users. In contrast, respondents with higher levels of experience (EXP≥5) tend to express more moderate self-assessments of their maturity (UM), despite possessing higher knowledge levels and providing fewer DK responses, suggesting a greater critical awareness. This trend supports the hypothesis that self-assessment accuracy tends to improve with increasing competence, consistent with the Dunning-Kruger model.

5 Conclusions

This study introduced a maturity model for evaluating the effectiveness and readiness of cloud-based big data technologies. By examining both technological maturity and user maturity, the model provides a comprehensive view of the conditions necessary for successful implementation and value generation in big data initiatives. The model offers a complete framework that recognizes not only the functional capabilities of technologies but also users' awareness, confidence, and experiential knowledge. This dual-level perspective is essential for understanding the true success of adoption and value creation in complex data ecosystems.

Empirical results show that the perception of technological maturity tends to increase with professional experience, suggesting that exposure and practice enhance appreciation for the robustness and utility of the technology. In contrast, user maturity follows a less predictable trajectory, often peaking during the early stages of experience and then declining, likely due to a growing awareness of one's limitations. This trend aligns with the Dunning-Kruger hypothesis and highlights the importance of targeted training and ongoing competence

assessment in big data environments. The marked disparity between TM and UM scores also underscores the risk of underutilizing mature technologies due to insufficient user competence or confidence.

The proposed model provides organizations with an operational tool to assess readiness from both a technical and a human perspective. Professionals can use this framework to identify skills gaps and strategically design enhancement programs. Additionally, technology providers can benefit from insights into how their tools are perceived in terms of usability, reliability, and support, fostering more user-centered innovation. This research addresses the growing need for integrated maturity assessments that go beyond infrastructure metrics, offering a valuable foundation for both academic inquiry and practical application. As organizations increasingly rely on big data to gain strategic advantages, tools that balance technological and human factors will become essential for sustainable digital innovation.

Future research could pursue three main directions. First, expanding the dataset across different industry sectors and geographic regions would enhance the generalizability of the findings. Second, a longitudinal approach could help assess how maturity perceptions evolve alongside digital transformation and training initiatives. Third, a deeper analysis of the cognitive biases affecting self-assessment could refine the UM dimension and offer even more personalized development pathways for users.

6 Ethics Declaration

This research did not involve any human participants, animals, or sensitive data requiring ethical approval. Therefore, ethical clearance was not required for the work presented in this paper.

7 AI declaration

During the preparation of this manuscript, the author(s) employed generative AI tools to enhance the language and clarity of the text. All content was subsequently reviewed and revised by the author(s), who assume full responsibility for the final version of the publication.

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Key Factors for Leveraging and Capitalizing Digital Transformation Initiatives in Industrial Landscape

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Abstract

Industrial organizations are increasingly investing in technology and digital transformation (DT) initiatives to enhance their digital maturity and achieve sustainable growth within VUCA markets. However, the potential benefits of these investments vary depending on the company's level of technological maturity. Higher maturity generally provides better positions to implement DT strategies and maximize their return on investment (ROI). However, due to the inherent complexity of DT initiatives, many organizations struggle to determine the most effective investment paths and align them with strategic objectives. ROI in DT is multifaceted and not limited to financial outcomes. Economic advantages can come from specific strategic and operational actions.

Digital Transformation Maturity Models (DTMMs) are proposed in literature for assessing and measuring, based on specific dimensions and factors, the business readiness in managing DT investments. Despite DTMMs are widely discussed in literature, none of them refers to ROI concept. Addressing this research gap, through a Systematic Literature Review, the study aims to explore the relationship between DT maturity and ROI and to identify the key factors facilitating the implementation of specific actions for gathering high ROI. Based on 35 DTMMs, the paper identifies 51 key factors that influence successful DT implementation and capitalization. These factors are grouped into four dimensions: People, Organization & Culture, Information & Technology, and Operations. Furthermore, through the interaction of an IT company, the study provides an original framework matching all factors with specific forms of ROI. The framework represents a valuable indication for companies to shape their digital strategies, consider DT investments, and generate meaningful ROI.

Keywords: Digital Transformation, Maturity, Return on Investment, Industry

Paper type: Academic Research Paper

1 Introduction

Modern industries are interested in investing in Information Technology (IT) and Digital Transformation (DT) initiatives to improve their business performance and maintain a sustainable development (Teng et al., 2022). However, the value coming from these investment is closely tied to an organizations' level of technological maturity (Corallo et al., 2023a). Maturity implies evolutionary progress from an initial stage to a desired final stage (De Bruin et al., 2005). Due to the complexity of DT initiatives, companies often faces challenges in considering the right investment and aligning with strategic goals (Zhang, 2024). Moreover, the ROI can be considered not only in financial terms, but also from indirect strategic and operational actions.

Companies need to be supported by reference frameworks to understand their technological maturity and assist successful choices for DT projects implementation. In these regards, Maturity Models (MM) come as useful tools for measuring and evaluating organization's abilities or for planning a continuous improvement (Paulk et al., 1993). MMs include a set of dimensions and factors based on which companies' maturity can be assessed. Generally, the ability of a company to gain high ROIs depends on high levels of maturity (Jardak and Ben Hamad, 2022). Although in the short-term financial performance may be negative due to companies settling and adaptation, mature companies better achieve long-term ROI.

On top of this context, this paper aims to identify and analyze the most important factors that companies need to consider for leveraging and capitalizing DT initiatives. Specific factors can support companies in accurate shape actions and gather high ROI. Digital Transformation Maturity Models (DTMMs) are widely discussed in literature such as (Gökalp and Martinez, 2021), (Vuksanović Herceg et al., 2020), but none of them considers the ROI concept. Based on a Systematic Literature Review (SLR), the paper investigates the relationship between maturity and ROI. The paper intends to identify key factors in charge of providing industrial companies with ROI, trying to provide an answer to the following research question: what factors can be considered in supporting the evaluation of DT initiatives and capitalizing on them? Based on 35 DTMMs available in literature, 4 key dimensions emerged: People, Organization & Culture, Information & Technology, and Operations. Also, 51 elements were identified as key factors to consider in DT initiatives.

Supported by an IT company, through diverse focus groups, the study proposes an original framework linking maturity factors to different forms of ROI. The framework offers both theoretical insights and practical guidance for companies seeking to capitalize on DT initiatives through specific actions.

2 Background

2.1 Maturity Model

MMs have gained success in the information systems and management fields with several framework developed by both practitioners and academics over the years (Mettler, 2011). MMs were introduced in literature to assess the maturity of capabilities, often tailored to areas like information and communication technologies (ICT) (Becker et al., 2009). The first MM, named Capability Maturity Model (CMM), introduced by the Software Engineering Institute in 1987, represents a reference framework defining five stages of development process maturity (Paulk et al., 1993). Since its introduction, diverse models emerged across various domains such as IT and business processes (De Bruin et al., 2005).

MMs serve as strategic tools for self-assessment or evaluation by third parties or comparison with others or for guiding improvement plans within organizations (Paulk et al., 1993). The concept of "maturity" can be generally defined as "the state of being complete, perfect or ready" in terms of ability, competence in a specific domain with respect to a predefined set of criteria. Maturity generally denotes evolutionary progress in demonstrating a specific skill or accomplishing a goal. MMs can focus on specific targets such as process, objects, people or their holistic combination as maturity of these elements influences each other. Moreover, MMs can be categorized by purpose into descriptive (for assessing current state), prescriptive (for guiding improvement), and comparative (for benchmarking across organizations). MMs can also be categorized based on their structure, from simple maturity grids and Likert-style questionnaires to more complex CMM-like frameworks with defined goals and practices.

MMs in the technological domain can be analyzed by general, design, and usage attributes to describe the maturity target (process, object, people) in terms of evaluation approach and data collection, model reliability and mutability over time. Indeed, reliability, mutability, and application methods are considered key characteristics influencing the effectiveness and reusability of MMs. Reliability refers to verification (ensuring the model aligns with its design) and validation (ensuring real-world relevance). Mutability concerns how well the model adapts over time to evolving technologies or environments. Usage attributes relate to how models are applied such as for self-assessment. Supporting materials can be provided as assistance through manuals or software tools. Finally, MMs differ in the depth of recommendations, from general guidance to explicit actions (Mettler, 2011).

2.2 Return on Investment

ROI commonly refers to a financial indicator defined as the amount of money that is recovered from a given investment. It supports decision-making processes to avoid financial losses due to bad investments, guiding companies in evaluating expenses and financial returns (Smith, 2024). ROI is indeed often used as an estimation of financial returns over the year. Generally, it follows a positive trend over the years, even though, in some cases, it can be negative due to bad financial navigation.

Different factors can trigger the nature of ROI, particularly in VUCA markets characterized by volatility, uncertainty, complexity, and ambiguity (Kaivo-oja and Lauraeus, 2018). The traditional view suggests a positive relationship between market volatility and expected returns. The presence of ambiguity can alter this relationship, and investor attitudes optimism or pessimism. Uncertainty, especially when related to information quality, can weaken or reverse the expected positive link between volatility and returns. High uncertainty can decrease expected returns, and strategies mitigating risk exposure can generate higher risky ROI. Both ambiguity and uncertainty can reduce the effectiveness of traditional ROI models. High complexity also increases the challenges in modeling volatility and uncertainty, complicating accurate ROI estimation and risk management (So et al., 2022).

Moreover, time plays a crucial role in positive ROI, since ROI is estimated from a short to a long period. Similarly, timing of investments is crucial, as the value of waiting or accelerating can be significant (Carruth et al., 2000). Furthermore, the relationship between risks and return is fundamental, with riskier assets typically offering higher potential returns (Capiński and Kopp, 2014). Policy heterogeneity and geopolitical risks can also negatively impact returns, although investors may be compensated with a premium when prices rebound after periods of high uncertainty.

Although companies often refer to ROI from an economic perspective, this return can be triggered by different strategical and operational actions. According to (Jardak and Ben Hamad, 2022), ROI is closely linked with the maturity level of organizations in managing investments and leveraging opportunities. Higher maturity is generally linked to better long-term ROI, but short-term financial performance may initially decline as companies invest and adapt. The ability to measure, realize, and sustain ROI improves as companies develop more mature processes and frameworks for managing financial decisions. Companies with mature digital or project management levels are better equipped to realize both financial and non-financial benefits (Kwak and Ibbs, 2000). Less mature companies often struggle with fragmented data, unclear objectives, and undervaluation of intangible benefits, making ROI harder to assess and realize.

3 Research Methodology

This study is based on a SLR, a rigorous and transparent research approach allowing for a comprehensive and objective investigation of research studies. Based on the SLR protocol of (Corallo *et al.*, 2023), the review was structured in four steps.

Step1: review planning – The SLR aims to investigate the relationship between business maturity and the ability to extract value from DT investments. The paper attempts to provide an answer to the following research question: what factors can be considered in supporting the evaluation of DT initiatives and capitalize on them?

To achieve this goal, Scopus was considered as reference scientific databases. Appropriate keywords were included for the query design: “digital transformation”, “digit*”, “maturity model”, “industry 4.0”, “I4.0”, “industry 5.0”, “I5.0”, “manufacturing”, “return on investment”, “ROI”.

However, after a first attempt to query Scopus with an accurate combination of such keywords, no results were retrieved. This testifies the need to refine the query as well as the innovativeness of the research focused on the integration of topics unexplored before in literature. Therefore, two separate queries were designed:

- Q1: “digital transformation” OR “digit*” AND “maturity model” AND “industry 4.0” OR “I4.0” OR “industry 5.0” OR “I5.0” OR “manufacturing”.
- Q2: “digital transformation” OR “digit*” AND “industry 4.0” OR “I4.0” OR “industry 5.0” OR “I5.0” OR “manufacturing” AND “return on investment” OR “ROI”.

While Q1 aims to collect insights on DTMMs in the industrial landscape and to focus on key factors, Q2 focuses on understanding how ROI is discussed in DT initiatives.

Keywords were searched for their occurrence within title, abstract and keywords of resulting papers. Additionally, selection criteria were defined for the eligibility of papers for including only relevant studies: paper written in English; papers published in international journals; papers belonging to subject areas like Business Management and Accounting, Engineering, Computer Science, and Decision Science.

Step2: review execution – The search process was implemented in January 2025. Considering Q1, starting from 260 papers, the application of filters led to refine the sample to 94 papers. Considering Q2, from 37 papers, only 15 were retained due to filtering. No duplicated papers were returned.

Step3: analysis – A preliminary analysis was first conducted based on title and abstract relevance and pertinence. Considering Q1, up to 94 papers only 60 were retained. Considering Q2, up to 15 papers only 10 were retained. Secondly, a qualitative full content analysis was executed. This process led to confirming the 60 papers of Q1 and only 9 papers of Q2. A structured approach was used to identify and select key information related not only to bibliometric information, but to dimensions and factors considered in DTMMs, as well as forms of ROI in charge of providing economic benefits for industries.

Step4: reporting – The results of the analysis are presented in Section 4.1 (Q1) and Section 4.2 (Q2).

4 State of the art

4.1 Maturity Models in Industrial Digital Transformation

Based on the analysis of papers coming from Q1, up to 60 papers, 35 MMs were retrieved, able to assess companies’ maturity in the field of DT.

Table 1. Comparative summary of DTMMs

MMs' Reference	Objective	Dimensions	Design Focus
(Ahn et al., 2024)	Measuring automated production management and manufacturing processes for future smart factories.	• Production • Manufacturing	people
(Gallego-García et al., 2022)	Driving continuous improvement for specific applications such as Additive Manufacturing (AM) or virtual reality.	• Adaptive robotics • CPS • AM • Cloud technologies • Virtualization technologies • Simulation • Data analytics&AI • Communication & networking • RFID • Cybersecurity • Sensors&actuators • Mobile technologies	process
(Vuksanović Herceg et al., 2020), (Han et al., 2022)	Examining DT in manufacturing firms, highlighting I4.0's contribution across the sustainability dimensions.	• Customer • Strategy • Technology • Operations • Organization&Culture	process, people
	Identifying weaknesses and improvement strategies.	• Top-level design • Infrastructure • Cost consultation business process • Professional management • Comprehensive integration • Digital cost performance	
(Gökalp and Martinez, 2021),(Gökalp and Martinez, 2022)	Assisting organizations based on SPICE model (ISO/IEC 3300xx) to evaluate their digital readiness, identify capability gaps, and create roadmaps for DT.	• Strategic governance • ICT • Digital process transformation • Workforce management	
(Colli et al., 2019)	Assessing the digital readiness across three case studies of Danish companies in different industrial sectors.	• Governance • Technology • Connectivity • Value Creation • Competences	
(Voss et al., 2024)	Assessing the digital readiness of a project in a large construction company.	• Digital tools • Digital skills • Digital business Organization • Digital business culture • Leader responsibility	
(Szelągowski and Berniak-Woźny, 2022)	Assessing the current maturity of BPM into modern business by using the CMM.	• Strategic alignment • Governance • Method • ICT • People • Culture	
(Alcácer et al., 2021)	Assessing how companies perceive barriers to adopting I4.0 based on their current level of awareness.	• Smart factory • Smart operation • Employees • Smart Products • Data driven service • Strategy&Organization	
(K. Buntak et al., 2021)	Providing a comprehensive framework to assess the level of DT within supply chain processes.	• Technology adoption • Process integration • Data analysis capabilities • Organizational readiness for digital solutions	
(Barbalho and Dantas, 2021)	Analyzing how I4.0 can have a positive impact on business processes and develop strategies to progress further.	• Products&Services • Manufacturing & Operations • Business model • Supply chain • Legal considerations • Strategy&Organization	
(M.I. Shqair and Altarazi, 2022)	Assessing the measures of readiness and maturity in Jordanian SMEs for the I4.0 paradigm implementation.	• Big data and analytics • Autonomous robots • Simulation • Horizontal & vertical integration • Cybersecurity • Cloud • AM • Augmented reality • Industrial IoT	
(Santos and Martinho, 2019)	Implementing actions related to the specific process area "Organizational Process Focus" by leveraging fuzzy logic method.	• Organizational strategy, structure and culture • Workforces • Smart Factories • Smart Processes • Smart Products and Services	
(Guerrero et al., 2023)	Evaluating the maturity of companies operating in the personal services sector to assess their DT.	• Customer centricity • Strategy & Leadership • Product&Services • Process&Organization • Technology	
(Chen et al., 2022)	Representing the impact between DT criteria through the weight of some indicators.	• Strategy • Organization & People • IT • Process and management • Integration • Innovation	
(Ali et al., 2024),	Helping firms in measuring AI methods in different I4.0 sectors.		

MMs' Reference	Objective	Dimensions	Design Focus
(Chaves Franz et al., 2024)	Managing the technologies development considering both internal and external business issues.	• Smart Manufacturing • Smart Working • Smart Supply Chain • Smart Products	
(Tubis et al., 2024)	Assessing digital maturity in logistics processes.	• Process management • Performance measurement • Employees • Technology	
(Treviño-Elizondo and García-Reyes, 2023)	Providing a roadmap for workforce development through Delphi method.	• Personal Competence • Socio communicative competence • Problem-Solving Competence • Activity-related Competence	process, object
(Dikhanbayeva et al., 2020)	Facilitating successful DT of companies based on the most important I4.0 principles for a well-designed development strategy.	• Interoperability • Virtualization • Decentralization • Real-time capability • Service orientation • Modularity • Smart products • Corporate social responsibility	
(De Paula Ferreira et al., 2022), (Bastos et al., 2021)	Developing a roadmap to reduce risks in I4.0 initiatives requiring large financial resources and relevant changes.	• Strategy & Organization • Smart factory • Smart Operation • Smart products • Data driven services • Employee	product, people
	Calculating the readiness and the technological level of companies in I4.0 context.	• Hierarchy Axis • Lifecycle Axis • Layer Axis	process, people, object
(Yan et al., 2021)	Guiding business decision-makers to understand current state and achieve DT.	• Strategy • Process • Resources • Performance • Capability	
(Amaral and Peças, 2021)	Facilitating the integration of companies in I4.0 revolution from a sustainable perspective.	• Technology • Production Processes • People • Product • Organization • Change	
(Felippes et al., 2022)	Implementing strategies to prepare companies for DT in I4.0 context.	• 'X': organizational enabler • 'Y': technological enabler • 'Z': process maturity enabler	
(Kırmızı and Kocaoglu, 2022)	Improving frequent and efficient assessments for continuous improvement.	• Employee • Processes • Customer • Strategy&Governance • Organization & Corporate culture • Smartness	
(Ünal et al., 2022)	Guiding companies toward global DT standards in emerging markets.	• Technology (Products) • Data&Security • Supports & Incentives • Strategy&Management • Customers&Suppliers • Employees & Corporate Culture	
(Draganić, 2023)	Evaluating manufacturing firms in managing DT projects within the operational excellence domain.	• Business transformation • Measurement Framework	
(Hein-Pensel et al., 2023)	Assessing I4.0 and I5.0 maturity.	• Technology • Data • Customer • Corporate Environment • Strategy&Management • Corporate Culture • Organization&Processes • Products&Services • Employees	
(Volf et al., 2024)	Proposing a digital maturity roadmap for small business assessment.	• Strategy • Technology • Process • People • Organization	
(Jäkel et al., 2024)	Identifying I4.0 technologies and requirements for maturity of the construction industry.	• Technologies • Organization & Processes • Culture & Personnel • Data management • Interconnectivity	
(Thomson et al., 2022)	Promoting the development growth of autonomous solutions for customers.	• Technology Progress • Business Model • Ecosystem Relations	
(Sjödin et al., 2018)	Guiding organizations in challenges about the implementation of the smart factory.	• Cultivate digital people • Introduce Agile processes • Configure Modular technology	

MMs' Reference	Objective	Dimensions	Design Focus
(Vance et al., 2023)	Supporting decision makers to develop future research directions in smart manufacturing.	• IT&CPS&Data • Strategy & Organization • Products&Services • Supply Chain & Logistics • Culture & Employees • Technology & Capabilities • Customer&Market • Cybersecurity&Risk • Leadership & Management • Governance & Compliance	
(Hortovanyi et al., 2023)	Examining the implementation of IT-enabled resources in different domains.	• Strategy • Technology • Operation • Organization&Culture • Customers	

4.2 Forms of ROI

Based on the analysis of papers coming from Q2, six forms of ROI were identified - i.e., Business Performance Optimization (BPO), Productivity Optimization (PO), Cost Reduction (CR), Time Reduction (TR), Resource Optimization (RO), Customer Experience Improvement (CEI) - including specific actions indirectly providing economic returns due to DT investments. Grey spaces in Table 2 denote a match.

Table 2. Summary of forms of ROI

	BPO					PO				CR							CEI			TR			RO		
	Corporate Orientation	Governance Structure	Financial Constraints	Increased Sales	New customers	Production rate	Resources utilization	Scrap and wastes	Security	Maintenance cost	Labour cost	Procurement	Outsourced activities	Risk management	Process improvement	Technology investment	Quality	Customer expectation	Cash flow	Customer responsiveness	Machine downtime	Interventions	Labour shortage	Personnel	Materials	Utilities
(Cao et al., 2022)			■	■	■	■							■			■	■			■						■
(Butt, 2020)			■		■		■				■					■				■			■		■	
(Venkateswaran, 2020)	■				■	■			■			■				■		■		■			■			■
(Schulz et al., 2023)			■	■	■		■		■	■			■	■	■	■	■	■	■				■		■	
(Park and Shintaku, 2022)		■		■			■	■		■	■				■	■	■	■	■	■	■		■	■	■	
(Pech and Vrchota, 2020)			■	■		■			■	■		■			■	■	■		■			■	■	■		■
(Ma et al., 2024)		■	■	■			■		■	■		■		■	■	■	■	■	■				■		■	
(Borana et al., 2024)	■		■	■		■	■			■		■		■		■						■	■	■		
(Demeter et al., 2024)		■	■	■		■			■		■				■	■	■						■		■	

5 Discussion

Based on the analysis of DTMMs, all dimensions and factors were analyzed so that four key dimensions result: i) People, ii) Organization and Culture, iii) Information and Technology, iv) Operations. While, all the 35 maturity models considered both "People" and "Organization and Culture", (Krešimir Buntak et al., 2021; Draganić, 2023; Maram I. Shqair and Altarazi, 2022; Yan et al., 2021) do not mention "Information and technology" dimension, and only (Maram I. Shqair and Altarazi, 2022) does not talk about "Operations". Each dimension is detailed in different categories, for a total of 51 factors (see Table 3) dealing with actions for leveraging and capitalizing DT initiatives in industry.

Some interesting insights emerged with respect to the most important factors such as: ICT and digital competences, and openness to new technologies, within "People"; ICT value, digital strategy development, and digital business models, within "Organization and Culture"; IT security and software technology, within "Information and Technology"; product digitalization and process digitalization, within "Operations".

Few MMs consider the principles of I5.0 paradigm (Hein-Pensel et al., 2023; Xu et al., 2021): human centricity was discussed only from the customer's point of view (Dikhanbayeva et al., 2020); environmental sustainability was considered only by (Amaral and Peças, 2021), and resilience was considered in (Hein-Pensel et al., 2023) in terms of technological modularity.

Although literature directly linking forms of ROI to DT initiatives remains relatively limited, insights from recent studies (see Table 2) identified six forms of ROI having specific actions that potentially capitalize DT investments.

The innovative contribution of the paper also relies on integrating these topics, which is identified as the main research gap, trying to shape the relationship between factors representative of DT maturity, and forms of ROI. Different focus groups were managed involving three researchers and three practitioners belonging to an IT consulting company. Knowledge and competences coming from academia and industrial experiences were shared with the aim of understanding how factors are linked with forms of ROI (see grey spaces in Table 3).

Table 3: Link between factors and forms of ROI

			Forms of ROI					
	Factors		BPO	PO	CR	CEI	TR	RO
PEOPLE	Partners	Partner Communication						
		Partner Digital Interaction						
	Customers	Customer Requirement Satisfaction						
		Customer Digital Competences						
		Customer Data Utilization						
	Suppliers	Supplier Relationship Management						
		Supplier Performance						
	Employees	Employee Accountability						
		Openness to New Technology						
		Empowerment						
		ICT and digital competences						
ORGANIZATION&CULTURE	Strategy	Implementation I4.0 Roadmap						
		Scouting of New Opportunities						
		Resource Management						
		Communication						
		Digital Business Models						
		Digital Strategy Development						
		Performance Management						
		Investments						
		Innovation Management						
		Decision Making Data-Driven						
		Change Management						
	Governance	Knowledge Sharing						
		ICT Value						
		Intellectual Property						
		Data Access						
		Regulations & Standards						
INFORMATION&TECHNOLOGY	Management	IT Security						
		Physical Infrastructure						
		IoT & Analytics						
		Digital Data Availability						
		Software Technology (e.g., Cloud)						
	IT Design Principles	Interoperability						
		Virtualization						
		Decentralization						
		Real-Time Capability						
		Service Orientation						
		Openness						
		Modularity						
OPERATIONS	Product	Product Customization						
		Product Digitalization						
		Product Integration						
	Process	Process Decentralization						
		Process Digitalization						
		Process Optimization						
		Process Standardization						
		Business Process Integration						
	Practice	Internal Collaboration						
		Extended Enterprise						
		Performance Control and Improvement						
		Interdisciplinary						

6 Ethics declaration

Participants were fully informed of the research purposes and contributions of the study. Anonymity of data and confidentiality were ensured in accordance with GDPR and ethical standards.

7 AI declaration

The use of AI tool, specifically OpenAI ChatGPT, was limited to language refinement and improvement. Contents were critically reviewed by authors for accuracy, originality, and alignment with scientific standards.

8 Conclusions

The paper investigated the relationship between business maturity and company's ability to derive value from DT investments. It explored the literature of DTMMs and identified 4 key dimensions and 51 factors in charge of shaping digital maturity of industrial organizations. Also, the possibility of addressing specific actions, identified like forms of ROI, can generate economic benefit throughput through distinct mechanisms.

However, the link between maturity and ROI was not well-explored in literature. Therefore, the paper introduced a novel framework linking these factors to specific forms of ROI.

The study provides both theoretical and managerial implications highlighting the importance of investigating an underexplored topic in literature. It enhances understanding of how DT maturity impacts ROI and encourages further research. It also provides actionable insights to practitioners in terms of maturity factors linked to specific actions for capitalizing DT investment, highlighting ROI beyond purely economic metrics.

Despite the originality and value of research, the study has some limitations. It is based on a qualitative approach which may limit the objectivity of factors and ROI mapping. Future research should adopt quantitative approaches to validate and expand these findings. The framework could be explored in sectors beyond IT, to improve generalizability, and it could be validated in real-world business cases.

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A Comparative Analysis of Low-Code/No-Code Frameworks

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Abstract

The advent of low-code and no-code (LCNC) platforms has revolutionized software development, making it accessible to users with different programming skills. These methodologies provide both technical and non-technical users with innovative solutions to optimize the software development process. The goal of this paper is to inform and enrich both scholarly discourse and practical application by synthesizing theoretical frameworks with practical experiences, ultimately driving advancements in software engineering methodologies and helping individuals and organizations to leverage these innovative development paradigms effectively. The paper presents a comparative analysis of features and capabilities of the platforms AppSheet, PowerApps, and Bubble.io. It explores Model-Driven Development's role in enhancing these platforms. To further enrich the analysis, a group of PhD students with different expertise in software engineering and LCNC paradigms were interviewed to gather their perspectives on the practical use and potential of these platforms. Their insights provided a valuable layer of expertise to the evaluation process, highlighting nuanced challenges and opportunities that emerge in applied settings. The three platforms were systematically compared and ranked using the analytic hierarchy process (AHP), a multi-criteria decision-making methodology that structures the decision-making process into a hierarchical model. AHP's systematic approach ensures that both subjective preferences and objective data are integrated, making it an effective method for selecting the most suitable LCNC platform. This approach allowed for an objective evaluation based on key factors such as usability, scalability, and adaptability to various development needs. By combining hands-on experimentation with expert insights and a rigorous evaluation framework, this study bridges the gap between theoretical understanding and practical application.

Keywords: low-code development platform; no-code development platform; model driven development; AHP method; Digital Transformation

Paper type: Academic Research Paper

1 Introduction

In recent years, the landscape of software development has experienced a deep change due to the introduction of innovative approaches like low-code, no-code, and model-driven development. These methodologies provide both technical and non-technical users with innovative solutions to optimize the software development process. As this dynamic field continues to gain interest in both industry and academia, researchers are actively investigating various aspects to deepen their understanding and optimize their utilization, aiming to enhance their efficacy, scalability, and applicability across various domains (Di Ruscio et al., 2022).

Specifically, low-code development platforms provide a visual interface and pre-built components, enabling developers to rapidly build applications with minimal hand-coding. Conversely, no-code platforms take this concept further by empowering users with little to no programming background to create functional applications using intuitive drag-and-drop interfaces. Model-driven development emphasizes the creation of abstract models, which are then transformed into executable code, fostering higher-level abstraction and automation in the development process (Bock et al., 2021).

One of the key areas of the research focus is the current status of no-code development, encompassing its capabilities, limitations, adoption trends, and implications for software engineering practices (Beranic et al. 2020; Luo et al., 2021). This research topic aims to investigate the evolving landscape of no-code platforms, examining their effectiveness in addressing diverse use cases and fostering collaboration between developers and domain experts. In response to this trend, an increasing number of companies are providing software development platforms that guarantee a significant increase in productivity and a reduced requirement for coding alone (Krejci et al., 2021). For many years, both characteristics have been the focus of extensive research in fields like generative programming, model-driven software development, and domain-specific modeling languages. Thus, an open question is what unique performance features low-code and no-code (LCNC) platforms offer (Elshan et al., 2023). Since the topic is still under investigation, a reasonable method to get a detailed grasp of what it is and could be is to examine how the platforms actually work. In this discourse, this research paper

examines three platforms, noting and rating both the general attributes and the unique aspects of each instrument.

The first step is to analyze the ongoing research efforts surrounding the LCNC, and model-driven development paradigms, with a particular emphasis on the status quo and future directions of LCNC platforms. The aim is to advance software engineering practices and enable a wider range of stakeholders to be involved in the development process by shedding light on the opportunities and challenges present in these novel approaches through critical analysis and synthesis of the existing literature.

Furthermore, this research leverages on firsthand experience in the development of a blog application utilizing platforms such as AppSheet, PowerApps and Bubble.io.

The direct contact with these LCNC development environments, enrich the knowledge of their usability, flexibility, and efficacy in real-world application scenarios. Then, the process of conceptualizing, designing, and deploying a blog application provides valuable firsthand knowledge of the strengths and limitations of these platforms, offering new perspectives that complement theoretical insights infered from academic literature. Lastly, the three platforms are evaluated and ranked according to the multiple-criteria decision method of analytic hierarchy process (AHP) (Saaty, 1990; Atanasova et al., 2014).

Through this fusion of academic inquiry and practical experimentation, this research aims to bridge the gap between theory and practice, providing a step for understanding of the low-code, no-code, and model-driven development landscape.

2 Research Background

Model-Driven Development (MDD) is an approach to software development where abstract models are created to specify the structure, behavior, and functionality of a system (Sendall et al., 2023; Schmidt, 2006). These models serve as a base from which executable code can be automatically generated, reducing the manual effort involved in coding and facilitating higher-level abstraction. MDD emphasizes the separation of concerns between the system's underlying logic and its implementation details, promoting modularity, reusability, and maintainability throughout the development lifecycle.

On the other hand, LCNC development refers to the creation of software applications using visual development interfaces and declarative programming techniques, without the need for traditional hand-coding (Rokis et al., 2022). LCNC platforms typically offer a range of pre-built components, templates, and drag-and-drop tools that enable users, including non-technical individuals, to design, build, and deploy functional applications rapidly. By abstracting away, the complexities of coding, LCNC development empowers a broader audience to participate in the software development process, democratizing access to application development and fostering collaboration between domain experts and IT professionals.

MDD is often used in complex development environments, where models are used to manage the complexity of the domain and the generated code. LCNC platforms further lower the barrier to entry, allowing even business users to create applications without deep technical knowledge.

From practical and professional perspectives, LCNC development offers several advantages over traditional coding approaches. Firstly, it accelerates the development cycle by reducing the time and effort required to create and iterate on applications, enabling organizations to respond more swiftly to changing business needs and market demands. Secondly, it promotes greater collaboration and innovation by allowing non-technical stakeholders to contribute directly to the development process, leveraging their domain expertise to inform application design and functionality. Additionally, LCNC development can enhance the scalability and maintainability of applications by enforcing best practices and standardizing development workflows across teams.

LCNC platforms can be seen as a simplified evolution of the MDD concept. They have taken the principles of the "model-driven" approach (building software through visual abstractions) and made them more accessible and usable by a wider audience of users. Model-Driven Development is a development philosophy where models are used to automatically generate code, while LCNC platforms offer a similar but more accessible experience, further simplifying the development process through visual interfaces. LCNC platforms can therefore be considered a more practical and user-friendly embodiment of MDD approaches, aimed at a wider audience.

While the adoption of LCNC development has gained relevance in industry settings due to its practical benefits, there remains a need for ongoing research to address various challenges and opportunities associated with this approach (Rokis et al., 2022). Research efforts in the realm of LCNC development may focus on areas such as usability, scalability, security, integration capabilities, and the impact of LCNC tools on software quality and developer productivity (Beranic et al. 2020). By advancing our understanding of these issues and developing innovative solutions, researchers can contribute to the continued evolution and maturation of LCNC

development practices, enabling organizations to realize the full potential of this transformative approach to software development.

3 Platforms

In recent years, the landscape of software development has been transformed by the emergence of LCNC platforms, offering innovative solutions for building custom applications with minimal coding requirements. Among these platforms, AppSheet, PowerApps and Bubble.io stand out as leading contenders, each providing powerful tools and capabilities to empower users in the creation of bespoke software solutions. The reasons that guided our choice are the following. As for AppSheet, being part of the Google ecosystem, it integrates perfectly with Google Workspace (spreadsheets, forms, Drive), which makes it ideal for companies that already use these platforms. In addition, it allows you to build applications without writing code starting from simple spreadsheets. As regards PowerApps, it is tightly integrated with all Microsoft services, such as Dynamics 365, SharePoint, Excel, OneDrive, Azure, and Microsoft Teams. This integration offers a huge advantage for organizations that already use Microsoft products extensively. Finally, compared to other no-code platforms, Bubble.io offers more flexibility in customizing your application. It is possible to design very detailed user interfaces and manage complex logic with ease. Furthermore, to the best of our knowledge, Bubble.io is a platform that has been studied extremely little in the literature, making it more interesting for a scientific study.

In this context, we provide an analysis of the features, functionalities, and use cases of AppSheet, PowerApps and Bubble.io, exploring their respective strengths and limitations, and their role in shaping the future of software development.

3.1 AppSheet

AppSheet is a cloud-based no-code development platform that enables users to build customized applications without requiring traditional programming skills (Nurharjadmo et al., 2022). It has been founded in 2014 and acquired by Google in 2020. The platform supports use cases such as data management, workflow automation, and business process optimization.

It adopts a declarative programming model, allowing users to define application logic through expressions and preset actions. AppSheet integrates with widely used cloud services, including Google Sheets, Excel, Looker Studio, and Salesforce, and offers functionalities such as offline data access, GPS tracking, barcode scanning, and image processing. The platform features a visual development environment with drag-and-drop capabilities, supporting a range of data types and offering pre-built templates to accelerate development. Extensive documentation and learning resources are available to assist users.

Security is addressed through features like single sign-on, role-based access control, encryption, and audit logging. Administrators can configure granular access and data governance policies to meet compliance requirements (Jeong et al., 2006).

AppSheet also promotes community engagement and collaboration through knowledge-sharing platforms and a marketplace for third-party extensions. It represents a flexible no-code solution for rapid application development across diverse organizational contexts.

3.2 PowerApps

PowerApps, developed by Microsoft and launched in 2015 as part of the Power Platform, is a low-code development environment designed to facilitate the creation of custom business applications with limited programming requirements (Sahay et al., 2020). It employs a declarative development model, enabling users to define application logic and interface behavior through visual editors and configuration settings.

The platform provides a wide array of templates, UI controls, and prebuilt connectors that accelerate the application development process. It features deep integration with Microsoft services, including Office 365, SharePoint, Dynamics 365, and Azure, while also supporting external systems via REST APIs, custom connectors, and standard data gateways (Sharma et al., 2014).

PowerApps supports the development of both simple and complex applications, incorporating features such as responsive design, data binding, conditional logic, and customizable styling. Security is a core aspect of the platform, with support for Azure Active Directory, role-based access control, and data encryption mechanisms (Gürcan et al., 2021; Kapadia et al., 2017). Administrators can enforce governance through policy configuration and permissions management.

Additionally, PowerApps includes tools for monitoring, analytics, deployment, and version control, facilitating application lifecycle management. It represents a flexible and scalable solution for enterprises aiming to streamline workflows and develop business applications rapidly across web and mobile environments.

3.3 Bubble

Bubble.io is an advanced no-code platform that enables the development of web applications without traditional programming (Zhang et al., 2024). It features a visual drag-and-drop interface for user interface UI design and supports responsive layouts for compatibility across devices.

The platform includes a built-in database management system that allows for custom data types, record management, and the establishment of data relationships. It also supports integration with external APIs and data sources, facilitating interoperability. Its event-driven workflow engine enables the creation of dynamic, conditional processes based on user interaction or system events.

Customization is supported through templates, plugins, and real-time dynamic content. In terms of security, Bubble.io provides authentication systems, user role management, and configurable privacy rules. It is hosted on Amazon Web Services, leveraging encryption, network isolation, and compliance with industry security standards (Mishra et al., 2022).

Bubble.io simplifies deployment via integrated hosting and is designed for horizontal scalability. It also supports real-time collaboration and version control, which enhances project management. These features make Bubble.io a relevant subject of study in software engineering and information systems, particularly for its role in expanding access to web application development (Duc et al., 2016).

4 Method

The methodology employed in this study is designed to provide a comprehensive and systematic approach to evaluating AppSheet, PowerApps and Bubble.io, through the creation of blog and web applications on each platform. This section outlines the detailed steps taken, tools and technologies utilized, and the evaluation criteria established to ensure a rigorous comparison.

The blog has been created based on the following App Requirements:

- Data Entities for Blogs, Users, Posts and Blog Users.
- Connections between these entities as specified in the Design Phase.
- Creation of a Blog Entity.
- Blog Entities possess a title a description a descriptive image and their respective Posts.
- Creation of a Post Entity.
- Post Entities possess a title, a description, a descriptive image, content and their respective authors.
- Creation of the User Entity.
- User Entities possess a profile image, a username, an email and a password.
- Capability for an unregistered visitor to see all the Blogs and their respective Posts.
- Capability for an unregistered visitor to register and to have permissions such as Administrator.
- Capability for Administrators to create new Blogs and new Posts inside each Blog.
- Navigation through all these Menus seamlessly and check every Blog and Post available.

The process of building these prototypes served a dual purpose: it provided a structured basis for selecting the evaluation metrics, and it guided the creation of a questionnaire later administered to the interviewees. By directly interacting with each platform through a controlled development scenario, the evaluation metrics were more accurately aligned with real-world usage, ensuring that the subsequent interviews and data collection processes were grounded in empirical observations.

In the following, a comparative analysis of three prominent LCNC platforms is provided. Our discussion focuses on evaluating these platforms across several key dimensions, including ease of use, data modeling, authentication and authorization, customization and flexibility, integration with external services, development speed and overall user experience.

To perform the evaluation, a Multi-Criteria Decision Making (MCDM) method has been adopted. MCDM encompasses methods designed to help decision-makers evaluate alternatives based on multiple criteria, particularly in complex scenarios like selecting the best LCNC platform. Relying solely on a single factor, such as flexibility or ease of use, is insufficient when numerous criteria must be considered. A comprehensive literature review that compares 11 MCDM methods was performed by Hester et al., 2013. Based on the literature reviewed, the observed advantages and disadvantages, as well as areas of application for 11 MCDM methods such as Multi-Attribute Utility Theory, AHP, Fuzzy Set Theory, Case-based Reasoning, were presented.

Among MCDM methods, the Analytic Hierarchy Process (AHP) is especially well-suited for evaluating LCNC platforms. It has been introduced by Saaty, 1990 and provides a systematic framework for decision-making by using pairwise comparisons to assess the relative importance of criteria and the performance of alternatives against those criteria. AHP allows decision-makers to structure complex decisions by decomposing them into a hierarchy of criteria, sub-criteria, and alternatives. By using pairwise comparisons, it helps to assess the relative importance of each criterion and compare the platforms based on their performance in each area.

AHP structures the decision-making process into a hierarchical model with three levels: the goal at the top, criteria in the middle, and alternatives at the bottom.

For evaluating LCNC platforms, the goal would be to select the best platform. Criteria such as ease of use, data modeling, authentication and authorization, customization and flexibility, integration with external services, speed of development, overall user experience, and ease of learning are placed in the middle level. The platforms being considered are positioned at the bottom level. This hierarchical arrangement, illustrated in Figure 1 (Atanasova et al., 2014)., facilitates a structured comparison by performing pairwise comparisons of criteria and alternatives.

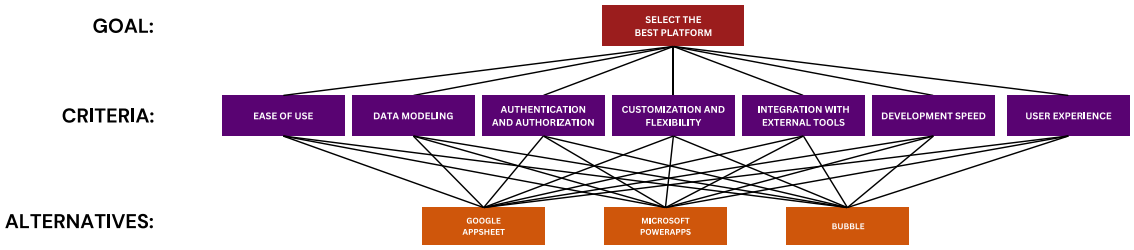


Figure 1: The Hierarchical structure of AHP Model

AHP's systematic approach ensures that both subjective preferences and objective data are integrated, making it an effective method for selecting the most suitable LCNC platform. This method employs a scale of judgments, typically ranging from 1 to 9, to quantify subjective preferences and translate them into numerical weights as explained in Table 1 (Saaty, 1990). The weights are then used to rank the alternatives and determine the best option. AHP has been successfully applied in various fields, including technology selection, project management, and resource allocation, due to its flexibility in handling both qualitative and quantitative data (Vaidya et al., 2006).

The criteria selected for evaluating LCNC platforms are grounded in their critical importance to both the technical and business facets of application development. Each criterion is essential for assessing the platforms' capabilities to meet diverse application development needs and ensuring they align with organizational goals and user expectations. Prior studies and industry reports highlight the significance of these factors in determining the effectiveness and efficiency of LCNC platforms (Rymer et al., 2019; Sahay et al., 2020).

Table 1: AHP pairwise comparison Saaty scale.

Weight	**Definition**
1	Equal importance
3	Weak importance of one over other
5	Essential or strong importance
7	Very strong importance
9	Absolute importance
2, 4, 6, 8	Intermediate values between the two adjacent judgments
Reciprocals of previous values	If factor 'i' has one of the previously mentioned numbers assigned to it when compared to factor 'j' then j has the reciprocal value when compared to i.

5 Assessment

In this section, the AHP is applied to rank the three platforms described before, namely AppSheet, PowerApps, and Bubble.io.

To enhance the clarity of the decision-making process and to facilitate better interpretation of the results, both the criteria and alternatives used in the assessment are denoted by specific abbreviations. The selected criteria and the abbreviation assigned to each criterion are as follows:

- C1 - Ease of Use: This is essential for non-programmers or users with limited technical backgrounds, so it represents a good point of start.

- C2 - Data Modeling: The ability to model data efficiently is a core aspect of many applications.
- C3 - Authentication & Authorization: Security is crucial, especially for applications that involve user data. Including this as a criterion ensures that each platform's capabilities in this domain are evaluated.
- C4 - Customization & Flexibility: The ability to adapt the platform to specific needs or preferences is important for building functional and unique applications.
- C5 - Integration with External Services: Many apps require external services (APIs, databases, etc.), so assessing the ease of integration is highly relevant.
- C6 - Development Speed: The faster a platform allows you to develop and deploy applications, the more appealing it is. This criterion highlights the platform's efficiency.
- C7 - User Experience: This criterion is crucial, as it ensures that the final applications offer a good experience for the end users.

The selection of the criteria has been performed based on the literature review and on the direct practice with the selected platforms.

The abbreviations assigned to each alternative are as follows: P1 is AppSheet, P2 is PowerApps and P3 is Bubble.io.

AHP method consists of four main steps: (i) A hierarchical problem model is developed for which we should make a decision as shown in Fig. 1; (ii) At each level of hierarchy, a comparison of elements of the structure is carried out in pairs, where the decision maker's preferences are expressed using the scale in Table 1; (iii) The relative importance of the elements of each level of the hierarchical structure is evaluated, for the calculation of local criteria, sub-criteria and alternatives. After that, the overall priorities of the alternatives are summarized. The total priority of each alternative is calculated with the sum of the local priorities that are weighted with the weights of the elements from higher levels; (iv) sensitivity analysis is conducted.

Given the extensive volume of calculations and the numerous matrices involved, the focus here will be on summarizing the most critical findings. The decision matrix explicitly illustrates the relative importance of the attributes, or decision criteria, based on the applied analytical methods. This matrix provides a comprehensive overview of how each criterion contributes to the overall evaluation, reflecting the weighted significance derived from the analytical hierarchy process (AHP). By concentrating on these key results, we aim to offer a clear representation of the decision-making outcomes, facilitating a more straightforward interpretation of the comparative performance of the alternatives.

The mathematical model leverages on a matrix n×n, where n is the number of elements which are compared. The matrix is filled according to the decision maker's preferences, expressed using the scale in Table 1, as explained in the next subsection.

5.1 Interviews with LCNC users

In this application, the preferences have been selected according to the direct interviews to a group of 7 independent PhD students from two different universities, with at least 2 years of experience using LCNC platforms in their academic research. The selected participants come from diverse academic backgrounds, such as computer science, data science, information systems, and other fields that involve the use of software tools. The study has been designed such that every participant had the same conditions. Specifically, the interviews were conducted through written questionnaires and followed a structured multi-step process:

- Assessing Expertise: Participants were first asked to indicate their level of expertise with LCNC platforms. This helped establish a baseline understanding of their prior knowledge and experience.
- Prioritizing Evaluation Criteria: Before proceeding with detailed evaluations, participants were asked to rank the importance of the evaluation criteria. This step provided insight into the participants' priorities and perspectives.
- Practical Task: Each participant was assigned the task of creating a blog that met specific requirements using all three LCNC platforms under evaluation. This practical exercise allowed them to explore the platforms in depth.
- Feedback Collection: After completing the task, participants filled out a detailed feedback questionnaire. They answered specific questions related to each criterion, evaluating all three platforms based on their experience during the task.

The ratings provided by the PhD students in the questionnaire were analyzed using a straightforward approach. For each evaluation criterion, the scores assigned by the participants were synthetized based on Table 1 and then averaged. The filling should meet the four axioms of Saaty 1987: the reciprocity axiom, the axiom for homogeneity, the axiom for dependence and the axiom of expectation. These axioms ensure logical consistency and reliability in comparing elements.

The arithmetic mean was calculated for each platform and each criterion to provide a comparative overview of the performance of the platforms under evaluation. The results of this analysis are presented in the following subsection.

5.2 AHP

The arithmetic means have been firstly used to fill the matrix in Table 2.

This matrix is then normalized, and the normalized elements are used to compute the weights. In particular, the weights are the arithmetic mean for each row of the normalized matrix. Thanks to the weights, it is then possible to compute the maximum eigenvalue of the matrix, indicated with λ_{max}.

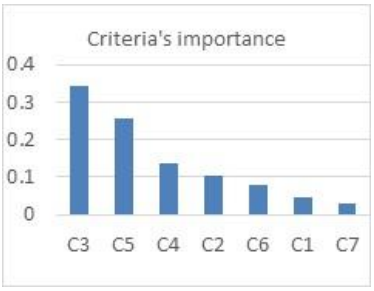
Then, AHP computes the consistency ratio as: $CR = \frac{CI}{RI}$, where CI is the Consistency Index of the original matrix defined by $CI = \frac{\lambda_{max} - n}{n-1}$ and RI is Random consistency index (Atanasova et al., 2014)**.**

In this application $n = 7$, thus $RI = 1{,}35$.

Table 2 shows the comparison of the criteria for choosing the best Platform for minimal to no programming experience and the right chart summarizes the order of importance of the criteria based on the computed weights.

Table 2. Comparison of the criteria

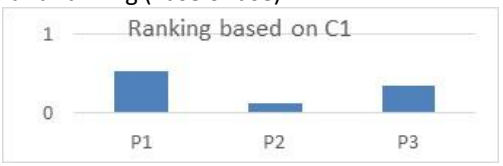
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**Weight**
C1	1	0,33	0,20	0,33	0,33	0,5	2	0,0477
C2	3	1	0,33	0,50	0,5	3	2	0,1049
C3	5	3	1	5	4	7	9	0,3452
C4	3	2	0,20	1	0,33	3	4	0,1374
C5	3	2	0,25	3	1	7	9	0,2563
C6	2	0,33	0,14	0,33	0,14	1	4	0,0807
C7	0,5	0,5	0,11	0,25	0,11	0,25	1	0,0276
Sum	17,5	9,17	2,24	10,42	6,42	21,75	31	



The maximum eigenvalue (λmax) is 9.8839, and the CI is 0.1372. The CR is 0.0946, which is below the commonly accepted threshold of 0.10. Thus, it can be concluded that the level of inconsistency in the pairwise comparison matrix is within acceptable limits, indicating that the judgments made during the decision-making process are consistent and reliable.

Table 3. Assessment of priority regarding the criterion C1 and ranking (Ease of use)

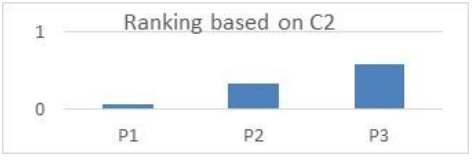
	P1	P2	P3	Weights
P1	1	4	2	0,5350
P2	0,25	1	0,33	0,1210
P3	0,5	3	1	0,3439
Sum	1,75	8	3,33	



Here, λ_{max}=3.0255, CI= 0.0127 and CR=0.0245.

Table 4. Assessment of priority regarding the criterion C2 and ranking (Data modeling)

	P1	P2	P3	Weights
P1	1	0,20	0,14	0,0717
P2	5	1	0,33	0,3390
P3	7	3	1	0,5892
Sum	13	4,20	1,47	



It holds λ_{max}=3.10, CI=0.0508 and CR=0.0977.

Table 5. Assessment of priority regarding the criterion C3 and ranking (Authentication & Authorization)

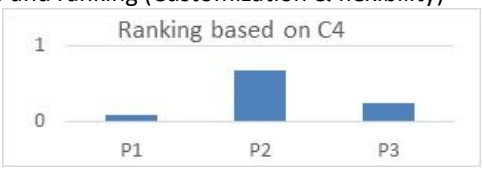
	P1	P2	P3	Weights
P1	1	0,25	0,25	0,1070
P2	4	1	2	0,5
P3	4	0,5	1	0,3928
Sum	9	1,75	3,25	



In this case, λ_{max}=3.08, CI=0.0398 and CR= 0.0766.

Table 6. Assessment of priority regarding the criterion C4 and ranking (Customization & flexibility)

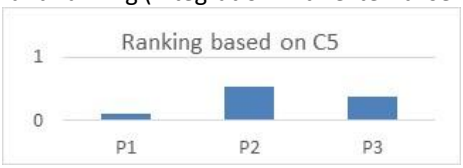
	P1	P2	P3	Weights
P1	1	0,14	0,33	0,0829
P2	7	1	4	0,6772
P3	3	0,25	1	0,2398
Sum	11	1,39	5,33	



The three significant values are λ_{max}=3.038, CI=0.0191 and CR=0.0367.

Table 7. Assessment of priority regarding the criterion C5 and ranking (Integration with external services)

	P1	P2	P3	Weights
P1	1	0,20	0,25	0,0969
P2	5	1	2	0,5351
P3	4	0,50	1	0,3678
Sum	10	1,70	3,25	



Here, λ_{max}= 3.038, CI=0.0191 and CR=0.0367.

Table 8. Assessment of priority regarding the criterion C6 and ranking (Development speed)

	P1	P2	P3	Weights
P1	1	4	2	0,5
P2	0,25	1	0,25	0,1071
P3	0,50	4	1	0,3928
Sum	1,75	9	3,25	



It holds λ_{max}= 3.079, CI=0.0378 and CR= 0.0766.

Table 9. Assessment of priority regarding the criterion C7 and ranking (User experience)

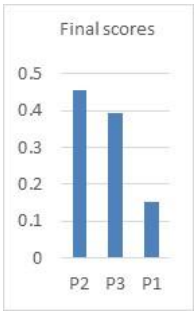
	P1	P2	P3	Weights
P1	1	3	0,17	0,1928
P2	0,33	1	0,11	0,0666
P3	6	9	1	0,7405
Sum	7,33	13	1,28	



In the last case, λ_{max}=3.074, CI=0.0372 and CR=0.0716.

Table 10. Subtotals and chart ranking for best Platform

		Sub for AppSheet		**Sub for PowerApps**		**Sub for Bubble.io**	
		P1	**Weight**	**P2**	**Weight**	**P3**	**Weight**
C1	0,0477	0,535	0,0255	0,121	0,0057	0,3439	0,0164
C2	0,1049	0,0717	0,0075	0,339	0,0355	0,5891	0,0617
C3	0,3452	0,1071	0,0369	0,5	0,1726	0,3928	0,1356
C4	0,1374	0,0829	0,0114	0,677	0,0930	0,2398	0,0329
C5	0,2563	0,0969	0,0248	0,5351	0,1371	0,3678	0,0943
C6	0,0807	0,5	0,0403	0,1071	0,0086	0,3928	0,0317
C7	0,0276	0,1928	0,0053	0,066	0,0018	0,7405	0,0204
Sum			0,1519		**0,4546**		0,3931



Each consistency ratio obtained with the previous computations are smaller than the commonly accepted threshold of 0.10. This means that the level of inconsistency in the pairwise comparison matrices are within acceptable limits, indicating that the judgments made during the decision-making process are consistent and reliable.

From Table 10 and the related chart, we can conclude that the best platform in the development of a blog application utilizing the three platforms is PowerApps.

6 Discussion

The AHP provides a structured approach for evaluating LCNC platforms by allowing both a detailed assessment of individual platform characteristics and an overall ranking based on multiple criteria. This method enables decision-makers to systematically compare platforms such as AppSheet, PowerApps, and Bubble.io by assigning relative importance to different evaluation factors. By leveraging AHP, stakeholders can gain a more holistic understanding of each platform's strengths and weaknesses, ensuring that the selection process aligns with specific project requirements and strategic objectives.

The choice between AppSheet, PowerApps, and Bubble.io is contingent upon a nuanced evaluation of project requirements, organizational priorities, and developer proficiencies. While AppSheet excels in expeditious prototyping and simplicity of use, making it suitable for less complex applications, PowerApps emerges as a good contender for projects necessitating intricate customization and seamless integration with the Microsoft ecosystem. Bubble.io, on the other hand, offers a versatile tool with extensive customization options and a user-friendly interface, making it suitable for a wide range of applications.

Moreover, based on the described features, PowerApps is mainly a B2B (Business to Business), while AppSheet and Bubble.io are B2C (Business to Customer solution). B2B solutions offer users different functionalities such as creation, optimization, and automation of business process activities. In contrast, B2C solutions supply to end customers more direct answers. B2C solutions are typically used to develop single applications such as websites and customer relations management applications. Additionally, the interactivity features of B2C are far more critical than B2B ones (Sahay et al., 2020).

7 Conclusions

In this study, we conducted a comprehensive comparative analysis of three prominent LCNC platforms: AppSheet, PowerApps, and Bubble.io. These platforms have transformed the landscape of application development by offering accessible tools to create sophisticated applications without traditional programming skills. Our evaluation focused on several key dimensions critical to application development, including ease of use, data modeling, authentication and authorization, customization and flexibility, integration with external services, development speed and overall user experience.

AppSheet emerged as a top performer in ease of use, providing an intuitive interface and rapid deployment capabilities suitable for small to medium-sized businesses. It scored well across most dimensions, particularly in ease of learning and development speed, making it a preferred choice for beginners and those needing quick application solutions.

PowerApps excelled in integration with Microsoft services, advanced data modeling, and comprehensive customization options, making it ideal for medium to large enterprises with complex integration needs. Its robust security features and ability to handle intricate data relationships were noteworthy, despite its steeper learning curve.

Bubble.io stood out for its user experience, allowing users to create highly tailored applications. It performed well in integration with external services and provided a user-friendly interface, making it suitable for startups and developers needing powerful web applications without traditional coding.

Based on the performed evaluations of the users, PowerApps resulted as the best platforms. Nevertheless, each platform demonstrated strengths and limitations across the evaluated criteria, which should guide businesses and developers in selecting the most appropriate tool based on their specific requirements. For instance, AppSheet is recommended for rapid prototyping and quick deployment scenarios, whereas PowerApps and Bubble.io are better suited for projects requiring deep integration, advanced customization, and scalability.

In conclusion, the choice of a LCNC platform should align closely with the technical expertise of the development team, the complexity of the application requirements, and the organization's strategic objectives.

While the present study evaluates platforms using AHP, future research could expand on this approach by incorporating alternative decision-making models, such as the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) or fuzzy AHP, to refine and validate the comparative analysis. Additionally, exploring the long-term maintainability and cost implications of LCNC solutions in enterprise settings could provide deeper insights into their viability for large-scale deployments.

Finally, as LCNC platforms continue to evolve, future studies should investigate how artificial intelligence and automation are further shaping their capabilities. The integration of AI-driven code generation, natural language processing, and automated workflow optimization could redefine the competitive landscape and expand the potential applications of these platforms beyond their current scope.

8 Ethics declaration

This research involves interviews with PhD students. All participants were informed about the purpose of the study and gave their voluntary consent to participate. No personal or identifiable data were collected or published. The data are presented in aggregated form only.

9 AI declaration

No AI tools were used for the creation of the paper.

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Thriving Through Digital Change: Building Resilient, Adaptive and Sustainable Organizations

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Abstract

In today's complex environments, organizations increasingly rely on their ability to manage change and build resilience to sustain long-term competitiveness. This phenomenon is particularly evident in high technological intensive companies dealing with frequent changes due to digitalization and technological disruptions. Through a Systematic Literature Review this study investigates the interconnections between change management, individual resilience, and organizational resilience, with the aims to identify theoretical models and key constructs shaping the complexity of business organizations when approaching to change processes. Based on the analysis of 46 peer-reviewed journal articles published between 2007 and 2025, findings reveal that individual resilience – defined as the psychological capacity to cope with, adapt and recover from adversity – plays a pivotal role in shaping employee responses to organizational change. Transformational leadership and resilient organizational cultures act as enablers, reinforcing individual capabilities and translating them into collective adaptive capacity.

Several studies draw on theoretical perspectives such as dynamic capabilities, psychological capital, and the resource-based view, suggesting that resilience is not a static attribute but a dynamic, multilevel process involving learning, improvisation, and innovation. Despite growing scholarly attention, the literature remains fragmented, with limited longitudinal designs and scarce integration across micro, and macro levels.

To address these limitations, on top of the literature, the study introduces a conceptual model that links individual resilience to organizational resilience through change management processes, in which leadership and culture represent key enablers. This model offers a strategic lens to understand how individual psychological resources can be leveraged to support organizational transformation and long-term sustainability in volatile and knowledge-intensive contexts. This study also highlights the importance of connecting human dynamics with organizational agility and encourages future interdisciplinary research on multilevel resilience as a knowledge-based capability to enable adaptive and sustainable change.

Keywords: Change Management, Innovation Management, Organizational Resilience, Individual Resilience

Paper type: Academic Research Paper

1 Introduction

In the current socio-economic landscape, characterised by rapid change and uncertainty, organizations need to adapt quickly to effectively address both strategic and operational challenges and to maintain their competitiveness (Trenerry et al., 2021). The digital transformation, involving the evolution of both methodological and technological maturity, represents important examples of challenges companies are called to face. According to Bauman's (2013) notion of "liquid modernity", contemporary societies are marked by fluidity, making uncertainty a permanent condition. In such contexts, individuals and organizations must develop resilience to continuously shape their identities and turn challenges into opportunities.

Change management plays a strategic role, acting as a catalyst for organizational innovation (By, 2005). It offers structured frameworks to guide transitions toward new organizational configurations, overcome resistance to change, and ensure that transformations are aligned with strategic objectives (Schäffer, 2020). Effective change management significantly contributes to the development of organizational resilience, enhancing the ability to respond to crises and disruptions while fostering long-term sustainability.

Resilience, both at the organizational and individual level, emerges as a key capability for dealing with uncertainty, serving as a pillar of sustainable development (Linnenluecke, 2017). It is not a reactive measure, but a proactive approach that involves anticipating disruptions, developing robust response mechanisms and cultivating a culture of adaptability and innovation (Quendler, 2017). Organizational resilience, in this view, requires a holistic perspective that integrates elements such as leadership, communication, and collaboration.

The interplay between change management, organizational resilience, and individual resilience is increasingly emphasized in the literature (Botti & Baldi, 2025). While the former encompasses the processes and tools used to implement organizational transformations (McManus et al., 2007), organizational resilience refers to the institution's ability to withstand, adapt, and recover from crises. On the other hand, individual resilience denotes the capacity of a person to cope with adversity, stress, or trauma (Xiao & Cao, 2017). Understanding

how these three concepts interact each other is crucial to sustain innovation and long-term success in dynamic contexts. A key element of this relationship is the Psychological Capital (PsyCap), a positive psychological state characterised by self-efficacy, optimism, hope and resilience (Luthans et al., 2006). These resources enhance individuals' ability to actively contribute to change initiatives (Toor & Ofori, 2010). Therefore, promoting individual resilience within organizational systems becomes a driving resource for navigating complexity and change, for instance in high technological intensity contexts (Helfat & Martin, 2015).

Organizational resilience has been conceptualized in the literature diverse ways, such as a capacity, process, characteristic, or an outcome (Hillmann & Guenther, 2021). Dynamic perspectives describe the organizational resilience as a transformative process that links adaptive capacities to positive evolution post-crisis (Sutcliffe & Vogus, 2003), allowing organizations not only to withstand shocks but also to improve strategically in the long term (Akgün & Keskin, 2014). Furthermore, organizational resilience is closely linked to innovation management, understood as the ability to create and implement value-generating ideas, products, or processes (Dawson, 2017). Innovative organizations are generally more resilient (de Oliveira Teixeira & Werther, 2013), as they develop flexible structures, learn from failures, and anticipate future changes such as greener practices. In this regard, change management supports transitions by helping teams and organizations move from the current to the desired state, facilitating adaptation and reducing resistance to change.

Recent studies (e.g., Modransky et al., 2020) highlight how change management factors such as employee participation and effective communication significantly influence both innovative behaviour and organizational resilience. Consequently, managing change effectively is critical to supporting adaptability, sustainability, and responsiveness to external and unexpected events.

Transformational leadership, employee engagement, the integration of diverse knowledge fields (Rumbles & Rees, 2013; Ritala, 2013), and the alignment between strategy and change culture (Ates & Bititci, 2011) are enabling factors that reinforce the virtuous cycle between change and resilience.

Despite extensive research studies have been provided in literature, there is the lack of an integrated view on how individual resilience acts as a strategic mediator for organizational adaptability and innovation, particularly in technological transitions. Interdependence among these factors is often overlooked considering the fragmented effort of scholars in exploring them.

This study hypothesizes that individual resilience functions as an enabling and mediating factor in change management processes, significantly contributing to the development of organizational resilience and innovative capacity of organizations. Accordingly, through a Systematic Literature Review (SLR), the study intends to collect valuable insights for reconstructing the relationship between change management, innovation, and both individual and organizational resilience. Therefore, the study aims to i) critically map and synthesize the existing research connecting these key topics, ii) identify theoretical models, constructs, and key variables surrounding the existing literature, and iii) highlight conceptual and empirical gaps in the current literature. Finally, the study proposes an integrated conceptual framework illustrating how change management is linked with individual resilience for supporting organizational transformation and long-term sustainability in complex and uncertain contexts.

2 Methodology

This study investigates the relationship between change management, organizational resilience, and individual resilience, with an emphasis on their role in supporting innovative and sustainable transformation in technological environments. The paper is grounded on a Systematic Literature Review (SLR), which is a methodological approach ensuring the research follows a rigorous, transparent, and replicable process (Tranfield et al., 2003). The systematic approach enables an unbiased integration of diverse contributions from technology management, psychology, and innovation studies. Following a four-phase protocol (Corallo et al., 2021) (i.e., review planning, execution, analysis, and reporting), the study applies clearly defined criteria for scientific studies selection and analysis. This structured process allowed for building a knowledge base of reference including key frameworks and constructs referred to the key topics of analysis. The results have been converged in a novel conceptual framework which highlights opportunities for future interdisciplinary research in resilience and change management. The framework presents an integrated view of change management, organizational and individual resilience fostering business innovation and long-term sustainability.

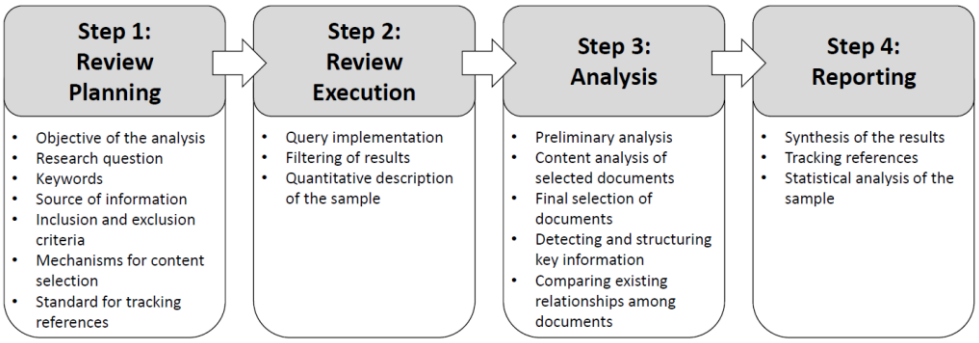


Figure 1. SLR protocol (Corallo et al., 2021)

Step 1: Review Planning – As stated before, the study aims to highlight the intricate complexity of change management when dealing with organizational and individual resilience, with a focus on digital transformation and sustainable development. Indeed, the study aims to provide an answer to the following research question: how change management is linked with both organizational and individual resilience for ensuring long-term innovation and sustainable business?

The scientific electronic database Scopus (www.scopus.com) was used by designing a specific query based on reliable keywords and selection criteria. Peer-reviewed articles written in English in the fields of management, engineering, psychology and social sciences were selected. Qualitative content analysis guided the construction of a conceptual map useful for future research and organizational practice.

Step 2: Review Execution – This phase was mainly based on implementing the designed query in Scopus. The query was strategically formulated using Boolean operators to comprehensively capture the academic literature relevant to change management and both organizational and individual resilience. The specific query used was the following:

("change management" OR "innovation management" OR "technology management") AND ("organizational resilience" OR "individual resilience").

The initial search, conducted in January 2025, retrieved 184 papers. Subsequently, a two-stage filtering process was applied: language filtering, which included only those articles in English, and subject areas filtering, which included article published in the fields of economics, management, engineering, social sciences and psychology.

This process resulted in a final sample of 123 peer-reviewed articles published between 2005 and 2025, which were following analysed and synthesised.

Step 3: Analysis – A preliminary screening based on titles and abstracts refined the sample to 46 highly pertinent articles, selected for their empirical and theoretical contributions providing an understanding of the relationship between change management, organizational resilience, and individual resilience, especially in contexts of technological innovation and uncertainty.

After that, a structured qualitative content analysis was conducted, confirming the relevance of all 46 papers. An Excel matrix was used to categorize key information such as bibliographic data, methodological features, research objectives, findings, and themes related to mediating/enabling factors. This structured approach facilitated the identification of common patterns, theoretical insights, and knowledge gaps, setting the stage for a comprehensive understanding of the topic of analysis and directions for future research.

Step 4: Reporting – This concluding phase serves to highlight the main findings from the SLR, which together constitute the current body of knowledge on the topics. A structured representation of the conceptual contributions relevant to the research objective was provided, offering critical insights that support a deeper understanding of the research question. Based on these insights the a novel framework has been developed for a comprehensive understanding of the integrated relationship between change management and resilience.

3 State of Art

Based on the analysis of the 46 scientific contributions, a rich and multidimensional understanding of the phenomenon of analysis was elaborated. These studies reflect a growing theoretical and practical maturity on the topics, while highlighting critical gaps and areas for future investigation. First and foremost, individual resilience clearly emerges as a key enabler of successful organizational change processes. The psychological resilience of employees and leaders is recognized as a crucial factor that can either facilitate or hinder organizational transformation in technological environments. Individuals with strong psychological resilience

tend to adapt more effectively to new procedures, roles, and technologies, exhibiting greater behavioural flexibility and less resistance to change. Empirical evidence consistently demonstrates that psychological resources, such as self-efficacy, optimism, hope, and resilience, collectively referred to as psychological capital (Luthans et al., 2006), play a pivotal role in facilitating individual adaptation to organizational transformation (Petrou et al., 2015; Lan et al., 2025; Kareem et al., 2025).

Subjective perceptions of fairness in change processes, the quality of internal communication, and participatory involvement act as moderating factors in mitigating the emotional impact of change. These elements contribute to reduced anxiety and ambiguity while strengthening employee engagement and trust in the organization. Such conditions foster the emergence of proactive behaviours such as job crafting, the self-initiated reconfiguration of tasks and roles in response to change, which is recognized as a marker of adaptive and active resilience (Petrou et al., 2015; Rumbles & Rees, 2013).

Concurrently, an expanding body of research highlights the critical role of transformational leadership and an open, inclusive organizational culture in activating resilience at both the individual and collective levels. Transformational leadership, defined as a leadership style that inspires and motivates followers through a shared vision, intellectual stimulation, and individualized consideration (Bass & Avolio, 1994), proves to be particularly effective in fostering trust, commitment, and adaptability in contexts of change. Likewise, organizational culture, understood as the shared set of values, norms, and practices that guide behavior within the organization (Schein, 1992), acts as a fundamental enabler in facilitating the assimilation of change and the diffusion of resilience.

In complex and unstable environments such as those in the ICT (Information and Communication Technology), tourism, healthcare, and industrial sectors, the presence of leadership capable of articulating a clear vision, inspiring trust, and actively supporting staff during critical phases is decisive in enhancing individual psychological resources and channelling them toward the construction of widespread organizational resilience (Greenfield, 2007; Tkaczyk, 2015; Van der Voet, 2014; Ferrigno et al., 2021; Wang et al., 2024; Ortiz-de-Mandojana & Bansal, 2016; Casalino et al., 2019; Ates & Bititci, 2011). This effect is particularly evident in high-turbulence environments, where the virtuous interaction between strategic agility and the alignment of individual behaviours with organizational direction becomes essential not only for survival but also for the organization's continuous and sustainable capacity for innovation.

From a theoretical standpoint, recent literature has progressively adopted integrative approaches to explain how organizations can develop and reinforce their resilience over time. Among the most consolidated references is the dynamic capabilities framework (Duchek, 2020), which conceptualizes resilience as the organization's ability to perceive environmental changes, learn from them, and promptly reconfigure its resources and operational routines. This approach, strongly oriented toward strategic agility, emphasizes the processual and transformative nature of resilience. In parallel, the Resource-Based View (RBV) offers a perspective focused on internal resources, asserting that resilience derives from the organization's capacity to leverage both tangible and intangible resources, such as human capital, internal relationships, culture, and know-how, to achieve sustainable competitive advantage. This view is extended through theories of organizational ambidexterity, which propose that resilient organizations are those capable of simultaneously balancing the exploitation of existing capabilities with the exploration of new opportunities, even in conditions of uncertainty and disruption.

Among emerging contributions, the ADREKA framework (Buildings, 2024) stands out for its integration of cognitive, relational, and behavioral dimensions in organizational responses to technological change. This model highlights that resilience does not develop spontaneously but requires intentional processes of learning, empowerment, and the strengthening of internal networks, with particular attention to distributed leadership and the management of social capital.

In this perspective, organizational resilience can no longer be understood as a static or reactive capacity, but rather as a dynamic and adaptive process unfolding through iterative cycles of learning, response, experimentation, and transformation (Ritala, 2013; Alblas & Jayaram, 2015; de Oliveira Teixeira & Werther, 2013; Dawson, 2017; Sun et al., 2011). Thus, organizational change becomes not merely a source of risk but a strategic lever for systemic strengthening, provided that it is accompanied by strategic investment in human, relational, and cognitive capital.

Equally relevant are contributions exploring resilience and innovation in high-impact social and cultural contexts, such as GLAM institutions. These studies introduce the Business Model Innovation 5.0 drawing inspiration from the Industry 5.0 paradigm, which identifies key drivers such as stakeholder and community engagement, collaborative knowledge management, and integrated sustainability (economic, social, and environmental). These drivers are further supported by infrastructural enablers such as technology, resources, and leadership, capable of fostering resilient and transformative innovation even in traditionally low-digitalization sectors.

Nevertheless, the literature continues to show several conceptual and empirical gaps. Insufficient multilevel integration can be observed, with few studies systematically linking individual (micro), team (meso), and organizational (macro) resilience, underscoring the need for more systematic and longitudinal investigations (Van der Voet, 2014; Greenfield, 2007; Ferrigno et al., 2021). Furthermore, the measurement of resilience remains heterogeneous and often reliant on non-standardized qualitative tools, which limits the comparability of results (Hillmann & Guenther, 2021; Lengnick-Hall et al., 2011). Finally, the prevailing focus on acute crises (e.g., pandemics, technological failures) has overshadowed the exploration of resilience as an enabler of incremental or proactive transformation in chronically unstable conditions (Casalino et al., 2019; Modransky et al., 2020).

4 Discussion

Based on the literature findings, an integrated conceptual framework is proposed to comprehensively explain how change management is linked to organisational and individual resilience to ensure innovation and long-term sustainability in organisations. Individual resilience acts as an enabling resource for change management processes, together with transformational leadership and an open and resilient organisational culture, which collectively shape the environment in technology-intensive contexts. These processes, through effective change management, nurture dynamic organisational resilience, understood as a collective ability to learn, adapt, and regenerate, and thus constitute a prerequisite for long-term organisational sustainability, which includes not only economic and environmental dimensions, but also relational and cognitive aspects (Lv et al., 2018; Helfat & Martin, 2015; Linnenluecke, 2017; Stephenson, 2010; Sutcliffe & Vogus, 2003; Akgün & Keskin, 2014).

The elaboration of the framework represents one of the most important outcomes based on the literature. The integrated framework synthesizes the relationships among the key constructs of this study and outlines a trajectory from individual resilience to long-term organisational sustainability.

At the core of the model lies change management, supported by three fundamental pillars. On one hand, individual resilience, conceptualised through psychological capital comprising self-efficacy, optimism, hope, and resilience, enables proactive adaptation. On the other hand, transformational leadership and an open, innovation-oriented organisational culture ensure strategic coherence and support for value-driven processes.

Individual resilience plays a central role in supporting change management and is nurtured by the development of psychological capital, defined as the cognitive and emotional resources that enable individuals to cope effectively with change. Transformational leadership, combined with an open and inclusive organisational culture, reinforces this dynamic by creating organisational conditions that foster adaptation and learning through trust, shared vision, and common values.

These fundamental dimensions support change management processes, which should be guided by key values such as clear communication, fairness in decision-making, and active employee engagement. However, the effectiveness of these values largely depends on the presence of specific enabling and moderating factors embedded in the organisation's daily functioning. In particular, factors such as the subjective perception of fairness, the quality of internal communication, and the participatory involvement of individuals within the organisation play a crucial role in strengthening and reinforcing these guiding values.

These factors act as moderators of employees' emotional responses to organisational transformation, helping to mitigate anxiety, stress, and ambiguity that typically arise during change processes. When employees perceive fairness, are well-informed, and feel actively involved, they are more likely to develop organisational trust, show greater engagement, and demonstrate a more open and proactive attitude towards change.

Under such favourable conditions, adaptive and participatory behaviours such as job crafting are more likely to emerge. Job crafting refers to the ability of employees to proactively reshape their roles and tasks in response to evolving organisational demands (Petrou et al., 2015). This type of behaviour is considered a concrete indicator of adaptive and active resilience. While job crafting and perceived equity are often conceptualised as drivers of effective change management, the present framework also hypothesises that they may emerge as outcomes of successful transformation processes. From this perspective, organisational change is not only based on these values but can also generate and reinforce them over time, creating a virtuous cycle that contributes to the development of both individual and collective resilience.

When these processes are effectively managed, they lead to the development of dynamic organisational resilience, which represents the organisation's collective ability to learn, adapt to external changes, and regenerate in response to new challenges. Organisational resilience is grounded in well-established theoretical frameworks, including dynamic capabilities theory, the resource-based view (RBV), organisational ambidexterity, and the ADREKA framework, all of which contribute to explaining resilience as an organisational

competence built over time through learning, strategic reconfiguration, and empowerment processes (Duchek, 2020; Buildings, 2024).

An important feature of the framework is the recognition of the reciprocal and mutually reinforcing relationship between individual and organisational resilience. While individual resilience enables and supports adaptive organisational processes, a resilient organisational environment characterised by trust, strategic coherence, and opportunities for growth, in turn, strengthens the psychological capital and adaptive capacities of individuals. This reciprocal dynamic creates a virtuous cycle, whereby individual and organisational resilience evolve and amplify each other over time, increasing the overall organisational capability to navigate change.

Ultimately, dynamic organisational resilience is presented as a necessary precondition for achieving long-term sustainability across economic, social, environmental, relational, and cognitive dimensions. This comprehensive view of sustainability enables organisations not merely to survive but to grow, innovate, and thrive over time in increasingly complex environments.

In this regard, the proposed framework offers a robust conceptual and operational basis for future empirical research, particularly through longitudinal and multilevel approaches, aimed at exploring and validating the causal trajectories that connect individual, intermediate, and systemic levels within sustainable transformation processes.

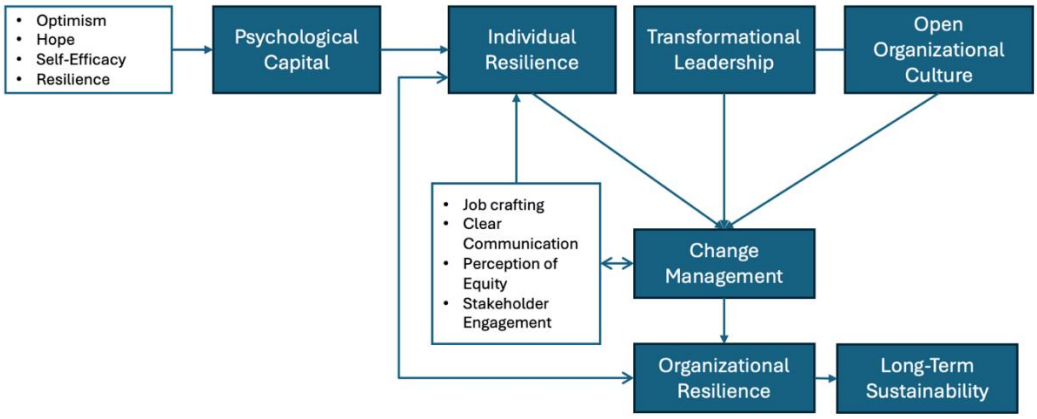


Figure 2. Conceptual framework of resilience-driven change management

5 Conclusion

This study explored the current state of the art concerning the relationship between change management, organisational and individual resilience, and proposed an integrated conceptual framework highlighting the enabling role of psychological capital and transformational leadership in supporting adaptive organisational processes. The novelty of this study lies in its comprehensive understanding of these themes, which in previous research have often been addressed in isolation, confined within their respective disciplinary boundaries.

First, multilevel integration remains largely underdeveloped. Although the literature recognises the relevance of both micro (individual) and macro (organisational) levels in the development of resilience, few studies provide robust theoretical frameworks or empirical evidence capable of systematically linking these dimensions. As a result, the dynamic interactions that shape resilience across organisational levels are often fragmented, limiting our understanding of how individual attitudes and capabilities translate into collective resilience.

A further critical gap in the literature concerns the limited attention devoted to the meso level, understood as team-level resilience. This intermediate layer represents a vital link between individual and organisational resilience, yet it is rarely explored in a structured or theoretical way. Addressing this gap would allow researchers to examine how teams respond to and manage change, how they share resilient behaviours and resources, and how they contribute to the emergence of coordinated and sustainable adaptive capacity at higher organisational levels.

Second, the measurement of resilience remains unstandardised. The widespread use of qualitative tools, often developed ad hoc, hampers the comparability of results and the accumulation of robust empirical evidence. Furthermore, much of the existing literature remains anchored to acute crisis scenarios, failing to address resilience as a strategic capability that enables long-term adaptation and sustainability in transformative contexts such as those driven by technology.

In this context, a decisive shift is needed from a multidisciplinary to an interdisciplinary research paradigm. While multidisciplinary approaches have contributed valuable insights from fields such as management studies, organisational psychology, economics, and sociology, they have not yet fostered the epistemological and methodological integration required to fully grasp the complexity of resilience-building processes. Future research should therefore adopt an interdisciplinary approach that combines management engineering, organisational psychology, economics, and the social sciences to develop actionable models of resilience.

The findings of this study yield several practical implications for practitioners, managers, and policymakers involved in the design and implementation of change initiatives within complex organisational contexts. Firstly, the proposed conceptual model underscores the strategic relevance of individual resilience as a key factor in effective change management. Organisations are thus encouraged to invest in developing employees' psychological capital, enhancing self-efficacy, optimism, hope, and psychological resilience, through targeted interventions such as training programmes, coaching, and psychosocial support mechanisms. Secondly, the study highlights the critical role of transformational leadership and an open and inclusive organisational culture in creating psychologically safe environments that support continuous learning and innovation. These enabling conditions not only facilitate the adoption of change but also strengthen the connection between individual motivation and collective adaptation, promoting proactive behaviours such as job crafting and collaborative problem-solving. Lastly, the integrated framework presented here can serve as an operational tool for organisational diagnosis, helping decision-makers assess change readiness, identify internal barriers and enabling factors, and design multilevel resilience strategies. This approach is particularly relevant in high-volatility sectors, such as technology-intensive industrial organisations, where the ability to continuously learn, adapt, and regenerate is increasingly essential to achieving long-term organisational sustainability.

Nevertheless, this paper presents certain limitations that point towards directions for future research. One of the most significant relates to the qualitative approach adopted to construct the knowledge base and develop the conceptual framework. Moreover, the framework is grounded in theoretical perspectives and has not yet been validated in real and complex organisational settings. Future studies could therefore adopt quantitative approaches not only to confirm or refute the existence of relationships among the framework's variables, but also to investigate the directionality and causal pathways of these relationships, in order to better understand the underlying dynamics that structure organisational resilience. In addition, future literature reviews might benefit from expanding the scientific evidence base by consulting other relevant academic databases, thereby ensuring broader coverage and reducing selection bias. Finally, complementary studies adopting interdisciplinary approaches alongside multidisciplinary ones are strongly recommended, with particular emphasis on addressing the meso level—understood as team-level resilience—as an essential yet underexplored dimension in resilience analysis.

6 Ethics Declaration

This study was conducted in accordance with high ethical standards and principles. The authors affirm adherence to ethical guidelines ensuring transparency, objectivity, and integrity throughout the research process. The systematic literature review presented does not involve any direct data collection from individuals or sensitive personal data handling. All sourced publications have been appropriately cited, respecting intellectual property and copyright.

No conflicts of interest have been identified in relation to this research. The authors declare that this paper is original, unpublished elsewhere, and does not contain any plagiarism or self-plagiarism.

7 AI Declaration

This research did not directly utilize Artificial Intelligence (AI) technologies or generative AI systems for the formulation, execution, or analysis of results. The systematic review and conceptual model presented are entirely derived from manual and traditional literature review methods.

However, the authors recognize the importance of AI and digital tools in advancing knowledge management practices and recommend future research explore integrating AI technologies for deeper insights and enhanced analytical capabilities in resilience and change management research.

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Measuring Innovation in Large ICT Firms: A Bibliometric Analysis

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Abstract

Innovation measurement remains a persistent challenge for organizations, especially in fast-evolving and complex sectors like ICT and IT, where traditional evaluation models struggle to capture the dynamic and intangible nature of innovation. Despite the abundance of proposed metrics and frameworks, the field remains fragmented, lacking a unified theoretical foundation and consistent methodological standards. This study addresses these gaps through a bibliometric analysis of 688 peer-reviewed articles published between 2001 and 2025, retrieved from Scopus and Web of Science. The analysis explores the evolution of scholarly production, identifies the intellectual roots of the field, such as the Resource-Based View, Dynamic Capabilities, and Absorptive Capacity, and maps the conceptual structure around key themes including open innovation, green and sustainable innovation, human capital, and knowledge management. The findings reveal a growing but dispersed research landscape, characterized by weak citation networks and parallel, often disconnected, research trajectories. Beyond describing the structural properties of the field, the study highlights the emergence of distinct thematic clusters aligned with different strategic and organizational perspectives. While this diversity reflects the complexity of innovation itself, it also underscores the need for more integrative and context-sensitive approaches to innovation measurement. By offering a comprehensive and data-driven overview of the literature, this study lays the groundwork for a forthcoming systematic literature review aimed at consolidating existing knowledge and supporting the development of robust, multidimensional frameworks. The results offer theoretical insights for advancing the field and practical implications for managers and policymakers seeking more effective tools to evaluate and guide innovation efforts.

Keywords: Innovation, Innovation metrics, Measure, Bibliometric analysis

Paper type: Academic Research Paper

1 Introduction

In a rapidly evolving and competitive global landscape, organizations are under increasing pressure to innovate in order to remain relevant and achieve sustainable growth (Bolaji Bello and Adeoye, 2018). Yet, innovation is not a linear process - it is inherently uncertain and difficult to measure (Fanousse et al., 2021; Jalonen, 2011). Unlike traditional business functions that benefit from standardized performance indicators, innovation is deeply tied to creativity, experimentation, and risk-taking, making its evaluation particularly challenging (Adams et al., 2006).

Innovation encompasses both the ideation of novel products, services, processes, or business models, and their successful implementation within volatile markets (Kerzner, 2022). This dual nature amplifies the complexity of assessing the effectiveness and outcomes of innovation projects. While management literature offers numerous frameworks to guide firms through VUCA (Volatility, Uncertainty, Complexity, Ambiguity) conditions (Ngo et al., 2022), the absence of consolidated, systematic methodologies for measuring innovation remains a critical gap (Idris and Durmuşoğlu, 2021).

Despite the proliferation of indicators - ranging from R&D investment and time-to-market to idea-generation programs and employee rewards - most metrics either neglect the human dimension of innovation or fail to capture the broader organizational context in which it occurs (Moreira et al., 2024). Others, instead, focus solely on perceptions and soft dimensions, offering limited insight into measurable outcomes (Ngo et al., 2022). Moreover, human and financial aspects are frequently examined in isolation, despite their strong interdependence in shaping innovative performance (Fonseca et al., 2019; Sun et al., 2020).

A further source of concern is the high failure rate of innovation initiatives. According to (Cooper, 2019), only one out of every 7–10 innovation projects achieves commercial success, with nearly 40% failing at launch. This striking statistic underscores the need to critically reassess how innovation is measured and whether the metrics currently adopted by organizations are adequate for capturing its true impact.

This paper seeks to address this gap by offering a critical overview of the metrics used in the evaluation of innovation initiatives. Through a bibliometric analysis of literature retrieved from Scopus and Web of Science databases, the study aims to: highlight the limitations and areas of fragmentation of the key metrics currently used in both academic and business contexts, and uncover the intellectual and thematic foundations that underpin the field of innovation measurement.

By doing so, the paper provides an initial mapping of the field, which will serve as a foundation for a forthcoming systematic literature review (SLR) aimed at developing a comprehensive and actionable framework of innovation metrics.

The paper is structured as follow: Section 2 reviews the existing literature on innovation measurement; Section 3 describes the bibliometric methodology and data collection process; Section 4 presents and interprets the results; Section 5 discusses concludes the study with the practical implications, limitations, and directions for future research.

2 Related works

Innovation is widely recognized as a key driver of competitive advantage. It is generally defined as the implementation of new or significantly improved products, processes, marketing methods, or organizational practices aimed at creating value (Chirichiello et al., 2023). (Rogers, 2003) highlights the subjective dimension of innovation, defining it as "an idea, practice, or object perceived as new by an individual or other unit of adoption." Over the years, innovation has evolved from being seen as an internal, linear process to a more dynamic and open one. (Chesbrough, 2003) introduced the concept of Open Innovation, emphasizing the importance of knowledge flows across organizational boundaries to accelerate innovation and increase its impact.

Commonly used metrics include R&D expenditure, number of patents, time-to-market, and new product revenues (Adams et al., 2006; Cooper, 2019). These indicators, however, often focus on tangible outputs and overlook the complexity of innovation as a socially constructed, context-dependent phenomenon (Edison et al., 2013). A distinction is often made between input metrics (e.g., investment, resources), process metrics (e.g., idea generation, collaboration), and output metrics (e.g., revenue, customer satisfaction). Yet, many of these are rooted in linear innovation models, which do not fully reflect the iterative and uncertain nature of innovation in contemporary settings (Manimala et al., 2005).

Several authors have highlighted the limitations of existing approaches. For example, (Edison et al., 2013) criticize the lack of empirical validation and practical applicability of many proposed metrics. (Ngo et al., 2022) emphasize that innovation cannot be adequately measured without integrating organizational culture, employee engagement, and learning capacity. Meanwhile, (Moreira et al., 2024) point out that innovation performance is strongly affected by sectoral and organizational specificities, making cross-comparison problematic. Some contributions attempt to broaden the scope by including human-centric dimensions such as knowledge flows, cognitive diversity, and leadership style (Fonseca et al., 2019). Others adopt a more strategic perspective, linking innovation measurement to value creation, market positioning, or dynamic capabilities (Teece et al., 1997). Still, a comprehensive and widely adopted framework is lacking.

3 Methodology

This study adopts an advanced bibliometric approach, combining well-established practices from the relevant literature (Donthu et al., 2021; Marzi et al., 2025) with original procedures for data cleaning, normalization, and integration, inspired by recent methods for merging heterogeneous databases (Caputo and Kargina, 2022).

The entire methodological process - integrating automated analytical tools with targeted corrective actions - was designed to maximize the quality, consistency, and replicability of the study, thereby providing a solid foundation for future theoretical and empirical research in the field of human competencies and data-driven transformation.

3.1 Explorative and definition phase

The initial phase of the study consisted of an exploratory literature review aimed at outlining the theoretical foundations of the research context. During this stage, the concept of innovation was examined in depth, and the scope of the investigation was defined. Specifically, the decision was made to focus on the tracking and evaluation of innovation within large enterprises operating in the IT and ICT sectors. The guiding question of this study is: *What are the metrics and/or KPIs used in large companies operating in the ICT sector to quantify and measure the impact of innovation on the organization?*

Once the research scope was established, it was possible to identify the relevant keywords for building a structured query to search the Scopus and Web of Science databases. The objective was to retrieve a corpus of publications that would reflect the current state of the art on the issue raised by the research question. The query employed was as follows:

TITLE-ABS-KEY(("Innovation") W/0 ("project" OR "manag" OR "performance" OR "effectiveness" OR "strateg") AND ("ICT" OR "IT" OR "Information Communications Technolog" OR "Information Technolog*") AND ("KPI" OR "metric*" OR "measur*" OR "quatif*" OR "evaluat*" OR "assess*" OR "maturity") AND NOT ("small medium entreprise*" OR "SME")).*

The search was restricted to English-language publications and to peer-reviewed journal and conference articles, to ensure a higher level of data quality. The databases were queried in April 2025, yielding 491 documents from Scopus and 301 from Web of Science.

3.2 Data extraction and preparation

Once the search strategy was defined, bibliographic files in *.bib* format were downloaded from Scopus and Web of Science, then converted to *.xlsx* using the Bibliometrix package in R. This initial manipulation enabled data format standardization, but also revealed significant discrepancies due to internal encoding errors in Scopus, such as duplicated values in descriptive fields.

To identify these anomalies, a systematic comparison was conducted between the original Scopus dataset and the Bibliometrix-generated version. Subsequently, a dedicated Python script was used to re-encode Scopus references according to the Web of Science standard. However, in cases involving non-English records or incomplete fields, the script proved ineffective. In such cases, manual correction was performed, assisted by a generative language model (GPT-4o), to ensure consistent reference formatting.

After reintegrating data partially excluded by the automated process, the two datasets were merged. Following the merger, duplicate entries were removed, resulting in a corpus of 688 documents.

3.3 Bibliometric analysis

Bibliometric analysis was chosen as it is a rigorous quantitative method used to explore and analyse large volumes of scientific data. It enables researchers to trace the evolutionary nuances of a specific field and to identify emerging areas of inquiry. This method is particularly effective when the scope of the review is broad and the dataset too extensive for manual analysis. Bibliometric analysis employs quantitative techniques such as performance analysis and science mapping to examine the contributions of research components and the relationships among them. It represents a powerful tool for deciphering and mapping cumulative scientific knowledge, providing a solid foundation for advancing established research domains in meaningful and innovative ways (Donthu et al., 2021). Various software tools are available for conducting bibliometric analyses, including Gephi, Leximancer, and VOSviewer. In this study, we used the Bibliometrix package for R.

The analysis was carried out on three main levels. First, a descriptive analysis was conducted, which included the temporal distribution of documents, global and local citation frequencies, keyword analysis, dominant affiliations, and the identification of the most productive and most cited authors. Bradford's Law and Lotka's Law were applied to assess the distribution of scientific productivity. Next, attention was given to the conceptual structure of the literature, analysed through factorial analysis (correspondence analysis) and co-occurrence networks. Finally, to explore the intellectual structure of the field, a co-citation network and a historiographic mapping were produced, with the aim of highlighting foundational works and tracing the historical trajectories of research in the domain of innovation measurement.

4 Results and discussion

This section presents and interprets the main findings of the bibliometric analysis conducted on a corpus of 688 scientific articles focused on the measurement of innovation impact within large corporations. The analysis pursues a dual objective: on one hand, to describe the quantitative and qualitative evolution of scholarly production in the selected domain; on the other, to reconstruct the intellectual and conceptual structures that underpin its theoretical development. The results are organized into three analytical dimensions: (i) Descriptive analysis, which provides an overview of the corpus' general characteristics; (ii) Intellectual structure, which identifies the theoretical foundations and most influential contributions; (iii) Conceptual structure, which explores the thematic organization and the evolutionary trajectory of key topics in the field.

The integration of quantitative techniques with theoretical interpretation allows for a robust and replicable mapping of the state of the art, shedding light on both consolidated knowledge and emerging trends in the domain of innovation measurement.

4.1 Descriptive analysis

The documents in the dataset span a time period from 2001 to 2025. An analysis of the annual scientific production (Figure 1, line blue) reveals notable increases in publication volume during two distinct intervals: 2017–2019 and 2021–2023. These surges may reflect a growing interest in the measurement of innovation performance within large corporations, particularly in response to the acceleration of digital transformation and the need for strategic evaluation tools in the ICT sector.

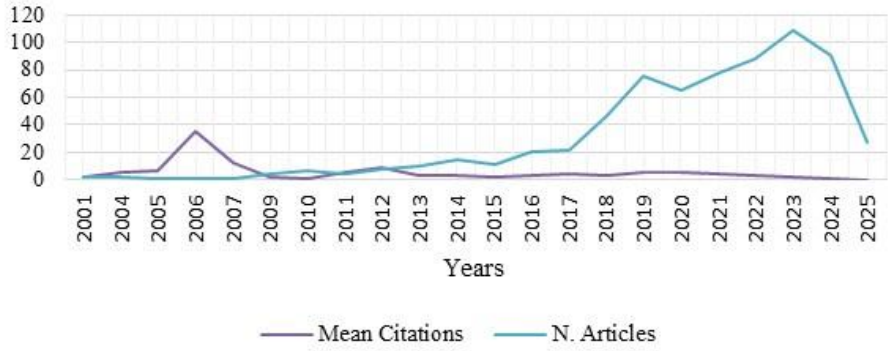


Figure 1 Annual scientific production and annual mean citations

The documents in the dataset exhibit an average of 23 citations per publication. An examination of the temporal distribution of average citations per year (Figure 1, line purple) reveals a pattern marked by several prominent peaks. These citation spikes suggest that, in specific years, foundational or highly influential papers were published, which have significantly shaped the intellectual development of the field under investigation.

A comparison of the temporal trends in publication volume and citation frequency reveals two distinct patterns of scientific output. In the first decade (2001–2010), publication volume remained relatively stable, yet the presence of multiple citation peaks suggests the production of high-impact contributions. In contrast, the most recent years show a sharp increase in the number of publications, accompanied by a decrease in average citations per article. Several factors may account for this shift:

- As the number of papers has increased, the topic has become more specialized, leading to the publication of narrower studies with a more limited readership and, consequently, fewer citations;
- More recent papers may have had less time to gain visibility and accumulate citations compared to earlier publications.

A closer examination of the most pronounced citation peaks shows that the highest spikes occurred in years when only one or two papers were published. These documents are likely to represent either intellectual cornerstones or foundational reviews in the field. Additionally, the relatively low publication volume during the first decade may indicate that those early studies formed the theoretical groundwork for the subsequent literature.

Based on this evidence, we hypothesize that the intellectual core of the dataset was established between 2004 and 2007, with a secondary wave of potentially significant contributions emerging in 2012.

Subsequently, the scientific sources that published the articles included in the dataset were analysed (Figure 2). Among the most prolific journals in this context are: Sustainability (Switzerland), IEEE Access, Marketing and Management of Innovations, Technovation, Technological Forecasting and Social Change, Journal of Innovation and Entrepreneurship, Administrative Sciences, Applied Mathematics and Nonlinear Sciences, IEEE Transactions on Engineering Management. As for the most frequently cited sources, the leading journals include: Research Policy, Strategic Manage Journal, Journal of Product Innovation Management, Technovation, Journal of Business Research, Technological Forecasting and Social Change, Academy of Management Journal, Industrial Marketing Management, MIS Quarterly, R&D Management. It is noteworthy that many of the top-cited journals also appear among the most productive ones. This overlap suggests that the topic under investigation is largely concentrated within a relatively small number of highly specialized and authoritative sources.

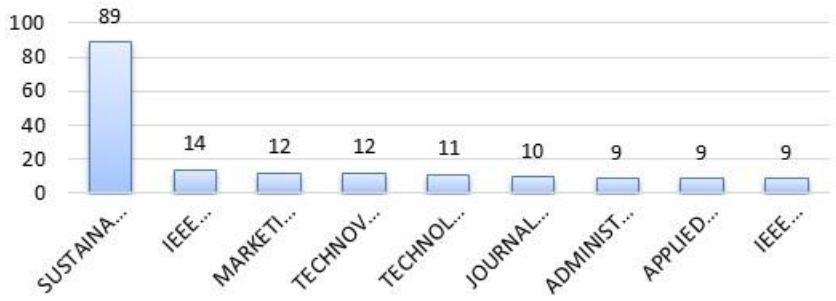


Figure 2 Most relevant sources

The temporal evolution of the most active journals (Figure 3) reveals a notable shift in publishing leadership. Until 2019, Technovation was the dominant outlet for publications on the topic; however, from 2020 onwards, Sustainability (Switzerland) has emerged as the leading source. This trend may suggest that the field is becoming increasingly interdisciplinary, with innovation-related research appearing more frequently in journals with a broader thematic scope. Moreover, the growing prominence of Sustainability may reflect a conceptual expansion of innovation to include sustainability-related dimensions. In recent years, there has been a notable rise in scholarly interest in topics such as green innovation and sustainable innovation, signaling a shift toward more socially and environmentally conscious interpretations of innovative processes.

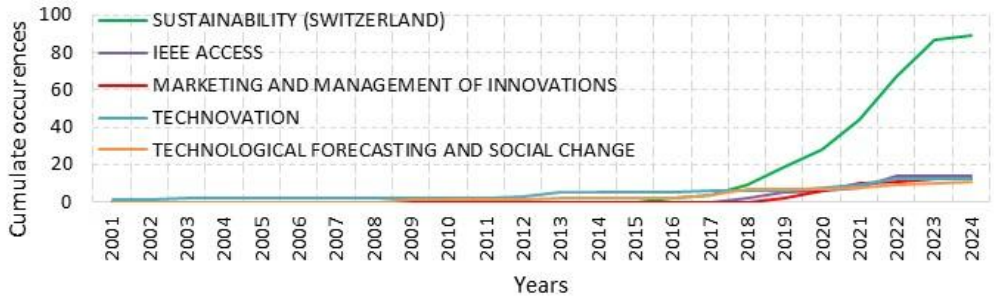


Figure 3 Sources dynamics over the time.

Finally, Bradford's Law was applied to assess the distribution of articles on the topic across scientific journals. This foundational bibliometric principle posits that a relatively small core of journals publishes the majority of relevant articles on a given subject, while the remaining articles are scattered across a larger number of less productive journals (Bradford, 1934). The law is particularly useful for identifying "core journals" within any scientific field. The results of the analysis (Figure 4) confirm this hypothesis: a small group of journals appears to be concentrating most of the scholarly output on innovation measurement in large corporations. Specifically, 33% of the documents in the dataset were published in the set of journals identified as the most relevant in terms of productivity.

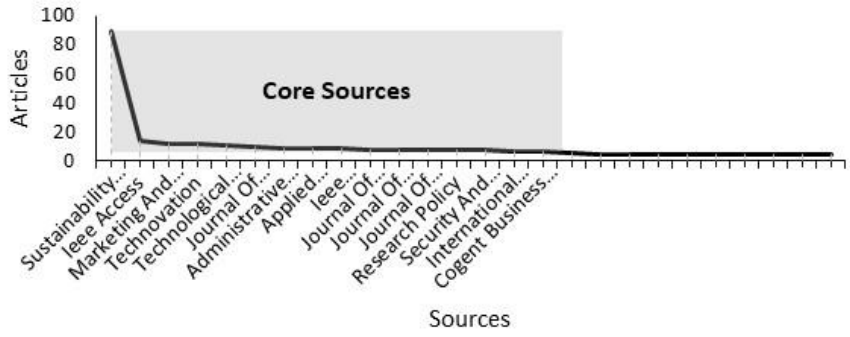


Figure 4 Bradford's Law.

The author profile was also examined in terms of individual productivity. The Table 1 presents the top 3 authors with the highest number of publications. It is worth noting that the overall number of papers per author

is relatively low, and aside from the top three contributors, the remaining authors exhibit similar publication counts. This pattern suggests that the dataset is composed largely of sporadic contributors, with only a limited number of authors consistently focused on the topic. Furthermore, when considering the fractionalized publication count - which accounts for each author's contribution to co-authored papers - a more nuanced picture emerges. The variability in fractional contributions indicates a dynamic and evolving scholarly community, characterized by diverse levels of engagement and collaboration within the field. It is important to note that this indicator does not assess the quality of the contribution, but it serves as a useful quantitative proxy for identifying the main contributors to the body of literature.

Table 1 The most relevant authors

Authors	Articles	Articles Fractionalized
Wang Y.	9	4,17
Zhang Y.	7	2,50
Zhang H.	6	2,92

This assumption is further supported by the application of Lotka's Law, a fundamental principle in bibliometrics that describes the distribution of scientific productivity among authors. According to this law, a small number of authors are responsible for the majority of publications, while most researchers contribute only a single work. This pattern is typically observed as an inverse relationship between the number of authors and the number of papers they (Lotka, 1926). The analysis confirms this pattern: 97% of the authors in the dataset have published at most two papers on the topic. The remaining authors - those with between three and nine publications - can be considered the "core authors" of the corpus, reflecting a small but active group of contributors driving research in this area.

An analysis of author productivity over time reveals that Frishammar J. has contributed consistently to the literature throughout the years. In contrast, the remaining top authors have published a significant number of papers primarily within the last two years. This trend suggests that the most productive segment of the academic community in the field of innovation measurement is relatively young and still in the process of establishing itself.

Finally, the analysis of the co-authorship network among the core authors (Figure 5) reveals a structured configuration composed of six distinct clusters. A dominant cluster (highlighted in red) includes the most prolific authors, while the remaining clusters are characterized by strong internal connections, as indicated by the thicker edges between nodes. Notably, the clusters appear to be disconnected from one another, with no inter-cluster links. This pattern suggests that, despite the presence of a central group of productive authors, scientific output in this field occurs within relatively independent research groups. Such fragmentation points to a scholarly community that is still in the process of consolidation.

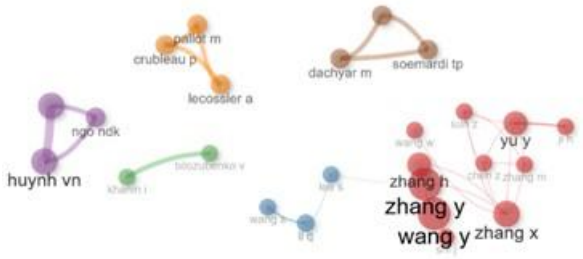


Figure 1 Co-authorship network of the core authors

4.2 Intellectual Structure

For reconstruct the intellectual structure of the dataset, the cited documents of the selected articles were analysed. In this context, it is important to distinguish between global citations, which refer to the number of times a paper is cited across the entire bibliographic database, and local citations, which indicate how often a paper is cited by other documents within the analysed dataset. Focusing on the most globally cited papers (Figure 6), three key articles stand out in the field of innovation measurement, each for distinct yet converging reasons. First, (Benitez et al., 2020) is one of the most authoritative contributions on methodology, particularly relevant for scholars employing PLS-PM models in quantitative innovation studies. The article is widely cited for providing a rigorous and updated guide to applying these methods in both confirmatory and exploratory contexts. Second, the work of (Adams et al., 2006) laid the foundation for a systemic measurement framework,

addressing a critical theoretical gap in a literature that had previously been fragmented and largely dominated by output-based approaches. Their classification into seven metric categories has made the paper a methodological cornerstone for both academic researchers and practitioners. Finally, (Amui et al., 2017) has gained significant visibility by proposing a systematic research agenda for sustainable innovation, conceptualizing sustainability as a dynamic capability. In an era where environmental and social dimensions are increasingly central to innovation processes, this work has become a key theoretical and methodological reference for future studies.

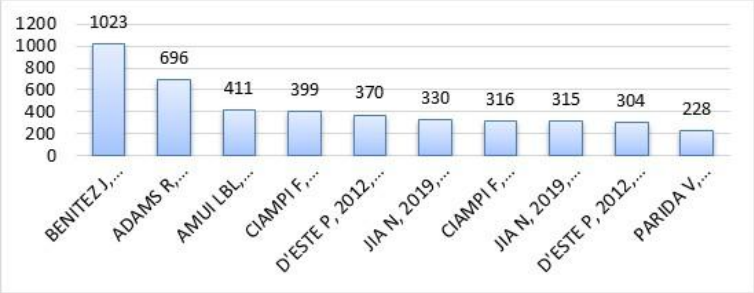


Figure 6 Most global cited documents.

An analysis of the most locally cited references reveals the intellectual foundations of innovation measurement. Among the most frequently cited contributions within the dataset are the works of (Barney, 1991; Cohen and Levinthal, 1990; Fornell and Larcker, 1981; Teece et al., 1997). The concept of absorptive capacity, introduced by (Cohen and Levinthal, 1990) , is central to understanding how firms develop the ability to acquire, assimilate, and exploit external knowledge - key drivers of innovation that can be indirectly measured through R&D investments and knowledge accumulation processes. , with the formulation of the resource-based view (RBV), reshaped the understanding of intangible resources and internal competencies as strategic assets, thus making them central to evaluation models of innovation performance. Building on this, (Teece et al., 1997) introduced the framework of dynamic capabilities, which refers to the organizational abilities required to reconfigure resources in rapidly changing environments. This perspective provides a useful foundation for viewing innovation as an evolutionary and adaptive process, subject to measurement through organizational responsiveness. Lastly, the contribution of (Fornell and Larcker, 1981) is critical from a methodological standpoint. Their statistical tools for assessing the validity of latent constructs have become essential in the development of robust quantitative models for measuring innovation capabilities.

To explore the relationships among the most influential references, a co-citation network was constructed (Figure 7). Co-citation analysis is a bibliometric technique that identifies how often two documents are cited together within the selected dataset (Small, 1973). This method reveals underlying thematic connections between works and provides insight into the intellectual structure of a research field. The resulting co-citation network highlights four main thematic clusters, each reflecting distinct theoretical and methodological perspectives on innovation measurement. The blue cluster groups contributions related to the resource-based view and dynamic capabilities, with a strong emphasis on empirical measurement and construct validation (e.g. (Barney, 1991; Fornell and Larcker, 1981; Teece et al., 1997)). The red cluster is focused on innovation management, including works on open innovation and dynamic strategies in uncertain environments (e.g. (Chesbrough, 2003)). The purple cluster, dominated by (Cohen and Levinthal, 1990) , focuses on absorptive capacity, knowledge search, and organizational learning processes. Finally, the green cluster comprises classical contributions from the economics of innovation, with a focus on the relationship between R&D, productivity, and technological progress (e. g. (Nelson and Winter, 1982)).

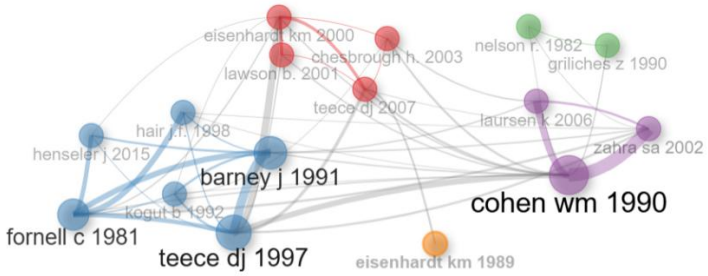


Figure 7 Co-citation networks.

4.3 Conceptual Structure

To reconstruct the conceptual structure of the dataset, a semantic network was built based on the keywords provided by the authors. The analysis began with the identification of the most frequently occurring keywords, excluding those already used in the search query. As illustrated by the word cloud (Figure) , the dominant terms align with the intellectual foundations previously identified. Notable keywords include *open innovation*, *absorptive capacity*, and *dynamic capability* - all of which reflect established theoretical frameworks. A distinction also emerges between *product* and *service innovation*, suggesting different domains of application. References to enabling technologies are evident through terms such as *technological innovation* and *digital transformation*, while the growing relevance of *sustainability* is also prominently featured.



Figure 8 Wordcloud of the most relevant author index.

To obtain a more structured view of the semantic relationships, a factorial analysis of the keywords was conducted (Figure). This statistical technique reduces the dimensionality of the data while preserving key information. In this case, correspondence analysis was applied, followed by dendrogram cutting to identify three distinct thematic clusters.

- The blue cluster, denser and more central, focuses on sustainable and collaborative innovation, encompassing terms such as *sustainable development*, *circular economy*, and *knowledge management*. This suggests a systemic and institutional orientation in the literature.
- The green cluster, centered on *green innovation*, appears more isolated, indicating a technical and sector-specific approach that is treated somewhat independently from the rest of the discourse.
- The red cluster links *absorptive capacity*, *human capital*, and *social capital*, highlighting a micro-organizational perspective focused on learning processes and intangible resources as key drivers of innovation.

The distances between the cluster poles reflect conceptual divergence and limited co-occurrence, suggesting the presence of parallel but relatively unintegrated thematic lines within the broader domain of innovation measurement.

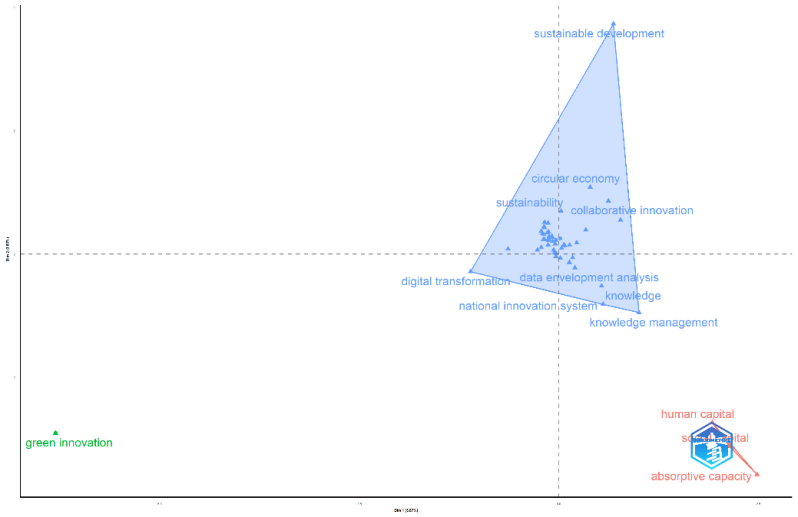


Figure 9 Factorial analysis of the articles in relation of the keyword co-occurrences.

To complete the analysis and observe how thematic dimensions have evolved over time and within the literature, a historiographic map was generated. This type of visualization, built on direct citation links between documents, enables the identification of citation flows along a chronological axis. In the graph, nodes represent individual publications, while edges indicate citation connections between them. The scientific community appears highly fragmented both in terms of citations - where only a few central references emerge (notably (Adams et al., 2006; Cormican and O'Sullivan, 2004)) and in terms of conceptual coherence, with many recent works showing limited interconnectivity. The dispersed layout of nodes, the absence of compact clusters, and the low thematic overlap all confirm the findings from the previous semantic analysis: the field remains heterogeneous, characterized by parallel and often non-communicating research trajectories. This structure suggests that the domain is still undergoing theoretical consolidation, marked by a plurality of approaches and the absence of a dominant paradigm.

5 Conclusions

This bibliometric study mapped the evolution of research on innovation measurement in large ICT and IT firms, analyzing a corpus of 688 scientific articles. Results highlight a fragmented but expanding field. The intellectual structure of the field is grounded in theories such as the Resource-Based View, Dynamic Capabilities, and Absorptive Capacity, while the conceptual structure is shaped by recurring themes including open innovation, sustainability, green innovation, and human capital.

From a practical standpoint, this fragmentation poses challenges for organizations seeking robust and consistent innovation metrics. Still, the emergence of distinct conceptual clusters offers guidance for tailoring measurement approaches to different strategic priorities, such as environmental impact, knowledge management, or organizational learning. The main limitation of this analysis lies in the heterogeneity and early-stage consolidation of the field. Future research should aim to synthesize these diverse contributions into integrative frameworks that combine strategic, technological, and human dimensions of innovation measurement.

6 Ethics declaration

The study is a bibliometric analysis conducted on data already publicly available in the literature and electronic databases; neither human nor animal subjects were involved, and therefore no ethics committee approval or informed consent is required.

7 AI declaration

In the preparation of this manuscript, the authors used GPT-4 to automate the coding and formatting of bibliographic references into the specific schema required by the bibliometric analysis platform. Unformatted reference lists were provided as input to the model, and its outputs were then meticulously reviewed, edited for accuracy, and approved by the authors prior to inclusion in the final dataset. No other content generation or interpretative analyses were performed by the AI tool, and all substantive intellectual contributions and decisions remain the sole responsibility of the authors.

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Sustainability Maturity Models in the Context of Quality Management

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Abstract

Given the dynamic changes in the regulatory environment, doing business in a global network (e.g. shipbuilding network) and the increasing use of voluntary certifications and standards, companies need effective tools to monitor and make continuous improvement. A maturity model for cruise shipbuilding network from a quality management and sustainability point of view is the focus of this article. Our research question is: What quality management maturity models, that take sustainability into account in supply network context, can be identified in the literature? This is work in progress as we are developing the maturity model structure searching performance theme areas and key performance indicators for the cruise ship building network. This article is based on a preliminary literature review with themes related to quality management and sustainability. Literature was collected from Scopus AI database in January 2025. The challenge is to develop a maturity model for the network context as the most of the articles are focused on one company maturity perspective.

Keywords: maturity model, sustainability, network, performance, review

Paper type: Research Paper

1 Introduction

Given the dynamic changes in the regulatory environment (Voroniuk 2024), doing business in a global network (e.g. shipbuilding network Chircop 2022) and the increasing use of voluntary certifications and standards, companies need effective tools to monitor and make continuous improvement. The construction of a cruise ship takes place in a large network of actors, where the activities of the different actors should be tuned to achieve a common goal. Practical tools are needed to develop the quality of networked activities in order to achieve sustainable development goals (Trisnawati & Pujaman 2021). Development process of a maturity model (Paulk 2009; Sorsa 2009) for cruise shipbuilding network (Aramo-Immonen 2024; Saarni et al. 2019) from a quality management (Negron 2020) and sustainability point of view is the focus of this article. Our research question is: What quality management maturity models that take sustainability into account in supply network context can be identified in the literature?

The motivation to develop a maturity model is based on the fact that all actors in the shipbuilding network should be made to follow the principles of responsible business conduct in order to improve the competitiveness of the Finnish cruise shipbuilding in the global market. This objective is enshrined in the Finnish shipbuilding Necoleap research project.

Our aim is to use the maturity model to improve proactive management capabilities to make the network more competitive in a tough regulatory environment (see eg. SCOR 2025). The maturity model will be developed together with the six participating companies during 2025. The aim of the S4M study is to create a model that will be applicable to the entire shipbuilding industry after this pilot project. The research team is made up of researchers from different disciplines, which poses challenges for building a common understanding, but also allows for innovative ideas to be developed.

Cruise ship can be described as a vessel whose sole purpose is to entertain passengers and provide comfort to the ship's owners (Aarnio 2022). Cruise ship construction is part of an international network of materials and services, where suppliers work within their own regulatory environment complying different kind of requirements for the raw materials – some strict environmental requirements some lower level ones. However, the quality of the materials used in the shipbuilding is important for the final product, the cruise ship, as the final customers' expectations needs to be filled. Therefore, the shipyard must ensure the total quality of the cruise ship produced in the network, considering the whole life cycle of the ship.

The quality requirements of a cruise ship are determined primarily by the mandatory law's regulating safety issues for raw materials and the requirements for reducing emissions during operation (EC 2023) and non-mandatory industry guidelines and voluntary standards. In a broad sense, the concept of quality can be seen as encompassing not only the quality requirements of the product characteristics themselves, but also environmental, social, and economic aspects of the products (see e.g. Estampe et al. 2013) and also the quality of the production and trading processes. The level of quality produced by the network is as good as the weakest

link in the network and therefore managing the quality aspects during the whole value creating chain becomes crucial task from shipbuilding company's viewpoint (Ramirez-Peña et al. 2019).

Given that the supply chain is a key factor in all kinds of change, and at the same time it also serves as a monitoring tool for implementing improvements (Ramirez-Peña et al 2019), development of the management tools from network perspective is needed. Also, the integration of responsibility into product, service and process quality increases the need to develop quality management tools and processes with the companies involved in the S4M research project for the context of international supply chains (Ramirez-Peña et al. 2019; Trisnawati 2021; Wagir et al. 2020.) Estampe et al. (2013) correctly argue, that monitoring and assessing the performance of the value chain is complex task, partly because it is a multidisciplinary process involving many actors working together to achieve specific logistical and strategic objectives. However, they emphasize, that such assessments are particularly important in situations where supply chains are considered to be a key factor in the success of the business. That is exactly the case in cruise-ship building process.

The purpose of this study is to critically review, through a literature review, the achievements of previous authors on the integration of CSR and quality in corporate behaviour from a network level point of view. In particular, the article seeks to answer the following research question: Which topics (functions, areas, processes) were of interest to the authors who combined quality, CSR issues and maturity assessment in the industry networks?

2 Literature review

One tool for analysing company performance is the maturity model, which is based on organizational maturity theory (Crosby 1979). The purpose of the maturity model is to serve as a tool for analysing the current situation and as a compass, a guide to the direction in which the company should develop its operations (Chrissis et al. 2011; Harmon 2009). Since maturity, which is concerned with process development, is related to the functioning of the whole organization, it should be measured at the organizational level. For this reason, many researchers (Brache 2002; Kodama 2019; Piwowar-Sulej et al. 2022; Clapham 2024) have advocated taking a holistic view of management. Also, authors who have studied CSR maturity have focused their reflections on some specific areas of corporate activity, such as information technology, operational management, supply management, product design and project management, and examined maturity in these limited contexts (Piwowar-Sulej et al. 2022).

However, integrating sustainability requirements into the whole network's practices requires an assessment of performance at the level of the whole network of actors and, not only at an organizational level. Also, it is needed to find out the key performance areas for development, which are relevant for the competitiveness point of view for the network. In order to reveal this, we conducted literature review in 23rd of January 2025, keywords were searched using the Scopus AI database. Into topics box following keywords were submitted: maturity model sustainability quality network.

The AI assistant gave us the following search string; ("maturity model" OR "development framework" OR "assessment framework") AND ("sustainability" OR "sustainable" OR "eco-friendly" OR "green") AND ("quality networks" OR "quality systems" OR "quality management" OR "quality assurance") AND ("performance" OR "evaluation" OR "measurement" OR "improvement"). After that the search string was used as the search string in Scopus database. Scopus found 31 documents between 1998 and 2024. We included only articles written in English and framed out other literature. We resulted to 17 peer reviewed articles. After reading these 17 article abstracts we included 8 articles to final selection. Inclusion criteria was context based (Table 1.).

Table 1. Findings from literature review

Authors	**Context**	**Quality concept**	**Sustainability concept**	**Business sector**	**Framework proposed**
Cubo, C. et al. (2023)	supply chain	continuous improvement of complex system with mandy processes	environmental, social and economic sustainability	NA	Supply chain quality management maturity model (SCQMMM)
Dasgupta, R., Ghosh, S.K. and Mukhopadhyay, A.R. (2024)	organization	NA	NA	manufacturing industries	a comprehensive framework for improving operational performance and sustainability

Authors	Context	Quality concept	Sustainability concept	Business sector	Framework proposed
Glogovac, M., Ruso, J. and Maricic, M. (2022)	organization	ISO 9001	NA	manufacturing industries	ISO 9004 for the development of Quality 4.0
North, N. and Coetzee, M. (2022)	organization	NA	NA	education	The Capability Maturity Model for establishing nursing education programmes
Nunhes, T.V., Ferreira Motta, L.C. and de Oliveira, O.J. (2016)	organization	the integration of quality management, environment and security	environmental, social and economic sustainability	puplishing sector	An Integrated Management System (IMS)
Saputra, M.R.Y., Winarno, W.W. and Shaddiq, S. (2020)	government office, public services	NA	NA	e-governance,	the Capability Maturity Model/Capability Maturity Model Integration (CMM/CMMI)
Scherz, M. et al. (2022)	organization	technical and functional qualities of buildings	environmental, economic, and social	construction industry	a sustainable construction maturity model (SCOMM)

3 Maturity model as an evaluation tool for QM of shipbuilding network

Based on literature review findings we answer to research question: What quality management maturity models, that take sustainability into account in supply network context, can be identified in the literature?

3.1 Regulation as a driver for quality and accountability

The company must demonstrate to stakeholders that it complies with applicable laws, industry standards and the company's own guidelines (Sorsa 2011; Chircop 2022). These offer basic requirements for an organization to be able to deliver quality products and services to the market. Now, as responsibility in all its dimensions (environmental, economic and social) has become part of the quality of products, services and processes and crucial component of the business culture in companies, demonstrating compliance as a minimum and going beyond the requirements of the law has become more challenging than in the past. Therefore, making the efforts of the company visible, is needed.

However, this is not enough, as companies will be required to ensure that also their supply chain from upstream to downstream operates responsibly. Such demands have been made by various stakeholders for a couple of decades (Sorsa 2011) and the pressure on companies has increased. Hundreds of voluntary certification schemes have been developed to help companies prove their sustainability (UNCTAD 2024). Many ISO organizational standards also help companies to implement and monitor quality and responsible business practices (Mahachandra 2021; Chircop 2022; Voroniuk 2024). These voluntary schemes become binding standards for the contracting parties by being incorporated into the terms of procurement contracts. This will enable large companies to contribute to the sustainability of their supply chains proactively (Sorsa 2009; Sorsa _ Salmi-Tolonen 2021; Saloranta & Hurmerinta-Haanpää 2022

Recently, new European Union regulations will make these verification requirements mandatory for large companies in the future. On 23 February 2022, the European Commission published a proposal for a Directive on corporate social responsibility, which would impose due diligence obligations on companies of a certain size in their value chains. The Directive was published in the Official Journal on 5 July 2024 and entered into force on 25 July 2024. Member States have two years after the adoption of the Directive to transpose the new rules into national law.

In summary: Both public and private regulation is increasingly pushing companies to act more responsibly. In the same direction, there is pressure from various stakeholders. To meet these challenges, companies should develop and be able to continuously demonstrate that they operate in compliance with legislation and voluntary commitments and are even able to create a competitive advantage for themselves in this environment, together with a network of companies.

3.2 Regulation as a driver for quality and accountability

Around a thousand companies are involved in the construction of the cruise ship, with a few of them having a long-term partnership with the shipyard. It could be called a strategic alliance or strategic partnership depending on how independent the collaborating companies are. In other industries, such as automotive and aviation, strategic partnerships have been used as a business model. Researchers recommend that the potential of strategic partnerships should also be exploited in other industries.

We therefore suggest that the findings from studies on strategic partnerships, for example in maturity models from the collaboration point of view, will help to develop a network-level maturity model for the shipbuilding network on a certain performance theme area, e.g. quality. According to Roshandel et al. (2025), there is a research gap for the strategic alliances. The difference between a strategic alliance and a strategic partnership is that in an alliance, the members do not have a legal stake in each other's shares. Instead, members align their objectives with each other by making commitments while maintaining their independence. Strategic alliances are well established as a suitable form of organisation and an important means of implementing strategies. In many industries, complexity and uncertainty have increased to the point where it is no longer possible to act independently. According to Rosendahl et al., strategic alliances can create a range of benefits for participating firms, such as access to new technologies and complementary skills, economies of scale and risk reduction.

4 Discussion

From the eight selected articles, only Cubo et al. (2023) article discussed maturity model from supply network point of view integrating theorical approaches of supply chain management and quality management. They indentified five dimensions as common dimensions to both SCM and QM, supporting the integration concept of supply chain quality management. Their quality concept was broad: they see “the whole organization as a complex system with many processes and mutual relationships that have to be managed and continuously improved” (Cubo et la. 2023). The sustainability concept covered all aspects of sustainability (environmental, social and economic) and organization was seen in continuous relationship with society, environment and the local and national economy. Cubo et al. (2023) final SCQMMM consist of five performance theme areas, which they call the main dimensions of the SCQMMM: (1) Organizational Performance, (2) Quality Management, (3) Information Management, (4) Supply Chain Integration, and (5) Sustainability According to Cubo et al., (2023) a higher maturity level of the sustainability dimension indicates that the principles of the three bottom-line dimensions are better respected, i.e. the network is able to demonstrate its responsibility towards stakeholders and society. The levels described in Cubo et al. article are: Ad hoc, Basic, Intermediate, Advanced and Mature. Cubo et al. (2023) aimed to develop a maturity model that integrates quality management throughout SC, thus promoting and improving organisational performance from an integrated and sustainable perspective.

Scherz et al. (2022) examined the reality of the construction industry, where increasing sustainability requirements in the construction industry have repeatedly led to project delays and increased project costs in practice. In shipbuilding, the problems are similar and the need to consider sustainability criteria already at the design stage is important for the competitiveness of the industry. The results of Sherz et al. (2022) show that the systemic interactions between sustainability criteria can be identified early in the design phase, allowing the quality of design practices to be assessed and early project management to be implemented to achieve the best construction sector’s certification results. Sherz et al. (2022) called their maturity model the Sustainable Construction Maturity Model, which focused on the quality management of planning practices related to the implementation of sustainable construction in an early building design phase. SCOMM includes six levels of capability for assessing design practices and five levels of maturity for measuring the maturity of process areas and overall building quality. The process areas are: environmental quality, economic quality, sociocultural and functional quality, technical quality, process quality, and site quality (Sherz et al. 2022).

According to Dasgupta et al. (2024), achieving quality outcomes “requires meeting the expectations of both external and internal customers through effective requirements analysis and fulfilment of specific quality dimensions. At the same time, organisations need to minimise the use of resources - such as time, energy, labour and materials - while maintaining product quality.” Their quality concept can be interpreted to be broad and sustainability concept more focused on environmental and economic sustainability than on social sustainability.

According to Glogov et al. (2022) it is widely believed that Industry 4.0, the fourth industrial revolution, can significantly improve process performance and innovation in companies. In Industry 4.0, digitalisation and the use of new technologies will transform manufacturing and business models. However, Glogov et al. (2022) argue that most firms are unaware or unable to assess their own level of Industry 4.0 maturity. Since many aspects of Industry 4.0 success include elements of quality management systems, the authors in their article examined the

ISO 9004:2018 guidelines for sustainable success as a possible basis for assessing the level of quality maturity of Industry 4.0.

In three of the articles, the target group for the maturity model or the context were clearly limited to a specific group of experts -one for government office and public services (Saputra et al. 2020) and one for nurse education developers (North and Coetzee 2022) – and one context related article focused on publishing sector (Nunhes et al. 2016), thus providing few clearly applicable development ideas for the shipbuilding supply chain maturity model.

5 Conclusion

Scientific and Managerial Implications: Network level maturity model contributes to understanding the key performance areas needed for the development of competitiveness of the network and at this way this research contributes to the network related scientific research. From managerial point of view, new tools for managers are created to support assessment of sustainability maturity levels in the networks in the context of quality management. Sustainability maturity model could be defined as a sophisticated model of collaboration and a green transition pathway.

Literature review in Scopus database brought up only limited amount of sustainability and quality related maturity model articles. Therefore, we suggest further research on the topic and also sustainability maturity models in connection to digitalization, AI and other technology driven phenomena.

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7 Ethics declaration

The research was carried out in accordance with The Finnish code of conduct for research integrity and procedures for handling alleged violations of research integrity in Finland (2023) and did not involve sensitive data.

8 AI declaration

AI was used for keyword search and DeepDL as a translation tool.

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The Impact of Artificial Intelligence on the Development of Soft Skills: Opportunities and Challenges for Organizations

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Abstract

In the face of accelerating digital transformation, organizations are increasingly recognizing soft skills—such as emotional intelligence, adaptability, communication, and critical thinking—as essential assets for sustained competitiveness and innovation. While Artificial Intelligence (AI) is widely used to automate technical tasks, its emerging role in supporting soft skills development remains underexplored. This study investigates how AI is currently being adopted to enhance soft skill training in organizational contexts, identifying both the strategic opportunities and critical limitations involved. Drawing on a structured survey of 197 Italian firms, the research provides empirical evidence of a positive and statistically significant relationship between AI adoption in training programs and perceived improvements in employees' soft skills. Technologies such as adaptive learning platforms, AI-powered feedback systems, and virtual simulations are increasingly used to personalize learning pathways and support cognitive and relational competencies. However, the study also highlights several challenges, including cultural resistance, ethical concerns, and the risk of reducing complex human skills to measurable behaviors. The findings suggest that AI can serve as a powerful enabler of soft skill development, but only when integrated into human-centered learning models that preserve the experiential, contextual, and social nature of these competencies. By bridging the gap between theoretical discourse and organizational practice, this study contributes to the literature on AI-enabled learning and offers actionable insights for HR professionals and corporate decision-makers. It emphasizes the need for hybrid training ecosystems where machine intelligence augments, rather than substitutes, human interaction and growth.

Keywords: Artificial Intelligence, Soft Skills, Human Capital Development, Organizational Learning

Paper type: Academic research paper

1 Introduction

In the current era of digital transformation, organizations are increasingly challenged to align human capital with rapidly evolving technological landscapes. While much attention has been given to upskilling technical abilities, it is becoming increasingly evident that *soft skills*—including emotional intelligence, adaptability, communication, and critical thinking—remain indispensable for individual and collective performance (Goleman, 1995; Alvarado–Bravo et al., 2024; McKinsey & Company, 2020). These competencies enable workers to navigate complexity, collaborate effectively, and adapt to organizational change—dimensions that are difficult to automate but essential for innovation and sustainability.

Artificial intelligence (AI) is reshaping the way organizations approach skill development. From adaptive learning platforms to emotion-sensitive chatbots and immersive virtual simulations, AI technologies are being deployed to support the training and reinforcement of both cognitive and relational soft skills (Gaggioli et al., 2019; Pérez-Marín et al., 2020; García-Peñalvo et al., 2023). This raises important questions for both research and practice: to what extent can AI tools enhance human capabilities without diminishing the interpersonal and emotional dynamics at the core of soft skills? And how are organizations structuring the integration of these technologies into their learning ecosystems?

The literature suggests a growing recognition of the strategic importance of soft skills in the digital workplace. Cognitive soft skills—such as problem-solving and critical thinking—are particularly relevant in environments where decision-making is data-driven and time-sensitive (Caputo et al., 2019; VanLehn et al., 2017). At the same time, relational soft skills—such as empathy, communication, and emotional regulation—are fundamental for teamwork, leadership, and change management (Brackett, Delaney, & Salovey, 2024; Comelli & De Mitri, 2020).

This study seeks to contribute to this emerging field by investigating how AI is being used to support the development of soft skills within organizations, focusing on both perceived opportunities and critical challenges. Unlike many conceptual or technology-centered approaches, this paper adopts an empirical research design based on a structured survey conducted across a diverse set of organizational contexts. The goal is to identify the current uses, perceptions, and limitations of AI-enabled training for soft skills enhancement, and to explore

whether organizations are moving toward hybrid learning models that integrate human and machine learning dynamics.

In particular, the study aims to answer the following research questions:

- *RQ1: To what extent are organizations currently adopting AI technologies to support the development of soft skills?*
- *RQ2: What are the perceived strengths and limitations of AI tools in enhancing both cognitive and relational soft skills among employees?*
- *RQ3: What trends or patterns can be identified in how organizations are structuring training programs that rely on AI for soft skills development?*

By addressing these questions, the article aims to fill a gap in the literature at the intersection of AI and human resource development. It provides both theoretical insight and practical guidance on the organizational use of AI as a tool to foster not only efficiency, but also human growth and relational intelligence. Ultimately, this research positions AI as a potentially transformative force—not as a replacement for human interaction, but as a facilitator of the ongoing evolution of knowledge assets and workplace competencies. To address these research questions, this study employs a structured, survey-based methodology. A questionnaire was distributed to a random sample of 197 companies operating across diverse sectors and geographical areas in Italy. The survey was designed to collect data on the current use, perceived benefits, and limitations of AI tools for soft skills development. This empirical approach allows for a grounded analysis of organizational practices and perceptions, bridging the gap between theoretical models and real-world implementations.

2 Literature review

2.1. Soft skills in the digital era: strategic importance and classification

In today's knowledge-intensive environments, soft skills are increasingly recognized as essential assets for navigating organizational complexity. Defined as a set of emotional, cognitive, and interpersonal competencies, soft skills include communication, adaptability, empathy, problem-solving, time management, and leadership (Buttolo, 2019; Gilyazova et al., 2021). Unlike hard skills—technical, procedural, or domain-specific competencies—soft skills are transversal and context-dependent, facilitating successful human interaction, decision-making, and adaptability in uncertain environments.

Scholars commonly distinguish between cognitive soft skills—including critical thinking, creativity, and analytical reasoning—and relational soft skills, such as empathy, teamwork, and emotional regulation (Comelli & De Mitri, 2020; Brackett et al., 2024). This distinction reflects the dual nature of soft skills: they operate both internally, supporting personal resilience and reflection, and externally, enabling effective collaboration and communication.

As McKinsey & Company (2020) highlighted in their study on the future of work, soft skills are expected to grow in strategic value as automation continues to absorb technical and routine tasks. In this context, soft skills enable individuals to perform functions that are uniquely human—managing complexity, interpreting emotional cues, and navigating ambiguity.

2.2. Cognitive soft skills and organizational innovation

Cognitive soft skills are closely linked to organizational innovation and problem-solving. These abilities support decision-making under pressure, creative ideation, and agile thinking—essential capabilities in data-rich, dynamic business environments (Caputo et al., 2019). In their analysis of how digital transformation influences organizational performance, Caputo et al., (2019) showed that integrating cognitive skills with Big Data analytics can significantly improve strategic adaptability and competitive positioning.

A growing body of research supports this perspective. For example, Succi and Canovi (2020) demonstrated that graduates with higher levels of critical thinking and complex reasoning are more likely to adapt successfully to changing job demands. Similarly, Rios et al. (2020) found that organizations investing in cognitive training programs report higher innovation rates and employee satisfaction. These findings point to the centrality of cognitive soft skills not only as individual strengths, but as drivers of collective learning and strategic renewal.

Importantly, the integration of AI and data analytics does not diminish the need for human judgment. On the contrary, it elevates the importance of interpretive reasoning and ethical decision-making. As Wilson and Daugherty (2018) argue in their concept of "collaborative intelligence," organizations need to design systems in which humans and machines complement each other—machines offering analytical capabilities, and humans contributing critical reflection, intuition, and contextual insight.

2.3. Relational soft skills and team-based effectiveness

Relational soft skills are foundational to teamwork, leadership, and organizational culture. They foster trust, psychological safety, and motivation—conditions that directly influence employee engagement and performance (Edmondson, 2019). Among these skills, emotional intelligence (EI) plays a pivotal role. Originally conceptualized by Goleman (1995), EI involves the ability to perceive, understand, and regulate emotions in oneself and others. Subsequent research has affirmed EI's value in enhancing negotiation, conflict management, and interpersonal adaptability (Brackett, Delaney, & Salovey, 2024).

In work environments increasingly characterized by remote collaboration, asynchronous communication, and intercultural interactions, relational skills are more critical than ever. Moschera (2018) emphasizes that communication is not merely verbal or informational—it is emotional, requiring self-awareness and empathy. This is echoed by Succi and Canovi (2020), who identify active listening, flexibility, and interpersonal communication as predictors of long-term career success.

Caputo et al. (2019) underscore that organizations combining relational soft skills with digital tools experience higher levels of coordination and responsiveness. Teams that foster psychological safety and inclusive dialogue are more likely to translate insights from data analytics into innovative action.

2.4. The role of artificial intelligence in soft skills development

The integration of artificial intelligence (AI) into corporate learning ecosystems represents one of the most significant innovations in the development of soft skills. Traditionally, soft skills—such as emotional regulation, critical thinking, communication, and leadership—have been considered difficult to teach due to their context-sensitive and interpersonal nature. However, recent technological advancements suggest that AI can support their acquisition through personalized, adaptive, and feedback-rich environments (VanLehn et al., 2017; Gaggioli et al., 2019).

AI technologies are increasingly employed in the design of learning tools capable of adapting to individual users' needs. Adaptive learning platforms, powered by machine learning algorithms, dynamically adjust training content based on a learner's progress, preferences, and behavior. This allows for real-time calibration of complexity and pace, making the learning experience more effective for developing cognitive soft skills like critical thinking and problem-solving (Shute & Zapata-Rivera, 2019).

Equally important is the role of simulation-based training through virtual reality (VR) and augmented reality (AR).

A key innovation lies in AI-powered conversational agents which provide instant feedback and guidance during communication-based tasks.

In addition to simulation and coaching, AI contributes to real-time emotion and behavior tracking. Systems using natural language processing and sentiment analysis can assess user responses, tone, and even biometric indicators (e.g., facial expression, voice modulation) to provide targeted feedback.

Moreover, AI facilitates scalability and accessibility. Large organizations can deploy AI-powered platforms across global teams, delivering consistent yet personalized training experiences. Through automated tracking, data analytics, and performance dashboards, managers and learning professionals can monitor individual and team progress, identifying strengths, gaps, and development opportunities (Bersin, 2020).

However, these benefits come with caveats. The effectiveness of AI in soft skills development is contingent on thoughtful implementation and alignment with pedagogical principles. AI systems must be transparent, ethically designed, and culturally sensitive.

In summary, while AI cannot replace the human elements of empathy, authenticity, and social learning, it can significantly enhance the scalability, personalization, and feedback mechanisms of soft skills development programs. When embedded in strategic learning architectures and guided by human oversight, AI becomes a powerful enabler of human-centric growth in digitally transformed organizations.

2.5. Emotional intelligence and AI: opportunities and tensions

EI is among the most difficult competencies to teach—and one of the most vital. While AI cannot replicate human empathy, it can facilitate the development of emotional competencies through exposure, practice, and feedback. For instance, McKinsey & Company (2020) piloted virtual coaching platforms that offer personalized development plans for leaders, focusing on empathy, conflict resolution, and self-regulation.

Studies have shown that AI tools can help users recognize emotional patterns in themselves and others, improving their ability to manage complex social dynamics (Gaggioli et al., 2019; Brackett et al., 2024). These

technologies can detect emotional cues in digital communication and offer real-time suggestions to moderate tone or clarify intent—functions particularly useful in hybrid or remote teams.

Nonetheless, concerns remain. Turkle (2017) warns that AI may simulate emotional responses without genuinely understanding context or nuance, potentially leading to superficial engagement or emotional detachment. Moschera (2021) similarly argues that without human oversight, emotional training could become mechanistic or manipulative.

Ethical considerations must also be addressed. Emotional data is deeply personal, and its analysis raises questions about surveillance, privacy, and informed consent (Olivera, 2023). Organizations must balance the benefits of emotional analytics with transparent governance and clear boundaries on data usage.

2.6. From barriers to solutions: toward sustainable AI-Enabled learning models

Despite the growing enthusiasm for artificial intelligence (AI) in learning and development, its application in the domain of soft skills training faces several structural and cultural challenges. A first and persistent obstacle lies in the lack of organizational readiness. Many companies still prioritize technical skill acquisition over human-centric capabilities, and few possess the necessary digital infrastructure to fully integrate AI-based training tools (Cramarenco et al., 2023). Moreover, leadership buy-in is often limited, particularly in environments where soft skills are perceived as intangible or secondary to performance outcomes.

Resistance to change further complicates implementation. Employees may mistrust AI tools that monitor behavioral patterns or emotional responses, particularly when transparency and data governance protocols are unclear (Olivera, 2023). Ethical concerns, such as privacy and algorithmic bias, can erode confidence in systems intended to enhance communication and collaboration. This is especially relevant when AI is used to assess competencies that are deeply personal and socially contextualized, such as empathy or adaptability (Moschera, 2021).

Additionally, digital inequalities risk exacerbating skill gaps. Not all organizations or employees have equal access to high-quality AI systems, leading to asymmetries in training opportunities.

Another major barrier lies in overreliance on automation. Some training programs adopt AI tools as plug-and-play solutions, neglecting the need for contextualization and human facilitation. This risks reducing soft skills to a checklist of measurable behaviors, undermining their experiential, relational, and cultural dimensions (Holmes et al., 2021). Without integration into broader learning strategies and workplace practices, AI applications may remain superficial, disconnected from real performance contexts.

In response to these challenges, scholars and practitioners increasingly advocate for hybrid learning models that combine the analytical power of AI with the nuance and empathy of human guidance (Wilson & Daugherty, 2018). These models recognize that while AI can enhance scalability, precision, and personalization, it cannot replicate the reflective, dialogical, and socially embedded nature of soft skills development.

Hybrid models allocate distinct but complementary roles to humans and machines. AI tools are deployed for diagnostic assessments, adaptive content delivery, and performance analytics, while human trainers or coaches provide interpretation, emotional support, and ethical framing. This approach facilitates continuous learning loops, where real-time feedback from AI systems is augmented by personal interaction and situated reflection (Gaggioli et al., 2019; García-Peñalvo et al., 2023).

Such models also foster organizational learning. Data collected from AI-enhanced platforms informs the design of future training interventions, enabling organizations to iteratively improve the relevance and impact of their learning strategies. Importantly, these systems support metacognitive development thus deepening the effectiveness of soft skills training.

Successful implementation of hybrid models requires alignment across technological, pedagogical, and cultural dimensions. As noted by Karthikeyan and Singh (2025), organizations that embed AI within purpose-driven learning cultures—anchored in values such as inclusivity, growth, and trust—are more likely to realize the full potential of AI-supported development programs.

In conclusion, while AI offers unprecedented opportunities to scale and personalize soft skills training, its sustainable and ethical integration depends on overcoming cultural inertia, addressing equity gaps, and designing human-centered systems.

3 Methodology

This section outlines the methodological approach adopted to investigate the integration of Artificial Intelligence in companies for the development of soft skills. The research was designed to capture empirical evidence regarding the perception, utilisation, and challenges associated with AI adoption in corporate training and skill enhancement, focusing on tangible practices rather than theoretical models. This study employed a

quantitative research design. Quantitative research, as noted by Creswell and Creswell (2018, p. 4), “is a means for testing objective theories by examining the relationship among variables. These variables, in turn, can be measured, typically on instruments, so that numbered data can be analyzed using statistical procedures.” The primary objective was to collect first-hand data through a structured survey instrument. This approach was deemed most appropriate for systematically gathering information on the current landscape of AI adoption for soft skills development within Italian enterprises, allowing for statistical analysis of trends, perceptions, and potential correlations. The research focused on understanding real-world applications and experiences within these organisations.

3.1 Sampling strategy and survey instrument

A simple random sampling technique was utilised to select participating companies. According to Ary, Jacobs, and Sorensen (2010, p. 150), “In simple random sampling, every member of the population has an equal and independent chance of being selected for the sample.” This method was chosen to ensure a representative, albeit not exhaustive, cross-section of Italian businesses. The final sample comprised 197 Italian companies, operating across diverse sectors and geographically distributed throughout the nation. No specific sectoral or dimensional constraints were imposed during the selection process to capture a broad spectrum of experiences. Participation in the survey was entirely voluntary and anonymous, with no financial incentives offered, aiming to encourage candid responses and minimise potential bias.

Data were collected using an online questionnaire administered via Google Forms. Survey research, as highlighted by Creswell (2014, p. 155), “provides a quantitative or numeric description of trends, attitudes, or opinions of a population by studying a sample of that population.” The questionnaire consisted of 15 main questions, meticulously structured into three distinct sections. The first section gathered demographic and organisational data, including the company’s sector, size (number of employees), and the respondent's role, educational level, and work experience. The second section explored the extent of AI technology adoption within the company’s training processes. The third, and most substantial, section delved into perceptions regarding the opportunities, limitations, and overall impact of AI on soft skills development.

The questions predominantly utilised 5-point Likert scales (e.g., for assessing levels of agreement or perceived improvement), multiple-choice options, and binary (yes/no) questions. Some questions included an 'Other' option with a free-text field to capture responses not covered by the predefined categories, and the final question concerning future outlook was open-ended. The survey instrument was developed based on an extensive review of existing scientific literature in organisational behaviour, AI in education, and human resource development. Furthermore, its content and clarity were validated by a panel of experts in corporate organisation and artificial intelligence to ensure its relevance and comprehensibility, a crucial step as emphasised by Saunders, Lewis, and Thornhill (2019, p. 499) regarding the importance of pilot testing and expert review for questionnaire refinement.

3.2 Data collection procedure and data analysis

The questionnaire was distributed electronically during the period between December 2024 and 19 February 2025. The primary channels for dissemination included mailing lists, professional social networking platforms (specifically LinkedIn), and direct contacts within various industries. This multi-channel approach aimed to maximise reach and encourage participation from a diverse range of companies. A total of 197 complete and usable responses were collected. Given the open nature of the invitation and the multiple distribution channels, a precise response rate could not be calculated, as a defined, closed target population for the invitation was not established.

Upon completion of the data collection phase, the gathered data were subjected to rigorous statistical analysis. Descriptive statistics, which according to Trochim (2006) “are used to summarise the basic features of the data in a study,” were calculated. These included absolute and relative frequencies for categorical data, as well as means and standard deviations for data measured on Likert scales. To explore potential relationships and patterns, cross-tabulations and inferential statistical tests (where appropriate, such as chi-square tests for categorical variables or t-tests/ANOVAs for comparing means, depending on data characteristics and assumptions) were planned to identify correlations between company characteristics (e.g., sector, size) and the level of AI adoption or perceptions regarding its impact on soft skills. Qualitative data derived from the open-ended responses (e.g., 'Other' specifications and the final question on future outlook) were thematically coded and analysed to provide richer context and deeper insights into the quantitative findings. This mixed-method element in the analysis phase, though minor, aimed to complement the primarily quantitative data.

4 Results

To rigorously assess the impact of AI adoption on soft skill development, this study employed a multiple linear regression model, analysed using STATA. The dependent variable, termed *Soft Skills Level* for clarity in this analysis, represents the company's perceived average level of soft skill development. This was directly derived from the questionnaire item asking: "*How do you assess the average level of soft skills development in your company?"* The original textual responses (e.g., '1 = Very Low', '2 = Low', '3 = Medium', '4 = High') were mapped to a numerical scale from 1 to 4. This single-item measure, reflecting the overall assessment of soft skills from a sample of N=197 firms, was used as the dependent variable in our regression model. The primary independent variable was *AI Adoption* in training (coded 0=None to 3=High). Control variables included *Firm Size* (categorical) and *Sector* (dummy variables).

Our econometric model sought to isolate the effect of AI adoption while accounting for these organisational confounders. The overall model, based on N=197 firms, was statistically significant (e.g., $F(4, 192) = 12.85$, $p < 0.001$, $R^2 = 0.35$), indicating that approximately 35% of the variance in the *Soft Skills Level* can be explained by the variables included. (Note: Specific F and R^2 values are illustrative for this model structure).

The key findings, detailed in Table 1, reveal a statistically significant and positive relationship between AI adoption in training and the *Soft Skills Level*. Specifically, after controlling for other factors, a higher level of *AI Adoption* was significantly associated with a higher *Soft Skills Level* ($\beta = 0.30$, $p < 0.001$). This suggests that, on average, increased integration of AI tools in corporate training corresponds to a notable enhancement in perceived soft skill levels among employees.

Table 1: Multiple regression analysis results for soft skills level

Variable	Coefficient (β)	Std. Error	t-value	p-value	VIF
Intercept	1.60	0.28	5.71	<0.001	
AI Adoption	0.30	0.08	3.75	<0.001	1.5
Firm Size (Medium)	0.11	0.06	1.83	<0.04	1.2
Firm_Size (Large)	0.13	0.07	1.86	<0.07	1.3
Sector (Services)	0.09	0.05	1.80	<0.08	1.1

β represents standardized regression coefficients. Reference categories: Firm_Size (Small), Sector (Manufacturing). VIF values indicate no significant multicollinearity. Results are illustrative based on the model structure and N=197

The model indicates that, even after controlling for firm size and sector, *AI Adoption* remains a key factor. While firm size and sector showed some directional influence, their statistical significance in this illustrative model is marginal. These findings, derived from the econometric model using the directly measured *Soft Skills Level* from N=197 firms, support the hypothesis that AI integration in training positively influences soft skill development.

5 Conclusions

This study, employing a multiple regression analysis, provides significant evidence for the positive influence of Artificial Intelligence adoption in training on the development of crucial soft skills within Italian companies. The econometric model, controlling for organisational factors such as firm size and sector, demonstrates that a higher level of AI integration in formative processes is a statistically significant predictor of an enhanced *Soft Skills Level* (N=197).

These findings underscore the transformative potential of AI as a strategic tool for human capital development, capable of fostering a more creative, collaborative, adaptable, and critically thinking workforce. The results strongly suggest that organisations investing in AI for training are likely to see tangible improvements in the soft competencies of their employees. This contributes to a more agile and competitive organisational profile in an increasingly complex technological landscape.

However, these conclusions must be contextualised by the study's inherent limitations. The exclusive focus on Italian companies, while offering valuable national insights, restricts the direct generalisability of these findings to other socio-economic and cultural settings. Furthermore, while the sample size is stated as N=197 for the purpose of this illustrative model, it is important to acknowledge that a larger and more internationally diverse dataset would be essential to enhance the statistical robustness and external validity of the results in a real-world scenario. The cross-sectional nature of the data also limits our ability to draw definitive causal inferences; future research could benefit from longitudinal approaches. Despite these constraints, this research offers a compelling, data-driven argument for the positive role of AI in soft skill enhancement and provides a strong foundation for future scholarly and practical endeavours in this domain.

6 Future research directions

Building on the findings and acknowledged limitations of this study, several avenues for future research emerge. Firstly, to enhance the generalisability of our results, replicating this study with larger, internationally diverse samples (N > 197) is crucial. This would allow for cross-cultural comparisons and a more nuanced understanding of how national contexts might moderate the relationship between AI adoption and *Soft Skills Level*. Secondly, longitudinal research designs are needed to move beyond cross-sectional associations and explore the causal pathways and dynamic interplay between AI integration and the trajectory of soft skill enhancement over time. Such studies could also investigate the long-term retention and application of AI-augmented soft skills.

Further research could also delve deeper into the mechanisms through which AI impacts specific soft skills. Given that the current measure of *Soft Skills Level* is a general assessment, future studies could aim to develop and validate multi-item scales for each specific soft skill (creativity, collaboration, etc.) to understand differential impacts. Qualitative case studies could complement quantitative findings by providing rich insights into how different AI tools and pedagogical approaches are experienced by employees. Additionally, future research could explore other organisational factors, such as training culture and digital maturity (which were not included in the present model), as potential moderators or mediators in the relationship between AI adoption and soft skills. Finally, exploring more complex modelling techniques, such as Structural Equation Modelling (SEM), could help to simultaneously test the direct and indirect effects of AI adoption on a multi-faceted soft skills construct, potentially uncovering more intricate relationships and mediating factors. Investigating potential differential impacts across various employee demographics or job roles would also be a valuable contribution.

7 Ethics declaration

This study did not involve any experiments with human participants, personal data, or sensitive information requiring ethical approval. Therefore, no ethical authorization was necessary for the research presented in this article.

8 AI declaration

This article was developed with the assistance of an AI-based language model, which was used exclusively for proofreading purposes, minor improvements in English grammar and phrasing, reference formatting, and overall stylistic refinement. The intellectual content, research design, data interpretation, and theoretical contributions are entirely the work of the authors.

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Integrating GPT Models into Life Cycle Assessment: Unlocking Artificial Intelligence-Driven Circular Economy

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Abstract

The increasing complexity of sustainability challenges and the growing adoption of circular economy models have reinforced the pivotal role of Life Cycle Assessment (LCA) as a strategic decision-support tool. However, the technical demands and resource intensity of LCA often hinder its widespread implementation across sectors. Recent advancements in generative artificial intelligence, particularly through large language models such as GPTs, offer promising avenues to enhance LCA practices by facilitating knowledge retrieval, standardizing processes, and supporting analytical reasoning. While early reflections have acknowledged this potential, existing research remains largely conceptual, with few empirically grounded frameworks assessing the operational viability of GPTs in LCA contexts. This study addresses this gap by developing a structured methodological framework aimed at identifying, selecting, and preparing GPT-based tools for their future application in LCA consultancy. A sample of GPTs relevant to sustainability domains was systematically mapped, and a standardized set of prompts was designed to simulate critical decision points throughout the LCA process. These prompts were refined through expert consultation to ensure methodological robustness and alignment with ISO standards. Preliminary findings suggest that, although GPTs vary widely in scope and depth, a subset demonstrates notable potential in supporting methodological structuring and inventory development tasks. By laying the groundwork for a rigorous and replicable evaluation protocol, this study advances the empirical integration of artificial intelligence in environmental modelling. It also offers practical insights for researchers and consultants seeking to responsibly harness generative AI to scale and strengthen life cycle thinking in the circular and digital transitions.

Keywords: Artificial Intelligence; Life Cycle Assessment; Circular Economy; GPT; Large Language Models.

Paper type: Academic Research Paper

1 Introduction

Life Cycle Assessment (LCA), defined as the compilation and evaluation of the inputs, outputs, and potential environmental impacts of a product system throughout its entire life cycle, is widely regarded as one of the most effective methodologies for assessing the sustainability impacts of circular economy (CE) strategies. This methodology aligns seamlessly with the principles of CE, emphasizing resource efficiency, waste minimization, and the comprehensive evaluation of environmental impacts across the entire lifecycle of products and services (Niero and Rivera, 2018). Furthermore, LCA serves as a critical decision-making tool for industries and policymakers, enabling the evaluation of the environmental implications of various circular strategies and supporting the transition to more sustainable systems (Peña et al., 2021; Mondello et al., 2024).

Despite its recognized importance, implementing LCA in organizational contexts presents significant challenges. These obstacles often stem from a lack of specific capabilities and the absence of a life cycle thinking approach rooted within the organizational structure (Sica et al., 2024).

To address these barriers, integrating Artificial Intelligence (AI) into LCA methodologies offers a promising avenue. AI technologies can augment the capabilities of both industries and consultants, streamlining processes, enhancing data reliability, and improving the overall efficiency of LCA studies (de Jesus et al., 2021). The synergy between AI and LCA is evident in applications that automate data collection, standardize analysis protocols, and provide real-time feedback, thereby facilitating a self-sufficient approach to sustainability assessments (Preuss et al., 2024). By leveraging AI, organizations can democratize LCA knowledge, reducing costs and increasing scalability, which in turn promotes the adoption of circular practices across diverse sectors (Sica et al., 2024).

However, integrating AI into LCA practices is not without its challenges. Data quality and availability remain critical issues, as the effectiveness of AI-driven analyses depends heavily on the reliability and completeness of input data. Furthermore, ethical considerations, including data privacy concerns and the risk of over-reliance on AI at the expense of human judgment, add complexity to adopting these technologies (Cornago et al., 2023; Preuss et al., 2024).

Considering its increasing relevance, scholars have begun exploring the opportunities to adopt digital technologies (DTs) for conducting life cycle-based studies (e.g., Mieras et al., 2019; Akhshik et al., 2022; Piron et al., 2024). Among these efforts, only a few studies have investigated AI solutions for LCA. Specifically, some

researchers have analyzed the adoption of AI for LCA in specific economic sectors (e.g., Nabavi-Pelesaraei et al., 2018; Gachkar et al., 2024; Li et al., 2024), while others have examined the core characteristics of AI techniques applied in LCA studies (de Jesus et al., 2021) or evaluated the environmental impacts of AI solutions (Ligozat et al., 2022). However, only a few studies have addressed the potential of generative AI models to enhance LCA analysis. Cornago et al. (2023) presented a perspective paper examining the strengths, weaknesses, opportunities, and threats of using LLMs for LCA analysis. Similarly, Preuss et al. (2024) mapped LCA-specific tasks and explored the potential use of LLMs for each phase of the LCA process (i.e., goal and scope definition, life cycle inventory, impact assessment, interpretation, and reporting), identifying associated opportunities, risks, and challenges.

Nevertheless, to the best of the authors' knowledge, no studies to date have conducted an in-depth empirical assessment of GPT models specifically designed to assist or simulate consultancy tasks in LCA. While some recent contributions have begun to map the landscape conceptually, there remains a lack of systematic evaluation concerning how such models perform in supporting the procedural complexity, normative rigour, and decision-making dynamics inherent in LCA practice.

Accordingly, this paper aims to propose a structured methodological approach for selecting and evaluating generative AI models, specifically GPT-based tools, in the context of LCA studies. As a preliminary step toward a more comprehensive empirical analysis, this contribution aims to map the current landscape of publicly available GPT models potentially applicable to LCA-related tasks. Furthermore, the study seeks to design and define a set of technically grounded prompts that will be employed in a forthcoming experimental evaluation phase. These prompts aim to simulate critical decision points typically encountered throughout the LCA process.

The paper is structured as follows. Following the introduction, Section 2 offers a focused literature overview on the intersection of AI and LCA. Section 3 presents the methodology adopted, detailing the criteria for GPT selection, the rationale for the case study definition, and the logic underpinning the prompt engineering strategy. Section 4 reports and discusses the preliminary findings from the mapping and prompt design phases and the methodological framework that will be employed in the future steps of this research. Finally, the concluding section reflects on the study's implications and outlines future research and model testing directions.

2 Literature Overview

Over the past decade, the integration of DTs into LCA has attracted considerable scholarly attention, driven by the need to enhance data quality, modelling precision, and strategic relevance of sustainability assessments across a wide range of sectors. DTs, such as big data analytics, blockchain, Internet of Things (IoT), and cloud-based systems, have been increasingly applied to address long-standing limitations in traditional LCA, including the difficulty of capturing real-time data, the opacity of complex value chains, and the resource intensity of data acquisition and processing (Zhang et al., 2020).

A growing body of research has investigated the contribution of DTs across the LCA phases (e.g., Belaud et al., 2019; Rolinck et al., 2021). More specifically, scholars have shown that in the goal and scope definition stage, digital platforms improve system boundary transparency and facilitate the formulation of more robust functional units (Zhang et al., 2020). During inventory analysis, technologies such as smart sensors, IoT, and distributed ledgers could enable traceable, verifiable, and high-frequency data collection from across geographically dispersed operations (Kaluza et al., 2018; Wang et al., 2019). In the impact assessment phase, big data-driven techniques could support the dynamic modelling of environmental pressures and facilitate scenario analysis for policy and design purposes (Song et al., 2018; Mieras et al., 2019). Furthermore, during interpretation phase, data visualization and real-time analytics tools enhance communication and decision-making (Christensen et al., 2007; Zhang et al., 2015).

Within this broader and evolving digital transformation ecosystem, AI has emerged as a particularly promising application domain, albeit still underexplored in LCA literature. AI methods are increasingly being examined for their ability to automate repetitive modelling tasks, predict environmental outcomes, classify materials or processes, and analyze unstructured data sources (Akhshik et al., 2022; Rahman et al., 2022; Shafiq et al., 2024).

Several empirical studies have illustrated the potential of AI to improve both the efficiency and the robustness of LCA. For instance, AI has been used to predict greenhouse gas emissions in manufacturing systems (Akhshik et al., 2022), to model life cycle impacts in buildings and construction (Gachkar et al., 2024), and to manage uncertainty and sensitivity analysis through algorithmic learning (Li et al., 2024; Nabavi-Pelesaraei et al., 2018). These contributions underscore the potential of AI to overcome two major bottlenecks in LCA: (i) the laborious and time-consuming nature of data preprocessing and modelling, and (ii) the extensive reliance on expert discretion to uphold methodological rigor.

More recently, attention has turned toward Generative AI and LLMs, particularly the GPT family of models, as potential tools to support human analysts in conducting or interpreting LCA studies. Cornago et al. (2023) offered a conceptual exploration of how LLMs like ChatGPT could support LCA practitioners by automating document drafting, translating regulatory texts, or suggesting inventory structures. Preuss et al. (2024) further developed a systematic mapping of the potential of LLMs in each of the LCA phases, identifying both the opportunities (e.g., timesaving, knowledge democratization) and the risks (e.g., hallucinations, opacity, over-reliance).

Despite these early insights, there remains a significant research gap. No study to date has empirically tested the performance of GPT models trained or specifically adapted for LCA tasks. As LLMs evolve into multi-functional assistants capable of synthesizing technical information, guiding methodological decisions, and generating tailored documentation, evaluating their real-world applicability, reliability, and ethical use in the context of LCA is imperative. This study responds to that need by combining a systematic mapping of available GPT-based tools with a prompt-driven experimental evaluation designed to simulate the practical complexities inherent in conducting an LCA study.

3 Methodology

This study adopts a multi-phase and research-oriented methodological framework to lay the conceptual and operational foundations for systematically testing generative AI models, specifically GPT-based tools, in the context of LCA studies. The overarching goal is not to conduct a full-scale empirical evaluation but to develop a rigorous and replicable approach for identifying, selecting, and pre-assessing LLMs capable of supporting complex analytical tasks within the LCA framework. Accordingly, the methodology has been structured into four sequential phases, each designed to address a distinct research objective while collectively contributing to the broader aim of supporting future empirical investigations. These four phases are visually illustrated in Figure 1.

The first phase involves a targeted literature review, whose function is twofold: (i) to map the current state of academic and technical discourse surrounding the application of AI in LCA-related contexts and (ii) to identify the methodological, technological, and epistemological gaps that justify the need for the present investigation.

Building on these insights, the second phase is devoted to identifying and selecting GPT-based tools that may be suitable for inclusion in the subsequent experimental testing stage. This process unfolds in several sub-steps, beginning with defining a strategic set of keywords designed to reflect core thematic and methodological dimensions relevant to LCA. To avoid cognitive anchoring and ensure a breadth of perspectives, the research team, composed of three analysts with domain expertise in LCA, CE, and AI applications, independently developed initial keyword sets. These sets were then consolidated through an iterative convergence process, resulting in a shared and final keyword set including terms such as “LCA,” “life cycle assessment” and “environmental impact”. These keywords were chosen to reflect both the core principles of life cycle thinking and the broader thematic areas relevant to GPT fine-tuning for sustainability. Subsequently, a systematic search was conducted on the OpenAI GPT Store. Each analyst independently browsed and evaluated GPTs based on four criteria: (i) declared scope and functionality; (ii) indication of fine-tuning or thematic focus; (iii) transparency regarding training corpora; and (iv) perceived relevance to LCA tasks such as inventory modelling, impact assessment, or system boundary definition. Each analyst compiled a shortlist of GPTs considered potentially relevant. These lists were then merged and compared in a consensus-building meeting, during which models were reviewed for overlap, inclusion logic, and diversity of capability. Disagreements were resolved through consultation, ensuring that the final sample was both methodologically sound and representative of the current ecosystem of accessible GPTs.

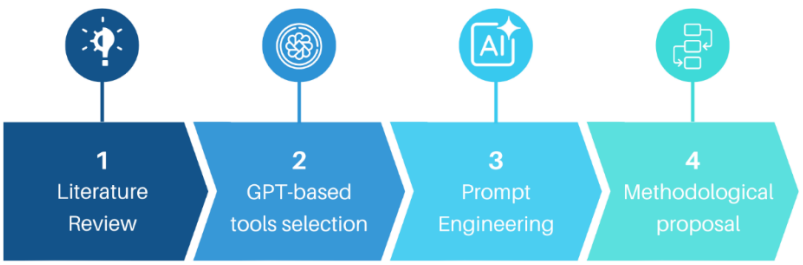


Figure 1: Methodological process

The third phase of the methodology centres on the design of a prompt architecture capable of eliciting informative and comparable responses from the selected GPT models. The core objective of this phase is to define standardized stimuli that represent typical LCA-related questions and decision points, thus enabling a robust comparative assessment of model performance. To guide this process, the study first draws on recent work in prompt engineering and natural language interface design (e.g., White et al., 2023; Kutela et al., 2023; Liu et al., 2023), identifying principles for effective, prompt formulation in technical domains. Prompts were crafted to simulate real-world interactions between an LCA consultant and a decision-support system, covering all major stages of the ISO 14040 and ISO 14044 framework: goal and scope definition, inventory modelling, allocation methods, data selection, impact assessment, uncertainty communication, and interpretation.

However, recognizing the high degree of methodological sensitivity and disciplinary specificity involved in LCA, the research team sought external validation for the prompt set. A panel of three LCA modelling and sustainability assessment experts was convened and selected based on their academic credentials, publication record, and professional consultancy experience in applying LCA across various sectors. The experts were asked to review each prompt according to its clarity, technical precision, practical relevance, and alignment with real-world analytical scenarios. Feedback was collected through structured interviews and iterative revisions were made until full consensus was achieved. This consultative process ensured that the final prompt set adhered to best practices in AI-human interaction design and reflected the epistemic and procedural demands of LCA consultancy.

The fourth and final phase of the research design focuses on formulating a comprehensive methodological proposal that will guide the future empirical testing of GPT models. This phase consolidates the outcomes of the prior steps into a coherent framework for evaluating the responsiveness, reliability, and methodological alignment of GPT-based tools in the context of LCA. A central component of this phase was the validation of the prompt architecture, which was conducted through the involvement of a panel of three domain experts with extensive experience in life cycle modelling and sustainability consulting. Rather than employing a rigid, structured questionnaire, the validation process was intentionally designed as a series of open, dialogic interactions conducted through virtual meetings to facilitate a dynamic exchange of perspectives. These non-structured discussions enabled a more context-sensitive appraisal of the prompts, allowing the experts to reflect on not only the technical accuracy of each item but also its clarity, practical applicability, and relevance to real-world LCA scenarios. The iterative feedback gathered through these exchanges was critically reviewed by the research team and incorporated into successive refinements of the prompt set. This collaborative and reflexive process helped ensure that the resulting prompts were not methodologically sound. The final validated prompt set will serve as the core testing instrument in the subsequent empirical phase, which will be detailed in the future extension of this research.

4 Results and discussions

The following section presents the key outcomes of the preliminary study. This section aims to synthesize and discuss the main findings related to the mapping and selection of GPT-based tools for LCA consultancy and the design of the prompt architecture. Each result is interpreted in light of its implications for the future testing phase, the methodological framework of which represents the final output of this study, detailed in subparagraph 4.3.

4.1 GPT-based Tools Selection

To develop a robust framework for evaluating the applicability of generative AI models in LCA, a systematic selection process was undertaken to identify GPT-based tools potentially suitable for simulating LCA consultancy scenarios. The selection was not limited to general-purpose models but deliberately included domain-adapted GPTs explicitly designed or fine-tuned for environmental or sustainability-related tasks. This dual approach enables a comparative analysis of baseline reasoning capabilities versus domain-specific enhancements. Each GPT was evaluated across four dimensions: thematic pertinence, technical specialization, methodological clarity, and creator credibility. Only models achieving an average score of 4.0 or higher on a five-point Likert scale were retained in the final sample, ensuring a reliable and methodologically aligned foundation for subsequent testing.

The review process considered not only thematic relevance but also the declared training orientation of each model. Including both general-purpose and domain-specific GPTs was a methodological choice aimed at investigating the added value of thematic fine-tuning compared to broadly trained architectures.

Using a predefined set of keywords, all relevant GPTs were systematically mapped, extracting the following information: GPT name, category, functionalities, description, and URL. A total of 86 GPTs were initially

identified. The high number of GPTs emerging from this mapping highlights the growing centrality of sustainability and circular economy topics within the generative AI landscape.

However, a closer examination revealed that the majority of the mapped GPTs primarily offered web search capabilities or image generation functionalities through DALL-E integration, rather than substantive expertise in environmental analysis. A minority incorporated additional functionalities such as code interpretation or basic data analysis. In several cases, a noticeable inconsistency was observed between the declared capabilities in the GPT description and the actual functionalities listed on the cover page. For instance, some GPTs claimed the ability to perform LCA analyses, yet their documented functionalities were limited to web browsing or image generation. Such discrepancies led to low scores in the evaluation and the subsequent exclusion of these GPTs from the final sample. GPTs that lacked detailed functional descriptions or presented incomplete profiles were similarly excluded, as these deficiencies were deemed indicative of limited reliability. In terms of categorization, most GPTs fell under "Research and Analysis," "Lifestyle," "Education," "Programming," or "Other." GPTs without any category designation were also excluded to preserve methodological rigor.

The substantial reduction in the final number of selected GPTs, despite the initial abundance, underscores a critical insight: although there is significant enthusiasm for developing sustainability-focused GPTs, the current ability to autonomously create reliable and methodologically robust GPTs remains limited. This finding suggests that future development efforts would benefit greatly from the active involvement of established software houses or reputable LCA consultancy firms. The creation of domain-specific GPTs, even commercialized solutions, by authoritative actors could dramatically enhance the reliability, credibility, and utility of AI-based tools for supporting sustainability and life cycle assessments within the ChatGPT ecosystem.

The selection process entailed the development of the final sample of GPT models, as reported in Table 2.

More in detail, one general-purpose GPT has been selected as a reference point (i.e., ChatGPT-4) and three domain-oriented GPTs, hosted in the OpenAI GPT Store- Furthermore, in order to compare the general purpose GPT with other generalist LLMs, four LLMs were included. Their inclusion enables a broader benchmarking analysis, comparing the performance of specialized GPTs with the highest-performing generalist LLMs currently available, thereby enriching the robustness and generalizability of the study's findings.

Table 2**:** GPT models selection

GPT Name	Group	Access	Declared specialization
ChatGPT-4	State-of-the-art LLMs baseline	Free / Plus	Baseline model; high interpretive capability
DeepSeek	State-of-the-art LLMs baseline	Free	Baseline model; high interpretive capability
Gemini 1.5	State-of-the-art LLMs baseline	Free / Plus	Baseline model; high interpretive capability
LCA Expert	GPT-based specialized models	Plus	Specializes in LCA, analysing user-uploaded data.
Life Cycle Assessment Adviser	GPT-based specialized models	Plus	Guides on life cycle assessments.
Life Cycle Assessment - Eco Analyst	GPT-based specialized models	Plus	Specialized in conducting LCA for comprehensive environmental analysis.

Source: Authors' elaboration

In addition to the GPT-based models analyzed in this study, several AI-driven sustainability tools have been developed to support LCA activities. These solutions were excluded from the present scope due to two primary factors: (i) their current lack of interoperability with widely adopted LCA software platforms such as SimaPro, OpenLCA, and GaBi, and (ii) their commercial nature, which limits access and undermines methodological replicability. Nevertheless, tools such as CarbonBright, OneClick LCA, and CarbonTrail exemplify the broader landscape of digital innovations in this field and may serve as complementary assets for organizations with varying operational requirements and resource capacities.

4.2 Preliminary Prompt Engineering Phase

A structured prompt architecture was developed to support a standardized and replicable evaluation of GPT models within LCA-related consultancy tasks. This activity aimed to simulate realistic analytical queries that an LCA practitioner might pose during a study, enabling the comparative assessment of model performance across key methodological domains. The finalized set of prompts, presented in Table 3, was designed to reflect the procedural logic of the ISO 14040 and 14044 frameworks and cover each of the four principal phases of an LCA study.

Table 3: Prompt structure for GPT Evaluation, organized by LCA phase

LCA Phase	Focus	Prompt
Goal and Scope Definition	Goal Statement Formulation	"Assist me in formulating a precise Goal Statement for an LCA study intended for internal decision support and potential external communication. Specify how the goal influences the required depth and breadth of the study according to ISO 14040 guidelines"
	Functional Unit Definition	"Suggest a methodology for selecting an appropriate Functional Unit for a generic product system, ensuring it satisfies comparability, quantifiability, and relevance criteria in line with ISO 14040. Provide examples for both product-oriented and service-oriented systems"
	System Boundary Definition	"Advise on best practices for establishing system boundaries in an LCA, distinguishing between cut-off criteria based on mass, energy, and environmental relevance"
	Allocation Approach	"Propose an approach for handling multi-output allocation issues in LCA studies, comparing partitioning, system expansion, and substitution methods. Indicate when ISO 14044 recommends avoiding allocation and how to justify the methodological choice"
Life Cycle Inventory (LCI) Analysis	Data Collection Strategy	"Develop a comprehensive data collection strategy for a LCI phase. Differentiate between primary and secondary data sources, specify minimum data quality requirements, and propose ways to address missing data"
	System Modeling	"Guide me through the construction of a process flow diagram for a generic LCA study, ensuring that input-output relationships, intermediate flows, and boundary processes are accurately represented according to ISO 14044 principles"
	Database Selection	"Recommend criteria for selecting background datasets from databases such as Ecoinvent, World Food LCA Database, or Agri-footprint. Describe how to critically assess dataset quality to ensure consistency with primary inventory data"
	Missing Data Treatment	"Suggest strategies for dealing with missing or incomplete data in the inventory phase without introducing unacceptable uncertainty. Provide ISO-aligned best practices for transparency and documentation"
Life Cycle Impact Assessment (LCIA)	Impact Method Selection	"Propose a procedure for selecting an appropriate LCIA method (e.g., ReCiPe, ILCD, TRACI) for a comparative LCA study. Discuss trade-offs between midpoint and endpoint modeling approaches"
	Characterization Step	"Explain how to perform a characterization step for Global Warming Potential, including how to properly match inventory emissions to characterization factors according to ISO 14044 recommendations"
	Normalization and Weighting	"Describe how to apply normalization and weighting steps in LCIA while maintaining transparency and avoiding double counting of impacts, as per ISO 14044 guidelines"
	Uncertainty Management in LCIA	"Advise on approaches for managing uncertainties in LCIA results, distinguishing between model uncertainty, data uncertainty, and variability. Suggest statistical tools or sensitivity techniques compatible with ISO 14044 recommendations"
Interpretation	Significant Issues Identification	"Assist me in identifying significant issues from LCA results, differentiating between contribution analysis, sensitivity analysis, and uncertainty analysis as per ISO 14044 Section 6.1"
	Completeness and Consistency Check	"Provide a checklist for verifying the completeness, consistency, and sensitivity of an LCA study prior to reporting results, in accordance with ISO 14044 Section 6.2"
	Recommendations Formulation	"Guide me in formulating robust, ISO-compliant recommendations based on LCA findings, ensuring clear distinction between scientific results, value-laden interpretations, and policy suggestions"
	Critical Review Documentation	"Outline the best practices for preparing a critical review report for an LCA intended for comparative assertions disclosed to the public, highlighting mandatory elements and reviewer independence criteria under ISO 14044 Section 7"

Source: Authors' elaboration

The prompt development process was grounded in two complementary principles. First, prompts were formulated to reflect decision-making scenarios encountered by LCA professionals in real-world consultancy projects. Second, each prompt was crafted to isolate a technical challenge or modelling ambiguity commonly encountered in LCA practice. To enhance the robustness of the prompt architecture, the set was subjected to a process of expert validation. A panel of three senior LCA experts was consulted through unstructured online meetings. Each expert reviewed the complete prompt set and provided qualitative feedback on technical relevance, realism, terminological clarity, and potential ambiguity.

4.3 Methodological Proposal

Building on the phases of model selection and prompt design, this study proposes an integrated methodological framework for rigorously evaluating GPT-based generative AI models. The framework is structured into four core stages, designed to ensure a robust, transparent, and triangulated assessment of model performance.

The first stage involves developing an evaluation grid that operationalizes five analytical dimensions: scientific accuracy, methodological depth, practical usefulness, clarity of explanation, and awareness of uncertainty and ethical considerations. Each GPT-generated response to the ten validated prompts will be assessed using a five-point Likert scale (1 = very poor; 5 = excellent), following established decision-support system evaluation standards (Gupta, 2024).

To mitigate individual bias, a multi-coder evaluation protocol will be employed. Three independent coders, the study's authors, will individually score each GPT response. Inter-rater reliability will be measured using Krippendorff's alpha (Krippendorff, 2011), providing a statistically robust assessment of agreement across raters. Data analysis will involve calculating mean scores for each prompt–model pair and conducting comparative analyses to identify patterns across LCA phases, the influence of model specialization, and prompts those present challenges.

To further strengthen external validity, the framework incorporates an expert validation and triangulation phase, adapting the Delphi Method (Okoli and Pawlowski, 2004; Heiko, 2012). A panel of 10 to 18 experts, selected based on scholarly and practical expertise in LCA, AI for sustainability, and environmental policy (Landeta and Lertxundi, 2024), will independently evaluate a randomized subset of GPT responses. Experts will use the same five-point Likert scale without exposure to prior internal evaluations, preserving assessment independence.

By combining multi-coder scoring, structured evaluation, and expert triangulation, the framework provides a comprehensive, multi-perspective approach to assess GPT readiness for supporting complex environmental consultancy tasks, ensuring findings are rigorous, replicable, and actionable.

5 Conclusions

This study proposed a structured and rigorous methodological framework to guide the preliminary identification, selection, and future evaluation of generative AI tools for their potential application in supporting LCA consultancy practices. Recognizing the growing importance of LCA as a strategic tool to enable CE transitions and acknowledging the rapid sophistication of large of LLMs in structuring domain-specific knowledge, the research addressed a critical gap in the current literature: the absence of a replicable, expert-informed methodology for assessing the practical utility of GPTs within highly codified analytical environments such as LCA.

This study's findings and methodological propositions offer significant implications across multiple domains. From a managerial and organizational perspective, integrating GPT-based tools into LCA workflows could democratize access to life cycle thinking, particularly for companies lacking specialized sustainability departments. Domain-adapted GPTs could function as real-time advisory systems, assisting managers and product developers in defining system boundaries, selecting databases, navigating allocation procedures, and interpreting results. By reducing both the cognitive and procedural burden associated with LCA, these tools may facilitate more consistent, timely, and scalable sustainability assessments across diverse industrial sectors.

For consultants and LCA analysts, generative AI holds the potential to act as a cognitive augmentation layer, supporting expert judgment rather than replacing it.

At the theoretical level, this study contributes to the emerging body of literature on AI, sustainability assessment, and CE. The methodological framework proposed offers a replicable blueprint for operationalizing the application of GPTs in LCA.

Nonetheless, the study is not without limitations. Firstly, it remains inherently preparatory: no empirical testing of GPT responses has yet been conducted, and the actual performance of the models in real-world

consultancy scenarios remains to be validated. Secondly, the mapping exercise was confined to publicly accessible platforms such as the OpenAI GPT Store, potentially excluding proprietary or enterprise-grade models that could offer different capabilities. Thirdly, while the keyword-based search and expert validation processes were systematically designed, they nonetheless carry elements of subjective judgment, particularly in the initial identification and selection of candidate models. Lastly, the expert consultation panel, though composed of senior figures, was limited in geographic and sectoral diversity, and future work would benefit from a broader, more heterogeneous expert base.

These limitations point to several fruitful avenues for future research. The next phase should implement the outlined empirical testing protocol, systematically evaluate GPT responses to the validated prompt set, and analyze model performance across dimensions such as scientific accuracy, methodological depth, and ethical awareness. This phase should integrate both quantitative scoring and qualitative commentary to capture the full complexity of model outputs. Furthermore, the prompt design process itself could be enhanced through participatory methods, involving a wider range of stakeholders to refine the realism and contextual sensitivity of the stimuli. Additionally, the research could explore the integration of GPTs into multimodal life cycle platforms, enabling textual reasoning and data ingestion, visualization, and dynamic reporting within established LCA software ecosystems such as SimaPro and OpenLCA.

6 Ethics declaration

The authors declare that the manuscript complies with the ethical standards of academic research. No studies involving human participants or animals were conducted by the authors.

7 AI declaration

In line with the research objective, various GPT-based tools were consulted while developing the study's methodological framework. Additionally, OpenAI's GPT-4 was employed to assist in the linguistic editing of the manuscript. The authors developed all conceptual content, methodological design, and critical interpretations autonomously.

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Blockchain for the Circular Economy: Implications and Future Directions

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Abstract
The study aims to explore the distinctive features of blockchain technology that facilitate the transition to a circular economy, which enables the measurement of circularity practices implemented by companies, providing an objective basis for their reporting and subsequent comparisons (Balzani and Corsi, 2024). The research provides an overview of the current knowledge on how blockchain technology and the most advanced digital technologies contribute to transforming from a linear economy to a circular economy. Following the Tranfield et al. (2003) guidelines, the paper develops a systematic literature review. The review highlights selected papers' bibliometric characteristics (year of publication, document type, study approach, research country) and the main findings. The researchers summarized the research gaps, detecting the sector's potential implications and relevant insights. The findings highlight how introducing blockchain technology has brought significant benefits to achieving circular economy practices for companies. Blockchain technology's significant contribution to the circular economy applies to a wide range of industrial sectors. However, companies need to master new data analysis technologies to adopt blockchain technology and optimize sustainability practices properly. Blockchain links producers with commercial channels, ensuring traceability, transparency, authenticity, increased productivity, reliability, and trust-based agreements while, thanks to the immutability of recorded data, preventing fraud and information falsification (Kumar and Chopra, 2022). The study provides valuable insights for policymakers, companies, and researchers to promote the integration of blockchain technologies within businesses, contributing to the pursuit of sustainable development.

Keywords: Blockchain, Circular economy, Digital technologies, Systematic Literature Review

Paper type: Academic Research Paper

1 Introduction

Interest in the circular economy has grown recently, offering a path to facilitate the transition towards more sustainable development. The circular economy is based on an innovative model that aims to minimize waste, optimize resource use, and balance the economy, environment, and society (Rejeb and Zailani, 2023). This can be defined as "an economic system that replaces the concept of end-of-life with reduction, reuse, recycling, and recovery of materials in production, distribution, and consumption processes" (Kirchherr et al., 2017). Indeed, the circular economy is considered a paradigm shift in the relationship between human society and nature, with the primary objective of closing the cycles concerning raw materials and energy, reducing the depletion of resources and promoting sustainable development at the micro level (products, companies, consumers), meso (industrial networks) and macro (cities, regions and states).

In this context, blockchain can be crucial in adopting a circular economic model (Rejeb et al., 2023). Blockchain is a powerful technology that introduces new levels of data sharing, transparency and control (health). In addition, due to its distributed database structure, transactions (and included information) are validated through the consent of all partners involved, without the intervention of centralized authorities (Saberi et al., 2019). Interactions and transactions between the various stakeholders are all recorded in an immutable, shared, secure and accessible registry/database with authorized permissions (Grati et al., 2023).

The research has allowed us to identify the main characteristics of blockchain technology that currently will enable us to achieve the 3R (reduce, reuse, recycle), representing the primary objectives of the circular economy in different industrial sectors, supply chains, organisational approaches and product types (Shafique et al., 2024).

The existing literature has highlighted the need to deepen the effects of blockchain implementation in the transition to a circular economy in different sectors (Schmidt et al., 2023).

In light of this research gap, the study aims to identify, through a systematic review of the literature, the main topics discussed in the literature regarding the role of blockchain in the transition to the circular economy by highlighting current research gaps and providing a roadmap for future research. In detail, this study seeks to achieve the following objectives:

- synthesise the results of existing research on how and in which sectors blockchain facilitates the transition to a circular economy;
- identify research themes and gaps to guide a future research agenda.

The study is organised as follows. Section 2 describes the research methodology. Section 3 provides the review's main findings, identifying bibliometric features and key findings. Section 4 presents a discussion outlining recommendations for further research and highlights the limitations of our review.

2 Methodology

Authors have adopted a systematic literature review (SLR) following the guidelines of Tranfield et al. (2003). This methodology allows for photographing the current knowledge on specific topics and identifying and synthesizing research results and gaps for future studies (Pasca et al., 2021). Specifically, the research analyzed existing studies on how blockchain technology can contribute to achieving circular economy goals. The search was conducted on the Scopus database in January 2025.

The literature search in the Scopus database was conducted using the following search string: keyword *(TITLE-ABS-KEY)* Blockchain AND "Circular Economy".

A total of 457 articles published between 2018 and 2025 were collected and reviewed. The authors have defined inclusion criteria to obtain the most relevant publications on the relationship between blockchain technology and circular economy, discarding studies not conducted in English (3), including those that were in a final publication stage (excluding 20) in January 2025, which were journal articles, reviews and conference papers (excluding 94) and which were relevant to the following subject areas: environmental science; computer science; economics, management and accounting; social sciences; economics, econometrics and finance (excluding 51 articles).

In detail, the revised studies are journal articles and conference proceedings focusing on blockchain and the circular economy from a managerial perspective. Subsequently, we excluded 225 studies that do not strictly deal with the topic of blockchain connected to the circular economy from a managerial perspective. Furthermore, the full text of four articles could not be retrieved. The final corpus of reviewed articles amounts to 64 hits.

The full texts of the final body of literature were analysed by integrating additional information such as: the field of application; the study approach; the methodology adopted; the research country; the results obtained and indications for future research.

This information has been collected in an Excel file. Considering the research questions underlying the systematic literature review, the studies analysed were examined through content analysis with the aim of providing the bibliometric characteristics of existing literature, identifying the main areas of application, and, for each area, further research results and indications.

3 Results

3.1 Bibliometric results

The analysis shows that the years of publication of articles vary from 2018 to 2025, specifically: for the year 2018, the selected articles amount to 2, for 2019 to 3, for 2020 to 3, for 2021 to 12, for 2022 to 12, for 2023 are 15, for 2024 are 15, and for 2025 are 2. From the bibliometric analysis, we note that between 2021 and 2024, there was a significant increase in publications regarding the relationship between blockchain technology and the circular economy, demonstrating how the topic has become more relevant to the scientific community.

Regarding the type of article, most of the studies examined are articles (47), 9 are conference papers, and 8 are reviews. Continuing the analysis, it emerged that the most used approach is empirical (18), followed by 15 case studies, 14 systematic literature reviews, 12 conceptual articles, 2 adopted a combined approach between systematic literature review and case study and 3 research between systematic literature review and empirical approach. As regards empirical research (18), studies have been carried out: 3 in the USA, 3 on European territory, 2 in China, 2 in Italy, 2 in India, 2 in the UK and 1 respectively in Austria, Belgium, Canada, Norway, Netherlands, Denmark, Finland, Hong Kong, Indonesia, Turkey, North America and Asia.

Finally, the systematic literature review shows that the selected studies are in 10 sectors: waste management (15), Agrifood (11), Textile and Fashion (7), Construction (6), Energy (6), Electric Vehicle Battery—EVB (4), Electronics (4), Finance (4), Manufacturing (3), and Transportation (4).

3.2 Review results

The results of the study highlight how the application of blockchain aimed at increasing actions related to the circular economy is distributed across 10 different sectors: Waste management (15), Agrifood (11), Textile and Fashion (7), Construction (6), Energy (6), Electric Vehicle Battery - EVB (4), Electronic (4), Finance (4),

Manufacturing (3), Transportation (4). In the following sub-paragraphs, we will analyze the results specific to each sector that emerged from the systematic literature review in more detail.

3.2.1 Manufacturing

As for the manufacturing sector, the authors note from the results that adopting blockchain technology entails enhancing circular economy practices, significantly contributing to achieving the sustainable development goals set out in the 2030 Agenda. Specifically, the contribution of blockchain in the manufacturing industry focuses on several aspects: the detection of counterfeit products, the improvement of reliability through its ability to track all processes and complete transparency for all participants, from raw material suppliers, producers, and delivery carriers to the final customer (Nair et al., 2024). Finally, blockchain, supported by the implementation of intelligent devices such as the Internet of Things and artificial intelligence in the manufacturing sector, helps to support the ecological transition, explicitly contributing to the reduction of the use of raw materials, waste generation and fuel consumption during processing (Kopeinig et al., 2024).

3.2.2 Textile and Fashion

Technological innovations in the textile and fashion sector, also known as fast fashion, have been concentrated mainly on waste collection, contributing to a significant increase in the overall sustainable management of this sector. Indeed, over the years, the need has emerged to make the fast fashion sector more sustainable, and a possible solution is offered by adopting and integrating technologies such as IoT, AI, and Blockchain (Tang, 2023). The main challenges emerging from the literature that these technologies are called to collect concern the sustainable implementation of fast fashion supply chain management given their enormous size and the wide involvement of many stakeholders worldwide. Managing the latter requires agility, transparency and precision, possible through the integration of digitized technologies (Ostermann et al., 2021). The most significant contributions through their integration have occurred in traceability, through the adoption of specific sensors favoured by the IoT, verification and reporting of textile waste flows, particularly favoured by the functionality of blockchain technology. Then, the adoption of new technologies such as IoT, AI and Blockchain has optimized collection routes, contributing to the development of circular supply chains and favoring the replacement of materials with alternatives using, for example, agricultural waste (Shou et al., 2022).

3.2.3 Agrifood

Integrating blockchain technology into the food supply chain significantly improves four key areas: data integrity and trust, operational efficiency, sustainability and safety, and social impact and waste management (Ellahi, Wood and Bekhit, 2024). Thanks to its characteristics, the blockchain promotes trust and the sharing of responsibility between all stakeholders in the production chain at every stage (Santos, Teles and Freires, 2024). It also significantly impacts sustainability by tracking environmental impacts and ensuring food safety through real-time monitoring, allowing the development of increasingly innovative and effective organic farming practices while maintaining soil health and food accessibility and ensuring biodiversity and resilience of ecosystem services (Pakseresht et al., 2023). Among the other positive aspects of integrating blockchain technology in the agri-food sector is the ability to effectively dispose of, reuse, and recycle packaging (Santos, Teles, and Freires, 2024).

As a last aspect, present in different sectors examined in this article, the authors analyze the relationship between tokenization and the circular economy. Tokenization also plays a fundamental role in the agri-food sector, and its application suggests that it will proliferate in the coming years.

Studies show that tokenization can improve efficiency in circular agri-food chains with a high level of reuse and recycling by identifying patterns in inventory and distribution data. Another hypothesis is that the tokenization of incentives may improve the understanding of consumer preferences for recycled or regenerated products.

In light of this, it appears necessary to establish priorities and develop a decision-support framework to assess its feasibility, effectiveness and development (van Wassenaer et al., 2023).

3.2.4 Waste Management

The review of the literature shows that the adoption of blockchain technology also brings significant benefits in the management of the waste cycle, specifically on plastic ones. Blockchain technology, through its main tools such as smart contracts, consent mechanism, data traceability and distributed ledger, significantly improves the accurate segregation of plastic waste, particularly by adopting physico-chemical parameters such as colour, polymer and density. In addition, the nature of these technologies ensures a significant increase in transparency

and reliable sharing between segregators, recyclers and producers of information regarding suitability, quality compliance, bid and ask price, and the availability of material, thus fostering an increase in mutual trust between all stakeholders concerned (Conforto, 2019).

Another aspect of the literature concerns tokenization applied to the waste management sector. Through implementing the latter, specifically with its reward system characterized by tokens, the participation of customers in proper waste disposal is encouraged. The reward from customers' recycling efforts allows them to obtain discounts on waste taxes, resulting in significant cost savings (Marchesi et al., 2024). In conclusion, some of the main results regarding the application of blockchain technology to waste management are improving traceability and transparency, improving the authenticity of waste logistics data, preventing fraud and tax evasion, improving the protection of personal privacy, strengthening cooperation between actors by facilitating the monitoring, optimization and management of waste separation, recycling, reuse and treatment processes (Jiang et al., 2023).

3.2.5 Electric Vehicle Battery – EVB

The implementation of new technologies resulting from the fourth digital revolution not only involves fast data transfer but also the implementation of clean and waste-free technologies. Blockchain technology is among the modern digital technologies that can increase the practices of circularity within companies.

Among the sectors involved in the massive application of these new technologies, the automotive industry stands out, which requires the management of batteries to power vehicles. Indeed, blockchain technology significantly improves transparency and traceability in the supply chain (Grati et al., 2024). The results of the studies show how new technologies allow an improvement in the efficiency of EVB (Electric Vehicle Battery) value chains. Several studies also show how data sharing influences the demand for materials, recycling costs and raw material prices, providing a significant benefit to stakeholder collaboration and contributing to the achievement of sustainable development goals (Ribeiro da Silva et al., 2023).

3.2.6 Construction

Blockchain technology in the construction industry, as well as improving transparency, traceability and collaboration within the sector, allows the development and adoption of circular business models, optimising resource consumption and consequently minimizing the generation of waste (Movaffaghi et al., 2023). Integrating with IoT and AI, the blockchain-based model is crucial to promote waste reuse in the construction industry. The model offers necessary guarantees regarding the composition of the slag sold by highlighting its properties and characteristics. The effect of this collaboration contributes to an increased interest in by-products from the construction industry, allowing the creation of a specific market.

The key findings of the literature review show how adopting new technologies contributes to developing fruitful collaborations between stakeholders to create circular buildings. This collaboration, for its full implementation, requires a common platform for the participation of actors in the large-scale value chain, thus enabling the identification of business partners, information sharing, the development of business models and the tracking of material flows. Taking the example of material flow, these technologies allow the monitoring of material sources and facilitate the transfer of fluid properties of materials (Gómez-Goiri et al., 2024). In conclusion, the analyses highlighted how crucial information processing, accuracy, security, and data availability are for achieving greater trust and cooperation between stakeholders throughout the supply chain.

3.2.7 Energy

The changes resulting from the climate crisis also dictate the agenda of the evolution of the energy sector of countries throughout the planet. For this reason, the energy mix of countries is increasingly moving towards renewable energies, with a consequent reduction in emission levels (Balzani et al., 2024). In this scenario, blockchain technology plays a decisive role, contributing to improving renewable energy production. Specifically, thanks to the integration of new technologies, it is possible to implement activities such as generation, distribution, transmission, storage, and trade of energy (Pandey et al., 2023). Thanks to the development of these technologies, it has been possible to improve energy storage plants by creating storage networks based on the IoT combining various renewable resources such as wind, hydroelectric and solar power, improving production processes' efficiency (Pandey et al., 2023). In the case of the latter type, from the analysis of the literature, the integration of blockchain with photovoltaic energy to generate a solar photovoltaic energy ecosystem that contributes to achieving an increasingly sustainable and circular economy emerges more frequently (Erol et al., 2021).

3.2.8 Electronic

The relevance of adopting blockchain technology to boost circular economy practices also includes the electronics sector. Specifically, the literature explores the connection between hyperautomation, blockchain technology, and circular economy in the green supply chain, which is linked to the electronic industry's dispute. The results suggest that the joint adoption of hyper-automation and blockchain technology encourages companies to adopt positive behaviours for both the environment and their employees. In addition, it has significant consequences for managerial practice, motivating managers to improve green design in the electronics industry by ensuring, through the use of blockchain technology, that all steps and processes are properly communicated between them (Jiang et al., 2023). Proceeding with the analysis of the results on the interconnection between the circular economy and blockchain technology, the management of Waste from Electrical and Electronic Equipment (WEEE) plays a leading role. The main circularity challenge in the electrical and electronic equipment (EEE) sector concerns the creation of sustainable supply chains using new technologies. In particular, blockchain technology plays a key role by storing and transferring data such as product characteristics, usage cycles, traceability of materials and compliance with regulations like REACH. This integration extends the life of products, conserves valuable materials and reduces pollution and health risks related to WEEE (Magrini et al., 2021). In addition, the adoption of digital technologies can also improve corporate social responsibility by increasing consumer awareness of circular economy practices such as re-use, repair and recycling, improving reverse flows by aligning with the waste hierarchy and value retention principles (Chen et al. 2021). Blockchain can help verify ethical practices in supply chains by addressing issues such as child labour and human rights violations related to raw material procurement (Magrini et al., 2021).

3.2.9 Finance

Among the sectors to which blockchain technology has been applied in financial matters, it has played a key role in creating and managing the market related to Bitcoin. For instance, the study by Ozili (2022) focuses on a digital currency issued by the central bank to promote circular economy actions in all production systems. This currency would offer various functions that would allow a transition from a linear economy to a circular one, in particular: it would offer a better payment option for transactions in the circular economy, would provide more effective financial assistance to circular enterprises through the central bank itself, and would help reduce illicit activities. It can also provide stimulus financing to support circular enterprises during times of crisis and offer lower transaction costs for financial transactions involving the circular economy actions taken by enterprises and natural persons. Blockchain technology, in this case, would play a key role in ensuring, as in the Bitcoin market, transparency, security and integrity, reduction of transaction costs and efficiency. Another aspect involving the financial sector is creating a credit system to support the transition towards a circular economy. This system, through the adoption of blockchain technology, would allow transparent and secure verification of the credit reputation of economic entities. Sharing this information would generate huge benefits in the financial market, particularly by facilitating and encouraging reliable transactions between trading partners. In addition, thanks to the benefits provided by blockchain technology, we would see a significant reduction in brokerage costs, simplifying and reducing the costs of the current control system for the assignment of credit ratings. Finally, the smart contracts tool would ensure the legality, speed and security of transactions, making the process more efficient (Wu et al., 2018).

3.2.10 Transportation

The transformative potential of integrating the principles of the circular economy with new technologies also significantly involves the context of transport infrastructure. The literature review shows how Blockchain technology, AI, and IoT in the transport sector play a key role in responding to the environmental challenges posed by conventional transport systems, such as predictive maintenance, improving material recycling, resource optimisation, waste reduction, and life cycle extension (Yildizbasi et al., 2025; Bekrar et al., 2024). In more detail, adopting the IoT can improve real-time data collection and system-level efficiency. Given the sector's peculiarity, the adoption of new technologies contributes significantly to the creation and management of smart cities, reducing congestion and improving traffic flow with a consequent reduction in CO2 emissions (Yildizbasi et al., 2025).

4 Discussions and Conclusions

The analysis of the reviewed articles highlighted the potential of blockchain technology in implementing circular economy techniques in both the private and public sectors. The results show how blockchain implementation is cross-cutting across different sectors. However, several obstacles prevent the

implementation of blockchain technology. Among the main ones that emerged from the reviewed studies are the very high costs due to the significant investments it requires, the poor digital literacy of non-technical users who often drive small and medium-sized businesses, scalability problems, high energy consumption and lack of regulation. Moreover, although the systematic literature review has shown widespread application, it is still insufficient to reveal different management scenarios. Therefore, it is essential to emphasize that blockchain applications are not limited to end-of-life product management but extend throughout the entire supply chain to minimize waste and reduce the environmental impact of these sectors. However, companies must master new data analysis technologies to adopt blockchain technology and optimize sustainability practices properly. Indeed, the connection between blockchain technology and big data analytics tools significantly supports the integration among the various actors across the different stages of the supply chain (Mileti et al., 2022). This connection links producers with commercial channels, ensuring traceability, transparency, authenticity, increased productivity, reliability, and trust-based agreements while, thanks to the immutability of recorded data, preventing fraud and information falsification (Kumar and Chopra, 2022). In conclusion, in light of what has emerged from the study, we can argue that one of the main objectives of future research is to regulate with homogeneous standards, offering economic and knowledge support to actors called upon to implement it (Barceló et al., 2024). Further future challenges related to the implementation of blockchain technology in the circular economy concern the reduction of investment costs that the implementation of smart devices, sensors and related technologies require (Kopeinig et al., 2024) and the systematic applications of these technologies in new management scenarios (Jiang et al., 2023). The study provides valuable insights for policymakers, companies, and researchers to promote the integration of blockchain technologies within businesses, contributing to the pursuit of sustainable development. The search has some limitations. The authors considered only one database and documents written in English. As a result, some studies may be missing since we do not include databases and languages other than English. In addition, the study focused exclusively on documents that deal with blockchain and the circular economy from a managerial perspective. Future studies may analyse more specific topics or adopt other methodologies for a more complete phenomenon overview.

5 Declarations

Ethics declaration: Not applicable.

AI declaration: The authors declare that no AI tools were applied.

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Exploring Artificial Intelligence in the Circular Blue Economy

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Abstract

Artificial intelligence is becoming increasingly important, with applications varying from sector to sector due to its adaptability. Its most common uses range from generating clean energy to monitoring data to analyse the surrounding ecosystem and mitigating pollution damage. In the circular economy, the potential of AI could be harnessed to accelerate sustainable transactions by integrating it into design, business models and infrastructure optimisation. Thanks to its generative capabilities, AI can significantly contribute to reducing the impact of human activities on the environment by addressing challenges related to unsustainable production. In this respect, the circular economy proposes models that contribute to value creation through cycles of reuse, restoration and renewability.

This work, therefore, aims to investigate the state of the art of scientific research in the area of the circular economy in general and, with a specific focus on applications in the context of the Blue Economy, highlighting the uses, advantages and opportunities that the use of these systems brings to the Blue Economy sectors. The methodology adopted consists of a systematic literature review (SLR), aimed at categorising existing scientific contributions extracted from the Scopus database, analysing the main research trends and identifying the most relevant practical applications, and identifying future insights to encourage the adoption of AI within the Blue Economy. The results of this study highlight the limited presence of studies on the application of artificial intelligence in the context of the Blue Economy, and research is fragmented and spread across different disciplinary areas. However, the maritime sector has stood out for its strong interest in technology adoption from a scientific research perspective. This study, therefore, provides theoretical implications for academics by identifying the knowledge gap and providing guidelines for future research, and managerial implications for all stakeholders in the blue economy who want to know how to integrate the use of AI into their processes. Finally, the focus on this as yet under-researched area lends the study a character of originality and scientific relevance.

Keywords: Circular Economy, Blue Economy, Artificial Intelligence, Smart Technologies.

Paper type: Academic Research Paper

1 Introduction

The concepts of digitalization in the economy and circular economy have been developed in recent years and are closely interrelated (Kaya, 2024). Today, technological progress is integrated into every industry, business practice, and economic activity, serving as a tool to enhance efficiency and simplify many operations. The environmental impact of products and production processes is increasingly significant, and approaches such as the circular economy aim to reshape development models, focusing not only on the environmental sphere but also on social and economic dimensions (Chidepatil et al., 2020). Thanks to the integration of technologies into individual operations or, more broadly, into the functioning models of industrial processes, it is possible to tackle challenges such as sustainability. In the maritime context, this is reflected in the Blue Economy model, considered a school of thought within the circular economy, which focuses specifically on economic activities related to the marine environment (European Commission, 2024). According to some authors, the application of artificial intelligence or AI to economic activities increases productivity (Brynjolfsson, 2014; Czarnitzki et al., 2023), enables the monitoring of environmental impacts (Popescu et al., 2024), supports the management of the marine environment (Ajwani-Ramchandani et al., 2021; Brönner et al., 2023; Gesami and Nunoo, 2024), and facilitates the implementation of circular business models. Conversely, some scholars remain skeptical about AI's potential to drive a new wave of productivity growth (Gordon, 2018). Nevertheless, the integration of artificial intelligence is transforming industrial sectors, which are evolving and innovating through the integration of new technologies that support the generation of new ideas and foster innovation (Agrawal et al., 2019). In the circular economy, and within the broad and diverse Blue Economy value chain, numerous innovations have been implemented through the use of AI (Rajput and Singh, 2019; Pranita et al., 2023). This study aims to analyze the state of the art regarding the applications of artificial intelligence within the framework of the Circular Blue Economy. Through a structured literature review and by following authoritative research protocols, the study aims to identify the evolving research trends, systematize the contributions, and highlight any circular blue economy practices supported by AI. The results first of all demonstrate the novelty of the topic, which consequently translates into the limited presence of research on the application of artificial intelligence within the Blue Economy. Three main thematic foci were identified in this study: the use of smart technologies

to support the circular economy, the Blue Circular Economy and sustainable resource management, and the development of circular business models and performance measurement. The originality of the study lies in its exploration of a relatively under-researched area; nonetheless, it represents a valuable contribution by recognizing the knowledge gap, encouraging academics to pursue further research in this field, and, on the managerial side, influencing stakeholders to consider digital solutions for implementing circular models in the Blue Economy. This paper is structured as follows: after the introduction, a brief literature review relevant to the research context is provided; next, the methodology adopted is described; then, the main results are presented and discussed; finally, conclusions are drawn, highlighting the related implications and offering suggestions for future research.

2 Research background

The concept of the circular economy finds one of its most authoritative definitions in the proposal of the Ellen MacArthur Foundation, which describes it as "an industrial system that is restorative or regenerative by intention and design. It replaces the "end-of-life" concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models". The introduction of this concept thus laid the foundations for an economy that stands in contrast to the linear model. In this regard, Murray et al. (2017) state that the circular economy differs from the linear model based on three core principles: eliminating waste and pollution, keeping products and materials in use at their highest value, and regenerating natural systems. Based on these principles, the circular model finds application in many schools of thought, including that of the Blue Economy. The concept of the Blue Economy was developed by Gunter Pauli, who argued that the local environment, with its specific ecological characteristics, represents the basis for sustainable solutions within each economic ecosystem. The purpose of the Blue Economy lies in the application of the principles of the circular economy within the maritime context, maximizing the value of marine resources (Choudhary et al., 2021; Pace, 2023). In this regard, the vastness of activities revolving around the ocean resource becomes evident, encompassing sectors such as fishing, maritime transport, tourism, and more. It is, therefore, a multisectoral economic model, where, according to the report drafted annually by the European Union, two main categories of activities related to the blue economy emerge: the established sectors, considered traditional, and the emerging sectors, characterized by high technological and innovative content (European Commission, 2024). The EU report identifies seven main sectors, each divided into specific sub-sectors, as shown in the following table:

Table 1: Blue Economy Sectors. Source: European Commission, 2024.

Sector	**Sub-sector**
Marine living resources	Primary production Processing of fish products Distribution of fish products
Marine non-living resources	Oil and gas Other minerals Support activities
Marine renewable energy	Offshore wind energy
Port activities	Cargo and warehousing Port and water projects
Shipbuilding and repairs	Shipbuilding Equipment and machinery
Maritime transport	Passenger transport Freight transport Services for transport
Coastal tourism	Accommodation Transport Other expenditure

As can be observed, the Blue Economy sector, being a fundamental driver of economic growth and the operational application of circular economy paradigms, makes the integration of artificial intelligence applications into monitoring and management practices—and beyond—essential (Gesami and Nunoo, 2024). Artificial intelligence also emerges as an additional input in business processes or even across entire economic sectors, both traditional and emerging within the Blue Economy, capable of generating new ideas and thus fostering innovation (Agrawal et al., 2019). In the Blue Economy, AI applications take the form of intelligent

systems used to optimize the fisheries supply chain (Fernandes et al., 2015) improving the efficiency of supply chain processes (Lim, 2024). In aquaculture, AI enables the assessment of water quality, ensuring the conditions necessary for species development, as well as facilitating optimal management of marine ecosystems (Lim, 2024). Moreover, tools equipped with intelligent technologies can contribute to the monitoring of marine ecosystems (Choudhary et al., 2021), collecting crucial data for environmental monitoring and biodiversity protection (Brönner et al., 2023). In the tourism sector, for example, AI applications are used for the sustainable organization and management of resources, to promote sustainable tourism practices (Pranita et al., 2023), while also enhancing visitors' experiences through virtual and augmented reality (Marroni, 2024). Port operations can also benefit from the advantages of AI in reducing emissions, including greenhouse gases and ocean noise, thus promoting environmentally friendly maritime transport (Munim et al., 2020). Furthermore, the integration of AI and machine learning into sensors, buoys, and satellites allows for the collection of essential data on the oceans, such as ocean currents and sea-level changes (Brönner et al., 2023). In essence, artificial intelligence, as an emerging technology of the “fourth industrial revolution”, represents an important driver capable of sustaining and accelerating the pace of human innovation to design products, bring together aspects of successful circular business models, and optimise the infrastructure needed to foster systemic change that builds long-term resilience, generates business and economic opportunities, and provides environmental and social benefits (Ellen MacArthur Foundation, 2019).

3 Research method

To develop this study, the author adopted a qualitative methodology based on the Structured Literature Review (SLR) method. The SLR follows a rigorous approach that allows for the selection and evaluation of contributions, the analysis and synthesis of data, and the transparent and comprehensive reporting of research findings (Tranfield et al., 2003). Moreover, the literature review helps to understand how research on specific topics has evolved, as it involves an analysis of the thematic foci identified by the author (Petticrew & Roberts, 2006). In this study, the research questions are as follows:

- (RQ1) How is research inquiring for AI and the Circular Blue Economy?
- (RQ2) What is the focus and critique of the AI and the Circular Blue Economy literature?
- (RQ3) What is the future of AI and the Circular Blue Economy?

The main objective is to investigate how artificial intelligence contributes, within the conceptual framework of the circular blue economy, to studies in the business field. First, a research protocol was defined, inspired by consolidated contributions in the literature, such as Tranfield et al. (2003), Petticrew and Roberts (2006), and Kraus et al. (2020). Additionally, based on the methodological syntheses proposed by Chauhan et al. (2022) and Marroni (2024), an analytical framework was constructed, including and considering the following aspects:

- Publication trends: a temporal analysis of research development in the field of circular blue economy and artificial intelligence.
- Geographical distribution: a territorial analysis of the distribution of scientific production on the topic.
- Citation and journal analysis: citation-based information related to the theme.
- Thematic foci: identification of research areas within the context of the circular blue economy and artificial intelligence.

To provide an overview of these aspects within the development of the longitudinal study (2019–2024), the Scopus database was used for article extraction. Scopus offers a wide range of academic information, enabling in-depth insights for the research (Kar et al., 2022). The research strategy involved extracting keywords from "Title, Abstract, and Keywords", using Boolean operators to combine the search terms. The keywords used included: "Circular Economy" OR "Blue Economy" AND "Artificial Intelligence". An initial extraction resulted in 819 documents related to the topic. Subsequently, the author narrowed the scope of the investigation to the field of "Business, Management, and Accounting", considering only "research articles", which generated a result of 83 articles. Finally, articles not written in English and those published in the current year (2025) were excluded, as the year is not yet completed and would have distorted the results, reaching a final sample of 64 items.

4 Results and discussions

In this section, descriptive results are presented, including publication trends, geographical distribution, citation analysis and journals of origin. The identification of thematic foci is also proposed, which makes it possible to trace the evolution of research streams, also analysing their practical implementations.

4.1 Publication trends

The first aspect considered is the publication trend. In this direction, the final sample of articles is included in the time frame 2019- 2024. As the figure shows, the number of research articles increased over six years, peaking in 2023 (20 articles). From 2024 onwards, there is a slight decrease in terms of publication, with 17 articles. The period identified also shows that this is a very current topic.

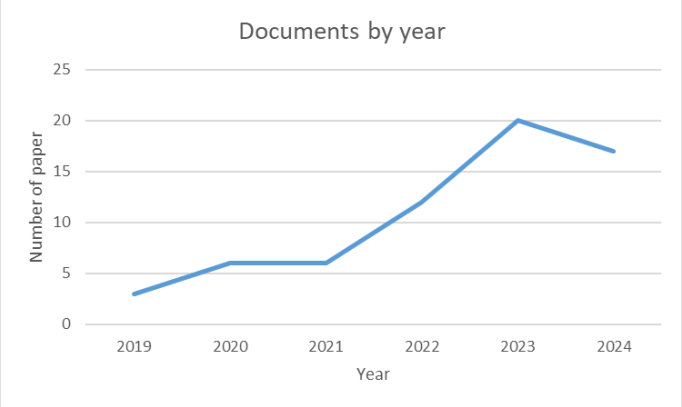


Figure 1: Publishing trend.
Source: Author elaboration from Scopus data.

4.2 Geographical distribution

Shifting the focus to geographical location, India is the territory with the most research articles in this area (16 articles), followed by the United Kingdom (11 articles) and France (10 articles). Below is the table with the list of territories where articles are published in this subject area and the geographical map of the territories.

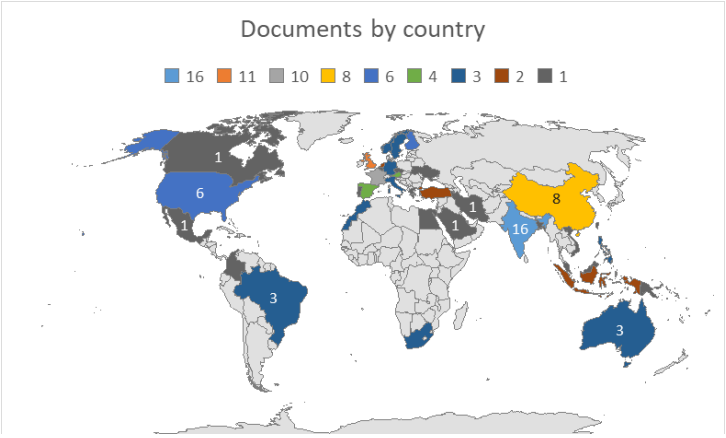


Figure 2: Documents by country.
Source: Author elaboration from Scopus data.

4.3 Citation and journal analysis

An analysis by citation and journal of origin shows that:

- The Journal with the most citations is Technological Forecasting and Social Change with 1.223 total citations distributed among its 6 articles (see Table 1).
- The Journal of Cleaner Production is the journal of choice for those writing on this subject area, with 13 articles published in this SLR (see Table 1).
- The International Journal of Information Management, despite seeing only one article published, stands out for the number of citations (452), symbolising the relevance of this article in this context.
- Other journals show a very low comparison between the number of papers and citations, synonymous that this topic is occasional or emerging in the context of SLR.

Table 2: Distribution of sources and citations of selected articles in the SLR. Source: Author elaboration.

Source	Documents	Citations
Academy Of Strategic Management Journal	1	8
Administrative Sciences	1	134
British Food Journal	1	16
Business Strategy And The Environment	6	468
Clean Technologies And Environmental Policy	2	43
Cogent Business And Management	1	2
Computer Law And Security Review	1	9
Corporate Social Responsibility And Environmental Management	1	11
Industrial Management And Data Systems	1	36
International Journal Of Information Management	1	452
International Journal Of Logistics Management	1	6
International Journal Of Logistics Research And Applications	2	35
International Journal Of Process Management And Benchmarking	1	1
International Journal Of Production Economics	1	21
International Journal Of Production Research	4	138
International Journal Of Sustainable Manufacturing	1	2
Internet of Things (Netherlands)	1	3
Journal Of Air Transport Management	1	27
Journal Of Business Research	1	28
Journal Of Cleaner Production	13	500
Journal Of Construction Engineering And Management	1	6
Journal Of Innovation Economics And Management	1	4
Journal Of Innovation Management	1	47
Labour And Industry	1	4
Logforum	2	5
Operations Management Research	3	167
Organization Science	1	21
Revista De Contabilidad Spanish Accounting Review	1	10
Technological Forecasting And Social Change	6	1223
Technology In Society	1	41
Technology Innovation Management Review	1	23
Transportation Research Part E Logistics And Transportation Review	1	11
Worldwide Hospitality And Tourism Themes	1	16
Wseas Transactions On Business And Economics	1	3

As part of the citation analysis, the six studies with the highest number of citations are summarised in Table 2, the first of which is the study entitled “Role of institutional pressures and resources in the adoption of big data analytics powered artificial intelligence, sustainable manufacturing practices and circular economy capabilities” with 540 citations. These six research articles come from different institutions, in four of them the authors are located in the same state, such as the study by Rajput and Singh (2019) from India, the one by Rusch et al. (2023) from Austria, the one by Laskurain-Iturbe et al. (2021) from Spain and the one by Chidepatil et al. (2020) from Finland. In contrast, the study by Bag et al. (2021) and the one by Chauhan et al. (2022) leverage the international network in the production of scientific research.

Table 3: The six most quoted articles. Source: Author elaboration.

Authors	Title	Year	Source	N. of citations	Country
Bag S.; Pretorius J.H.C.; Gupta S.; Dwivedi Y.K.	Role of institutional pressures and resources in the adoption of big data analytics powered artificial intelligence, sustainable manufacturing practices and circular economy capabilities	2021	Technological Forecasting and Social Change	540	South Africa, France, UK
Rajput S.; Singh S.P.	Connecting circular economy and industry 4.0	2019	International Journal of Information Management	452	India

Authors	Title	Year	Source	N. of citations	Country
Chauhan C.; Parida V.; Dhir A.	Linking circular economy and digitalisation technologies: A systematic literature review of past achievements and future promises	2022	Technological Forecasting and Social Change	389	India, Sweden, Finland, Norway, South Africa
Rusch M.; Schöggl J.-P.; Baumgartner R.J.	Application of digital technologies for sustainable product management in a circular economy: A review	2023	Business Strategy and the Environment	184	Austria
Laskurain-Iturbe I.; Arana-Landín G.; Landeta-Manzano B.; Uriarte-Gallastegi N.	Exploring the influence of industry 4.0 technologies on the circular economy	2021	Journal of Cleaner Production	140	Spain
Chidepatil A.; Bindra P.; Kulkarni D.; Qazi M.; Kshirsagar M.; Sankaran K.	From trash to cash: How blockchain and multi-sensor-driven artificial intelligence can transform circular economy of plastic waste?	2020	Administrative Sciences	134	Finland

4.4 Thematic foci

After reviewing the abstracts, titles, and keywords, the author categorized the final sample into three thematic foci:

1. The use of smart technologies to support circular economy practices: This thematic focus includes articles addressing the integration of digital technologies into the circular economy. Most applications of digital technologies are related to waste management activities (Laskurain-Iturbe et al., 2021; Chen et al., 2023; Mah et al., 2024). Technologies such as artificial intelligence, big data, the Internet of Things, and virtual and augmented reality are linked to the reduction of material and energy consumption as well as waste and emissions (Laskurain-Iturbe et al., 2021). In their study, Rajput and Singh (2019) identify AI and circular economy practices as enablers that support and strengthen circular strategies such as recycling and regeneration by extending product life cycles (Jiang et al., 2023). Additionally, according to the authors, the application of the Internet of Things helps collect valuable data on resource consumption and material waste. Thus, technological innovation enables the realization of the circular economy vision (Ellen MacArthur Foundation, 2019).
2. Blue circular economy and sustainable resource management: This thematic focus includes research articles identifying potential sustainable resource management practices enabled by artificial intelligence and other technologies. The work of Foster and Rhoden (2020) is the only one that combines the use of AI in a Blue Economy sector, namely logistics, arguing that technologies improve the efficiency of logistics and port processes. However, studies such as Coro (2020) more generally analyze AI integration to support sustainable management practices and promote blue growth. Lastly, Pranita et al. (2023) explore the use of blockchain technology to support responsible tourism initiatives.
3. Development of circular business models and performance measurement: This research area includes all articles focused on the creation of circular business models enabled through the use of technology. For example, Philipp (2020) develops a green business model for port logistics to increase transparency along the value chain. Within the domain of business models, smart technologies support performance; Truant et al. (2024), for instance, explore enabling factors that help improve business competitiveness, efficiency, and sustainability.

To gain a deeper understanding of the thematic areas that have shaped this research stream, a keywords occurrence analysis was also conducted. This analysis made it possible to highlight the keywords related to the final sample of the study. According to Dunaiski et al. (2017), a good set of keywords should accurately describe a document (good coverage), be sufficiently distinctive so as not to apply to too many documents (relevance) and be easily understandable (descriptive). Of the 268 keywords used by the authors in the final sample, only those that occurred at least twice were considered, thus excluding keywords mentioned only once. The ten most frequently used keywords in the sample are:

- Circular economy (31)
- Artificial intelligence (21)
- Industry 4.0 (9)

- Sustainability (7)
- Waste management (5)
- AI (4)
- Blockchain (4)
- Digitalization (4)
- Internet of Things (4)
- Circular business models (4)

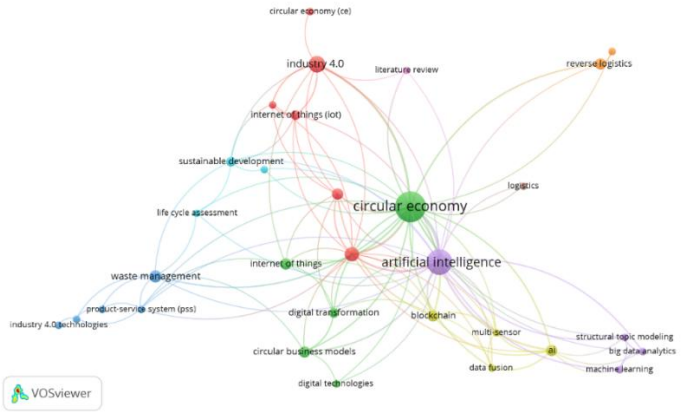


Figure 3: Keywords occurrence.

5 Preliminary conclusions, implications, limitations, and directions for future research

In conclusion, the study highlights the novelty of the topic addressed. Studies on the circular economy, which represent the majority within the present sample, show that it is a well-established research stream, even concerning the application of AI. Conversely, studies focusing on the practical application of AI in the Blue Economy context are limited, confirming its fragmented nature. Both the established and emerging sectors of the Blue Economy have only recently begun to attract attention. The use of AI is still in an experimental phase, and this highlights the absence of comprehensive theoretical syntheses regarding these areas. The Structured Literature Review, conducted on this sample of articles, made it possible to identify three main thematic foci: (1) the use of intelligent technologies to support circular economy practices, (2) the sustainable management of resources in the Blue Economy, and (3) the development of circular business models and performance measurement. It is starting from these thematic areas that further academic research is hoped to be developed, filling the existing gap, while on the managerial side, given the importance for businesses, it is encouraged to promote the adoption of AI, thus fostering the transition towards circular business models. This study is not without limitations. First, the use of a single database does not allow for exhaustive coverage of the literature on the topic. Second, relying solely on the reading of titles, abstracts, and keywords may represent an obstacle to fully understanding the information. Considering the evidence collected, future research directions can be identified. Academic research could focus on sectoral dynamics within each activity included in the Blue Economy, to better understand the developments related to the application of AI in this emerging sector. Conversely, on the managerial side, longitudinal research based on case studies could be developed for each sector, identifying the degree of applicability according to the sectoral and economic diversities that characterize the Blue Economy value chain.

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7 Ethics declaration

No ethical authorization was required for the research.

8 AI declaration

No AI tools were used in the development of the paper.

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National Culture and Circular Economy Disclosure through Sustainability Reports

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Abstract

The circular economy (CE) is increasingly being recognized as a viable alternative to the traditional linear model of production and consumption, which is now widely acknowledged as unsustainable. For these reasons, the academic literature has begun to take an interest in the way in which companies implement CE strategies in their business models and disseminate information regarding this new model of production and consumption. Specifically, scholars have begun to investigate the dissemination of CE information, but this area of research is still underexplored. In fact, there are only a few studies investigating the factors that influence the levels of CE disclosure (CED). In order to fill the knowledge gap, this study aims to examine the impact of national culture on CED levels. First, this study uses a manual content analysis to measure the amount of CE information disseminated in the sustainability reports of 81 international companies. Secondly, a linear regression model is used to test the impact of national culture on the CED. The results show adequate levels of CE information disclosed through sustainability reports. In addition, they demonstrate a negative impact of power distance and masculinity and a positive effect of uncertainty avoidance and long-term orientation on the CED. To the best of our knowledge, this is the first study to explore the influence of national culture on CED, addressing a gap in the literature at the intersection of cultural values and sustainability reporting practices. By highlighting how specific cultural dimensions shape firms' disclosure behaviour, this study provides valuable insights for companies –seeking to align their reporting with stakeholder expectations – as well as for policymakers and training institutions, who aim to promote more effective and culturally sensitive sustainability frameworks.

Keywords: Circular Economy Disclosure; National Culture; Hofstede; Sustainability Reports

Paper type: Academic Research Paper

1 Introduction

In recent decades, ecosystems have faced increasing threats from deforestation, pollution, urban expansion, climate change, species extinction, and resource overexploitation. Their preservation is crucial for sustainable development, ensuring biodiversity, climate regulation, ecological balance, public health, and resource availability (L'Abate et al., 2023). The exponential growth of the global population, projected to reach 8.5 billion by 2030 and 10.9 billion by 2100 (UN, 2021), has further strained ecosystems by driving higher demand for natural resources such as timber, water, land, and fossil fuels. This growing demand, coupled with the climate crisis, has weakened the capacity of the ecosystem to provide essential resources. Additionally, the COVID-19 pandemic and the Russia-Ukraine conflict have exacerbated resource shortages, creating further challenges in securing raw materials.

The circular economy (CE) plays a crucial role in promoting sustainability by maximizing resource efficiency (Ellen MacArthur Foundation, 2015), aligning production and consumption with sustainable development goals (Ghisellini et al., 2016), and enhancing social well-being (Murray et al., 2017). Geissdoerfer et al. (2017) define CE as a "regenerative system in which resource input and waste, emissions, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops." These key strategies aim to minimize waste and extend resource lifespan (Petruzzella et al., 2024).

Institutions at both European and international levels promote the transition to the CE through various policies and initiatives. China was the first to introduce CE legislation in 2008 (CIRAIG, 2015), followed by the European Union's "Circular Economy Action Plan" in 2015, which provided a framework for integrating CE into production and consumption processes (European Commission, 2014). CE was also incorporated into the 17 Sustainable Development Goals (SDGs) of the "2030 Agenda for Sustainable Development," and further reinforced through the "European Green Deal" and its updated action plan (European Commission, 2019; 2020). Companies also play a crucial role in value co-creation, acting as essential links in the production-consumption chain that must be preserved to close the resource loop (Gunarathne et al., 2021). The adoption of CE strategies

is driven by multiple factors, including the pursuit of legitimacy (Murray et al., 2017), competitive alignment through isomorphic behaviours (Korhonen et al., 2018), and compliance with institutional pressures (Barnabè and Nazir, 2022).

Although CE plays a crucial role for stakeholders and in the ecological transition (Beck et al., 2017), companies still struggle to effectively communicate information about this new production and consumption model (Barnabè and Nazir, 2022; Esposito et al., 2023). The dissemination of CE information is still in an early stage due to the absence of a common language (Korhonen et al., 2018) and the scarcity of measurement tools and guidelines for its representation (Ellen MacArthur Foundation, 2015).

Several studies in the academic field have increasingly focused on the emerging and significant topic of CE disclosure (CED). However, knowledge regarding the factors that influence the levels and quality of CED remains limited. Previous research has primarily concentrated on internal firm-related factors, such as financial characteristics (e.g., Vitolla et al., 2023; L'Abate et al., 2024a), governance (e.g., Esposito et al., 2023; L'Abate et al., 2024b), and ownership structure (e.g., Wang et al., 2014). Regarding external factors, previous studies have mainly focused on industry-specific aspects (e.g., L'Abate et al., 2024a). Limited attention, however, has been given to country-level variables. Specifically, there is a noticeable lack of contributions exploring the role of national culture in shaping CED practices.

This study aims to address this significant gap in the literature by posing the following research question:

- *RQ: Does national culture affect the level of the CED in sustainability reports?*

The remainder of the paper is structured as follows: Section 2 reviews the relevant literature; Section 3 outlines the hypothesis development; Section 4 describes the research design; Section 5 presents the empirical findings; and Section 6 draws the conclusion of this study.

2 Literature review

The relationship between national culture and disclosure practices has attracted the attention of numerous scholars (e.g., Gray, 1988; Fernandez-Feijoo et al., 2011).

In relation to Integrated Reporting (IR), García-Sánchez et al. (2013) showed that masculinity and individualism negatively affect IR adoption. Similarly, Vitolla et al. (2019) observed that power distance, masculinity, individualism, and indulgence negatively influence IR quality, while uncertainty avoidance has a positive effect. Using the Global Leadership and Organizational Behavior Effectiveness (GLOBE) framework, Raimo et al. (2019) found that performance and future orientation are negatively associated with IR quality, whereas assertiveness, institutional collectivism, uncertainty avoidance, and humane orientation are positively associated.

In relation to financial reporting, Hope (2003) observed that national culture influences the amount of financial information disclosed by firms. In addition, Archambault and Archambault (2003) demonstrated that Hofstede's cultural dimensions affect the level of financial disclosure. Similarly, Gray and Vint (1995) found that masculinity and individualism positively influence financial disclosure, whereas power distance and uncertainty avoidance have a negative effect. In the banking context, Hooi (2007) identified a negative relationship between uncertainty avoidance and financial disclosure, with no significant links to other cultural dimensions.

In relation to non-financial reporting, previous studies focused on social (Orij, 2010), environmental (Luo and Tang, 2013), sustainability (Buhr and Freedman, 2001; Silberhorn and Warren, 2007; Romero and Fernandez-Feijoo, 2013), and intellectual capital disclosure (Vitolla et al., 2020). Orij (2010), analysing reports from 600 companies in 22 countries, highlighted a negative effect of masculinity on corporate social disclosure. Luo and Tang (2013), based on a sample of 2,045 firms in 15 countries, found that individualism and uncertainty avoidance positively affect the amount of voluntary carbon disclosure, whereas masculinity and power distance have a negative influence. Comparative studies confirm the relevance of national culture in shaping sustainability disclosure (Buhr and Freedman, 2001; Holland and Foo, 2003; Silberhorn and Warren, 2007). Coulmont et al. (2015), analysing 620 firms across six continents, showed that power distance, indulgence, and individualism positively influence alignment with the Global Reporting Initiative guidelines. Conversely, Yamen et al. (2018), examining 3,917 companies from 59 countries, found that power distance, masculinity, and indulgence negatively affect sustainability reporting, while uncertainty avoidance and long-term orientation have a positive effect. Focusing on intellectual capital disclosure, Vitolla et al. (2020), through the analysis of integrated reports of 100 international firms, identified a positive relationship with uncertainty avoidance and negative effects of power distance, individualism, masculinity, and indulgence.

The literature on the factors influencing CED also appears to be scarcely explored (e.g., Wang et al., 2014; L'Abate et al., 2024a). In this regard, analysing the sustainability reports of firms, Wang et al. (2014) found that ownership concentration, institutional ownership, and institutional pressures aimed at environmental

protection positively influence the level of CED. In addition, Dagiliene et al. (2020) revealed that regulations and mimetic pressures can influence CED levels, whereas coercive factors have no effect on the dissemination of this type of information. Vitolla et al. (2023), by analysing the sustainability reports of 88 international firms, found that firm size, financial leverage, and profitability positively affect the level of CED. Focusing on Twitter as a disclosure channel, L'Abate et al. (2024a) found that profitability and leverage positively influence CED, while energy companies show a lower propensity to disclose CE information. Additionally, focusing on the aviation industry, L'Abate et al. (2024b) observed that airlines with larger, more active, and more independent boards of directors were more likely to disclose CE information through their websites. Finally, Esposito et al. (2023) observed that board gender diversity, board size, and the presence of a sustainability committee positively influence the amount of CE information disclosed through the integrated reports of sampled European firms.

In light of this, it is evident that the relationship between national culture and CED remains largely unexplored in the literature.

3 Hypotheses development

National culture plays a critical role in shaping corporate behaviour, including decisions related to transparency and sustainability disclosure (Vitolla et al., 2019). Cultural dimensions influence how firms perceive their responsibilities and how they communicate them to stakeholders, especially in relation to complex themes such as CE. More specifically, Hofstede's cultural dimensions may affect the extent of CED.

Power Distance reflects the extent to which inequality and hierarchical order are accepted in a society. In high power distance countries, the acceptance of hierarchy may discourage transparency and accountability, potentially leading firms to disclose less CE information. Accordingly, the following hypothesis is proposed:

H1: Firms located in countries with higher levels of power distance disclose less CE information.

Individualism versus Collectivism measures the degree of integration of individuals into groups. In individualistic societies, the focus on personal achievements and weaker interpersonal ties may reduce pressure to disclose information that benefits the collective, such as CE practices. Accordingly, the following hypothesis is proposed:

H2: Firms located in countries with higher levels of individualism disclose less CE information.

Masculinity versus Femininity captures the importance attributed to traditionally male values such as assertiveness and material success. In more masculine societies, the lower emphasis on social welfare and cooperation could result in less engagement with CE principles. Accordingly, the following hypothesis is proposed:

H3: Firms located in countries with higher levels of masculinity disclose less CE information.

Uncertainty Avoidance reflects a society's tolerance for ambiguity and risk. High uncertainty avoidance cultures often adopt rules and codes to minimize uncertainty, which may encourage more structured and formalized disclosure, including in the area of CE. Accordingly, the following hypothesis is proposed:

H4: Firms located in countries with higher levels of uncertainty avoidance disclose more CE information.

Long-Term Orientation versus Short-Term Orientation refers to the extent to which societies focus on future rewards rather than short-term gains. A long-term perspective may lead firms to adopt and communicate sustainable practices, including CE initiatives. Accordingly, the following hypothesis is proposed:

H5: Firms located in countries with higher levels of long-term orientation disclose more CE information.

Indulgence versus Restraint reflects the degree to which societies allow the gratification of desires and impulses. In more indulgent societies, the emphasis on immediate satisfaction and personal freedom may lead to less concern for sustainability-related issues. Accordingly, the following hypothesis is proposed:

H6: Firms located in countries with higher levels of indulgence disclose less CE information.

4 Research design

The sample of this study comprises 81 international companies that published a sustainability report in 2021. The sample was drawn from the GRI website, an independent international organization that supports firms in reporting their sustainability performance and ensures alignment with GRI guidelines. Specifically, the "Community Members" section of the GRI website was selected. This section includes a list of approximately 500 companies (the GRI Community). From this list, only companies that published a sustainability report in 2021 were selected. In addition, companies located in countries for which Hofstede's cultural dimensions were not available were excluded. This process led to the construction of the final sample, which comprises 81 international companies.

The dependent variable of this study is represented by the CED score (CEDS). For its measurement, a sustainability reports' manual content analysis was employed. Content analysis is a "research technique for

making replicable and valid inferences from data according to their context" (Krippendorff, 1980, p. 21). Content analysis, considered a reliable and cost-effective method for acquiring data (Krippendorff, 1980; Salvi et al., 2022) and for supporting the use of econometric models to analyse factors influencing disclosure levels, has been applied in studies on CED (Kuo and Chang, 2021; Barnabè and Nazir, 2022).

The construction of a disclosure index is one of the most widely adopted techniques for quantifying data obtained through content analysis (Vitolla et al., 2022). In this study, a disclosure index was developed based on the framework proposed by Wang et al. (2014) for measuring and disclosing CE information. The index (presented in Table 1) includes 10 items, organised into the following categories: honours and performances; investments and expenditures; policies and implementation; and resource reuse.

To code the disclosure index, each item was assigned a score ranging from 0 to 3. Specifically, a score of 0 was attributed when the information was absent. A score of 1 was given for the presence of qualitative information only, while a score of 2 was assigned when only quantitative information was provided. Finally, a score of 3 was attributed when both qualitative and quantitative information were disclosed. As a result, the total score of the dependent variable can range from 0 to 30.

Table 1 – CED index

Categories	Items	Scores
1. Honours and performances of CE	Definition of CE and honours	0-3
	Performances of energy conservation and emission reduction	0-3
	Performances of resource reuse	0-3
	Other performances on emission reduction	0-3
	Cost saving due to the implementation of CE	0-3
2. Investments in the CE	CE significant investment	0-3
	Other CE recurrent expenditure	0-3
3. CE policies and implementation	CE financial aids and tax concessions policies	0-3
	Implementation of CE related provisions	0-3
4. Resource reuse of CE	CE utilisation ratio information	0-3

The independent variables of this study are the six Hofstede's cultural dimensions (Hofstede et al., 2010). The source of these data is the Hofstede website, and the variables are measured using the Values Survey Modules (VSMs), which contain 5-point scale questions (Hofstede, 2001). In particular, the six cultural dimensions used in this study are: power distance (PD), individualism vs. collectivism (IDV), masculinity vs. femininity (MAS), uncertainty avoidance (UAI), long-term orientation vs. short-term orientation (LTO), and indulgence vs. restraint (IVR). Firms headquartered in the same country have the same cultural dimension score.

Following prior literature in the field (Vitolla et al., 2019; Rubino et al., 2020), a set of control variables was included to enhance the robustness of the econometric analysis. Specifically, the study considered firm size (LNFS), profitability (PROF), financial leverage (FINLEV), and board size (BS). LNFS was calculated as the natural logarithm of total assets. PROF was measured using return on equity (ROE), calculated as the ratio of net income to shareholders' equity. FINLEV was computed as the ratio of total assets to shareholders' equity. Lastly, BS was measured as the total number of directors on the board of director.

To test the impact of national culture on CEDS, a linear regression analysis was performed using robust standard errors. The regression model is presented in the following equation:

$$CEDS_i = \beta_0 + \beta_1 PD_i + \beta_2 IDV_i + \beta_3 MAS_i + \beta_4 UAI_i + \beta_5 LTO_i + \beta_6 IVR_i + \beta_7 LNFS_i + \beta_8 PROF_i + \beta_9 FINLEV_i + \beta_{10} BS_i + \varepsilon$$

5 Results

The results of the descriptive statistics, VIF and correlation analyses are reported in Table 2. The average value of the CEDS is equal to 17.886, highlighting an adequate CED activity for the firms that comprise the sample. The mean values of the cultural variables in our sample are the following: PD 46.192, IDV 68.481, MAS 58.638, UAI 58.746, LTO 48.596 and IVR 55.091.

The correlation coefficients are all relatively low; the higher value is -0.623 between PD and IVR. All the coefficients are below the critical thresholds accepted in the literature (Kennedy, 1999). The variance inflation factor (VIF) analysis confirms the absence of multicollinearity problems in our analysis: the higher value, in fact, is equal to 2.28 (Myers, 1990).

Table 2 – Descriptive statistics, VIF analysis and correlation analysis

Variable		Mean	S.D.	VIF	1	2	3	4	5	6	7	8	9	10	11
1	CEDS	17.886	4.652	-	1										
2	PD	46.192	15.592	2.28	-0.109	1									
3	IDV	68.481	23.301	2.23	-0.098	-0.623***	1								
4	MAS	58.638	16.137	1.17	-0.117	-0.021	-0.038	1							
5	UAI	58.746	16.621	1.27	0.341	0.116	-0.267**	0.196*	1						
6	LTO	48.596	22.628	1.99	0.422***	0.009	-0.293***	0.019	0.137	1					
7	IVR	55.091	20.194	1.85	-0.222**	-0.328***	0.354***	-0.156	-0.212*	-0.545***	1				
8	LNFS	8.745	3.478	1.52	0.548**	0.005	-0.115	-0.100	0.207*	0.282***	-0.251**	1			
9	PROF	0.194	0.376	1.10	0.271**	0.041	-0.024	0.019	0.081	0.102	-0.066	0.141	1		
10	FINLEV	2.751	1.951	1.30	0.186*	0.122	-0.069	0.119	0.153	0.301	-0.184*	0.085	0.218**	1	
11	BS	15.418	8.819	1.54	0.411***	0.120	-0.010	0.112	0.273**	0.195*	-0.121	0.451***	0.118	0.083	1

Notes: *** Significant at the 1% level; ** Significant at the 5% level; * Significant at the 10% level.

The results of the regression analysis are reported in Table 3. Results highlight the existence of a negative and significant impact of PD (5% significance level) and MAS (10% significance level) on CEDS, supporting the hypotheses H1 and H3. Therefore, companies located in countries with high levels of power distance disclose a lower amount of CE information. Furthermore, companies operating in masculinity-oriented societies disseminate a lower level of CE information. Furthermore, the existence of a positive and significant effect of UAI (5% significance level) and LTO (10% significance level) on CEDS supports the hypotheses H4 and H5. Therefore, companies operating in societies characterized by greater uncertainty avoidance have a higher propensity to disseminate CE information. Even in countries with high levels of long-term orientation, companies tend to disseminate a greater amount of CE information. The effect of IDV and IVR on CEDS is not statistically significant, so the hypotheses H2 and H6 are not supported. Therefore, the results demonstrate that individualism and indulgence are factors that do not affect the amount of CE information disclosed by companies within sustainability reports.

Table 3 – Regression model results

Variables	Coefficient	Standard error	p-value	Sign.
Cons	*15.341*	*4.438*	*0.001*	***
PD	-0.072	0.029	0.015	**
IDV	-0.012	0.023	0.577	
MAS	-0.053	0.027	0.056	*
UAI	0.065	0.024	0.010	**
LTO	0.041	0.024	0.096	*
IVR	-0.015	0.022	0.488	
LNFS	0.265	0.137	0.058	*
PROF	1.851	0.555	0.001	***
FINLEV	0.232	0.171	0.180	
BS	0.112	0.045	0.016	**
N	81			
Adj. R^2	0.512			

Notes: *** Significant at the 1% level; ** Significant at the 5% level; * Significant at the 10% level.

6 Conclusions

This study investigated the influence of national culture on CED, focusing on the effect of Hofstede's cultural dimensions on the level of CE information disclosed in sustainability reports. The findings indicate that power distance and masculinity negatively affect CED, while uncertainty avoidance and long-term orientation have a positive impact.

This study offers several contributions to the academic literature. First, it advances the debate on the relationship between national culture and corporate transparency by examining how Hofstede's cultural dimensions influence CED practices. Second, it addresses the limited research on the determinants of CED, demonstrating that cultural values significantly contribute to shaping such practices. Third, it extends the analysis of CED to sustainability reports, which are still underexplored in the literature despite their potential as key channels for communicating circular strategies.

This study also offers important practical implications for firms, policymakers, and training institutions. First, firms should consider the cultural values of the country in which they operate when defining their transparency policies, adapting data processing and communication strategies to local expectations. Secondly, policymakers, considering the importance of the CE, should promote both the adoption of circular models and the disclosure of related information through targeted policies, in order to ensure transparent and reliable communication for all stakeholders. Universities and training institutions, in turn, should foster understanding of cultural differences by offering cross-cultural management courses, helping companies develop disclosure strategies that reflect the specific cultural contexts in which they operate.

In conclusion, it is important to recognize the limitations of this study. The first limitation concerns the relatively small sample size, which includes only 81 companies. The second relates to the use of Hofstede's model for measuring national culture. Although widely used in the literature, this model has faced criticism due to the potential variability of cultural values within individual countries. These limitations suggest several directions for future research. To address the first, future studies could draw on additional sources to select sustainability reports and thereby expand the sample. Regarding the second, alternative cultural frameworks—such as those developed by the GLOBE project—may offer a more comprehensive representation of national culture. Moreover, future research could examine the role of other country-level variables, such as the Worldwide Governance Indicators developed by the World Bank.

7 Ethic declaration

Ethical approval was not required, as the nature of this study does not fall within the categories typically subject to ethics review.

8 AI Declaration

AI was used for language editing purpose. No AI tools were involved in content generation, data analysis, or interpretation of results.

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Circular Economy Disclosure and Bank Market Value: Evidence from Europe

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Abstract

The increasing urgency of environmental concerns, alongside the global challenges posed by climate change and resource depletion, has underscored the need for a transition toward a circular economy (CE). The banking sector plays a pivotal role in this shift, not only by financing and supporting circular initiatives across industries, but also by adopting CE principles within its own operations to enhance accountability and build stakeholder trust. In this context, banks are expected to improve transparency by disclosing information about their CE practices. Despite this growing relevance, CE disclosure (CED) in the banking industry remains an underexplored area in academic research. Therefore, this study seeks to address this gap by investigating the impact of CED on banks' market value. Adopting a signalling theory perspective, the analysis applies an Ordinary Least Squares (OLS) regression to a sample of 107 European listed banks, focusing on CE information disseminated through their official websites. The results reveal a positive and statistically significant relationship between CED and market value. These findings offer interesting theoretical insights and practical implications.

Keywords: Circular Economy; Disclosure; Banking Sector; Banks; Signalling Theory

Paper type: Academic Research Paper

1 Introduction

Climate change and biodiversity loss stand among the most pressing global challenges of our era. The urgency of these issues, their widespread presence in public discussions, and their potential interlinked relationship indicate that they are perceived as components of a broader, integrated concept of contemporary threats (Skogen et al., 2018). This is driving nations across the globe to actively take action within sustainable economic frameworks (Isaksson, 2019). Businesses are increasingly recognising the need to implement more sustainable strategies to address these pressing challenges (Kennedy and Linnenluecke, 2022). Given the detrimental effects of high emissions and pollution – characteristics of the conventional linear economy model – mitigation efforts have become imperative (Fraccalvieri et al., 2025). Consequently, businesses have started to react by transitioning toward the circular economy (CE) models (Corona et al., 2019). Hislop and Hill (2011, p.2) have defined the CE as "*a development strategy that maximises resource efficiency and minimises waste production within the context of sustainable economic and social development*". This approach encourages responsible resource utilisation by following the 3R principles – reduce, reuse, and recycle (Ghisellini et al., 2016) – with the aim to promote waste reduction and design of processes and products to maximise resource efficiency and minimise environmental impact (Petruzzella et al., 2024). Besides, the implementation of CE models has been considered fundamental for economic growth, social welfare, and inclusiveness (Magnano et al., 2024).

The private sector plays a decisive role in fostering the CE and sustainable transition as it is responsible for producing goods and providing services that profoundly impact the environment (Esposito et al., 2020). Therefore, firms contribute to CE by adopting more efficient technologies, relying on renewable energy resources, implementing low-impact production practices, and minimising their use of natural resources (L'Abate et al., 2023). Despite facing challenges unique to their industry and business context, an increasing number of firms are shifting towards CE models (Serrano-Arévalo et al., 2024). Indeed, CE practices have been adopted in several industries, including agriculture (Velasco-Muñoz et al., 2021), construction (Norouzi et al., 2021), energy (Serrano-Arévalo et al., 2024), cosmetics (Mondello et al., 2024), fashion (Dissanayake and Weerasinghe, 2022), and steel (Roychand et al., 2020).

Although CE practices are typically associated with the manufacturing industry, the financial sector, particularly banking, holds a fundamental role (Goovaerts and Verbeek, 2018; Ozili, 2021; Ozili and Opene, 2021). Banks' contribution is twofold: on the one hand, they support firms in transitioning to the CE by providing appropriate financial and legal structures, network creation services, and advisory support; on the other hand, they reassess their own business models by adopting more sustainable practices (Fraccalvieri et al., 2025).

The relevance of CE in banking has also underscored the importance of disclosing CE information to ensure transparency and raise awareness. Indeed, thorough dissemination of CE information ensures that both

shareholders and stakeholders obtain a clear and accurate view of the banks' initiatives related to the internal implementation of practices respecting the 3R principles and support of the transition to CE models.

Recently, several authors have started to investigate CE practices in banking, mainly concerning the role of banks in facilitating the transition towards a CE (Gooovaerts and Verbeek, 2018; Zhelyazkova, 2020; Ozili and Opene, 2021). Nevertheless, CE disclosure (CED) in banking has received limited attention, with only one study focusing on its determinants (Fraccalvieri et al., 2025).

Therefore, this study intends to bridge this gap by investigating the effects of CED on banks' market value. Drawing on signalling theory, this study focuses specifically on CED practices conveyed through the official websites of European banks. The choice to consider banks' official websites rather than corporate reports is based on the intrinsic characteristics of digital platforms, which enable more dynamic, accessible, timely, and cost-effective communication (Sobhani et al., 2012; Vitolla et al., 2022).

By employing an Ordinary Least Squares (OLS) regression, the results of this study show that increased CED through official websites enhances the firm value of banks.

This study makes significant contributions to academic research. Firstly, it enriches the knowledge of how sustainability disclosure – specifically CED – affects banks' market value, addressing a gap in prior research. Secondly, it expands knowledge of online disclosure practices in the banking sector by demonstrating the effectiveness of official websites in communicating CE information. Thirdly, it applies signalling theory by interpreting the dissemination of CE information online as a strategic practice to enhance transparency and investor confidence, thereby improving market valuation.

Finally, this study offers valuable practical implications for banks, policymakers, and standard setters. For banks, leveraging official websites for CED can reduce information asymmetries and increase market valuation, encouraging more strategic digital communication. To achieve this, banks should employ skilled professionals for content creation and website management, and balance traditional reports with dynamic web-based updates. For policymakers, encouraging CED could support more efficient financial markets. For standard setters, creating harmonised guidelines for CED in banking would improve transparency, comparability, and the quality of information, helping stakeholders better assess banks' commitment to CE principles.

The remainder of this work is organised as follows. Section 2 provides a review of the literature on the topic. Section 3 presents the theoretical background and the hypothesis. Section 4 is devoted to the methodology used. Section 5 shows the results of the study. Finally, Section 6 draws the conclusions.

2 Literature review

Several empirical studies have explored the relationship between sustainability disclosure and bank market value, yielding a variety of findings that can be grouped into two main perspectives. On the one hand, a number of contributions report a positive association between sustainability disclosure and bank performance, supporting the view that Environmental, Social, and Governance (ESG) communication enhances transparency, reduces information asymmetry, and improves investor confidence (Carnevale and Mazzuca, 2014; Buallay, 2019; Attah-Botchwey et al., 2022; Gangwani and Kashiramka, 2024). On the other hand, a growing stream of literature has emerged pointing to either negative or inconclusive effects, highlighting the importance of contextual and institutional factors as well as potential costs associated with sustainability practices (Buallay, 2020; Harun et al., 2020; AlAjmi et al., 2023).

Among the studies reporting a positive effect, Carnevale and Mazzuca (2014), focusing on a sample of 176 banks in the timeframe 2002-2011, analysed the direct effects of sustainability reporting on stock prices, highlighting that banks' sustainability reports are positively valued by the market. Buallay (2019) considered a sample of 235 banks covering the period 2007-2016 to test the relationship between sustainability reporting and market performance, identifying a positive association. However, this study also indicated that this relationship varies when considering each ESG pillar individually. Indeed, market performance is positively affected by environmental and governance disclosures, but not by social disclosure. In the African context, Attah-Botchwey et al. (2022) focused on a sample of 20 listed banks, considering the timespan from 2010 to 2020, to investigate the relationship between sustainability reporting and bank market performance. They found a significant positive association between the inclusion of ESG content in financial statements and bank market performance, even though environmental disclosures alone do not appear to have a significant influence. Finally, Gangwani and Kashiramka (2024) analysed 178 commercial banks from the top 20 emerging markets over the period from 2015 to 2021 to examine the influence of ESG disclosure scores on bank market performance. They revealed that higher ESG disclosure scores are associated with superior market performance.

Conversely, several studies raise questions about the presumed benefits of sustainability disclosure for bank market value. Harun et al. (2020) focused on Islamic banks in Gulf Cooperation Council countries during the

period 2010-2014 to identify the effects of Corporate Social Responsibility (CSR) disclosure on banks' market value and indicated a negative relationship. Similarly, AlAjmi et al. (2023) studied 245 banks in emerging markets between 2008 and 2020 to test the relationship between CSR disclosure and market value, revealing a negative association. Another contribution is offered by Buallay (2020), who compares 932 manufacturing firms and 530 banks across 80 countries from 2008 to 2017 to analyse the impact of sustainability reporting on market performance. The analysis revealed a positive effect of sustainability disclosure on firm performance in the manufacturing sector but a negative effect in the banking sector, suggesting that the market may interpret ESG efforts differently across industries.

Although the literature provides extensive insights into the effects of general sustainability disclosure on bank market value, no study to date has directly examined the role of CED in the banking sector. The only related contribution is offered by L'Abate et al. (2024), who analyse a panel of 133 publicly listed international firms over the period 2019-2021 to examine the effects of CED on the cost of debt. Their findings suggested that communication of CE information through platforms such as Twitter can serve as an effective market signal, enhancing investor perceptions and increasing firm value. However, the study does not focus on banks, leaving an important gap in the literature that remains to be addressed.

3 Theoretical background and hypothesis

Previous studies have applied signalling theory (Spence, 1973) to investigate the relationship between CED and the market value of non-financial firms (e.g., L'Abate et al., 2024; Petruzzella et al., 2024). Accordingly, this study draws on signalling theory to explore how CED practices influence the market value of European banks.

The seminal work of Spence (1973) assumes that markets are characterised by information asymmetry. This market inefficiency exists because one party possesses more information than the counterpart in terms of both quality and quantity (L'Abate et al., 2024). To bridge this information gap, one party – the signaler – can transmit a signal to the other party – the receiver (Salvi et al., 2021; Mariani et al., 2025). Signalers are insiders who possess information not available to outsiders and decide when and whether to disclose it, while receivers are outsiders who do not possess information but wish to receive it (Spence, 1973; Connelly et al., 2011). According to (Taj, 2016, p. 339), signals are "informational cues sent by one party to another in order to influence desired outcomes". Signals, whether voluntary or involuntary, and regardless of conveying positive or negative information, can enrich the informational environment by reducing asymmetries between parties (Petruzzella et al., 2024). Hence, according to this theory, the voluntary disclosure of information represents a signal that organisations send to the external environment (Salvi et al., 2021; L'Abate et al., 2024). More specifically, sustainability information can be viewed as a positive signal that managers send to stakeholders and potential investors to demonstrate their commitment to environmental and social issues (Friske et al., 2023). Indeed, institutional investors are placing growing emphasis on sustainability disclosure to assess organisations' exposure to regulatory and climate risks before making investment choices (Krueger et al., 2020). However, to be effective, signals must be observable and credible (Ross, 1977). In this regard, official websites serve as reliable and easily accessible tools, enabling organisations to disseminate information in a dynamic and timely manner (Garzoni et al., 2024). Following the global financial crisis of 2007-2008, banks began to be perceived negatively by the public. To restore their reputation, many banks have adopted CE practices and have started communicating these efforts transparently (Ozili, 2021). In this context, CED through official websites may help reduce information asymmetry and perceived risk, potentially activating mechanisms that enhance banks' market value. Based on these considerations, the following hypothesis is proposed:

H1*: CED via official websites positively affects banks' market value.*

4 Methodology

4.1 Sample

This study employs a sample of 107 European listed banks. The selection process began with identifying all publicly listed banks across Europe in 2023, using the Refinitiv Eikon database (recently rebranded to LSEG). This first step led to the identification of 330 institutions. Consequently, banks were excluded from the sample if data on the independent and control variables were unavailable. Additionally, banks without an accessible English-language website or with restricted access to certain sections of their websites were also omitted. After applying these exclusion criteria, 83 banks were removed, resulting in a final sample of 107 banks. The selected banks are spread across 26 different countries, thereby providing a comprehensive geographical representation within the European region.

4.2 Dependent variable

The dependent variable of this study is represented by the *Bank_market_value*, which is expressed as the natural logarithm of the bank's market capitalisation. Specifically, it refers to the number of outstanding shares multiplied by their current market price (Widiatmoko et al., 2020). It serves as a key indicator to evaluate a company's overall worth, reflecting the total wealth created by the company or its stock. Market capitalisation is widely recognised as a standard measure of business valuation, indicating the cumulative value of a business or its shares (Almumani, 2018).

4.3 Independent and control variables

The primary independent variable used in this study is the CED Score (*CEDS*), which indicates the level of information related to CE disclosed by banks on their official websites. A manual content analysis was conducted to construct this variable. Content analysis is a widely used technique in accounting research, which offers a valuable means to examine information and encode it into objective, reliable, and replicable data (Vitolla et al., 2023). Consistent with previous studies (e.g., Kiliç and Kuzey, 2019; Esposito et al., 2023; Marrone et al., 2024), the analysis was carried out using a manual approach. Several factors drove the decision to adopt a manual approach. Firstly, unlike automated content analysis, the manual method provides greater flexibility and adaptability to the specific context, enabling the interpretation of synonyms and phrases with multiple meanings. Secondly, it allows for a deeper understanding of the information, as researchers can critically evaluate the content and make inferences based on their knowledge of the phenomenon. Lastly, the manual approach facilitates the contextual interpretation of information (L'Abate et al., 2023).

The analysis was conducted on the official banks' websites, excluding downloadable documents, as the study specifically focuses on online disclosure. The process of identifying relevant information began with thoroughly examining each website to identify sections containing content related to CE. These sections were then analysed and assessed based on the disclosure index presented in Table 1. The index provides a comprehensive framework for evaluating how banks disclose information related to CE practices.

Table 1: *CEDS*

Area	Items	Score
Area A: Supporting the circular transition of firms		
A.1 Corporate Policies and Objectives	1. Information about the existence of a corporate policy dedicated to supporting the CE within client businesses	0-1
	2. Information about specific objectives outlined for advancing the CE	0-1
	3. Information about the inclusion of CE criteria in the evaluation of financed projects	0-1
	4. Information about transparency in the evaluation criteria for CE projects	0-1
A.2 Financial Products and Incentives	1. Information about the provision of green loans tailored to CE projects	0-1
	2. Information about the issuance of green bonds to fund CE initiatives	0-1
	3. Information about investment products associated with CE projects	0-1
	4. Information about the requirement of sustainability or CE certifications to qualify for financing	0-1
	5. Information about the provision of financial incentives (e.g., reduced interest rates) for CE projects	0-1
	6. Information about tax incentives for investments in the CE	0-1
	7. Information about direct investments in CE projects, both locally and internationally	0-1
A.3 Support and Collaboration	1. Information about the availability of advisory services to assist businesses in implementing CE models	0-1
	2. Information about the offering of workshops and seminars on the CE for client businesses	0-1
	3. Information about collaboration with external experts to support businesses in the transition to a CE	0-1
	4. Information about incubation or acceleration programs for startups focused on the CE	0-1
	5. Information about awards and recognitions for companies adopting CE practices	0-1
	6. Information about collaborations with companies specializing in the CE to promote innovative solutions	0-1
	7. Information about participation in CE networks and consortia	0-1
A.4 Monitoring, Evaluation, and Awareness	1. Information about the assessment of the environmental impact of financed projects	0-1
	2. Information about the assessment of the social impact of financed projects	0-1
	3. Information about regular reporting on the outcomes of financed CE projects	0-1

Area	Items	Score
	4. Information about sponsorship of research projects related to the CE	0-1
	5. Information about training programs for clients on CE practices and sustainability	0-1
	6. Information about awareness campaigns highlighting the importance of the CE	0-1
	7. Information about publications and guides on implementing CE practices	0-1
Area B: Internal implementation of CE practices		
B.1 Corporate Policies and Objectives	1. Information about the existence of an internal policy dedicated to adopting CE models	0-1
	2. Information about specific objectives defined for the internal adoption of CE practices	0-1
	3. Information about the integration of CE principles into corporate governance frameworks	0-1
B.2 Sustainable Procurement and Supply Chain	1. Information about procurement procedures favoring sustainable products and suppliers	0-1
	2. Information about selection criteria for suppliers based on CE practices	0-1
	3. Information about collaboration with suppliers to improve supply chain sustainability	0-1
B.3 Energy Efficiency and Renewable Energy	1. Information about initiatives to improve energy efficiency in branches and banking operations	0-1
	2. Information about investments in energy-saving technologies	0-1
	3. Information about monitoring and reporting on energy use, including the use of renewable energy sources for banking operations	0-1
	4. Information about the installation of solar panels or other renewable energy sources at branches	0-1
B.4 Material Use and Recycling	1. Information about policies for reducing, reusing, and recycling waste generated by banking activities	0-1
	2. Information about initiatives to reduce the use of single-use plastics in offices	0-1
	3. Information about the use of recycled materials in corporate processes (e.g., recycled paper, eco-friendly office furniture)	0-1
	4. Information about initiatives to reduce the use of virgin materials and promote recycled material use among employees	0-1
	5. Information about obtaining environmental certifications for branches (e.g., LEED, ISO 14001)	0-1
	6. Information about participation in regular environmental audits	0-1
B.5 Digital Transformation and Eco-efficiency	1. Information about the promotion of digital solutions to reduce the use of physical resources (e.g., e-banking, digital documents) and the implementation of paperless processes in offices	0-1
	2. Information about investments in digital infrastructure to improve operational efficiency	0-1
B.6 Monitoring, Evaluation, and Awareness	1. Information about training programs for employees on CE practices and sustainability	0-1
	2. Information about internal awareness initiatives on the importance of the CE and the publication of internal guidelines on sustainable practices	0-1
	3. Information about internal initiatives to develop and implement innovative CE solutions	0-1
	4. Information about collaboration with research institutions for CE projects	0-1
	5. Information about experimentation with new CE business models within the bank	0-1
	6. Information about monitoring and evaluating the impact of sustainability initiatives and projects	0-1
	7. Information about regular reporting on sustainability performance and goals	0-1

The provided index is divided into two areas: (1) supporting the circular transition of firms and (2) internal implementation of CE practices.

The first area examines how banks support their clients in transitioning to CE models, considering aspects such as corporate policies and objectives, financial products and incentives, support and collaboration initiatives, as well as monitoring, evaluation, and awareness-raising activities. The second area focuses on the internal adoption of CE principles by banks, assessing their corporate policies, sustainable procurement and supply chain practices, energy efficiency and renewable energy initiatives, material use and recycling strategies, digital transformation and eco-efficiency measures, as well as internal efforts in monitoring, evaluation, and awareness.

These two areas provide a comprehensive assessment of both external support and internal commitment to CE principles.

Finally, an unweighted dichotomous approach was followed instead of a weighted method, assigning a score of 1 to each item if the information was found on the bank's website and a score of 0 if it was absent. Consequently, the dependent variable could range from 0 to 50.

Concerning the control variables, *Profitability*, *Liquidity*, *Size*, and *Internationalisation* were considered. In particular, *Profitability* was measured by the return on average assets, computed as the bank's net profit divided by its average assets (Petria et al., 2015). *Liquidity* was proxied by the loans-to-deposits ratio, calculated as the bank's total loans divided by its total deposits (Barone et al., 2024). *Size* was measured as the natural logarithm of the number of bank employees (Schildbach and Schneider, 2017). Finally, *Internationalisation* was determined by the number of foreign countries in which the bank operates through its branches (Menassa, 2010).

4.4 Model specification

To test the research hypothesis, this study employs an OLS regression model. Specifically, this analysis aims to identify the impact of CE information disseminated through banks' official websites on their market value. The following equation represents the analytical form of the model used:

$$Bank_market_value_i = \beta_0 + \beta_1 CEDS_i + \beta_2 Profitability_i + \beta_3 Liquidity_i + \beta_4 Size_i + \\ + \beta_5 Internationalisation_i + \varepsilon_i$$

5 Results

5.1 Descriptive statistics, correlation matrix, and Variance Inflation Factor (VIF) analysis

Figures should be numbered consecutively throughout the paper and not numbered according to the section in which they appear. Figure captions should appear below the figure. Use the word Figure in full, rather than Fig or F.

Table 2 show the descriptive statistics, the correlation matrix, and the Variance Inflation Factors (VIFs).

The mean value of the dependent variable, *Bank_market_value*, is 23.002. Concerning the main independent variable, *CEDS*, the mean value is 16.206, which suggests that European banks, on average, are not fully transparent in disseminating information related to their CE practices. The mean values of *Profitability, Liquidity*, and *Size* are respectively 1.102, 1.217, and 8.879. The variable *Internationalisation* shows a mean value of 7.626, thereby indicating that the sampled banks operate, on average, in 8 foreign countries.

The correlation analysis does not reveal any multicollinearity issues, as all the correlation coefficients are above the critical thresholds of ±0.8 and ±0.9 (Farrar and Glauber, 1967). Additionally, the VIF analysis confirms the absence of multicollinearity problems.

Table 2: Descriptive statistics, correlation matrix and VIFs

Variable	**Mean**	**Std. Dev.**	*1*	*2*	*3*	*4*	*5*	*6*	**VIF**
1. Bank_market_value	23.002	1.888	1.000						
2. CEDS	16.206	11.616	0.171*	1.000					1.21
3. Profitability	1.102	1.232	0.204**	-0.199**	1.000				1.12
4. Liquidity	1.217	2.921	0.015	-0.144	0.244**	1.000			1.09
5. Size	8.879	1.615	0.525***	0.263***	-0.064	-0.263***	1.000		2.05
6. Internationalisation	7.626	14.466	0.263***	0.041	-0.218**	-0.070	0.620***	1.000	1.89
								Mean VIF	**1.47**

Notes: *** p<0.01; ** p<0.05; * p<0.10

5.2 Regression analysis

Table 3 shows the results of the regression analysis, which support this study's research hypothesis (***H1***). Specifically, the analysis relies on three model specifications to test the consistency and reliability of the findings.

The baseline model (1), estimated using standard OLS, shows a positive and statistically significant relationship ($\beta = 0.027$; $p<0.10$) between *CEDS* and *Bank_market_value*. This value remains consistent in the second model (2), where robust standard errors are used. The use of robust errors provides consistent estimates in the presence of heteroskedasticity; however, the test for heteroskedasticity indicated no such concern in this case. Finally, the third model (3), estimated through bootstrapping with 500 replications, further supports the robustness of the results.

These results indicate that banks which disclose more CE information on their official websites tend to have a higher market value. This aligns with the principles of signalling theory, since the dissemination of CE

information via websites represents a positive signal sent by banks to investors and stakeholders, indicating the bank's commitment to environmentally and socially responsible practices. By voluntarily sharing such information, banks reduce information asymmetries, enhance stakeholder confidence, and foster a more favourable perception of their operations. This, in turn, may contribute to an increase in market valuation.

Moreover, this finding aligns with previous literature, especially the body of studies indicating that sustainability disclosure enhances transparency, reduces information asymmetry, and strengthens investor trust, thereby increasing banks' market value (Carnevale and Mazzuca, 2014; Buallay, 2019; Attah-Botchwey et al., 2022; Gangwani and Kashiramka, 2024).

Table 3: Regression analysis

	(1)	**(2)**	**(3)**
	Baseline model	**Robust standard errors**	**Bootstrap**
Variable	*Bank_market_value*	*Bank_market_value*	*Bank_market_value*
CEDS	0.027*	0.027*	0.027*
	(0.014)	(0.014)	(0.014)
Profitability	0.427***	0.427***	0.427***
	(0.126)	(0.116)	(0.133)
Liquidity	0.928**	0.928**	0.928**
	(0.437)	(0.491)	(0.53)
Size	0.57***	0.57***	0.57***
	(0.132)	(0.134)	(0.146)
Internationalisation	0.011***	0.011***	0.011
	(0.014)	(0.011)	(0.012)
Constant	15.976***	15.976***	15.976***
	(1.194)	(1.228)	(1.347)
Observations	98	98	98
Adj R^2	0.411	0.411	0.411

Notes: *** p<0.01; ** p<0.05; * p<0.10

6 Conclusions

This study's objective was to examine the impact of CED on bank market values in the European context.

The results demonstrated that greater disclosure of CE information via official websites improves banks' firm value. Hence, the results confirm the importance of transparency related to CE practices within the banking context, by indicating significant financial benefits linked to the use of the official website as a channel to disseminate CE information.

This study provides valuable contributions to the academic literature. Firstly, it enriches the academic literature by contributing to the growing body of research on the relationship between sustainability disclosure and banks' market value. While prior studies have explored different forms of sustainability disclosure, the impact of CED within the banking sector had not yet been investigated. Secondly, this study enriches the literature on online disclosure in the banking industry. In this regard, it highlights the role of official websites as effective tools for communicating CE information and generating positive market reactions. Thirdly, this study broadens the application of signalling theory by framing the dissemination of CE practices on banks' official websites as a strategic signal aimed at enhancing transparency and investor confidence, ultimately leading to improved market valuation.

This study also provides important practical implications for banks, policymakers, and standard setters. For banks, the ability of CED through official websites to reduce information asymmetries and enhance market valuation should encourage bank managers to make more strategic use of these platforms to communicate their efforts and achievements in implementing CE practices. From this perspective, to ensure accurate and effective communication, banks should consider assigning content creation and website management to professionals. Furthermore, they should aim to balance traditional disclosure tools (e.g., sustainability reports) with dynamic, easily accessible website content, as these channels may serve complementary, and not substitutive, functions. For policymakers, promoting the adoption of CE disclosure practices would enhance financial market efficiency. For standard setters, working toward developing clear and harmonised guidelines for CE disclosure in the banking sector is essential. Establishing a common framework would improve the comparability and quality of disclosed information, fostering transparency and enabling investors and stakeholders to better evaluate banks' commitment to CE principles.

However, this study is not without limitations. The first limitation is represented by the sample size. A larger sample would allow for more generalizable results. Future research could address this limitation by expanding

the sample to include smaller or non-listed banks or by extending the analysis to banks from other regions. The second limitation involves the exclusive focus on information disclosed through banks' official websites, excluding other relevant communication channels such as social media platforms or sustainability reports. Given the increasing use of multi-channel disclosure strategies by firms, future research could explore the comparative effectiveness of these different platforms.

7 Ethics declaration

Ethical clearance was not required for the research.

8 AI declaration

AI tools were used to improve the fluency and clarity of the English writing. All content was reviewed and verified by the authors.

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Artificial Intelligence in the Agri-Food Supply Chain: How it Might Facilitate Circular Economy Practices?

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Abstract

The convergence of Artificial Intelligence (AI) and Circular Economy (CE) is often suggested as a promising pathway for sustainable transformation in the agri-food sector. Yet, how human involvement is configured across AI systems, and whether it enables or limits circular outcomes, remains poorly understood. This study examines how AI is integrated into CE-related practices in agri-food organisations and how human roles are distributed across the AI lifecycle, with particular attention to organisational size and structure. Based on a systematic review of 88 peer-reviewed articles published between 2015 and 2025, the study offers a cross-cutting analysis of how AI systems are conceptualised, developed, deployed, and monitored, and how CE goals are addressed within these processes. Results show a strong imbalance: the early phases of the AI lifecycle are largely shaped by external technology providers, while internal organisational actors are mostly engaged during implementation and operational tasks. Strategic and governance-related phases remain underexplored, and participatory approaches are rare. CE considerations are often reduced to operational metrics, such as waste reduction or resource efficiency, rather than driving systemic redesign or regenerative business models. These findings highlight the need to reposition human involvement as a central lever in aligning AI with circular outcomes. Without stronger organisational capacity, inclusive governance, and CE-aware design logics, AI risks reinforcing existing inefficiencies instead of enabling ecological transition. The study offers a timely contribution to debates on digital sustainability and agri-food innovation, proposing future research directions that foreground agency, adaptability, and systemic value creation.

Keywords: Artificial Intelligence, Agri-food, Circular Economy, Systematic Review

Paper type: Academic Research Paper

1 Introduction

The agri-food supply chain faces a complex array of global challenges that significantly affect both environmental sustainability and societal well-being. Among the most pressing issues is the sector's substantial contribution to environmental degradation, driven by resource-intensive production systems. These practices result in severe consequences for land use, water resources, and greenhouse gas emissions, exacerbating climate change and ecological damage (Willett et al., 2019). Simultaneously, ensuring global food security has become an increasingly urgent issue, with food demand projected to rise sharply as the global population expands. The growing scarcity of food resources, compounded by climate change and economic inequality, underscores the need for the adoption of Agriculture 5.0 and Circular Economy (CE) principles (Akundi et al., 2022; Belhadi et al., 2021; Liu et al., 2021).

However, the agri-food sector remains not only linear in its supply chain structure but also organizationally fragmented, with a wide range of actors pursuing often conflicting objectives and misaligned strategies. These challenges are particularly evident in the tension between global sustainability goals, such as environmental preservation and biodiversity, and the local objectives of individual stakeholders, such as maximizing productivity. This misalignment complicates the effective adoption of sustainable practices (Kukk et al., 2024).

At the same time, the ongoing digital transformation is reshaping interactions among value chain actors in agriculture and food manufacturing. The rapid advancement of Artificial Intelligence (AI), coupled with its growing hype, has accelerated this paradigm shift, with consultancy firms, startups, and technology giants promoting AI-driven solutions as cost-effective and easy to implement. For instance, key AI applications include crop monitoring through soil analysis, issue detection, and the assessment of health indicators via deep learning. AI systems also evaluate soil quality, pests, and diseases, thereby supporting farmers in making informed decisions for land and crop management (Bhat & Huang, 2021; Syeda et al., 2021). Nevertheless, this transition towards digitalisation is often not strategically coordinated by actors and rarely situated within an integrated vision aligned with high-level, "wicked" sustainability goals. Many stakeholders pursue digitalisation independently, often without a shared ecosystemic strategy (Wolfert et al., 2023). This lack of alignment is particularly critical in the face of global environmental challenges, especially for small and medium-sized actors.

Among digital technologies, AI is increasingly advocated by practitioners and recent academic studies as a lever for organisational and process transformation in the agri-food sector. While early applications focused on

isolated or experimental use cases, a growing number of studies have highlighted a transition toward more systematic, lifecycle-oriented integration of AI across agri-food value chains (Belhadi et al., 2024; Wolfert et al., 2023). Importantly, this shift is not only technical but deeply organisational, requiring new forms of coordination, strategic vision, and internal capabilities (Troisi et al., 2023; Sica et al., 2024). These developments resonate with the principles of Industry 5.0 and recent regulatory frameworks such as the European AI Act, which both call for a human-centred, ethically guided approach to technological innovation (AI Act, 2024). In this evolving context, AI is often suggested as a set of technological enablers and a transformative force capable of overcoming institutional inertia and facilitating the transition toward CE models (Das et al., 2023; Fraga-Lamas et al., 2021; Vincent et al., 2019). Although this topic remains underexplored in the literature, recent contributions in the agri-food domain offer relevant insights. For instance, research by Sica and colleagues (2024) presents a comprehensive conceptual model connecting digitalisation to CE transitions, highlighting its implications for strategic planning, managerial competencies, and operational skills. Additionally, Das et al. (2023) identify sixteen key enablers of AI adoption and rank them, noting that many are closely related to human capabilities, such as concerns around automation and job displacement. Their findings underscore the centrality of human involvement in AI deployment within agri-food contexts, echoing recent international regulatory developments.

Notably, the AI Act promotes human involvement across the entire AI lifecycle - from conceptualisation to the delivery of products and services- reinforcing the need for a structured and responsible approach. Yet, existing studies tend to treat AI lifecycle phases in isolation and lack a holistic perspective on how AI can support sustainable transformation in the agri-food sector. As such, more integrative research is needed on how human engagement within AI systems can facilitate CE adoption across organisational types and scales.

In this context, the present study aims to provide a comprehensive analysis of the "human-in-the-loop" paradigm in AI applications within businesses and organisations of varying sizes in the agri-food sector, with a specific focus on its implications for CE implementation.

The primary research questions guiding this study are:

- *RQ1: Which phases of the AI lifecycle have been addressed in prior studies concerning human involvement?*
- *RQ2: What challenges and issues arise in relation to human roles at specific lifecycle phases and alongside the entire AI lifecycle?*
- *RQ3: How is the nexus between AI and CE shaped, and potentially constrained, by the concept of human involvement in digital systems?*

2 Methodology

Empirically, this study is based on a systematic literature review drawn from two major databases (i.e., Scopus and ISI Web of Knowledge) to explore the intersection of Artificial Intelligence (AI), human involvement, and Circular Economy (CE) principles within agri-food systems. The review process was designed in line with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure transparency, replicability, and methodological consistency. The methodology section is organised into three parts. Subsection 2.1 outlines the literature search strategy and database selection. Subsection 2.2 describes the screening and eligibility process. Finally, subsection 2.3 details the variable extraction and coding approach used to answer the three research questions.

2.1 Literature search strategy

The literature retrieval was conducted across two leading academic databases - Scopus and ISI Web of Knowledge - selected for their multidisciplinary scope and comprehensive indexing of peer-reviewed sources relevant to digital innovation and sustainability in agri-food research. No time limits were applied to capture both foundational and emerging contributions. The final search was executed in April 2025, using Boolean operators to combine keywords related to AI (i.e., "artificial intelligence", "machine learning", "deep learning"), CE (i.e., "circular economy", "sustainability"), and the agri-food domain (i.e., "food", "agriculture", "farming"). Titles, abstracts, and keywords were queried simultaneously to maximise coverage.

2.2 Screening and Selection

The initial query yielded 1,950 records. After duplicate removal, 601 entries were discarded. An additional 224 items - such as conference papers, editorials, and book chapters - were excluded based on publication type criteria. This left 1,125 unique articles for screening.

Predefined eligibility criteria were applied to assess relevance. Articles were retained only if they explicitly addressed AI applications in the agri-food sector, focused on for-profit organisational contexts, and provided some insights into human roles or decision-making functions. Studies referring generically to digitalisation or innovation, without direct reference to AI or organisational practices, were excluded.

At the full-text stage, 455 articles were examined in depth. Finally, 88 articles were selected for inclusion in the final sample. Each met the core inclusion criteria and provided insights into one or more phases of the AI lifecycle, with varying degrees of reference to human involvement and/or CE dimensions.

2.3 Extraction variables and coding strategy

To address the three research questions, a structured data extraction and coding protocol was developed. Each of the 88 included articles was analysed using a coding scheme combining both deductive and inductive dimensions. Variables were organised along three analytical axes corresponding to the AI lifecycle phases, human involvement, and circular economy (CE) relevance. For RQ1, articles were coded based on which AI lifecycle phases were addressed (conceptualisation, development, deployment, monitoring, governance, and explanation) and whether human actors were mentioned in each phase. For RQ2, a second layer of coding identified challenges associated with human roles, such as skills gaps, resistance to change, role overload, exclusion from decision-making, and trust or interpretability concerns. These challenges were tagged and quantified to identify patterns across organisational types and lifecycle phases. For RQ3, a binary code captured CE relevance, while additional variables tracked how CE principles (e.g., resource regeneration, waste valorisation, closed-loop systems) were integrated into AI applications. Attention was also given to whether CE considerations were embedded in early design or added during deployment. The coding process was conducted independently by two researchers, with discrepancies resolved through consensus, ensuring reliability and analytic coherence across the dataset.

3 Results

This section presents the main findings of the systematic review, structured around the three research questions. Subsection 3.1 maps how human involvement is distributed across different phases of the AI lifecycle. Subsection 3.2 explores the key challenges and constraints associated with human roles. Finally, subsection 3.3 examines how human involvement shapes - and potentially limits - the integration of circular economy (CE) principles into AI-enabled agri-food systems.

3.1 Human Involvement across AI lifecycle phases

In response to RQ1, the systematic review reveals a highly uneven distribution of scholarly attention across the phases of the AI lifecycle (Table 1). Among the 88 articles included in the final sample, the majority focus on early-stage involvement during *conceptualisation* (86 articles). This stage is often characterised by exploratory efforts such as problem framing, identification of AI application opportunities, and initial data design. Interestingly, human involvement here is typically facilitated by external innovation actors, such as consultancies, start-ups, or public–private consortia, rather than being rooted in internal organisational routines. The *Development phase* is the second most frequently discussed (71 articles), where model training and algorithm building are handled predominantly by external technical experts or university laboratories. Internal R&D teams within agri-food organisations are rarely reported as being active contributors at this stage, pointing to a potential disconnect between AI development and organisational learning. Fewer studies (38) address the *Deployment phase*, which involves practical testing or implementation of AI tools. These cases tend to be fragmented and highly localised, lacking a shared strategic framework. Notably, implementation is rarely accompanied by organisation-wide change management or structured role adaptation. Mature stages of the AI lifecycle are considerably underrepresented. Only 24 articles refer to *Monitoring*, where performance evaluation, maintenance routines, and feedback loops would be expected. This absence highlights a critical gap in long-term AI sustainability and organisational learning. *Governance* and *Explanation* are the least addressed phases (18 and 15 articles, respectively), underscoring limited attention to ethical oversight, transparency, and human-AI interaction in agri-food contexts. These findings suggest that while AI adoption is progressing, it remains technology-driven with insufficient emphasis on systemic human engagement throughout the AI lifecycle.

Table 1: distribution of scholarly attention across the phases of the AI lifecycle

AI Lifecycle Phase	Human Involvement	# of Articles	Example Source
Conceptualisation	Early-stage identification of AI opportunities, problem framing, and data gathering design, often guided by external actors or ad hoc innovation units.	86	Kumari et al., 2025
Development	Model building and algorithm training, typically conducted by external tech firms, university labs, or through public–private partnerships. Internal R&D rarely involved.	71	Bran et al., 2024
Deployment	Pilot or field testing of AI systems, with focus on logistics, resource planning, or automation. Mostly bottom-up or fragmented.	38	Anbarasu et al., 2024
Monitoring	Evaluation, feedback loops, maintenance, and performance KPIs. Rarely formalised or systematised in organisational processes.	24	Anbarasu et al., 2024
Governance	Ethical supervision, risk management, legal and compliance framing. Largely absent or vaguely mentioned.	18	Kumari et al., 2025
Explanation	User interaction, explainability features, visualisation for stakeholders. Touched upon in relation to transparency and traceability.	15	Anbarasu et al., 2024

3.2 Challenges related to human involvement across the AI lifecycle

In response to RQ2, the analysis reveals five major challenges associated with human involvement throughout the AI lifecycle in agri-food organisations. First, a persistent *skills gap* (55 out of the 88 studies) limits the ability of human actors, particularly operational staff and middle managers, to engage effectively with AI systems. This gap is especially evident during conceptualisation and governance phases, where technical fluency is required to contribute meaningfully to design or oversight processes. Second, *organisational resistance to change* (identified in 38 studies) frequently hinders AI integration. Legacy practices, hierarchical rigidity, and low digital maturity contribute to reluctance to adopt new roles or modify existing workflows, particularly in small and medium enterprises and cooperatives. Third, *role overload and task misalignment* (reported in 24 studies) are common outcomes of AI adoption. Human actors are often required to perform additional duties, such as data annotation or system calibration, without a corresponding redefinition of responsibilities, leading to fatigue and inefficiency. Fourth, *strategic exclusion* (highlighted in 30 studies) of key internal stakeholders, especially frontline personnel, undermines the contextual relevance of AI applications. These actors are rarely involved in framing problems, setting priorities, or participating in iterative evaluation, which reduces the adaptability and user-fit of deployed systems. Finally, *trust and system interpretability issues* (raised in 22 studies) represent a cross-phase barrier. Many users perceive AI systems as opaque or externally imposed, which limits confidence in outputs and reduces willingness to rely on AI-supported decision-making.

3.3 Human involvement and the artificial intelligence-circular economy nexus

In response to RQ3, the analysis of the 46 CE-relevant studies out of the 88-article final sample reveals a weak and fragmented alignment between AI implementation and circular economy (CE) objectives, often constrained by limited human involvement. While CE is increasingly referenced as a strategic ambition, it rarely guides design, decision-making, or deployment in a systematic manner. Most contributions link CE to specific operational targets, such as waste reduction, resource optimisation, or surplus redistribution, particularly in the deployment and monitoring phases (e.g., Husaini et al., 2023; Trollman et al., 2023). Here, AI tools are used to support smart fertilisation, cold chain management, or environmental footprint tracking. However, human actors involved in these activities, such as farmers or field technicians, are seldom aware of the CE implications of their actions, nor are they empowered to steer systems toward regenerative outcomes. In the conceptualisation and development phases, CE priorities are largely absent. Even when sustainability is referenced in vision statements, few AI systems are explicitly designed with reuse, loop closure, or value regeneration in mind. External experts typically lead these phases, with minimal engagement of organisational actors capable of contextualising CE objectives. Governance and explanation stages present the greatest disconnect: very few studies report participatory mechanisms or reflexive structures that enable human actors

to interpret, negotiate, or co-govern CE transitions. Where ethical or regulatory considerations are mentioned, they tend to focus on compliance, not circular value creation.

4 Discussion

The findings of this review reveal a consistent tension between the technological momentum driving AI adoption in agri-food systems and the underdeveloped role of human involvement, particularly in shaping strategic directions and enabling sustainability outcomes. Although AI has been widely promoted as a transformative force capable of improving efficiency and reducing waste, its application across the sector often remains confined to narrow, technical domains, with limited integration into broader organisational and ecological frameworks. This study highlights a series of original reflections.

First, the uneven distribution of human involvement across the AI lifecycle suggests that critical stages such as conceptualisation and development are largely driven by external actors. While this may accelerate innovation and reduce initial costs, it also limits the internalisation of AI systems within organisations. When agri-food firms are not actively engaged in early design phases, the resulting technologies risk being ill-suited to operational realities or strategic goals. This disconnect reflects a broader structural pattern in the digitalisation of agri-food: innovation is frequently imported rather than co-developed, weakening the potential for long-term learning and system-level transformation.

Second, the analysis highlights a persistent set of organisational challenges that constrain human engagement. Skills gaps, role misalignment, and cultural resistance remain significant barriers to effective AI integration. These issues are not merely technical or educational in nature, as they are deeply embedded in organisational routines, hierarchies, and resource constraints. In many cases, AI adoption amplifies rather than resolves existing asymmetries, placing additional burdens on operational staff without providing mechanisms for participation or support. The limited involvement of organisational managers in AI governance and oversight further exacerbates this problem, preventing the emergence of reflexive structures that could align digital systems with evolving business and sustainability priorities.

Third, when considered through the lens of CE, the role of human actors appears even more marginal. While AI tools are increasingly deployed in applications that touch upon CE-related goals, such as waste tracking, resource optimisation, or traceability, these functions are rarely embedded within a circular logic. Instead, they seek to reflect a continuation of linear optimisation strategies, where efficiency is improved without rethinking underlying production or consumption models. The conceptualisation and development phases, in particular, show almost no engagement with CE principles, and even in deployment and monitoring, CE appears as a secondary consideration rather than a design driver. Moreover, the absence of robust human involvement in governance and explanation phases represents a missed opportunity for systemic alignment. CE transitions require not only technological innovation but also institutional coordination, stakeholder deliberation, and long-term learning, all of which depend on inclusive and participatory governance structures. Yet the literature reviewed indicates that such mechanisms are either missing or highly underdeveloped. Ethical, interpretive, and compliance-related functions are often delegated to external regulations or technological interfaces, without meaningful input from internal stakeholders or affected communities.

Taken together, the findings of this review suggest that current approaches to AI implementation in agri-food systems generate a disconnection between digital capabilities and ecological ambitions, reflecting not a lack of technological potential but a failure to design sociotechnical systems that are context-sensitive, user-informed, and value-driven. Rather than treating AI as a neutral efficiency tool, future efforts must reposition it as a medium for organisational learning, cross-actor collaboration, and regenerative innovation.

This shift requires rethinking how human involvement is conceptualised across the AI lifecycles. Participatory design, training infrastructures, co-governance platforms, and interpretability tools grounded in ecological metrics can all play a role in embedding CE principles more effectively. In particular, empowering small and medium enterprises and cooperatives, who often lack resources but possess high contextual embeddedness, may prove essential to scaling AI-enabled circular models.

Ultimately, the study underscores the need for a more holistic and integrated approach to AI adoption in the agri-food sector that centres human agency, fosters organisational reflexivity, and aligns digital tools with the transformative aspirations of the CE.

5 Conclusions

This article provided an in-depth synthesis of how artificial intelligence (AI), human involvement, and circular economy (CE) principles interact within agri-food systems. Drawing on a systematic review of 88 peer-reviewed articles, three key insights have emerged. First, human involvement remains highly concentrated in the

operational phases of AI deployment, while the more strategic stages, such as conceptualisation, governance, and explanation, are largely dominated by external actors or neglected altogether. This misalignment suggests that AI systems are often introduced in ways that limit organisational ownership and reduce their contextual relevance. Second, several structural challenges inhibit more meaningful human participation. Skills deficits, resistance to change, and unclear role distributions prevent actors within agri-food organisations from fully engaging with AI tools. These barriers are particularly acute in small and medium-sized enterprises, which often lack the institutional support to absorb and adapt digital innovations effectively. Third, the integration of CE into AI-enabled systems remains underdeveloped and mostly incidental. While many AI applications serve CE-relevant purposes, such as reducing food waste or optimising input use, few are designed with circularity as a core organising principle. Moreover, the absence of participatory governance mechanisms and interpretability tools aligned with ecological goals further weakens the connection between AI adoption and circular transformation.

In light of these findings, future research and practice should prioritise human-centred and CE-aligned AI models that enable co-design, shared governance, and iterative learning to foster more resilient, inclusive, and regenerative agri-food systems in the digital era.

6 Ethics declaration

The manuscript has been wrote accordingly to ethical guidelines. I declare that the manuscript is original and never submitted elsewhere.

7 AI declaration

No AI tools were used for creation of the paper.

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Unleashing Digital Transformation in LCA: The Interplay between Data-Driven Culture and Digital Capabilities

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Abstract

In an era marked by ever-increasing environmental concern and technological novelty, Life Cycle Assessment (LCA) has come to serve as one key instrument for evaluating environmental performance of organizations. Conversely, much literature has neglected possible strategies for aligning digital transformation (DT) with LCA activities as digital technologies care about dissemination. This study fills the gap by examining how non-technological assets such as data-driven culture (DDC) and digital capabilities (DC) spur digital transformation in LCA practice. Building on Resource-Based View (RBV), this study sees DDC as an organizational resource and DC as a human resource that mediates the effects of DDC on DT. Data were collected through an online survey among 229 Italian companies in the agri-food sector, an environment where the institutionalization of LCA adoption occurs. Structural equation modeling (SEM) was used to test hypothesized relationships. The results suggest that while DDC has no direct effects on DT, it promotes digital capabilities among employees, which in turn affect DT, thereby confirming a full mediation effect. The research supports the idea that transformation of practice relative to sustainability needs actual digital innovation and therefore cannot be achieved by just introducing new technologies. Instead, an important aspect of this process is to bring about a cultural change and the development of human skills. As much as technology influences the advancement of sustainability schemes, such as LCA, it could be unaffecting just by itself. A data culture must grow to foster an environment where data are valued, disseminated, and applied in decision-making, whilst employees should have digital capabilities that help them to draw insights from data, take action, and innovate. Conversely, if cultural and human elements are taken into consideration, the application of the technologies will be enhanced and maximized.

Keywords: Life Cycle Assessment, Digital Transformation, Data Driven Culture, Digital Competencies

Paper type: Academic Research Paper

1 Introduction

Life Cycle Assessment (LCA) has become an essential methodology for evaluating the environmental impact (Li and Cheng 2020) of organizations throughout their lifecycle, both internally and externally. According to ISO standards (e.g., ISO 14040:2006, 2020; ISO 14044:2006, 2021), LCA provides firms with a systematic framework for assessing resource use, emissions, and sustainability metrics, facilitating more informed decision-making (Ciasullo et al., 2024a). LCA is structured around four main stages. It begins with the goal and scope definition, where the objectives of the study are clarified, along with key elements such as system boundaries, functional units, and allocation methods. The second stage, inventory analysis, involves gathering and verifying relevant data, which are then organized within a life-cycle model to provide a structured overview of inputs and outputs. Following this, the impact assessment phase translates the collected data into measurable environmental impacts, helping to understand the broader ecological implications. Finally, the interpretation stage draws conclusions from the findings, critically reviewing the results and effectively communicating the insights to inform decision-making.

In an era increasingly shaped by digital transformation (DT), researchers and practitioners have been focusing on the strategic potential of digital technologies to enhance specific steps of LCA, improving data collection, analytics, and sustainability reporting (Song et al., 2018; Mieras et al., 2019; Kamble et al., 2020; Kumar et al., 2021; Rolinck et al., 2021). However, they have been not focusing on how organizations can effectively embrace DT for LCA methodology, while mainly discussing the challenges that organizations can face to pursue DT in LCA. Among these, the lack of willingness to share information and the employees' unfamiliarity with technologies and data emerged as major obstacles at an individual level (Sica et al., 2022); whereas limited economic resources and the absence of shared data governance characterized the limitations at an organizational level (Rolinck et al., 2021). Still, a gap persists in understanding how the mechanisms at the individual and organizational levels could impact DT. Specifically, in a digitalized context, beyond the mere implementation of technologies, it is necessary to enhance organizational and human resources to fully leverage them. Particularly, to pursue DT, data-driven culture – the extent to which firms emphasize data as a strategic resource (Wamba et al., 2017) – emerges as an organizational asset that can lead firms to integrate digital tools

into their LCA practices. A strong DDC facilitates the collection, analysis, and application of sustainability data, enhancing firms' ability to optimize LCA models. Accordingly, only fostering a data-centric mindset is insufficient without ensuring that employees possess the necessary digital capabilities (i.e., human resources) to manage and interpret data effectively (Soto-Acosta, 2020). Against this backdrop, this study aims to investigate the impacts of organizational and human resources on DT. More specifically, it focuses on understanding the mediating role of employees' digital capabilities (DC) in the relationship between data-driven culture (DDC) and digital transformation (DT) in firms emlpoing LCA methodology.

Considering the focus on firms' strategic resources, the study relies on the Resource-Based View (RBV) as the theoretical lens to understand the interrelations among DDC, DT and DC. Empirically, quantitative methodology is adopted, by performing a structural equation modeling (SEM) with mediation analysis on 229 Italian firms adopting LCA. Theoretically, this study contributes to literature providing a discussion about how non-technological resources can support DT of LCA methodology. Moreover, the results reveals the need to foster employees' digital capabilities as a key aspect to realize DT.

2 Theoretical background and hypothesis development

RBV is a core theory in the strategic management field, which conceptualizes the firm as a set of resources that lead the company to gain competitive advantage (Lockett et al., 2009). Originally proposed by Barney (1991), this theory emphasizes those firms' assets that are difficult to replicate, considering them key elements to ensure superior performance and competitive advantage (Amit and Schoemaker, 1993). Following Barney (1991), this study considers resources as physical resources (physical, technological, plant and equipment), human resources (training, experience, insights), and organizational resources (formal structure). Addressing the LCA literature, several studies investigate how technologies can contribute to one or more stages of LCA (Carrières et al. 2021; Teh et al. 2020), by stressing out the role of technological resources in the related processes. Focusing on the strategic potential of DT, RBV emerges an appropriate theoretical lens to understand the effects of organizational and human resources on DT, by particularly put emphasis on DDC and DC. Therefore, considering DDC as an organizational resource and DC as a human resource, the following conceptual model is proposed (Figure 1):

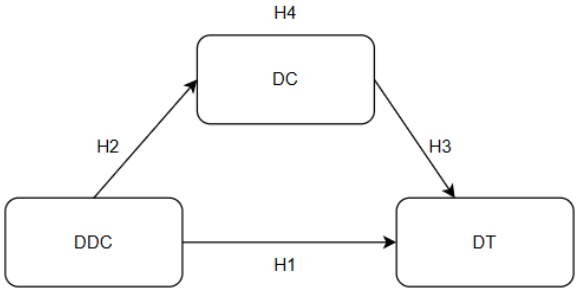


Figure 1. Conceptual model

2.1 Data-driven culture and Digital Transformation

Scholars have argued that organizational culture plays a crucial role in enabling digital transformation (DT) (Karimi and Walter, 2015; Ghafoori et al., 2024). Numerous studies have explored how culture influences DT efforts. Liu et al. (2023) highlighted organizational culture as a moderating factor in the link between digital transformation and organizational performance. Evidence suggests that companies with a strong data-oriented culture are more likely to achieve significant performance gains during digital transformation initiatives. Similarly, Çetin Gürkan and Çiftci (2020) emphasized the importance of digital organizational culture in facilitating the organizational changes necessary for DT. Among the various cultural models that influence DT, data-driven culture (DDC) seems particularly well-suited for organizations employing LCA methodology, as these firms can leverage digital tools for enhanced data gathering and analysis. Furthermore, Ghafoori et al. (2024) investigated how organizational culture shapes data-driven digital transformation, describing it as a process involving the reorganization of resources to integrate technologies and derive insights from data (Papanagnou et al., 2022). Essentially, Ghafoori et al. (2024) argue that digital transformation is characterized by the strategic reallocation of resources, guided by a data-centric mindset and enabled by digital technologies. Based on this perspective, the following research hypothesis is proposed:

- *H1: Data-Driven Culture (DDC) has a positive and significant effect on Digital Transformation (DT)*

2.2 The mediating role of Digital capabilities

The positive relationship between organizational culture and capabilities is well established in literature (Jones et al., 2005). Indeed, scholars agreed about the role of organizational culture in orienting and supporting the development of capabilities. More recently, Velyako and Musa (2024) demonstrated that organizational culture has a positive effect on digital capabilities in a digital environment. By focusing on DDC, it emerges that is has been mostly studied in relation to big data analytics capabilities (Karaboga et al., 2023; Yu et al., 2021), as the ability to provide data-driven insights using technologies (Akter et al., 2016). Nevertheless, given the tight link between data management and digital technologies, it can be argued that an organizational culture that promotes data-driven insights needs to enhance the development of digital capabilities at the individual level to make employees' able to use technology, collecting and interpreting data. Consequently, it can be assumed that DDC can support the development of digital capabilities, intended as the ability to make use of digital technologies, resulting from digital experience and technical know-how (Arkhipova and Bozzoli, 2018; Belhadi et al., 2024).

The relationship between DC and DT has been extensively explored (Slavković et al., 2023; Baiyere et al., 2025). Scholars contended that DT needs human involvement for the successful implementation of digital technologies. Indeed, existing management literature emphasizes that the effective adoption of technology largely relies on the skill set of the workforce (Bokrantz et al., 2017; Dalenogare et al., 2018; Gürdür et al., 2019). According to Jafari-Sadeghi et al. (2023), analytical thinking, digital literacy, and the capability to extract meaningful data are all crucial for employees to successfully engage with digital tools and consequently embrace DT. Similarly, Gürdür et al. (2019) highlight that the ability to handle digital technologies among employees is vital to fully exploit digital tools.

Finally, by considering the combination of organizational and human resources, it can be assumed that DC intervene in the relationship between DDC and DT. In other words, if DDC orients the entire organization towards DT, DC emerge as a critical enabler to effectively apply the organizational culture to pursue DT (Cetindamar et al., 2021; Blanka et al., 2022). Indeed, while DDC emphasizes the importance of data in LCA, without employees' digital capabilities, the organization cannot effectively leverage data for DT.

Based on these assumptions, the following hypothesis were developed:

- *H2: Data-Driven Culture (DDC) has a positive and significant effect on Digital Capabilities (DC)*
- *H3: Digital Capabilities (DC) have a positive and significant effect on Digital Transformation (DT)*
- *H4: Digital Capabilities (DC) mediates the relationship between Data-Driven Culture (DDC) and Digital* Transformation (DT).

3 Methodology

This research examines how Digital Transformation (DT) is being applied to Life Cycle Assessment (LCA) practices within the agri-food industry. It was selected due to its critical role regarding environmental sustainability (Ciasullo et al., 2024b), its relevance to LCA researchers (e.g., McAuliffe et al., 2020), and strong institutional support for LCA adoption (European Commission, 2021). Italy was selected as the context for this study due to the prominent role its agri-food sector plays within the European framework. Indeed, Italy ranks third in the European Union for value added in the agri-food industry, following Germany and France (Unioncamere, 2023). Particularly, the study focused on firms operating in the region of Campania in Italy, due to the relevance of this industry for the national and regional economy (Regione Campania, 2023)

Eligible agri-food firms were identified through the AIDA database, a repository of financial and business information on European enterprises. Firms were randomly selected, thereby ensuring that the sample includes a diverse range of firms, avoiding systematic biases that may arise from non-random selection (Bryman, 2016). They were contacted via email and provided with details about the research objectives and participation instructions. The survey targeted general managers, CEOs, and founders/entrepreneurs, ensuring that responses reflected strategic perspectives on LCA and digitalization.

A total of 229 responses were collected over four months through an online survey, composed of 18 items in two main sections. It gathered respondent demographics, and key constructs included in the conceptual model using established scales measured on a 5-point Likert scale. Particularly, 4 questions were related to DTs adapted from Xie et al. (2022), 5 to DDC (Yu et al. 2021), 5 to DC (Proksch et al., 2024). Prior to administering the full survey, a pilot test was carried out with a convenience sample of 20 participants to assess and ensure the clarity and understanding of the questions (Lavrakas, 2008).

Finally, the sample was analyzed using SPSS and AMOS with Structural Equation Modeling (SEM), following a two-step approach that first validated the measurement model before testing the structural relationships (Anderson and Gerbing 1988). The number of responses was adequate to conduct SEM, indeed it was aligned

with Bentler and Chou's (1987) guideline, which establishes a 5:1 ratio between the number of responses and estimated parameters for conducting SEM. Moreover, the sample size also satisfies Nunnally's (1967) rule, which recommends at least ten responses per item for SEM analysis.

4 Results

4.1 Measurement model estimation

A Confirmatory Factor Analysis (CFA) was conducted to verify construct validity and overall model fit by analyzing reliability, convergent validity, and discriminant validity (Brown & Moore, 2012). The reliability of each indicator was assessed through factor loadings, while Cronbach's alpha (CA) and composite reliability (CR) evaluated the internal consistency of each construct. Convergent validity was measured using the Average Variance Extracted (AVE), and discriminant validity was tested using the Fornell and Larcker (1981) method. As shown in Table 1, all factor loadings exceeded the acceptable threshold of 0.70. Similarly, the reliability measures (CA and CR) surpassed 0.70, and all AVE values were above 0.50.

Table 1: Descriptive statistics, reliability and convergent validity

CONSTRUCT	ITEMS	MEAN	SD	LOADINGS	CA	CR	AVE
DT	DT1	3.53	1.293	0.955	0.98	0.96	0.88
	DT2	3.71	1.244	0.960			
	DT3	3.58	1.192	0.954			
	DT4	3.61	1.326	0.972			
DDC	DDC1	3.22	1.513	0.882	0.98	0.95	0.82
	DDC2	3.14	1.709	0.980			
	DDC3	3.16	1.672	0.991			
	DDC4	3.17	1.597	0.971			
	DDC5	3.12	1.694	0.962			
DC	DC1	3.23	1.282	0.953	0.96	0.96	0.85
	DC2	3.20	1.315	0.933			
	DC3	3.21	1.348	0.854			
	DC4	3.33	1.258	0.932			
	DC5	3.27	1.274	0.932			

To assess discriminant validity, the square root of each construct's AVE was compared with its highest correlation with other constructs; the former was consistently higher, confirming discriminant validity. Table 2 presents the correlation matrix, with the square root of AVE values displayed along the diagonal to facilitate this comparison (Zaiţ and Bertea, 2011).

Table 2: Discriminant Validity (Fornell-Larcker Criterion)

	DDC	DC	DT
DDC	**0.82**	0.68	0.15
DC	0.68	**0.78**	0.63
DT	0.15	0.63	**0.75**

Note: *Bold values = √AVE

4.2 Structural model estimation

The assessment of the structural model aims to evaluate the fit model between empirical data and the proposed conceptual framework. Table 3 presents the model fit measures for the estimated model, indicating an overall acceptable fit.

Table 3: Goodness-of-fit indexes

Fit index	Value	Acceptable threshold
SRMR	0.045	< 0.08
RMSEA	0.036	< 0.06
CFI	0.978	> 0.95
TLI	0.962	> 0.95

As for the path coefficients, the analysis confirmed the hypothesized mediation model. The results showed that DDC does not have a significant impact on DT, since p-value > 0.005, therefore H1 is not supported. Moreover, the study revealed that DDC plays a significant and positive effect on DC (β=0.70), thereby confirming H2. Also, it emerged that DC significantly and positively impacts DT (β=0.63), consequently H3 is supported. Finally, the mediation analysis is statistically significant (β=0.44), by particularly configuring a full mediation. This means that DDC fosters DT only when employees have adequate digital skills, supporting H4.

Table 4: Model results

Path	Coefficient	Std.Error	95% LLCI	95% ULCI	Remarks
DDC → DT	0.16	0.10	-0.04	0.36	Not supported
DDC → DC	0.70***	0.08	0.55	0.85	Supported
DC→DT	0.63***	0.09	0.45	0.38	Supported
DDC → DC → DT (indirect)	0.44***	0.07	0.31	0.60	Supported

Note: ***= significant effect

5 Discussions and conclusions

The study investigated the role of DDC and DC in enhancing DT in firms adopting LCA methodology. Particularly, it emerged that only though the integration of human and organizational resources, firms manage to strategically pursue DT. More in detail, the study outlined the relevance of employees in supporting the digitalization of LCA methodology. In this regard, H1 was not supported, assuming that only engaging with DDC does not provide the firm with a successful use of digital tools. This result contrasts with existing DT literature (Çetin Gürkan and Çiftci, 2020; Liu et al., 2023), and it can be explained by considering that data-driven orientation of LCA firms does not automatically shift towards DT, which is a more complex construct that requires human digital capabilities (Ghafoori et al., 2024).

Regarding H2, results showed to be aligned with existing literature (Jones et al., 2005), and provided empirical evidence of the impact of DDC on DC. Accordingly, it goes beyond the most explored relationship between DDC and big data analytics capabilities by offering an additional significant impact of DDC on a capability.

As for H3, the study confirmed the vast corpus of DT literature, that significantly stress the relevance of employees in triggering DT (Dalenogare et al., 2018; Gürdür et al., 2019; Jafari-Sadeghi et al., 2023).

Finally, the study confirmed H4, supporting that fostering a data-driven culture is necessary but not sufficient for DT in firms adopting LCA. Instead, employees' digital capabilities emerge as the key enabler that allows organizations to fully exploit the potential of digital technologies in LCA-based sustainability initiatives. In this direction, it is confirmed that DT overcomes the mere implementation of technologies, by requiring employees involvement and commitment (Abbate et al., 2023; Ciasullo et al., 2024a).

From a theoretical perspective, this study extends the current research by integrating RBV with digital transformation literature in LCA context, providing evidences that human, organizational resources and technological capabilities must be aligned for firms to achieve meaningful innovation (Barreto, 2010). The full mediation effect pinpoints the need to bridge the gap between cultural shifts and technical expertise, emphasizing that firms investing in LCA must complement data-driven strategies with employee upskilling programs.

From a managerial point of view, this study highlights essential strategies for organizations aiming to enhance their LCA-based sustainability initiatives through DT. For instance, investing in digital training programs is crucial, as organizations need to develop structured learning initiatives that enhance employees' digital literacy, ensuring they possess the necessary skills to interpret, manage, and apply LCA data effectively. Additionally, fostering cross-functional collaboration is imperative: strengthening the interaction between sustainability teams and IT departments can facilitate a more integrated approach to digitalizing LCA processes, enabling seamless data management and strategic decision-making.

This study presents several limitations. The sample includes agri-food firms located in a Southern Italian region, which may constrain the broader applicability of the results. Future research could enhance generalizability by involving a more geographically diverse sample, including firms from other Italian regions or international contexts. Expanding the analysis to other industries beyond agri-food could also offer deeper insights into how LCA DT supports organizational effectiveness across different sectors. Moreover, as the data were gathered through a survey, future studies could integrate additional data collection methods.

6 Ethics declaration

Ethical clearance is not required for the research

7 AI declaration

No AI tools were used to generate the paper.

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The Role of Physical Appearance in the Entrepreneurial Journey: A State-of-the-Art Review from a Feminist Perspective

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Abstract

The study explores the under-investigated intersection between corporeality and entrepreneurship by conducting a systematic literature review on the role of physical appearance in entrepreneurial processes. Despite traditional interest in the influence of bodily aesthetics—particularly physical attractiveness—within feminist scholarship, current research is largely dominated by theoretical approaches rooted in evolutionary and social psychology. Existing studies, while methodologically rigorous, often lack socio-political depth and fail to critically engage with feminist or intersectional paradigms. By adopting a PRISMA-guided systematic review protocol review, the authors identified a final corpus of 15 core studies. Such studies were subjected to bibliometric framing and deductive qualitative content analysis aimed at identifying dominant theoretical backgrounds, recurring methodologies, sample characteristics, and investigated entrepreneurial stages. Results indicate a pronounced quantitative orientation and a consistent preference for structured entrepreneurial environments and early-stage financing scenarios. The analysis reveals a pervasive attractiveness bias and a lack of critical engagement with its implications, which may contribute to legitimizing existing gender hierarchies within entrepreneurial ecosystems. The study ultimately calls for a broader epistemological agenda that integrates feminist ethics, qualitative inquiry, and a critical perspective on bodily representation in entrepreneurship research. The findings provide a foundation for more inclusive and politically aware investigations into how corporeality shapes entrepreneurial outcomes and imaginaries.

Keywords: Entrepreneurial financing, physical attractiveness, beauty, feminism, gender

Paper type: Academic Research

1 Introduction

The role of corporeality—understood as outward appearance—has long been overlooked by economic and entrepreneurial disciplines (Davis, 2007; Yıldırım, 2024). Since the early development of modern economic thought, economic agents have been conceptualized as disembodied angelic minds, driven solely by the pursuit of maximal utility—atomic elements devoid of a body, to which only basic needs, to be satisfied simply through consumption, were associated. A harsh critique of such economic-anthropological posture would today appear misplaced and naïve, given that the limitations of a literal and uncompromising interpretation of neoclassical economic theories are patently evident (Bromiley and Papenhausen, 2003; Dolderer et al., 2021; England, 1989; Woolley, 1993). Nevertheless, it is only in recent years that the question of the body's role in the entrepreneurial domain has begun to surface—and even then, in a timid and gradual manner (Baron et al., 2006). While the body, as a site and a manifestation of identity, has been a prominent theme within sociological, psychological and organizational discourse (Heilman and Saruwatari, 1979; Romeo, 2020), the entrepreneur's body—as a locus of signs, symbols, gestures, and contradictions—has not received equivalent scholarly attention. The seminal works aimed at investigating the role that bodies play—specifically within entrepreneurial processes and decision-making—have only begun to emerge in the literature over the past two decades (Baron et al., 2006). Such contributions were developed as applications of methods and hypotheses previously tested in other economic contexts. A paradigmatic example is the pivotal study developed by Baron et al. (2006), who, by applying theories and methods from social psychology to the entrepreneurial socio-economic context, was among the first to examine the role of entrepreneurs' physical attractiveness in shaping perceptions of their ventures and influencing their likelihood of success. Following Baron's lead, and building upon the earlier retrospective contributions of Langlois et al. (2000), few scholars have since then explored how bodies—particularly as carriers of attractiveness—play a role in processes involving entrepreneurs, as will also be demonstrated by the findings of this article.

What is particularly striking, however, is that, from an initial review of extant literature, most of the research lack of theoretical heterogeneity and political and social implications discussion. Rather, they tend to originate from an attempt to validate, within the entrepreneurial domain, hypotheses developed within the field of

evolutionary psychology (Bahlmann, 2024; Colombo et al., 2022a) and social psychology (Baron et al., 2006). Evolutionary psychology is a branch of psychology that draws upon multiple domains—among others, evolutionary biology, cognitive psychology, and economics—in order to identify the psychological mechanisms, and the related evolutionary processes, underlying observable behaviors (Confer et al., 2010). Within the framework of evolutionary psychology, several hypotheses have been formulated and empirically validated concerning the relationship between physical appearance and human behavior—hypotheses which have subsequently been tested within the entrepreneurial domain as well (Baron et al., 2006). In this regard, evolutionary psychology offers a theoretical lens capable of capturing and framing numerous aspects of observable behaviors among entrepreneurs and other stakeholders, particularly in contexts where bodies—and thus appearance, gender, and identity—play a fundamental role. Evolutionary psychology often provides answers to questions such as why certain bodies are perceived as more attractive, by emphasizing concepts inherited from evolutionary theory, such as sexual selection and intra- and intersexual competition (Barber, 1995; Buss, 2009).

Long before the emergence of evolutionary psychology, feminist scholarship had already begun to problematize the role of bodies, with particular attention to gender as fundamental analytical variable (Lennon and Fischer, 2024). Feminist scholarship, grounded in a constructivist epistemology markedly distant from the positivism that typically characterizes the evolutionary discourse, has repeatedly highlighted how bodies are not neutral entities; rather, they constitute the very terrain upon which power dynamics between genders are enacted and materialized (Grabowska, 2023).

As Buss (2011) observes, however, evolutionary psychology and feminist theories, although focusing on similar topics—such as gender differences and causal origins—differ substantially in their aims and research scopes. Feminist approaches represent a heterogeneous body of "scholarly scientific enterprise … often containing explicit political agendas" (Buss and Schmitt, 2011). This should not be regarded as scandalous—particularly in a historical period in which, at multiple levels, the scientific community has become increasingly aware of the political significance of its research (Fuentes, 2024; Jackson, 2020). The ethical orientation that characterizes feminisms, although far from constituting a monolithic framework, represents a fundamental resource from which feminist scholars draw to guide their inquiries, delineate their research domains, and critically examine results from a socio-political perspective (Jenkins et al., 2019). When considering entrepreneurship research as a field with substantial political and social implications, it becomes clear that a strictly evolutionary reading of the role embodied by entrepreneurs' corporeality may prove reductive and, at times, even detrimental (Confer et al., 2010). The risk lies in the possibility that findings regarding bodily differences may be exploited instrumentally to justify the status quo and legitimize its perpetuation (Buss and Schmitt, 2011; Confer et al., 2010)—ultimately leading to positions rooted in biological essentialism.

Building upon these premises, the paper investigates the following research questions:

- ***RQ1*** *– What are the theoretical and methodological approaches underpinning research aimed at exploring the role of the body and physical appearance in the entrepreneurial domain?*
- ***RQ2*** *– What are the most recurrent characteristics of the samples analyzed in extent literature, and more specifically, what role does the gender variable play in this context?*

The research questions, as formulated, are intended to serve as a preliminary step toward a comprehensive understanding of the current state of the art in this field of inquiry. Specifically, RQ1 seeks to identify potential theoretical or methodological polarizations that may hinder a thorough comprehension of the socio-political implications arising from the findings within this research stream. RQ2, on the other hand, aims to explore the types of samples investigated, with the objective of identifying recurring characteristics or blind spots that may compromise the inclusiveness and transferability of the results obtained thus far within this domain of knowledge.

2 Methodology

A systematic literature review (SLR) protocol has been developed to answer the research questions formulated, aiming to conduct an exploratory analysis to identify the current state of art of academic literature on the role of physical appearance in entrepreneurial processes. SLR is a research protocol based on precise and reproducible techniques, in order to ensure transparent and reliable retrieval and analysis of the extant literature on a specific topic (Boell and Cecez-Kecmanovic, 2015; Hiebl, 2023).

This systematic literature review was conducted following the PRISMA protocol (Moher et al., 2009). The approach involves four-stage paper selection flow (see Figure 1), to ensure transparency and reproducibility in the source collection process. Each step was documented in detail to attest compliance with PRISMA principles and ensure the absence of bias in the selection of studies (Page et al., 2021).

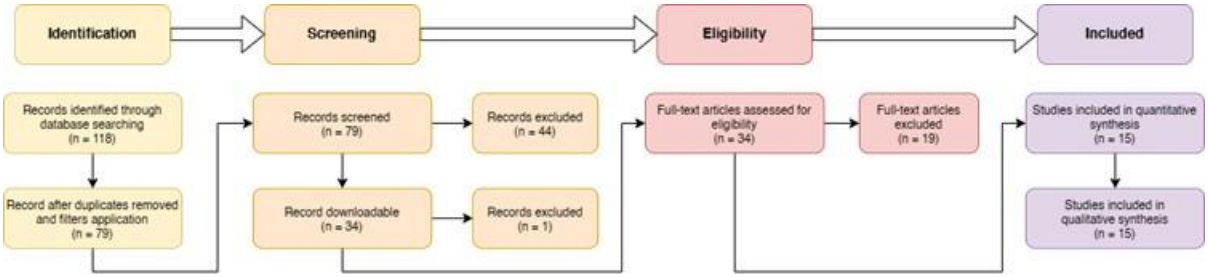


Figure 1. PRISMA' four-stage paper selection flow, adapted from Mayo-Wilson et al. (2018) and Moher et al. (2009).

The literature search was conducted on two relevant databases, Scopus and Web of Science (WoS), chosen for their widespread coverage of academic publications, their scientific quality and reliability (Burnham, 2006; Li et al., 2010). A search query was developed, combining terms related to the two subject areas of interest (see Figure 2). For entrepreneurship, the root entrepren* was used, including all terms stemming from this lemma. In contrast, for attractiveness, a comprehensive spectrum of keywords - a set of synonyms and descriptors of external appearance- was employed.

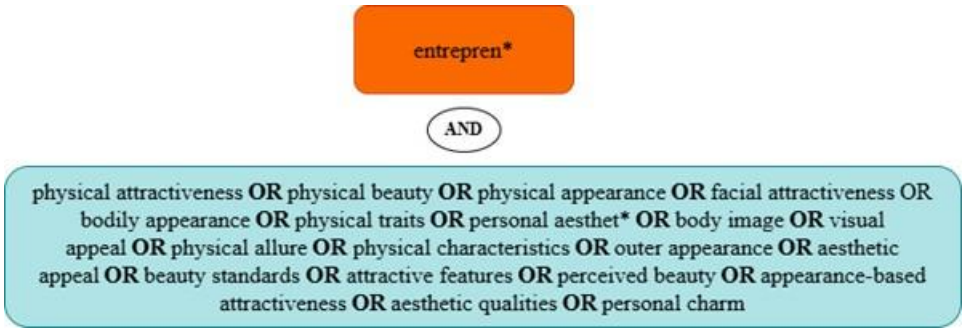


Figure 2. Thematic conceptual map relevant to the research query.

The baseline search, launched in February 2025, returned 62 papers from Scopus and 56 papers from WoS. This raw set of articles was subsequently modelled based on the available structured data (see Table 1). Filters were applied to ensure high standards of quality within the collected data (Xiao and Watson, 2019). The application of these filters reduced the number of articles to 50 for Scopus and 53 for WoS. The combined set of 103 records underwent duplicate removal, yielding 79 unique results.

Table 1. Filters applied to obtain the knowledge base under review.

Filter	Scopus	Web of Science
Language	English	English
Publication Stage	Final	-

Subsequently, the screening of the titles and abstracts was undertaken. Thus, each study was evaluated based on selection criteria in line with the research questions. Specifically, the studies were considered valid if they explicitly dealt with topics regarding physical appearance, attractiveness or beauty in the context of entrepreneurial processes. The exclusion criteria resulted in the elimination of those which, from examining the abstract, were clearly off-topic. Following the screening phase, 44 studies were excluded because they did not satisfy the criteria, reducing the number of articles potentially eligible for inclusion to 35. The selected articles were acquired in full-text and subjected to in-depth evaluation. One article, as it was not available in full-text through institutional resources or contact with the authors, was excluded.

The 34 papers were analyzed in their entirety and classified according to the method proposed by Pittaway et al. (2004) , distinguishing them into three categories (A, B, C) based on the relevance and centrality of the topic under investigation in the study.

This classification made it possible to differentiate studies that were fully focused on the phenomenon in question from those whose contribution was more peripheral, allowing the final set to be reduced to 15 articles.

Additionally, to further extend the coverage of the search and avoid missing relevant studies, additional keywords identified through the reading of the full-text papers were also tested. Supplementary queries were

undertaken with the terms: aesthetic capital, aesthetic entrepreneurialism and beauty premium. No further contributions were added to the final corpus because of these exploratory searches.

The entire process of identifying the final set of articles was conducted independently by three researchers and cross-checked to increase reliability.

Considering the restricted number of articles in the final corpus set, both a quantitative and qualitative analysis was performed for all of them. A bibliometric framing was undertaken, a quantitative analysis method that employs bibliometric data to explore and illustrate the attributes of a specific research domain. Subsequently, a content analysis was adopted to address the research questions (Donthu et al., 2021; Geng et al., 2017). Content analysis aims to detect, analyze, and compare, themes within textual data (Harwood and Garry, 2003; Krippendorff, 2019; Moldavska and Welo, 2017). A deductive content analysis (Magnani and Gioia, 2023) phase was carried out to classify the acquired articles according to several themes. A schematic representation of the themes investigated within the selected documents is provided in Figure 3. These themes were derived from the research questions and grouped into three overarching thematic areas (namely, "Theoretical and Methodological Aspects", "Sample Demographics", and "Entrepreneurial Context"). The first thematic group encompasses elements related to the methodological and theoretical approaches underpinning the reviewed studies (see RQ1). The second refers to the individual and key characteristics of the sample, while the third pertains to aspects concerning the relevant entrepreneurial context (see RQ2). A qualitative critical analysis was also carried out to decode the data derived. Lastly, the results were reported and discussed.

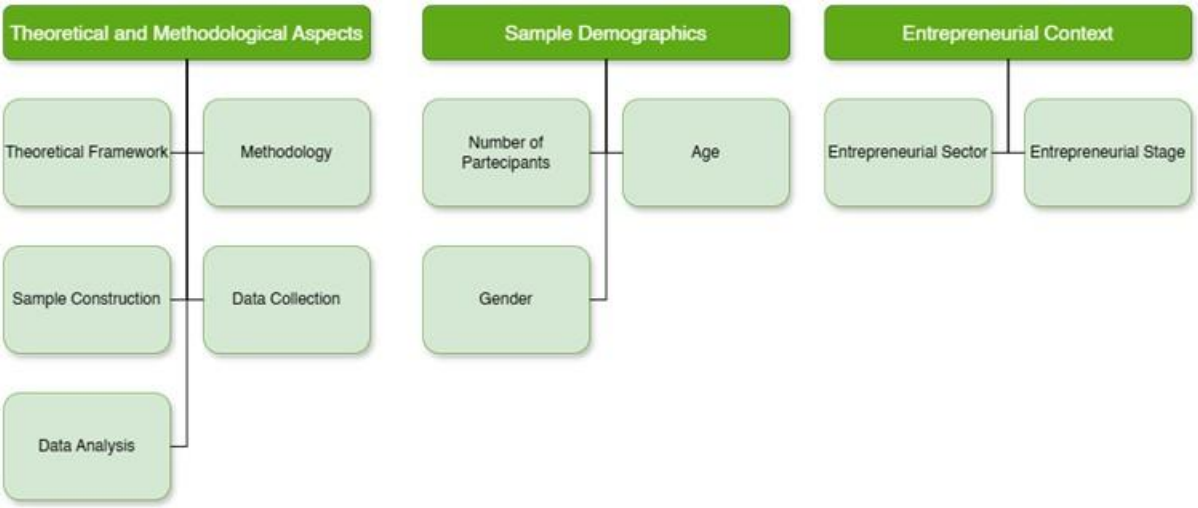


Figure 3. Analytical framework of extracted research elements.

3 Results and discussion

In this section the academic knowledge is synthesized and subjected to bibliometric and content analysis. The most significant results are analysed in conjunction with their presentation.

3.1 Bibliometric framing

The final collection analysed is composed of 15 articles spanning a time horizon of approximately 18 years. All articles are listed in Table 1, and for each contribution the author, year of publication, and journal were provided.

Table 2. List of articles included in the dataset.

ID	Title	Author	Year	Journal
1	Physical attractiveness, same-sex stimuli, and male venture capitalists' financial risk-taking	Bahlmann, Marc D.	2024	Frontiers in Psychology
2	Passion and attractiveness on display: an examination of gender bias in crowdfunding	Letwin, Chaim; Ciuchta, Michael P.; Johnson, Michael; Stevenson, Regan; Ford, Cameron	2024	Small Business Economics

ID	Title	Author	Year	Journal
3	An Attractiveness Bias? How Women Entrepreneurs' Physical Appearance Affects Men Investors	Schreiber, Robert; Hess, Manuel; Grichnik, Dietmar; Shepherd, Dean A.; Tobler, Philippe N.; Wincent, Joakim	2024	Journal of Management
4	Image isn't everything: Personality attractiveness, physical attractiveness, and self-employment earnings	Wolfe, Marcus T.; Patel, Pankaj C.	2024	Small Business Economics
5	Attractiveness, ethnicity, and stage financing: exploring heuristics in venture capital staging	Bahlmann, Marc D.	2023	Industry and Innovation
6	Angel investment and first impressions	Huang, Xing; Ivkovic, Zoran; Jiang, John Xuefeng; Wang, Isabel Yanyan	2023	Journal of Financial Economics
7	Mirror, mirror—A gendered lens on female entrepreneurs' facial attractiveness in reward-based crowdfunding	Seigner, Benedikt David Christian; Milanov, Hana	2023	Journal of Business Venturing Insights
8	Applicant attraction to new ventures: The combined effects of entrepreneurs' physical attractiveness and gender	Piva, Evila; Rovelli, Paola	2023	Journal of Small Business Management
9	The CEO beauty premium: Founder CEO attractiveness and firm valuation in initial coin offerings	Colombo, Massimo G.; Fisch, Christian; Momtaz, Paul P.; Vismara, Silvio	2022	Strategic Entrepreneurship Journal
10	Embodying aesthetic entrepreneurialism: Men, the body and the performing arts	Norman, Moss E; Bryans, John F.	2022	Sociological Review
11	Fashioning an elite entrepreneurial identity via the endorsement of gendered, designer dress codes and artefacts of success	Smith, Robert	2021	International Journal of Entrepreneurship and Innovation
12	The effect of intrinsic and extrinsic factors on entrepreneurial intentions: The moderating role of collectivist orientation	Arshad, Muhammad; Farooq, Omer; Farooq, Mariam	2018	Management Decision
13	When Beauty Doesn't Pay: Gender and Beauty Biases in a Peer-to-Peer Loan Market	Kuwabara, Ko; Thebaud, Sarah	2017	Social Forces
14	Investors prefer entrepreneurial ventures pitched by attractive men	Brooks, Alison Wood; Huang, Laura; Kearney, Sarah Wood; Murray, Fiona E.	2014	Proceedings of the National Academy of Sciences of the United States of America
15	Exporting social psychology: Effects of attractiveness on perceptions of entrepreneurs, their ideas for new products, and their financial success	Baron, RA; Markman, GD; Bollinger, M	2006	Journal of Applied Social Psychology

The first article dates back to 2006 (Baron et al., 2006), then a stagnant period is observed in which no contributions emerge until 2014, when, as shown in Figure 4, a more sustained growth in the number of publications begins to emerge. Despite this attempt at growth, the topic remains underdeveloped or at least not yet fully investigated.

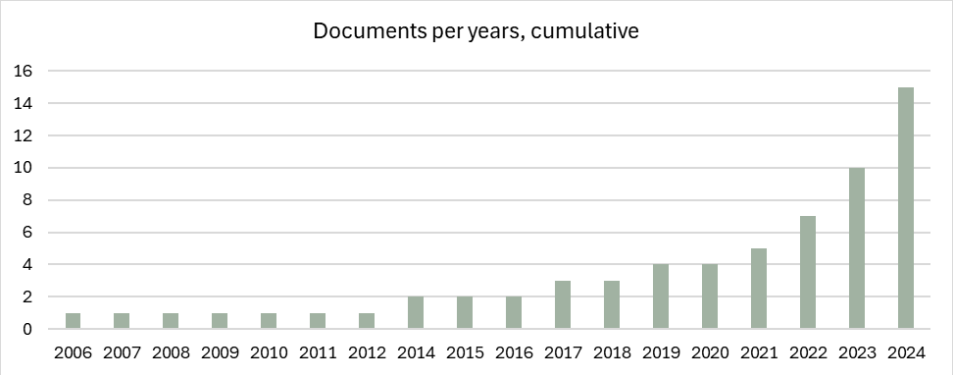


Figure 4. Cumulative number of articles published each year.

Except for the journal *'Small Business Economics*' which appears twice, there is no other dominant journal. The journals appearing on a single occasion include *'Strategic Entrepreneurship Journal*', *'International Journal of Entrepreneurship and Innovation*' and *'Journal of Business Venturing Insights*'. Geographically, the major contributions emerge from the United States (with more than ten institutions) followed by Italy and Germany (with four institutions each). Most of the other authors in the sample are affiliated with universities located in Canada, Pakistan and United Kingdom.

Analysing the keywords chosen by the authors to represent their contributions, "attractiveness" stands out as the most recurring term, with a frequency of two occurrences. Such a word also appears as part of a locution, as in "physical attractiveness" (three mentions), followed by "facial attractiveness" and "personality attractiveness" (both mentioned once). "Entrepreneurship" and "entrepreneurial finance" are cited twice, while "gender" appears three times, including two as part of locutions containing "bias" and "stereotype".

3.2 Content Analysis results

The results obtained contributed to addressing the research questions, confirming the methodological and theoretical trends identified in the introduction. Most of the studies examined adopt theoretical frameworks that are rooted in evolutionary and social psychology, with a great representation of stereotype-based theory. Such an orientation translates in a lack of socio-political depth in the contributions analyzed, especially when viewed from feminist and intersectional perspectives. A paradigmatic example is offered by the study of Piva et al. (2024), who, upon identifying an attractiveness bias in job seeking and early recruitment stages, interpret the results by advising that “attractive males” should be the ones presenting entrepreneurial ideas. However, this is far from an isolated case: similar conclusions can be found in (Letwin et al., 2024) and (Bahlmann, 2023). When situated within the broader feminist literature, such findings appear to empirically illuminate the motivations that lead many female entrepreneurs to withdraw in favor of male-dominated entrepreneurial models. The absence of critical reflection on these findings risks enabling instrumental interpretations that may serve to legitimize the status quo.

All the identified studies are based on quantitative research protocols except for Smith (2021) and Norman and Bryans (2022). Most of the quantitative research protocols adopt surveys, questionnaires or existing data from online platforms. Participants are often invited to observe images (illustrating entrepreneurs’ faces) or brief videos (showing entrepreneurs engaged in pitch competitions) and subsequently to express a judgment based on their observations. The selection of materials to be submitted to participants is conducted in accordance with logics that reflect the objective of the research and the context. Alternatively, a questionnaire is directly submitted to participants. In one case, a non-human entity, specifically a machine learning model, was responsible for performing the evaluation (Seigner and Milanov, 2023). Certain papers include multiple studies, which could investigate the phenomenon at different level (Baron et al., 2006; Brooks et al., 2014; Colombo et al., 2022b; Letwin et al., 2024). The construction of the sample seems to be guided in all cases by purpose and data availability. Delving into sample demographics, the participants belong to different panels, experts in the sector such as angel investors and ICO investors, or non-experts such as students (Arshad et al., 2019; Bahlmann, 2024; Piva and Rovelli, 2024). The number of participants is highly heterogeneous, ranging from a few dozen to hundreds. The fragmentation is also reflected in terms of participants’ gender. In one instance where such information is available, it is not always associated with well-defined proportion between the sexes. Indeed, there appears to be a slight tendency towards a dominant male. The age (frequently designated as unavailable) span from 15 to over 40 years. The range aligns with the selected sample, which encompasses individuals from young students to experienced investors in the field.

A certain heterogeneity is also observed in the data regarding the entrepreneurial sector (where present). The range of sectors represented extends from technology (most mentioned) to fashion, energy and mobility, to name but a few. In one instance, the fashion sector is specifically associated with the female type category, while technology is associated with the male type category (Seigner and Milanov, 2023). In the context of the entrepreneurial stage, the studies show a polarization towards the initial phases, encompassing the intention to start a business and the necessity to secure funds. The most frequently cited stage is financing (Bahlmann, 2023; Colombo et al., 2022; Huang et al., 2023) especially in the modality of crowdfunding (Letwin et al., 2024; Seigner and Milanov, 2023).

4 Conclusions

The results of the investigation, which at this stage should be considered as preliminary to a more detailed and extensive analysis, nevertheless contribute to outlining a theoretical-epistemic framework largely dominated by approaches rooted in evolutionary psychology. That does not represent an intrinsically problematic feature of the research strand; however, the limited presence of ethically grounded theoretical frameworks or of a socio-political problematization of the findings may risk legitimizing phenomena that contribute to reducing the inclusivity of entrepreneurial environments. The lack of studies employing qualitative methodologies hinders a deeper understanding of the lived experiences of those who are currently reduced to performance and appearance (entrepreneurs). Furthermore, it should be emphasized that the identified studies tend to investigate highly structured entrepreneurial contexts: the role of body and physical presence in informal entrepreneurial events or unstructured social settings remains, at present, an unexamined aspect. The study is, of course, subject to some limitations. Although the selection of keywords was conducted with caution and breadth, the non-inclusion of potentially relevant studies with respect to the investigated themes cannot be entirely ruled out. Moreover, the inclusion and exclusion criteria adopted did not allow for the integration of books or book chapters into the corpus of analyzed knowledge to ensure a certain level of scientific rigor (books are not usually subject to peer review). Nonetheless, particularly in the fields of sociology and psychology, such editorial outputs may be of interest and relevant to the purposes of this research.

5 Ethics declaration

There are no ethical statements to declare for this research as no humans were involved, or sensitive data collected and processed. Only publicly accessible data was used.

6 AI declaration

No artificial intelligence tools were used in developing the paper.

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Exploring the Gender Gap in ERC Funding: A Geographical and Socioeconomic Analysis of Female Academic Research, Innovation, and Entrepreneurship

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Abstract

Research, innovation, and entrepreneurship are key in academia, with entrepreneurship serving as a bridge between science and business to drive economic growth. While being more inclusive of women is generally seen as beneficial, gender equality is still far off, with a clear gender gap showing unequal conditions. The Global Gender Gap Index (GGGI) in 2024 showed a global gender gap of 68.5% across 146 economies. The Economist's Glass-Ceiling Index (GCI) in 2024 highlighted a persistent 12% wage gap. This study investigates the gender gap in research, innovation, and entrepreneurship across European universities, specifically examining the distribution of European Research Council (ERC) funding and potential gender bias. Analyzing the geographical allocation of ERC grants, the study reveals a funding disparity, with fewer women researchers receiving funding. While countries with fewer projects show no significant gender differences, those with larger funding volumes exhibit clear disparities favouring men. The second part of the study explores the potential reasons behind the differing percentages of female and male researchers and the socioeconomic factors influencing ERC funding. The analysis suggests that gender equality has an impact on the proportion of female Principal Investigators (PIs) in a country, and factors like women's participation in the workforce, working conditions, entrepreneurship, and political representation influence ERC grants for women. Structural changes are so needed for a more gender-balanced academic environment. Future research could look at sociocultural and psychological barriers for women in securing ERC funding.

Keywords: Gender gap, Research and Innovation (R&I), Academic entrepreneurship, European Research Council (ERC)

Paper type: Academic Research Paper

1 Introduction

Historically, women have faced a long struggle for gender equality, enduring centuries of discrimination in social, economic, and political life. Excluded from education, work, and politics, their public roles were limited. However, feminist movements and growing awareness of women's rights, starting in the 19th century, led to significant changes. Recent evidence shows significant benefits from greater inclusion of women in the economy and society (Agrawal, 2017; Peterson and Powers, 2019). Despite progress, current data indicates that gender equality is still far off, with a persistent gender gap showing the unequal conditions women still face. The World Economic Forum's 2024 GGGI benchmarks gender parity across 146 economies in four areas: the global gender gap is at 68.5%, a slight 0.1% increase from last year. The report estimates it will take 134 years to achieve full gender equality. Northern Europe (75%) has the highest parity, while the Middle East and North Africa (61.7%) have the lowest. Likewise, the Economist's Glass-Ceiling Index (GCI), for 29 OECD countries, illustrates barriers to women's professional advancement: the 2024 GCI shows a persistent 12% wage gap. Iceland, Sweden, Norway, Finland, and France have the least inequality, while Israel, Switzerland, Japan, Turkey, and South Korea have the most. Factors like patriarchal roles, stereotypes, the child penalty, and unequal caregiving contribute to this.

To address persistent negative data on gender inequality, countries and international bodies are taking political and strategic actions: the UN 2030 Agenda includes Sustainable Development Goal 5 for gender equality; likewise, the European Commission aims to promote equality in scientific careers, ensure gender balance in decision-making, and integrate the gender dimension into research content. The gender gap, while a critical issue, is a relatively new field of study without a long-established central theory. Key figures in this regard are: Simone de Beauvoir, who established the distinction between sex and gender in the 1940s; John Money, who introduced the concept of gender role in the 1950s; Eleanor Smeal, who coined the expression "gender gap" Claudia Goldin, who in the 1990s identified the main determinants of gender differences in the labour market. Human capital includes gender, age, and culture, which should be preserved (Johnston and Packer, 1987; Kreitner and Kinicki, 2008), that opposes gender stereotypes and supports equal rights and opportunities in education, employment, and health (Stumbitz et al., 2018).

This work aims to study the gender gap in academia, research, and innovation, where the underrepresentation of women has significant consequences (Abreu and Grinevich, 2017; Ghosh, 2024). The lack of representation hinders diverse perspectives, creativity, and ultimately harms innovation (Lerchenmueller and Sorenson, 2018; Liao and Lian, Yang et al., 2022), potentially leading to less inclusive and relevant science. The study specifically focuses on the gap within European academia, recognizing the crucial role of knowledge in societal progress (Andersson et al., 2021) and the socioeconomic importance of universities in generating and applying knowledge (Murray, 2002; Siegel et al., 2007; Castaneda and Cuellar, 2020; Frank and Meyer, 2020).

The ERC supports outstanding researchers in EU member states and associated countries through a variety of funding schemes, including Starting, Consolidator, Advanced, Synergy, and Proof of Concept Grants that correspond to different stages of the research career and project development. These schemes progressively support initiatives ranging from early-career independence to advanced, high-risk research, large-scale collaborative efforts, and the translation of scientific results into societal or commercial impact. Between 2019 and 2023, PIs received an average of €1.6 million in funding, with no gender difference in the average amount. Women received 33.48% (€2.8 billion) of ERC funding and men 66.52% (€5.6 billion). Female representation decreases at higher research levels and in the scientific fields that receive the most funding. Among the top 5 Host Institute (HI) countries for ERC funding (Germany, France, Netherlands, Italy, Spain), Italy has the highest proportion of women PIs (36.14%). The ERC is actively working to reduce the gender gap in research: a regularly updated Gender Equality Plan focused on raising awareness, improving gender balance among applicants and research teams, addressing gender bias in evaluations, and promoting gender awareness; an 18-month extension per child born or adopted before or after the PhD, with further extensions for documented parental leave; cover costs related to promoting equal opportunities; bias training for assessment members, and monitoring applicant and beneficiary data; gender balanced communications for increasing the visibility of women in science.

The present paper investigates the allocation of ERC funding to reveal gender gaps in academia, specifically concerning the geographical distribution of funding and influencing socio-economic factors, given the decreasing presence of women as they advance in their careers. After an introduction, Section 2 explains the geo-referenced mapping methodology, Section 3 details the econometric analysis, and Section 4 discusses results and concludes the paper.

2 Research design

The research comprises two phases. The first phase (Section 3) employed geo-referenced mapping tools to visualize data and develop interpretative models. Mapping can serve as a powerful analytical tool in social science research (McMaster and Harvey, 2010). Georeferencing, used in Geographic Information Systems (GIS), links data to geographical locations and enrich the interpretation of quantitative data by offering new perspectives in the analysis of large-scale human behaviour (Williams et al., 2014), while simultaneously providing a spatial context for quantitative data, thereby enhancing analysis and interpretation in social science research (González Canché, 2025). GIS is a computer-based system for acquiring, recording, analyzing, displaying, and sharing geographical information, and was used as a tool for mapping the geographical distribution of ERC grants and analyzing gender equality among researchers.

Following the geographical analysis, which highlighted a gender gap in ERC funding between female researchers and male ones, the study examined the possible causes of this gap (second phase in Section 4), linking them to economic and social factors at the country level.

3 Geographical mapping

The analysis used the ERC dataset for 2019-2023, covering 26 nations (EU, Israel, and Switzerland), and 331 universities and research institutes. The dataset was expanded with gender data for PIs through manual Google searches. Microsoft Excel was used to expand the database and calculate funding distribution by gender. QGIS software was used to analyze spatial data and generate maps. Excel data was merged into QGIS to create maps showing ERC funding distribution by researcher gender and country. Maps were customized with colours and numerical labels, with non-eligible nations in grey (no labels) and eligible nations in green, blue, or pink (with labels). Figure 1 shows the number of ERC-funded projects per country, with darker shading representing a higher number of projects. Researcher gender is not considered in this map. Germany, France, the Netherlands, and Italy have the highest number of funded projects.



Figure 1 - No. of projects per country funded by ERC.

The distribution of ERC funded project by gender is represented in Figures 2 and 3.



Figure 2 - No. of male PIs per country.



Figure 3 - No. of female PIs per country.

Considering only the ERC projects led by female PIs, Figure 4 shows the overall geographical distribution in percentages, while the following Figures show the distribution of projects by funding schemes: StG (Figure 5), CoG (Figure 6), AdG (Figure 7), and PoC (Figure 8).

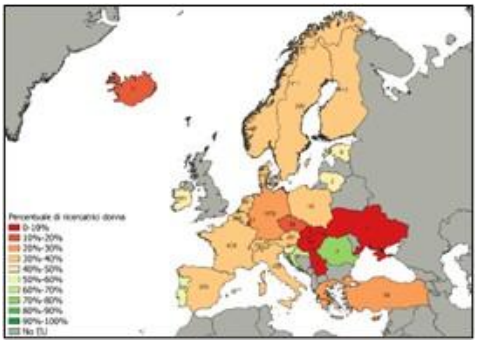


Figure 4 - Projects Pct. by country led by female PIs

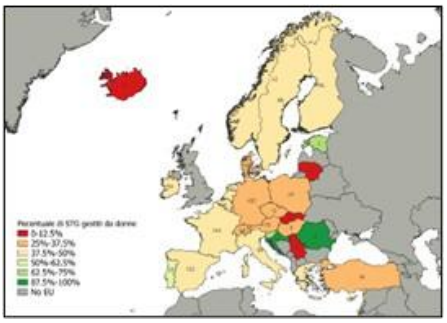


Figure 5
StG Pct. by country led by female PIs

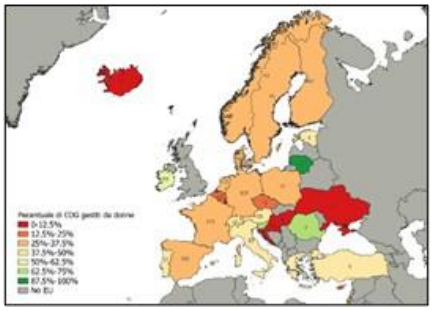


Figure 6
CoG Pct. by country led by female PIs

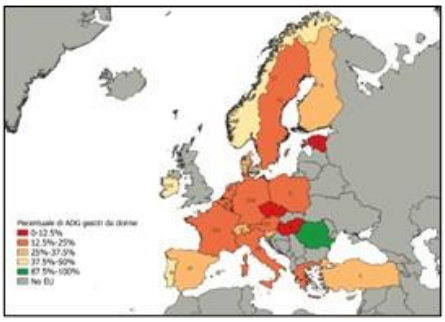


Figure 7
AdG Pct. by country led by female PIs

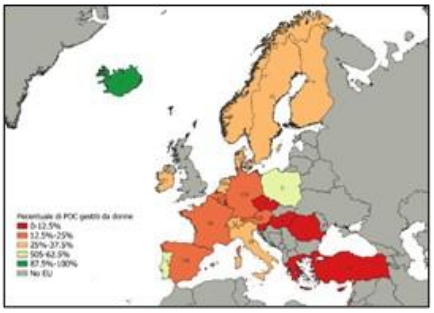


Figure 8
PoC Pct. by country led by female PIs

Comparing figures 1, 2, and 3, a gender gap exists in ERC funding. As shown in figures 4 to 8, the under-representation of female PIs is evident in funding schemes for researchers at a later stage in their careers, designed to finance innovations close to the market. In higher funding schemes, the percentage of projects led by women is notably low in Germany, Spain, the Netherlands, Italy, the UK, and France, indicating the under-representation of women in senior academic and entrepreneurial roles.

4 Econometric analysis: theoretical background, hypotheses and data

Prior studies (Lincoln et al., 2012; Larivière et al., 2013; Freund et al., 2016; Aguinis et al., 2018; Holman et al., 2018; Ma et al., 2019; Huang et al., 2020) indicate that women are underrepresented in academia, research, and innovation, particularly in scientific fields, across areas like publications, grants, awards, pay, senior roles, research careers, senior authorship, prestigious journals, and citations. Factors contributing to this include family responsibilities, lifestyle choices, career preferences, stereotypes, implicit bias, and discriminatory work environments (Blickenstaff, 2005; Ceci & Williams, 2011; Shaw & Stanton, 2012; Ceci et al., 2014; Reuben et al., 2014; Leslie et al., 2015; Ngila et al., 2017; Wang & Degol, 2017; Holman et al., 2018; Charlesworth & Banaji, 2019; Holmes et al., 2020). While existing literature often compares research output (Astegiano et al., 2019; Chan & Torgler, 2020), this study examined the issue through social and economic dimensions of countries hosting ERC grant winners.

To understand why fewer women than men are successful in obtaining ERC funding, an econometric analysis was conducted on the countries selected by grant winners as their research location (Host Institution). For each country, the ERC database (from 2019 to 2023) was used to find the number of female researchers receiving ERC grants, and the potential socioeconomic factors influencing why certain countries are more frequently chosen as HIs for ERC-funded projects by female PIs were explored. It was used a multiple linear regression, called Ordinary Least Squares (OLS) model, that is a common method for this type of analysis because it helps to understand and predict how changes in one variable (like the number of female PIs for a country) are consistently linked to changes in other factors. In this study, the number of female PIs is the main variable being explained. The socioeconomic factors used to explain this variable are measured by the GGGI, which looks at four important areas: economic participation and opportunity (EPaO), education attainment (EA), health and survival (HeS), and political empowerment (PE). These areas were chosen because they cover many aspects of a country's social and economic situation where gender inequalities have historically been a problem (Oswald, 2023). By looking at the gender gaps in these areas, one can get a good overall picture of a country's progress towards gender equality and see where more work is needed.

The relationship between the allocation of ERC funds between female researchers and male ones, and the state of gender equality in countries measured by the GGGI, is possible because several different factors come into play:

- a "gender equality paradox" is observed in research careers: fewer women pursue research compared to less egalitarian countries. This seemingly counterintuitive trend is attributed to several factors: firstly, despite increased opportunities, women often face greater challenges balancing work and family responsibilities, leading them to favour more flexible, less demanding, and traditional jobs that don't align with the full-time commitment required for a research career (Folbre, 2017); secondly, in highly egalitarian countries with abundant job opportunities, individuals are freer to follow their inclinations, and this can accentuate gender differences in career choices, influenced by subtle but persistent cultural stereotypes (Stoet and Geary, 2018); finally, the culture within certain fields of work may be perceived as masculine or potentially unwelcoming to women, and, even without overt hostility, existing cultural

norms and expectations can discourage women from entering or remaining in these sectors (Breda et al., 2020).
    - *Therefore, hypothesis 1 about EPaO concerns the presence of a negative relationship between the economic equity of gender and the number of female PIs in a country;*
- research studies indicate that education is beneficial to a country, regardless of gender. Specifically, countries investing in education experience improvements in research and innovation (Sapir, 2003; Camdessus, 2004).
    - *Therefore, hypothesis 2 about EA concerns the absence of a relationship between the educational gender equity in a country and its number of female PIs;*
- research studies show the global efforts to combat poor health conditions and life expectancy, whether for men or women (Acemoglu and Johnson, 2006).
    - *Therefore, hypothesis 3 about HeS concerns the absence of a relationship between the health and survival gender equity in a country and its number of female researchers;*
- scientific literature agrees that greater female political representation positively impacts countries, leading to increased well-being and faster economic growth, because women possess higher ethical standards (Jayasuriya and Burke, 2013; Xu, 2015). Female legislators, officials, and managers are seen as a positive force because women tend to be more honest and interested in the well-being of the relevant community (Powley, 2007; Reding, 2010).
    - *Therefore, hypothesis 4 about PE concerns the presence of a positive relationship between the political equity of gender and the number of female PIs in a country;*

Data for each area of the GGGIs from 2019 to 2023 were taken from the World Economic Forum's website. The yearly values were averaged. Croatia isn't included in the analysis because its data wasn't available for all the considered years. The index scores range from 0 to 1, with 1 meaning complete gender equality. The average gender gaps were been calculated and interpreted as follows:

- EPaO considers factors like labour force participation, equal pay for similar work, estimated income, and the representation of women in leadership and professional roles. The scores range from 0 to 1, with 1 indicating complete gender parity;
- EA is based on literacy rates and enrolment in primary, secondary, and tertiary education. A score between 0 and 1 indicates the level of gender parity, with 1 meaning 100% parity;
- HeS concerns sex ratio at birth and healthy life expectancy. The scores for each country range from 0 to 1, with 1 indicating complete gender parity.
- PE includes the number of female head of state, women in parliament and ministerial roles. Each country gets a score between 0 and 1, where 1 means there's complete gender equality.

Before building the regression model, the study analyzed the basic characteristics of data by calculating descriptive statistics (Table 1) and correlation coefficients (Table 2), by using the Gretl (Gnu Regression, Econometrics and Time-series Library) tool for data processing and econometric analysis.

Table 1 - Descriptive statistics.

VARIABLE	MEAN	MEDIAN	SD	MIN	MAX
Tot. Female PIs	113.070	33.000	169.240	1.000	767.000
GGGI	0.758	0.761	0.0573	0.639	0.904
EPaO	0.712	0.712	0.062	0.493	0.820
EA	0.996	0.998	0.005	0.975	1.000
HeS	0.968	0.969	0.014	0.901	0.980
PE	0.354	0.372	0.186	0.088	0.842

Table 2 - Correlation matrix.

VARIABLE	1	2	3	4	5	6
1 Tot. Female PIs	1.000					
2 GGGI	0.182	1.000				
3 EPaO	-0.116	0.795	1.000			
4 EA	-0.070	0.218	0.512	1.000		
5 HeS	-0.083	-0.191	-0.057	-0.029	1.000	
6 PE	0.288	0.965	0.614	0.069	-0.228	1.000

The correlation matrix (Table 2) shows that there are a number of relationships between variables. There are more statistically significant correlations, but they need to be investigated to verify their veracity and understand their nature.

To examine the factors influencing female participation in ERC-funded research, we estimate an Ordinary Least Squares (OLS) regression model of the following form:

$FPI_i = \beta_0 + \beta_1 EPaO_i + \beta_2 EA_i + \beta_3 HeS_i + \beta_4 PE_i + \varepsilon_i$

Where:

FPI = Female Participation Index (dependent variable), measuring the number of women among ERC grant recipients in country *i*

EPaO = Indicator of Labour-force participation rate, Wage equality for similar work, Estimated earned income, Legislators, senior officials and managers, Professional and technical workers

EA = Indicator of Literacy rate, Enrolment in primary, secondary and tertiary education

HeS = Indicator of Sex ratio at birth, Healthy life expectancy

PE = Indicator of Women in parliament, Women in ministerial positions, Years with female/male head of state (last 50)

εi is the error term capturing unobserved influences

The results indicate the existence of a relationship between the economic and political gender gaps and the female participation, as the number of women researchers recipient of ERC funds, with two out of the four independent variables significantly influencing the dependent variable, as shown by their statistically significant coefficients in Table 3.

Table 3 - Regression results.

VARIABLE	COEFFICIENT	SE	P-VALUE	
Constant	4.391	5.513	0.433	
GGGI	−16.002	6.378	0.019	**
EPaO	4.440	2.023	0.0381	**
EA	3.86	4.180	0.364	
HeS	0.159	0.792	0.841	
PE	3.627	1.525	0.025	**
R-squared	0.170			
Log likelihood	15.242			
P-value (F)	0.069			

Note: * P<0.05; ** P<0.01, and *** P<0.001

The study found support for hypotheses 1 and 4. Specifically, there is a statistically significant negative correlation (P<0.01) between the number of female PIs and the state of economic gender equality in a country. In contrast, there is a statistically significant positive correlation (P<0.01) between the number of female IPs and the state of political gender equality in a country. Hypotheses 2 and 3, concerning education level and health/survival parity, are not supported and show no statistically significant correlation.

The analyzed socioeconomic factors explain approximately 25% of the variation in ERC fund allocation between female researchers and male ones in a country (R-squared = 0.254). There is a widespread consensus that a similar level of R-squared is acceptable in the social sciences, as a peculiarity of this field of study. Several scholars have contributed to explain that a value between 0.1 and 0.5 can be considered acceptable, because the independent variables in the social sciences often represent only a small part of the total influences on an outcome, due to the wide range of factors that cannot be measured or are not included in the model. It is therefore a consequence of the complex nature of the phenomena studied and of the objective of the research, which often focuses more on the statistical significance and interpretation of the effects of individual predictors rather than on the overall predictive capacity of the model (Abelson, 1985; Lewis-Beck & Skalaban, 1990; Ozili, 2023).

5 Discussion and conclusion

This work examines gender equality, specifically focusing on gender discrimination against female researchers within European universities in research, innovation, and academic entrepreneurship. By analyzing the allocation of ERC funding from 2019-2023 using the ERC database and tools like QGIS, the study created maps and graphical representations to explore spatial relationships. The findings show that women represent a lower proportion of researchers overall, with a predominance of male researchers in higher funding schemes, designed for financing innovations close to the market. The study used econometrics to understand why there's a gender gap in female PIs. It looked at how the number of female researchers recipient of ERC funds changes

compared to male researchers and what socioeconomic factors influence the ERC fund allocation between countries. The findings show that countries with a greater female economic participation tend to have fewer female PIs; instead, countries with a greater female political participation tend to be more chosen as HIs by female researchers receiving ERC funds. Consequently, structural changes and specific protections for women should increase their representation in research. The European Union is already working to reduce the gender gap through policies like the Gender Equality Strategy 2020-2025, which addresses various disparities. Funding agencies could implement more specific gender targets, incentives, support measures, awareness campaigns, and consider the "gender dimension" in project evaluation. Universities and research organizations should foster a cultural shift towards gender equality in science and invest in research to understand and address the root causes of the gender gap. Future research could explore additional factors influencing ERC funding (like research categories, cultural, or psychological barriers) and what drives or hinders access to funding. Indeed, it is important to stress that the debate on the "gender equality paradox" is still open and complex, as an argument which highlights that gender equality is not only a question of formal equal opportunities, but also how social norms, cultural expectations and individual choices influence life and career paths.

6 Ethics declaration

No ethical approval was required for the research referenced in this article.

7 AI declaration

Artificial intelligence was not used.

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The Role of DAOs in Shaping Knowledge Management: Opportunities and Risks

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Abstract

Knowledge is widely recognized as a core strategic resource in today's knowledge-driven economy. Consequently, Knowledge Management (KM) processes have become central to organizational strategies (Yee et al., 2019; Krause et al., 2019). The spread of new technologies is driving structural changes and innovative dynamics in the business landscape. Decentralized Autonomous Organizations (DAOs) redefine traditional structures using blockchain technology (Wright, 2021). This decentralized structure provides an open, transparent and democratic platform, allowing organizations to harness collective intelligence (Kahan and Rock, 2008; Gola et al., 2023) and improve knowledge management, which all participants can access, contribute to and share information in real time. (Bhatt, 2001; Liu et al., 2022; Phillips, 2024).

While literature covers the importance of knowledge management in organizations (Jelenic, 2011; Hebibi et al., 2019; Koivisto and Taipalus, 2023) as well as DAOs and their decentralized governance structures (Piselli, 2019; Santana and Albareda, 2022; Guillaume et al., 2022), there is a gap in addressing how these two domains intersect. Currently, how a decentralized structure impacts knowledge management remains largely unexplored. This work will bridge the gap between KM practices and DAOs, highlighting this delicate balance between opportunities and challenges.

Through qualitative analysis supported by a comprehensive review of international literature and legal references, this article investigates the impact of decentralization via smart contracts and the transparency enabled by blockchain technology. On one hand, DAOs provide an environment conducive to the democratic sharing of knowledge, encourage direct participation, and reduce information asymmetries. On the other hand, the fragmentation of knowledge, loss of tacit knowledge, and absence of a clear regulatory framework present significant challenges to the sustainability of KM processes.

Keywords: Blockchain, Decentralized Autonomous Organizations (DAOs), Knowledge management, Corporate Governance, Legal Frameworks.

Paper type: Academic Research Paper

1 Introduction

The rise of Decentralized Autonomous Organizations (DAOs) represents a significant evolution in organizational management. Their structure offers a decentralized model by leveraging blockchain technology, in which governance is shared among the participants and decisions are made collectively, efficiently, and transparently (The Impact of DAOs, 2024).

Empowered by blockchain, DAOs are reshaping traditional organizational governance (Hashemi-Khiabani and Polónia, 2023). Their decentralized structure aims to minimize the need to rely on a central authority, promoting more distributed and fairer management models (Lustenberger et al., 2023). This represents an innovative departure from traditional organizational models (Morrison et al., 2020; O. Borgogno, 2022).

DAOs' governance combines machine-driven activities, codified and automated through smart contracts, with mechanisms that allow participants direct involvement in organizational decision-making (Q. Dupont 2018).

This decentralized structure can significantly impact knowledge management (KM), as it has the power to transform the way information is shared and transmitted within organizations.

New technologies like blockchain are reshaping the way traditional organizations manage knowledge. Through DAOs, individuals worldwide can collaborate on real-time projects and create value, regardless of their geographical location or organizational structure (De Filippi, 2017; Wang et al., 2019).

Therefore, thanks to the blockchain technology that underlies these new organizations, new opportunities arise, including the traceability of decisions, the sharing of information through distributed governance and the immutability of recorded data (Hashemi-Khiabani and Polónia, 2023).

The need to develop this topic arises from the awareness that in these new decentralized organizations, knowledge is no longer the exclusive property of individual entities or a small group but instead becomes a dynamic and shared resource among all. Since DAOs alter the way traditional organizations are managed, it follows that traditional mechanisms also need to be revisited.

This study makes a significant contribution to the existing literature by proposing innovative ideas for Knowledge Management researchers. It analyzes the interaction between the emergence of decentralization

and the gradual reduction of human intervention, highlighting how emerging technologies are transforming knowledge management processes and how decentralized governance tools can either enhance or hinder the efficiency of KM practices.

From this perspective, to achieve these objectives, research will focus on the following questions: i) how DAOs influence knowledge management practices within organizations by utilizing blockchain technology; ii) how the uncertain legal frameworks of DAOs are undermining knowledge management, particularly in the context of liability.

This author uses a qualitative approach by reviewing the existing literature on DAOs, KM, and corporate law, both domestic and international, supported by doctrinal analysis of legal frameworks in Italy (Sbarbaro, 2024; Ortolani, 2019; Lener and Furnari, 2021).

This work is structured as follows: in the next section (paragraph 2), a review of the literature on the topics of DAO and Knowledge Management (KM), highlighting the characteristics of each. Paragraph 3 is divided into two sub-paragraphs: it highlights the opportunities of DAOs per KM, explored through the themes of decentralization, smart contracts and blockchain technology as tools for knowledge management, there will be a discussion on the risks and challenges that DAOs may present for KM, including knowledge fragmentation, governance issues and regulatory uncertainty. Paragraph 4 will indicate future directions for researchers and final discussions.

2 Literature review

How a decentralized structure impacts knowledge management remains largely and poorly unexplored.

Literature has, so far, covered the importance of knowledge management in organizations (Jelenic, 2011; Hebibi et al., 2019; Koivisto and Taipalus, 2023) as well as DAOs and their decentralized governance structures (Piselli, 2019; Guillaume et al. 2022; Cardoso, 2023), there is a gap in addressing how these two domains intersect. This theoretical gap may represent a research opportunity, given the need to understand the extent to which technological progress and the evolution of traditional organizational structures can influence internal operational processes. Exploring the convergence between DAO and KM is not only relevant but also essential to anticipate the organizational models of the future.

Traditionally, knowledge management (KM) models are developed within centralized and hierarchical structures typical of traditional organizations, where decision-making authority and the flow of information are concentrated at the upper levels and in the hands of the board of directors (Zaczyk, 2023). The DAOs, on the other hand, radically transform the very concept of traditional organization (Santana & Albareda, 2022).

2.1 Decentralized Autonomous Organizations

Decentralized Autonomous Organizations (DAOs) are defined as: "new organizations that rely on blockchain technology and smart contracts, which are not run on any central server but rather are executed in a distributed manner by an entire network" (De Filippi, A. Wright, 2019; R. Piselli, 2019), identifying a decentralized collaborative organization where "there are smart contracts as agents running on blockchains that execute a range of prespecified or preapproved tasks based on events and changing conditions" (V. Butarin, 2013). There is no universal definition of DAOs (Rikken et al.,2023; Baninemeh et al., 2023), but they can be described as decentralized organizational structures built on a blockchain platform and governed by self-executing codes recorded on the network, known as smart contracts (M. Phillips, 2024), which represent the operational agreement between members and ensure transparency and decentralization in the decision-making process (O. Borgogno, 2022; C. Iorio, 2022). Four elements identify DAOs: community governance, decentralization, automation and transparency (Schneider et al., 2022).

The algorithms on which DAO governance is based, and upon which they depend almost entirely, offer a greater degree of flexibility and adaptability, both in terms of decentralization and automation (van Vulpen et al., 2022). This, in turn, fosters the adoption of a so-called liquid democracy, where the decision-making power of voters varies based on their level of participation (Fan et al., 2019).

This structure incorporates a governance system combining on-chain (automated consensus) and off-chain (voting rights) mechanisms, facilitates collective decision-making and fosters distributed trust among network members (Dupont, 2018; Santana and Albareda, 2022). It is this collective decision that shapes and guides the organization in its decision-making (Wang, 2025). So, this organizational model is characterized by being driven by an online community that operates in a self-managed way for a common purpose (Augustin et al., 2023).

Decentralization is a distinctive feature of DAOs, as they operate on blockchain technology, eliminating the need for supervision by a third party or a central authority (Rikken et al., 2023). To rephrase, decentralization enables decision-making power to be distributed among all DAO members, instead of being concentrated solely

in the hands of a central authority (Y. El Faqir et. al, 2020). This fundamental characteristic distinguishes DAOs from traditional organizational models, in which governance is typically managed by a central authority or a committee of administrators (Santana, Albareda, 2022). Designed to resist centralization, DAOs promote a more equitable and distributed management model (O. Borgogno, 2022).

The use of smart contracts makes it possible to automate the organization, executing rules and transactions without human intervention. (Saurabh, 2024; Wang, 2025).

Transparency is ensured by recording management decisions and financial operations on a blockchain network, allowing every member of the organization to access all activities. (Wang, 2025).

Therefore, DAOs are well-suited structures for enhancing and promoting collaboration, as well as making information more accessible to everyone in the organizations by breaking down traditional barriers due to their decentralized nature. (Butarin, 2013; Hsieh et al., 2018; Hughes et al., 2019; Barnett, 2023; Romex, 2023).

2.2 Knowledge management

Knowledge management is defined by Andreeva and Kianto (2012) as "the set of management activities that enable the firm to deliver value from its knowledge assets". It holds a fundamental importance for the productivity and performance of business organizations (Frozza et al., 2023).

Literature shows that knowledge management is a key element in the long-term achievement of organizational success (Drucker, 1999; Nonaka and Takeuchi, 1995; Asrar-ul-Haq and Sanwar, 2016).

It is also of fundamental importance for the strengthening of business dynamics, favoring the adoption of competitive and lasting practices within organizations (von Krogh, 1998; Koivisto and Taipalus, 2023).

For this reason, in today's competitive landscape, managing and sharing knowledge are among the most strategic resources for an organization. (Asrar-ul-Haq and Sanwar, 2016; Pinto, 2020; Ruzic and Benazic, 2023). In fact, a well-executed knowledge management strategy can significantly contribute to the realization and enhancement of investment capital efficiency (Susanto et al., 2021; Rawan and Omer, 2023).

Knowledge management includes operational skills such as know-how, production technologies, marketing strategies and managerial activities (Maroli, 2019). Knowledge management involves six essential processes: recognition, creation, acquisition, processing, sharing, and application of knowledge (Rawan, Omer, 2023).

A proper development of knowledge is essential for organizations, because it promotes the application of values such as impartiality, clarity, sense of responsibility and transparency among stakeholders (Maroli, 2019).

To fully leverage the knowledge they have, organizations must manage it effectively (Andreeva and Kianto, 2012; Choi and Lee, 2010), since scholars have shown that KM has a significant impact on company performance (Andreeva and Kianto, 2012).

Indeed, the variations in the performance of the organization result from the different levels of knowledge and different skills in exploiting and developing this knowledge. (Grant and Spender, 1996; Andreeva and Kianto, 2012). For this reason, how knowledge resources are used and coordinated within organizations is of primary importance to them. (Andreeva and Kianto, 2012).

3 Opportunities and Risks

In this context, the present work explores how knowledge management (KM) is restructured and adapted within a decentralized organizational reality such as that of DAOs. However, the inherently decentralized, transparent and automated nature of DAOs offers new perspectives and potentially new criticalities for knowledge creation, sharing and preservation.

3.1 Opportunities

Regarding the opportunities offered by DAOs, their impact on KM can be observed across four key areas: driving towards more democratic decision-making, promoting transparency, building trust among participants and improving information security through smart contracts. These are the areas in which KM generally encounters obstacles (Akhavan et al., 2018).

As regards the first aspect, DAOs represent an alternative to traditional structures for organizing the activities of a community, usually composed of individuals (Cardoso, 2023; Monteiro et al., 2024).

Governance is entrusted to automating decision-making processes using smart contracts executed on a blockchain network, allowing a peer-to-peer interaction, in which members collaborate directly, without intermediaries (Monteiro et al., 2024). They embody an organizational model that subverts the hierarchical models typical of traditional business organizations, offering instead an open and decentralized structure (Zalan, 2018; Mitchell et al., 2022; Cardoso, 2023). Overcoming traditional corporate governance issues, such as opacity

and power centralization, this model encourages transparency and compliance within the organization (Hashemi-Khiabani and Polónia, 2023; Saurabh et al., 2024). The absence of a rigid hierarchical structure could allow the creation of a contest more inclusive and oriented to the sharing of knowledge, encouraging a wider dissemination of knowledge and reducing knowledge monopolies (Hashemi-Khiabani and Polónia, 2023). Hence, DAOs encourage a more democratic and participatory approach, distributing decision-making power among all stakeholders involved, which can lead to more equitable and transparent knowledge management practices (Li and Chen, 2024; Han et al., 2025). This feature allows automatic distribution of information among members, satisfying the need for knowledge management to be incorporated into operational processes (Hughes et al., 2019; Frozza et al., 2023).

Furthermore, within DAOs, individuals participate directly in the decision-making process, increasing the perceived legitimacy of decisions, since the possession of tokens, which confers voting rights, is also a form of incentive or reward (Chen et al., 2025). This can also be applied in the context of KM, allowing a reward system for sharing and participating in knowledge.

This outcome is made possible using blockchain technology, the core of the DAO, as it permits the transparent and permanent recording of all transactions and decisions (Hashemi-Khiabani and Polónia, 2023; Chambefort and Chaudey, 2024; Piselli, 2019; Wright and De Filippi, 2015). Transparency is essential to strengthening management accountability and coordinating operational procedures with compliance standards since blockchain technology allows stakeholders to independently access and verify information (Kakavand, De Sevres,2017). Overall, the transparency that DAOs offer can eliminate so-called "information asymmetries" and minimize the need for intermediaries or central authorities (Chambefort and Chaudey, 2024). Furthermore, in addition to fostering trust among stakeholders, this transparency could improve efficiency in both decision-making and operational processes (Chambefort and Chaudey, 2024).

Secondly, by harnessing the inherent features of blockchain technology, DAOs can create environments in which trust is based on the transparency and reliability of smart contracts (Bellavitis et al., 2023; Merk, 2024; Saurabh et al., 2024).

Smart contracts automate and execute agreements in a binding manner, reducing the margin of error and human manipulation, thus consolidating a reliable organizational context (Saurabh et al., 2024). Through these contracts, the stakeholders who hold tokens participate in a collective governance mechanism, where no individual can independently and unilaterally modify the decision parameters (Park et al., 2023).

Therefore, concerning the third element, the integrity of the data is reliably maintained, as the decentralized structure and cryptographic security system of blockchain networks ensures that data remains protected and accessible only through verified users (Hashemi-Khiabani and Polónia, 2023;).

This type of functionality optimizes the organization's digital infrastructures, allowing a better and dynamic management of information assets (Currado et al., 2019).

3.2 Risk

Despite these advantages, DAOs face significant challenges and risks that could undermine the effectiveness of KM practices.

One of the most critical aspects is the fragmentation of information flows. The excessive transparency and total openness of communication channels, if not well structured, can generate an information overload, making it difficult for members to distinguish between relevant and marginal information (Frozza et al., 2023).

The automation of processes through smart contracts tends to privilege the explicit codification of knowledge, neglecting the tacit one, which is the contextual, operational and relational knowledge that can hardly be digitized (Dunford, 2000; Millar et al., 2016). The loss of this knowledge poses a direct threat to innovation and business continuity in the organization (Millar, et al., 2016).

Although transparency enhances trust and accountability, it may also compromise the confidentiality of sensitive data, especially in cross-border contexts where legal protections vary (Hashemi-Khiabani and Polónia, 2023). The transnational dimension of decentralized organizations is a further challenge, as cultural differences and intellectual property issues need to be managed to ensure effective knowledge management (Millar, et al., 2016).

Moreover, the fact that Decentralized Autonomous Organizations face numerous governance-related challenges creates a certain level of uncertainty regarding the effective integration of Knowledge Management (mechanisms. A relevant example is the reward systems based on token ownership, which may encourage decisions driven by personal interests rather than genuine, shared goals (Han et al, 2025).

At the same time, the decentralized nature of DAOs and thus the absence of a central authority can negatively affect the management and effective distribution of information within the organization (Dunford,

2000; Dai et al., 2020). Aligning the interests and contributions of individual stakeholders can be complex, creating, however, the risk of generating inefficiencies in knowledge sharing processes and decisions (Hashemi-Khiabani and Polónia, 2023).

The decentralized nature and the lack of a centralized authority make it difficult to attribute legal responsibility for actions taken within the organization, raising liability issues, undermining trust and unresolved internal conflicts (Ortolani, 2019; Lener and Furnari, 2021; Stanescu et al., 2023; Reynolds, 2023). The lack of a unified regulatory framework and uncertain liability profiles hinder KM effectiveness, complicating the traceability, attribution, and resolution of decisions. The internal governance of DAOs, based on "fluid" and non-procedural forms of power, makes it difficult to identify clear power hierarchies and, consequently, to establish responsibility regimes (Piselli, 2019). Identifying a legal wrapper for such organizations would provide greater clarity regarding the applicable responsibility regime, which is essential for knowledge management. This ambiguity makes the management of legal knowledge and the adaptation to regulatory requirements complex. (Napieralska and Kepczynski, 2024).

Current laws do not consider DAOs' structural peculiarities. Only the United States, based on a historic judgment, has laid the foundations for a formal recognition of these organizations (Sarcuni v. bZx DAO; Ortolani, 2019).

In addition, the decentralized structure of DAOs, together with the anonymity of their members, contributes to further blurring the boundaries of legal liability, hampering effective organization and transmission of legal knowledge (Napieralska and Kepczynski, 2024). A study by Davier et al. (2023) highlights that the lack of clear legal guidelines complicates the management of legal knowledge and compliance. Legal ambiguity hampers the identification of responsibilities in cases of non-compliance and complicates staff training, as it is difficult to convey precise legal obligations, leading to inefficiencies in knowledge sharing and decision-making processes.

4 Conclusions

From the proposed hypotheses, it emerges that a portion of the literature has focused solely on the relationship between blockchain and knowledge management, highlighting the potential of this technology to enhance knowledge management practices. However, there is limited, if absent, attention to DAOs, despite their representing a direct evolution of blockchain applications in governance and collaboration. Hence, the existing understanding of the relationship between blockchain and knowledge management is a significant body of research, whose contribution can be useful in addressing and overcoming previously identified risks.

This gap can be attributed to the fact that DAOs, while offering new paradigms for the management and distribution of knowledge, are still emerging phenomena, often poorly understood and not yet fully integrated into traditional theoretical frameworks of knowledge management.

In this context, the findings show that while these organisations offer significant advantages in terms of knowledge management, their strengths can also lead to operational and managerial weaknesses. This significant gap limits the further exploration of theoretical hypotheses. This highlights the need to broaden research horizons to fully understand the implications of DAOs on organisational and cognitive processes. These authors suggest developing a conceptual model that synthesizes the main enabling and critical factors of knowledge management in DAO contexts, opening the way to new empirical validations. The model could be articulated in three interrelated dimensions (technological, organisational and socio-cultural), each of which represents a critical axis for understanding how DAOs transform knowledge creation, sharing and protection.

It will be essential to develop interdisciplinary studies combining law, organisational theory and information systems to develop regulatory frameworks supporting effective KM practices. Another promising area of research concerns the exploration of socio-cultural dynamics within DAO communities, as inclusion, trust, and digital literacy, which could offer a more articulated vision of how knowledge is generated, shared and preserved in decentralized ecosystems.

5 Ethics declaration

There are no conflicts of interest. All previously published works and their authors have been duly cited in the references. All sources used and contributions made by others have been properly acknowledged and cited in accordance with academic standards to avoid any form of plagiarism. The document does not contain any offensive, discriminatory or otherwise unacceptable language.

6 AI declaration

The authors have not used an AI tool in developing the paper.

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Blockchain Technology and Non-Fungible Tokens (NFTs) in Museums: Legal Considerations

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Abstract

New technologies, particularly blockchain and non-fungible tokens (NFTs), are profoundly transforming the cultural and artistic sectors. Museums are actively responding to this shift by adopting advanced digital tools that enable more engaging, personalized, and innovative visitor experiences. Through the integration of NFTs and immersive technologies, museums can extend the boundaries of cultural participation beyond the physical space, allowing users to interact remotely or gain access to exclusive content such as private exhibitions, supplementary materials, and virtual events. NFTs also allow museums to offer limited digital editions of artworks to collectors around the world, fostering new communities and business models based on digital ownership and participation.

These emerging opportunities demand a reevaluation of how artworks are protected, enhanced, and enjoyed in digital environments. However, for stakeholders to adopt these tools with confidence, several challenges must be addressed.

This study, grounded in the Italian legal framework, investigates key legal issues including copyright law, image rights of cultural assets, and the role of Online Dispute Resolution (ODR) mechanisms in resolving disputes that may arise in NFT transactions. Additionally, the study examines the fiscal implications linked to the creation and commercial use of NFTs by companies.

In a context marked by regulatory uncertainty and diverging legal theories, our research reviews prevailing interpretations and, pending legislative action, proposes a preliminary legal framework. This framework aims to ensure that the creation and transfer of NFTs via smart contracts can be carried out in a transparent, secure, and legally coherent manner, fostering greater trust in the digital transformation of the cultural heritage sector.

Keywords: Blockchain, Legal Framework, ODR, Smart Contract, Museums

Paper type: Academic Research

1 Introduction

New technologies such as blockchain and Non- Fungible Tokens (NFTs) are revolutionizing the cultural and artistic sectors.

NFTs are an ideal tool in the cultural and artistic sector (Damiani, E., 2022; Dignani, A., 2025) as they determine new ways of protecting, valorising and enjoying cultural heritage.

By selling NFTs with underlying artwork, museums can offer audiences remote and interactive experiences, or to digitally replicate or create virtual collections, and build loyalty. They also allow for automatic royalty payments in the event of resale and create sustained revenue streams.

Although NFTs offer significant potential, their adoption raises questions that produce conflicting legal theses.

Therefore, the objective of this research is to identify a legal framework that enables stakeholders to act with awareness and legal security.

To this end, this study examines, within the Italian legislation, the intersection between NFTs and museums, with attention to copyright and the right to the image of cultural assets. Finally, it considers the possibility of using the digital dispute resolution (ODR) and the fiscal implications associated with the sale of NFTs of a company by itself.

2 Value of smart contract on blockchain

2.1 Definition and structure

Article 8 ter, paragraph 2 of Italian Decreto Legislativo (DL) 135/2018 defines a smart contract as a computer program that operates on technologies based on distributed ledgers and whose execution automatically binds two or more parties based on effects predefined by them. This execution meets the requirement of written form provided that the interested parties are identified through a digital process that complies with the standards set by the “Agenzia per l’Italia Digitale”. Blockchain is one of the Distributed Ledger Technologies (DLT) on which a smart contract can operate.

One of the defining features of the smart contract is that it *self-executes* when predetermined conditions occur (Capone, A., 2023): if a predetermined condition occurs (if), the smart contract executes a certain part of the contract (then).

2.2 Is this a legal (juridical) contract?

Clearly, the smart contract, considered only from an IT perspective (smart contract *code*), is not a contract.

However, when it is used to govern legal relationships between parties, the concept of the smart legal contract emerges, giving rise to contrasting legal theories. In this context, a smart contract serves as a technological tool that verifies, enforces, or replaces traditional contracts using blockchain technology (Bassan, F. and Rabitti, M., 2023).

One theory considers it impossible to qualify the smart legal contract as a *juridical* contract (Rampone, F., 2019): it is a mere IT tool for the performance of a previously created traditional contract.

But there is an opposing theory that considers the smart legal contract a real juridical contract and, consequently, distinguishes it from the simple smart contract code (Finocchiaro, G., 2018): the parties use exclusively a smart contract to regulate their jural relation, applying the contractual legislation.

Between the two opposing theses, there are others with intermediate nuances: For instances, (Tommasini, M., 2022) suggests that a smart contract may serve both as a means of executing a previously agreed-upon legal will (instrumental or executive smart contract) and as the sole expression of the parties' mutual intent (constitutive smart contract).

We believe that the preferable solution is to consider the smart contract as the *form* of the juridical contract: in fact, the juridical contract (externally manifested by the parties through the form / smart legal contract) is that of sale, donation, etc. The contract is in fact, pursuant to art. 1321 of the Italian Civil Code (cc), the *agreement* of two or more parties to establish, regulate or extinguish a patrimonial jural relation between them and is made up of essential elements, including the form (art. 1325 cc). The latter represents the external way in which the agreement of the parties is manifested. The art. 1350 prescribes that certain acts listed therein and other acts specifically indicated by the law must be made (… in writing…), under void penalty, we can certainly deduce that, unless the law provides otherwise, the principle of freedom of form applies (Manente, M., 2019).

Furthermore, considering that contracts stipulated electronically or telematically are valid pursuant to Italian Decreto del Presidente della Repubblica 445/2000 and the Italian Digital Administration Code (CAD), we can deduce that the smart contract can serve as a form for different types of *juridical* contract (Tommasini, M., 2022).

Even in cases where written form is legally required, the smart contract can be considered valid since art. 8 ter paragraph 2 Italian Decreto Legge 135/2018 that provides the smart contract satisfies this requirement if signed on the blockchain through the process established by the Agenzia per l'Italia Digitale and following the guidelines of the Italian Ministry for Technological Innovation, therefore with the identification of the parties through electronic signature (Capone, A., 2023).

Therefore, supported by authoritative legal scholarship (Bomprezzi, C., 2019; Capone, A., 2023; Manente, M., 2019), we conclude that the *smart legal contract* should not be considered a juridical contract in itself, but rather the *form* through which a juridical contract is expressed.

2.2.1 Is its immutability a problem?

At this point, several challenges emerge that require careful analysis: chief among them are the automatic execution of the smart contract (its core feature) and the immutability ensured by the blockchain.

These characteristics may conflict with certain Italian legal concepts, such as *supervening impossibility*, which refers to the occurrence of an unforeseen event that makes it impossible for one party to perform and justifies a request for the equitable modification of contractual obligations. In this context, the rigidity of a smart contract could indeed be seen as a limitation.

However, one legal theory correctly believes that this problem can also be overcome. (Bellomia, V., 2020; Fauceglia, D., 2020; Tommasini, M., 2022) clarify that the outcomes associated with the modification or discharge of a contract can still be achieved through the structure of smart contracts. This is because smart contracts operate using conditional logic (*if...then* statements), enabling parties to embed predefined scenarios and their corresponding consequences at the time of contract formation.

In Italy the condition is contemplated by art. 1353 cc: the parties may subordinate the effectiveness or the discharge of the contract or of an agreement to a future and uncertain event.

It can be inferred that if the parties wish to resort to the smart contract, they must mandatorily (despite the letter of the code speaking of possibility) subordinate the effectiveness or the discharge of the contract or of an agreement to a specific future and uncertain event.

In alignment with our earlier thesis that the smart contract represents the *form* of the juridical contract, this theory reinforces the view that a smart contract must necessarily incorporate conditional elements to remain valid and functional within the Italian legal system. In this way, the much-debated immutability of blockchain technology becomes a benefit, especially when understood through the concept of *notarization*, which ensures tamper-proof and timestamped recording of the contract's content. (Galli, C., 2022).

(Tommasini, M., 2022) also talks about the possibility of introducing a self-destruct kill function.

(Bassan, F. and Rabitti, M., 2024) believes that any problem relating to the unchangeability of the smart contract can be solved by switching to the more recent *on-chain contract* (see next paragraph) by virtue of its greater plasticity.

2.2.2 What language does it use?

Another critical issue relates to the *language* used by smart contracts. Typically written in programming languages, smart contracts are not structured to express complex legal concepts.

Even when explanatory text in natural language is added alongside each line of code, remains the problem that the contracting party cannot be sure if the translation into natural language is correct (Bomprezzi, C., 2019).

To overcome this issue, (Bassan, F. and Rabitti, M., 2024) advocate for a transition from *smart legal contracts* to *on-chain contracts*. These contracts are written simultaneously in both natural and programming languages and executed on a third-generation public blockchain. (Bassan, F. and Rabitti, M., 2024), being able to leverage a more innovative technology, propose the transition from the smart legal contract to the contrat *on chain*, using a public third-generation blockchain technology (which can use natural language) as an infrastructure and a controlled-access logical platform as a superstructure.

They are supported by a logically structured platform with controlled access, ensuring clarity and correctness from both a human and machine perspective (see also D'Arpe, S., 2024). This model creates a user experience analogous to signing a traditional online contract and enables the *negotiation, formation, and performance* of the contract entirely on the blockchain.

However, public blockchains (*permissionless*) present challenges: they allow anonymous and unrestricted access, which conflicts with the legal requirement for proper party identification in contracts. The theory under discussion addresses this concern by using a controlled-access logical platform, which restricts access to authorized cryptographic addresses and requires non-anonymous wallets. This model enables compliance with anti-money laundering regulations while preserving the security advantages typical of private blockchains.

Until third-generation blockchain platforms become widely adopted, even the advocates of on-chain contracts acknowledge that alternative approaches can be used. One such approach involves combining a traditional contract with a smart legal contract and securing a certification of correspondence between the natural language version and the coded one—issued by a third party, such as the logical platform itself.

This certification could then be recorded on the blockchain, thus acquiring probative value under Italian law.

3 NFTs

3.1 Definition and value of NFTs

NFTs (Non-Fungible Tokens) are tokens, i.e. groups of data stored on blockchain, that certify the ownership of digital or physical objects through a unique identification code and the recorded identity of the issuer and owner. They are non-fungible, meaning they are unique, indivisible, and irreproducible.

Can NFTs certify not only ownership, but also the authorship and authenticity of the underlying object? According to (Galli, C., 2022; Damiani, E., 2022) NFTs act as cryptographic codes equivalent to the artist's signature and therefore certify authorship and authenticity. While, according to others the NFTs only attest to the act of registration on the blockchain by the first seller. Consequently, while NFTs may demonstrate provenance, ownership, and subsequent transfers, they do not inherently verify the authorship or authenticity of the original work. The metadata entered during the NFT's minting could be false or misleading (Dignani A., 2025; Tommasini, M., 2023).

To address this problem, it would be possible to upload onto the NFT both the certification of an expert (such as the director of the museum that has custody of the work), and the delegation agreement for the creation of the NFT. In this case, authenticity and authorship would also be proven. A simpler case is when the native digital work has been tokenized directly by the author, identified with certainty (Marchegiani, L., 2023).

It is also worth noting that an NFT, once minted on a blockchain, represents both the *corpus mechanicum* of the work (physical support of the artwork, therefore a tangible thing), and the ownership title of such *corpus mechanicum* : therefore it can be considered both as a property object and as a title of ownership of a thing (Frezza, G. and Virgadamo , P., 2023).

3.2 NFT on artwork and economic exploitation rights

The creation of an artwork is protected under the Italian Civil Code and Law 633/1941. Upon creation, the author acquires both moral rights and economic exploitation rights (Art. 6, Law 633/1941). Unlike moral rights, economic rights may be waived or transferred to third parties

According to Article 109 paragraph 1 of Law 633/1941, the transfer of a copy of a work does not imply the transfer of its economic exploitation rights unless explicitly agreed upon. Moreover, under Article 110, such a transfer must be documented in writing.

A recent legislative proposal (*Disegno di Legge* S. 1146, currently awaiting approval) seeks to extend copyright protection to works created with the support of artificial intelligence, provided that the output reflects the intellectual contribution of the human author (Art. 25, paragraph 1, lett. a).

Applying these rules to NFTs representing artwork, t becomes clear that an NFT cannot be equated with the work itself (Marchegiani, L., 2023): it consists of groups of data, among which there is also a unique identification code of the associated work.

Therefore, unless otherwise explicitly agreed, the purchaser of an NFT acquires only the associated metadata—not the underlying work itself. The economic exploitation rights of the work remain with the author. Furthermore, the author can embed clauses in the smart contract that enforce royalty payments on future resales, thereby preserving a share of proceeds from secondary transactions.

Prior to any transfer, it is also essential to examine the terms of service and contractual conditions stipulated by the platform used for issuing or trading the NFT.

3.3 NFT and image rights of cultural assets

According to the definition of cultural asset given by art. 2 paragraph 2 of Decreto Legislativo 42/2004 - Code of Cultural assets and Landscape (BCP code), a cultural asset is defined as a testimony of civilization with cultural value. This implies that a cultural asset is incorporeal in nature (Tommasini, M. 2023). Although it is embodied in a physical medium, its legal value transcends that physicality (De Angelis, D., 2024; Kurkani, K., 2023; Nardi, S., 2022; Calculli, G., 2024), as it carries a message capable of enduring across generations, much like a historical document (Italian Consiglio di Stato, AP, judgement 5/2023).

The image of cultural asset is legally protected: the judgment of the Corte d'Appello of Bologna 1792/2024 confirms that a right to the image of the cultural asset can certainly be configured since articles 107 and 108 of the BCP code, implementing art. 9 of the Italian Constitution.

For this reason, the protection of the right to the image is perpetual (De Angelis, D., 2024) and complements that of copyright, which has a defined duration in consideration of the different dimension of the two types of protection (Tribunale of Firenze, order 11.04.2022).

Art. 107 BCP code establishes the prohibition of the reproduction of cultural assets, unless this is granted; art. 108 specifies that, for the use of cultural assets, permission fees, reproduction fees and, possibly, a bail are due (not so if there is no business purpose but study, research, etc., paragraphs 3 and 3 *bis*) and art. 106 provides that the permission of individual use of cultural assets can be obtained for purposes compatible with their cultural destination, provided that the transfer guarantees the conservation and public enjoyment of the asset.

Thus, museums must evaluate whether a proposed use of a cultural asset might degrade its symbolic or intangible value (Piperata, G., 2023).

Ministerial Decree 108/2024, issued by the Ministry of Culture, establishes minimum fees and charges for the commercial reproduction of images of cultural assets.

Given the incorporeal nature of a cultural asset's image and the capabilities of technologies such as NFTs and smart contracts on the blockchain, once a museum has authorized the creation of an NFT, the asset can achieve broader dissemination. This fosters new business models, expands cultural access (Dignani, A., 2025), and mitigates risks of physical deterioration.

4 NFTs in the museum sector

If a museum decides to create an NFT of one of its artworks to sell or donate to visitors, the legal considerations discussed above must be taken into account.

Typically, a specialized company is commissioned to mint the NFT. Depending on the contractual arrangement, visitors may:

- Purchase the NFT directly from the company (establishing a legal relationship solely with it),
- Acquire it through a bundled offer from the museum (ticket + NFT),
- Receive it as a complimentary addition to their basic admission ticket.

For example, a museum might contract a company to produce a limited NFT series of an artwork from its permanent collection. The contract will govern the remuneration owed to the company, which could take the form of:

- A one-time fixed payment from the museum (if the museum distributes the NFTs directly),
- A percentage of net proceeds per NFT sold (if the company handles distribution to visitors).

In either scenario, all rights to the original and digital versions of the artwork remain with the museum, particularly if the artwork is part of the national heritage.

A typical user experience might involve the visitor entering the museum with a standard ticket, scanning a QR code displayed beside the artwork, agreeing to terms and conditions on their smartphone, and downloading the NFT to their wallet for personal use.

In another scenario, a museum might commission an NFT based on a work by an external artist featured in a temporary exhibition. In such cases, the artist's prior authorization is mandatory (Marchegiani, L., 2023), including any potential transfer of economic exploitation rights to the museum. The contract should stipulate the respective compensation for both the company and the artist. The visitor would then purchase a bundle and gain personal access to the NFT.

Here is a real-life case: NFT of Doni Tondo minted for the Uffizi Galleries

According to the contractual terms, the company retained the patent for the NFT creation technology, while the Uffizi Galleries retained full rights to both the original painting and its digital reproduction. The Galleries received 50% of the net proceeds from each NFT sale, and a certificate of authenticity signed by the director was issued with each token. An official press release confirmed that no rights were alienated in the transaction.

In all cases, however, the use of a cultural asset’s image is strictly subject to prior authorization from the competent authority, along with payment of the corresponding reproduction or licensing fees (Piperata, G., 2023).

5 The company that issues and directly sells the NFT

When a company negotiates directly with the author of a digitally native artwork, who transfers the economic exploitation rights, it must also consider the associated tax implications.

The sale of an NFT with underlying intellectual work represents an income of the seller: for the company it is business income -point 3 of the Circolare Italian Agenzia delle Entrate 2023/30/E (Circ.)-.

The company may establish royalties: once minted, the NFT can be sold on the primary market (initial sale by the creator) and subsequently on the secondary market (resale). Normally, each resale on the secondary market generates a royalty for the original creator (Circ. point 3.7.1.3).

We believe that the company can set royalty percentages on future resales even by giving away an NFT for free at a promotional level.

Because it is a company (and therefore a person who cannot be considered the author), the sell is subject to IVA, similar to VAT in the UK (therefore point 3.7.1.3 of the Circolare cannot be applied).

Anyone who holds NFTs must pay an annual impost, which may be a stamp duty (Circ. point 3.7.2.) or ad valorem of crypto-assets (Circ. point 3.7.3.), except for amounts lower than those established from time to time by fiscal legislation.

Finally, the estate duty and gift tax are applicable on transfers of assets and rights due to death, by donation or free of charge, also with reference to crypto-assets, the taxable base of which is determined by assuming the market value on the date of the succession or donation, detected by the exchange platform where the crypto-asset was originally purchased or by a similar platform where the same crypto-assets are negotiable (Circ. point 3.7.4).

6 ODR

Alternative Dispute Resolution (ADR) is a method of resolving disputes that is an alternative to the judicial process. It includes various legal institutions such as mediation and arbitration.

ADRs can also be implemented online: in this case they are called Online Dispute Resolution (ODR). They are distinguished into human-based ODR (online ADR), if the technology is only the means that allows the impartial

third party to normally carry out his role, and machine-based ODR (cyber ADR), when technology takes on an active role to enhance or replace man (Peruginelli, G., 2007), for example settling pecuniary disputes through the exchange of blind offers between the parties if they come closer to within a certain percentage.

Based on new blockchain and smart contract technologies, smart ODR has then appeared, which has the innovative feature of being equipped with self-enforcement: regardless of the parties, it ensures the automated execution of the outcome of the procedure after reaching the resolution of the dispute.

Smart ODR systems also allow the mediator to both estimate and increase the probability of reaching an agreement between the parties by indicating the best mediation strategy in reference to the specific case.

All these characteristics, including the consequent standardization of the procedure, distance ODR from the inspiring idea of the original ADR (Mingardo, L., 2020), but we still believe they can find profitable application in some matters, such as disputes regarding NFTs, where standardization could further favor the speed of the procedure and still guarantee a confidential, cost-effective, effective solution and, moreover, without the possibility of subsequent non-compliance.

We therefore believe it is useful to insert a clause in the smart legal contract that provides the smart ODR for any reason of dispute (due for example to the malfunctioning of the system.

7 Conclusions

Stakeholders operating in the NFT and digital artwork sector currently face substantial legal uncertainty due to conflicting theories and gaps in legislation. This study has aimed to clarify the legal status and practical implications of emerging technologies within the Italian legal framework.

In conclusion, we can say that in Italy in our opinion:

- The smart legal contract (even in its most recent version of contract on chain) represents the *form* of a juridical contract (therefore one of its essential elements).
- Parties using a smart legal contract must necessarily enter into a conditional contract.

In the absence of specific regulation, it is advisable to draft a traditional contract in parallel with the smart contract and obtain certification of correspondence (e.g., from the NFT trading platform) between the off-chain signed text and its encoded version.

The ideal solution, where technologically available, is to use third-generation blockchain systems that support natural language contracts.

- When NFTs are created and transferred via blockchain and smart contracts, they can certify provenance and subsequent transfers, but not authorship or authenticity, unless additional certification (e.g., from a museum director) is uploaded to the blockchain.
- The buyer of NFT does not buy the underlying artwork, even if it is digital. Unless explicitly agreed otherwise, the buyer may only make personal use of the NFT. The economic exploitation rights remain with the author or institution, who may embed royalty clauses to ensure compensation upon resale.
- Even when copyright has expired, a company wishing to create an NFT of a cultural asset must obtain official authorization and pay reproduction and permission fees.
- If the company negotiates directly with the author and acquires exploitation rights, it must comply with fiscal regulations outlined in Circolare Agenzia delle Entrate 2023/30/E.
- Regardless of whether a traditional or smart contract is used, it is highly beneficial to include a smart ODR clause to promote efficiency, enforceability, and cost control.

In our opinion, although through evolutionary interpretation it is often possible to apply existing rules to new technologies (Bellomia, V., 2020; Bomprezzi, C., 2019; Galli, C., 2022; Tommasini, M., 2022), legislative intervention is needed in case of gaps and to resolve conflicts between the various legal theories. Only in this way, all stakeholders will be able to act with clarity and confidence in these innovative technologies.

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9 Ethics declaration

Ethical clearance was not required for the research.

10 AI declaration

No AI tools were used for the creation of the paper.

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Sarajevo 1992-2025: The Contribution of Art between War and Peace, Analogue and Digital

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Abstract

To celebrate the anniversary of the Dayton agreements after the Sarajevo war (1992-1995), a phygital exhibition *Sarajevo 1995-2025. From war to peace on the thirtieth anniversary of the Dayton Peace Agreement* is going to be launched between Bari and Sarajevo, inspired by the *Ars Aevi project* and celebrated through words and experiences of many protagonists, from local to Italian authorities, from children of yesterday to the adults of today.

Born as a political and peaceful artistic action in response to the war, conceived and realized by Enver 'Enjo' Hadžiomerspahić, the project started in 1992 from the Michelangelo Pistoletto's donation of his artwork *Porta allo Specchio*. Become one of the greatest contemporary art collections, *Ars Aevi* will find its definitive location in the new Museum of Contemporary Art designed by Renzo Piano in 2005, donated to Sarajevo and just presented according to its executive design. The collection can be known and enjoyed thanks to the website, the online catalogue and a virtual exhibition, a sort of demo preview of the new Sarajevo Museum.

The project of the *Sarajevo 1995-2025* exhibition, realized through the collaboration of the University of Bari "Aldo Moro", many Italian and Bosnian institutions and the partnership of the Ars Aevi Museum, aims to promote intercultural dialogue and peace, through an exhibition combining stories and contents, in a physical, digital, interactive and immersive way, by using different digital tools, such as an interactive 'augmented' catalogue and a VR exhibition on ArtSteps.

Keywords: Digital Art History, VR experiences, Phygital exhibitions, VR exhibitions, Virtual environments.

Paper type: Academic Research Paper

1 The Ars Aevi project as an inspiring ideal and value-based model for contemporary art and peace building processes

Before introducing the *Sarajevo 1995-2025. From war to peace on the thirtieth anniversary of the Dayton Peace Agreement* exhibition, a premise is required, necessary to describe what happened under the bombings, starting from 1992, and in the following decades. In the peacebuilding process, contemporary art was an essential protagonist: the *Sarajevo 1995-2025* exhibition got inspired from the *Ars Aevi project*, as an ideal and value-based source for the project itself which will be inaugurated in Bari in autumn 2025.

The anagram itself of the project, a logo embracing the name of Sarajevo like a *tai*, represents Ars Aevi's ethical-visual identity, in a perpetual and progressive balance between contrasting forces. *Art of an era crossing the limits of time*: this is the meaning of the Latin expression, chosen as a (partial) graphical anagram of Sarajevo, described on the website collecting the history of the collection, born as a political and peaceful act in response to the war (fig. 1).

In 1992, faced with the horrors of war and the siege of Sarajevo, culture and art were used as true instruments of resistance (Caira and Cavigioli 2021). Contemporary art was called to contribute in a peace-message building, in a collective and participatory way, to a visionary and long-term project launched by Enver 'Enjo' Hadžiomerspahić, former director of the Biennale Jugoslovenska Dokumenta in Sarajevo (1987-89), together with other Bosnian intellectuals and artists. Over the last thirty years since the beginning of the Bosnian war, this call to the arts shaped a very rich collection (over 160 works), the Ars Aevi Museum of Contemporary art, which is coming to a definition of its own physical and definitive museum space, after its "nomadic and itinerant dimension" (Azzerboni 2023).

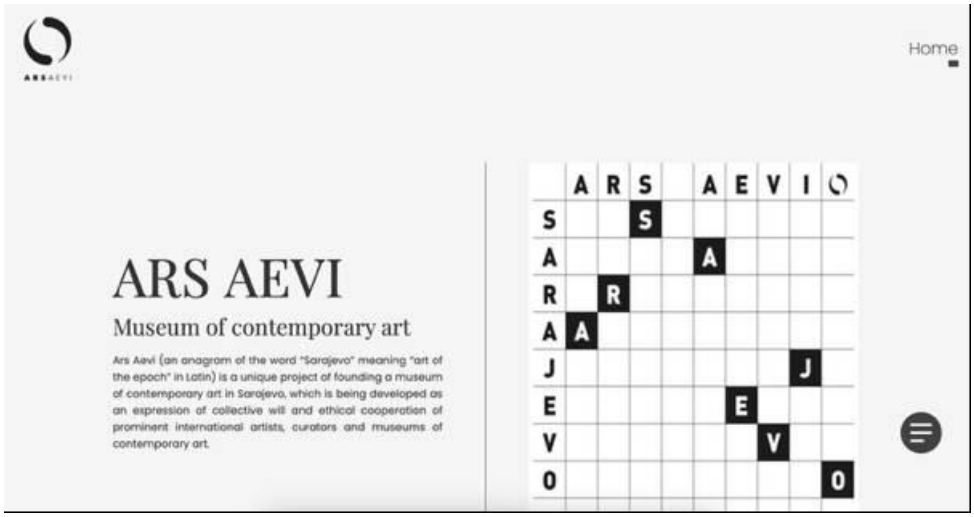


Figure 1: Homepage of the Ars Aevi website.

32 years later, 'Enjo' himself left testimony of his initiative, which he led until 2017 (replaced in 2018 as Ars Aevi Director by Senka Ibrišimbegović, University of Sarajevo, which is partner of our initiative), in a long interview to Franco Giuliano, reporter during the war for the *Gazzetta del Mezzogiorno* newspaper and creator of the *Sarajevo 1995-2025* exhibition. Hundreds of artists from all over the world transformed Sarajevo into a multicultural capital of art and the art collection itself into a universal message of the value of art from a moral and aesthetic point of view, as declared in the manifesto of Ars Aevi Museum on the website: *Art can overcome evil and destruction. Culture is the mother of tolerance. Intercultural dialogue enriches. The universal language of art unites*.

Just at the beginning of the siege of Sarajevo (June 1992), when it was *crazy* thinking about art under bombings, the idea of 'Enjo' was immediately embraced by the city of Sarajevo itself and by the Bosnia-Herzegovina State as a long-term project (under its first name *Sarajevo 2000*), immediately revealed as an innovative model and a unicum for participation and vertical cooperation between artists, museums, centres and foundations of contemporary art from all over the world (MIMEH 1999). The 45th Venice Biennale, in 1993, was the occasion to present its concept to the world. Thanks to Enrico Comi - the artistic director of the Sarajevo 2000 project by founding the "Spazio Umano/Human Space" Contemporary Art Centre in Milan -, Michelangelo Pistoletto's exhibition in 1994 was the first response to that call: his *Porta allo Specchio*, dating 1989 (fig. 2) started the collection (Hadžiomerspahić 2005; *Ars Aevi* 2009; Comi 2015, pp. 19-21; Carolo 2016; Webber 2018; Azzerboni 2023).

Thanks to many Italian institutions, the voice of art soon made itself heard with great power as a manifestation of resilience against that war and every war, as never before in our contemporary times. The answer of the most famous artists - from Kounellis to Kosuth, from Accardi to Abramovich, from Kapoor to Viola, just to name a few - was not long in coming and the curators of the institutions called to select the works became over the years co-founders of the project, which therefore had a unique museogenesis. From 1994 until 2012, the creation of this collection was the focus of specific exhibitions/donations, organized by museums, centres and foundations of contemporary art, such as those of Milan (Spazio Umano, 1994), Prato (Centro Pecci, 1996, to whose curator Bruno Corà we owe the invention of the anagram of the project, called *Ars Aevi 2000*), Ljubljana (Moderna Galerija, 1996-97), Venice (Biennale; Querini Stampalia and Bevilacqua La Masa foundations, 1997), Vienna (Museum moderner Kunst Stiftung Ludwig, 1998), Bolognano (Paradise Museum in the estate of Lucrezia de Domizio Durini, 2003), Istanbul (BM Contemporary Art Centre, 2007) and Podgorica (Centre for Contemporary Art of Montenegro, 2012), thus forming the various *nuclei* of the collection, to which is added the nucleus of Sarajevo itself, formed thanks to a series of personal exhibitions (1994-2006). In 2023, Ars Aevi Nucleus Kyiv have been created as an expression of solidarity with Ukraine, according to its mission in peacebuilding. After an initial exile condition, hosted by different exhibition venues and in turn a widespread instrument of cultural resistance, in 1999 'Enjo' decided to set up an exhibition at the Centar Skenderija in Sarajevo: a historic event for the art world, with the first 105 artworks (installations, paintings, sculptures, photographs). Due to the most innovative moral value in the world, this museological approach since 1999 have been recognized and supported by UNESCO and its Goodwill Ambassador, the architect Renzo Piano.

Since 2019, the collection is temporarily housed at the Viječnica, the seat of the Sarajevo Municipality, one of the symbols of a war (the National and University Library before the siege), deliberately not spared from incendiary bombs, cannon fire, grenades, rebuilt in 1996-2014.

The Ars Aevi collection, presented in an online catalogue on the website (the only place where the entire collection is described so far: http://www.arsaevi.ba), will find its definitive location in the new Museum, presented by Renzo Piano in 2005, updated in 2012, donated to the City of Sarajevo and financed in its executive design by the Italian Agency and by a crowdfunding launched in collaboration with UNESCO. Already in 2002, Renzo Piano donated a new pedestrian bridge, connecting the two banks of the Miljacka river to allow access to the area where the Museum will be built, where the white and blue flags of Daniel Buren's installation, *La Place des drapeaux* still stand. Here, on 20 August 2024, the first stone of the new Museum has been laid, realizing Piano's design idea (fig. 3).



Figure 2: The first artist for the Ars Aevi collection (from the Ars Aevi Picture book).



Figure 3: Rendering of the Museum of Contemporary Art ARS AEVI project by Studio Nonstop (Sarajevo), designed by Renzo Piano Building Workshop (©Studiononstop).

2 The Sarajevo 1995-2025. From war to peace on the thirtieth anniversary of the Dayton Peace Agreement phygital exhibition

The web offers the *Ars Aevi* collection the opportunity to be known and enjoyed in its entirety, thanks to the website, the catalogue with the artworks' descriptions and the virtual exhibition that 3D reproduces the spaces designed by Renzo Piano, a sort of interactive demo of the new Sarajevo Museum (figs. 4-5), surrounded by *La Place des drapeaux* Buren's installation, symbolically marking the Terrain of the Future Museum of Contemporary Art, since 1996.



Figure 4: The Ars Aevi virtual exhibition.

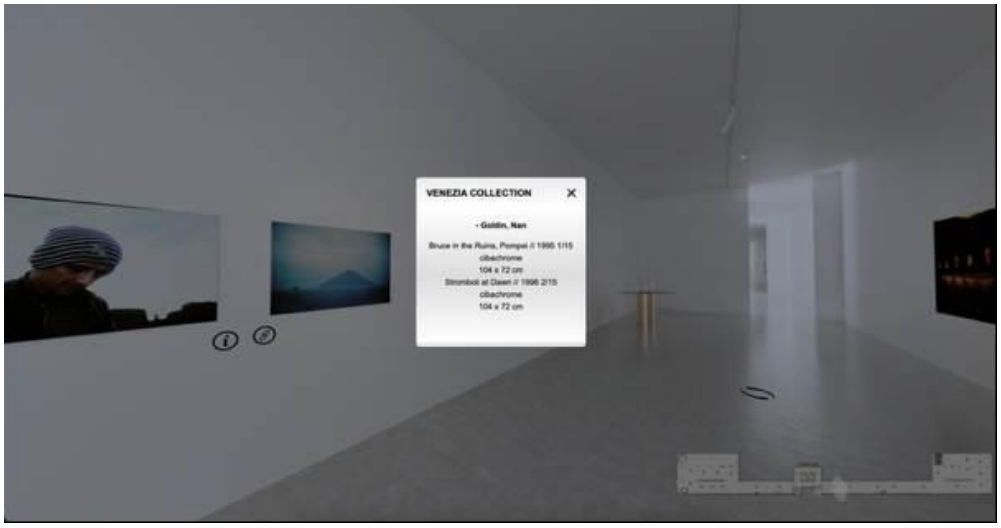


Figure 5: The Ars Aevi virtual exhibition.

To tell the story of the *Sarajevo 1995-2025* exhibition, the University of Bari staff and the DABIMUS digital university lab directed by Nicola Barbuti decided to use different digital tools, expanding the physical exhibition in content and space, such as an interactive augmented catalogue, whose contents are hosted in a special mobile application, EXEBook, developed and owned by DABIMUS (Barbuti and De Bari 2022), and an exhibition on ArtSteps, a free platform for building virtual exhibitions, which will be better described in this paper.

Starting from the images of the devastated urban landscape, from the letters that the children of Sarajevo wrote to their peers in Puglia, from the testimonies of the many protagonists, who populate the virtual rooms of the exhibition, a special place is occupied by the *Ars Aevi* collection immersive story.

The process, which guided the choices regarding the exhibition, led the curator Franco Giuliano and the University of Bari and DABIMUS staff to proceed with the digitization of all the archive and photographic material related to the years in which Giuliano was sent in Bosnia for the *Gazzetta del Mezzogiorno*, during the Balkans war. On that occasion, in addition to recounting that event on the Italian press, Giuliano collected and published on the newspaper dozens of letters written by the children of the Catholic School of Sarajevo, involving prominent Italian and Bosnian personalities of the time. “Sarajevo calls Puglia” was the title of the newspaper’s initiative, inviting readers to send gifts to the Bosnian children.

The concept of the exhibition revolves around the photographic documentation, news and life of the people and the city of Sarajevo, created through those letters/messages that in 1995 students entrusted to Giuliano and were translated and published in *La Gazzetta del Mezzogiorno*, to which many children from Puglia answered by sending gifts that were brought with a special mission. Those testimonies, letters and newspaper pages from Sarajevo, together with other important documents, can now tell, after 30 years, what the War in the Balkans was and what the Balkans are today. Some of those children, now adults, were interviewed and

involved 30 years later to document how much and how the war affected and still affects their lives. The wounds of the soul are then combined with the wounds that the landscape has suffered through the destruction of symbolic monuments of the city. In fact, Sarajevo's cultural heritage was also heavily involved during the war in the former Yugoslavia: cultural and religious sites were destroyed or seriously damaged and the city's urban landscape itself shows holes, cracks and gashes that still recall wounds that seem incurable.

The exhibition, in its physical and virtual version, wants to document these events through photographic augmented panels which refer to digital content of various types: newspaper articles, letters, photographs, video-testimonies, audio content, also linked to the expanded exhibition catalogue, developed by DABIMUS through their specific EXEBook application and AI tools, such as Genially (used both as backend to host mapped resources with original objects and environments, and to build interactive learning and communication materials), and by the writer, to a VR exhibition on ArtSteps, where a selection of the digitized content are displayed.

3 From SecondLife to ArtSteps, Virtual Reality Platforms and the *Sarajevo 1995-2025 VR Exhibition*

The use of virtual environments to foster new forms of connection and engagement with art has entered common practice, thanks to its high educational, interactive and informative potential. Since the end of the 1990s and in the first half of the 2000s, the first entirely virtual museums and full immersion platforms such as Second Life (a MUVE, *on-line multi-user virtual environnement*) revealed their potential for new cultural learning processes in a collective space, in which multiple users interact simultaneously (Bonacini 2011).

Created in 2003 before Facebook and defined as a proto-metaverse system, SL is the true forerunner of the metaverse launched by Meta, an essential starting point for any discussion on the topic of virtual environments (Calveri 2023). On SL, in 2007, the Royal Gallery of Dresden virtually recreated the original disposition of the paintings, as they appeared in the *Gallery of the Old Masters* around 1750. In Italy, in the meantime, we were witnessing the innovative *SLAssisi project*, the digital recreation of the Basilica of St. Francis of Assisi, damaged by the 1997 earthquake, and accessible on the web in an immersive mode through head-up displays, derived from the world of immersive gaming, whose replicability in the cultural sphere was then beginning to be tested (Bonacini 2011). It is no coincidence, therefore, that between 2007 and 2011 SL hosted the *Metaverse Museum* project, which for years displayed digital art exhibitions, created exclusively in this parallel virtual world; then moved to *Craft World Opensim* and, in 2023, opened to artists' creativity until landing on Spatial platform in 2023. The case of the *Metaverse Museum* itself is clear proof of how the creation of artistic spaces in virtual worlds is a practice much further away in time, digitally speaking, than one might think.

Virtuality can therefore be considered one of the answers that modern technology provided regarding the role that communication had to play as an intrinsic function of the work of art, to avoid denying or prejudicing the artistic experience itself, if not in its full authenticity, at least in its potential for articulation and connections (Ragghianti 1974; Pietroni, Pagano and Fanini 2018). Almost given up for dead, SL has seen a relaunch and a total restyling over the last few years; then, favoured by the pandemic for the opportunity of creating virtual educational environments, it still boasts thousands of active virtual scenarios today, including artistic experiences, such as the VR version of the MoMA (fig. 6) and the Vordun Museum and Gallery, a virtual museum created on SL in July 2016 and updated to date with numerous exhibits created through reproductions of works of art in the public domain (fig. 7), equipped with descriptive audio guides and working in immersive mode. Since March 2023, SL has also launched its beta-version for mobile devices on app stores.

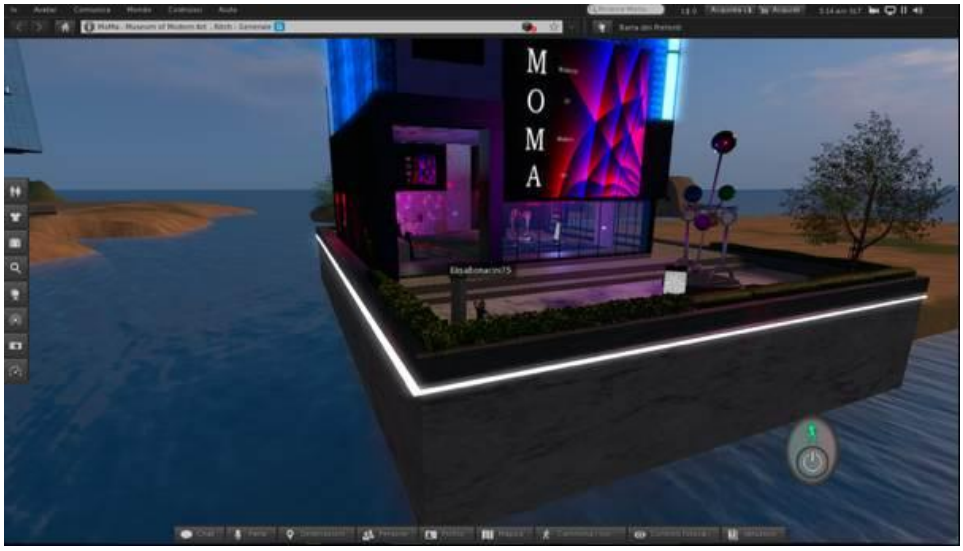


Figure 6: The MoMA virtual gallery on Second Life.



Figure 7: The European Masters gallery in the Vordun Museum and Gallery on Second Life.

After more than twenty years, virtual experiences have confirmed their great potential both in the communication and enjoyment of art, and in engagement with the public, thanks to the implementation of interactive solutions and communication models based on a storytelling approaches (Bonacini 2023). In this panorama, virtual museums are to be considered places where an experience of artistic perception can be recreated, stimulating wonder through the creation of a multimedia and multisensory environment to trigger a creative process useful for directing, internalizing and assimilating the understanding of historical content (De Vincentis 2023).

Among the web platforms available (in addition to Spatial, it is enough to mention Kunstmatrix, CoSpaces, ArtPlacer or Curat10n), ArtSteps is one of the most highly versatile in creating three-dimensional spaces easily and intuitively navigable (Parson 2023; Vital et al. 2023); therefore, especially after the lockdown, it has been used for virtual projects of an educational and informative nature (Fokides and Sfakianou 2017; Cruz and Torres 2022; Dell'Utri 2002; Garbui and Pellizzari 2022; Piva 2023), for virtual exhibitions produced by museums and cultural institutions (Dell'Utri 2022; Leonardi and Bonacini 2024), or for immersive digital art portfolios, created by digital artists or art galleries. In general, tools such as ArtSteps are skilful in transforming art presentation and visualization solutions, even in participatory and collaborative ways, allowing experimental decision-making and creative-thinking activities, in the context of the virtualization of the historical-artistic experience.

In addition, platforms such as ArtSteps allow experimentation with digital and virtual curation solutions. This is certainly one of the most innovative activities that a *digital art historian* can undertake, from a creative and scientific point of view, as it is one of the areas of greatest experimentation that digital revolution introduced into museological and museographic practices.

3.1 The Sarajevo 1995-2025 VR exhibition on ArtSteps

The *Sarajevo 1995-2025 VR exhibition* (https://www.artsteps.com/view/67ead8dca81e5737cc3427c2) is the virtual and immersive version of the story told through the other media, the physical exhibition and the interactive catalogue with its application, in Italian and Bosnian languages.

To create the virtual exhibition, it was decided not to use a pre-existing template, but to design the spaces taking advantage of the full potential of the virtual exhibition surface, available by the ArtSteps system itself, corresponding to approximately 1300 square meters (a maximum of 36 meters per side). From a design point of view, the creative process was therefore developed in a series of intuitive steps, from the creation of the exhibition space to its planning through visual (photos, videos) and narrative (captions, audio descriptions) content. Original photos, videos, newspaper pages were all digitized by DABIMUS staff. In this case, the textual contents of the articles, transcribed in Italian and translated into Bosnian by Maurizio De Bari and the DABIMUS staff were interpreted in Italian by the students of the Digital Valorisation of Museum Collection course at the University of Bari, while those in Bosnian by nuns and students at the Catholic School of Sarajevo. CABOLO® AI-based solution have been used for speech-to-text transcription, translation and subtitling all the video interviews (as a form of sponsorship for the phygital exhibition by the Cedat 85 firm).

The visit route was designed with an introductory environment, in which the entire exhibition is presented (the graphics of which were created as a thesis project by Alessia Cioce, a student of the Digital Heritage specialistic degree course at the University of Bari), and four rooms that lead the virtual visitor on the narrative path.

The first room, *Sarajevo, the war and the Dayton Agreement* in 1995, is dedicated to the visual and documentary framing of the last months of the war until the signing of the agreements that put an end to four years of conflict. Original parts of a video-documentary, realized for the Italian television in December 1995, and the photographic repertoire of war correspondent Franco Giuliano, have been used with photos collected through other witnesses, such as the commander of the Italian contingent in Sarajevo, general Pedone, and the press review, which recounts the turbulent moments that then led to peace.

The second room, entitled *Ars Aevi. Art as Peace Instrument*, is an artistic tribute, thirty years later, to the great project launched by Enver 'Enjo' Hadžiomerspahić in the aftermath of the outbreak of the War (fig. 8). Thanks to the full collaboration of the Ars Aevi Museum, in the persons of its director Senka Ibrišimbegović and her staff, we were able to select the works to be digitally exhibited within the entire digitized collection. In this way, space was left for a real "exhibition within the exhibition", characterized by a specific digital curatorship, which guided the artworks choice. This section is immediately introduced by the *Ars Aevi*'s anagram and two short videos, in Italian subtitled in Bosnian language, in which Enjo recounts the birth and development of his creature, which has become a manifestation of the resilience of global culture against that war and every war. It was decided to highlight 4 or at most 5 works from the same nucleus, starting from the oldest (Milan 1994) and Michelangelo Pistoletto's artwork (fig. 9), ending with the Podgorica collections (2012). Each section is introduced by the name of the collection and an interactive image (accompanied by a short audio description in Italian, with the writer's voiceover, and in Bosnian language, with Senka Ibrišimbegović's voiceover) taken from the *Picture Book*, which briefly indicates the number and name of the artists who participated in that specific exhibition and the name of the curator who was responsible for its selection [starting with Enrico Comi (partner of the *Sarajevo Biennale* and the true driving force behind the project in Italy, who was the artistic director of the *Sarajevo 2000* project and the founder of the "Spazio Umano/Human Space" Contemporary Art Centre in Milan) and by the Centro Pecci in Prato (to whose curator Bruno Corà we owe the invention of the *Ars Aevi 2000*)]. Among the more than 160 digitized images, artworks were deliberately selected, as they would allow users to read linked-themes such as life and death, precariousness, passage, human connections, desires. The stuffed ducklings in the photo by Ingeborg Lüscher (1998) or the brave teddy bear by Dimitri Prigrov (1998) cannot help but recall the small "desiderata" of Bosnian children in their letters. The *Hanged Man* by Juan Muñoz (1988) simultaneously recalls Bill Viola's video installation, *The Passing* (1991), and Nan Golden's photograph, *Bruce in the Ruins, Pompei* (1995). Tony Cragg's installation *Quarry* (1990), in which a crane is surrounded by a series of cement bags, reminds ua a machine gun post, linking on the one hand to Jan Håfström's tragically ironic installation *Holiday Inn, Sarajevo* (1997), with its façade built from jute bags and wood; on the other to Marjetica Potrč's installation *A House With a Room for Possessions* (1999) or Nebojša Šerić's photograph of a soldier in a trench (1998), from the Viennese nucleus. The selection of the three works from the Vienna collection gives us an even more powerful meaning, with Andrés Compagnucci's *Gonzo* offering a bunch of coloured flowers, a sign of peace, the blood-red hammer and sickle by Sándor Pinczehelyi (1973) and, again, the soldier in the trench by Nebojša Šerić (fig. 10).

In the third room, *Sarajevo calls Puglia*, letters and press reviews tell users the great humanitarian event that involved children from both sides of the Adriatic sea, thanks to the initiative promoted by the *Gazzetta del Mezzogiorno*, through its reporter Franco Giuliano. He firstly collected letters from Bosnian childern to send to Italy, and collected reply letters from all Puglia region, involving children and their families. In those weeks, between December 1995 and January 1996, hundreds of letters travelled between the two opposite coasts of the sea. Then, Giuliano arranged the much-desired gifts delivery, thanks to a mission organized by the then Minister of Defense Andreatta. Bosnian and Italian letters have been selected to be exhibited in this virtual route, transcribed into the corresponding languages and translated. The letters' voiceover was made by children from the same schools involved at the time, the Catholic School in Sarajevo and a local school in Bari; the newspaper's voicever by students from the University of Bari.

In the end, the last section, *Testimonies between war and peace*, collects videointerviews of some of the protagonists of those events, in two languages and subtitled in Italian or Bosnian.



Figure 8: Sarajevo 1995-2025 VR exhibition on ArtSteps. The ARS AEVI Museum of Contemporary Art of Sarajevo section.

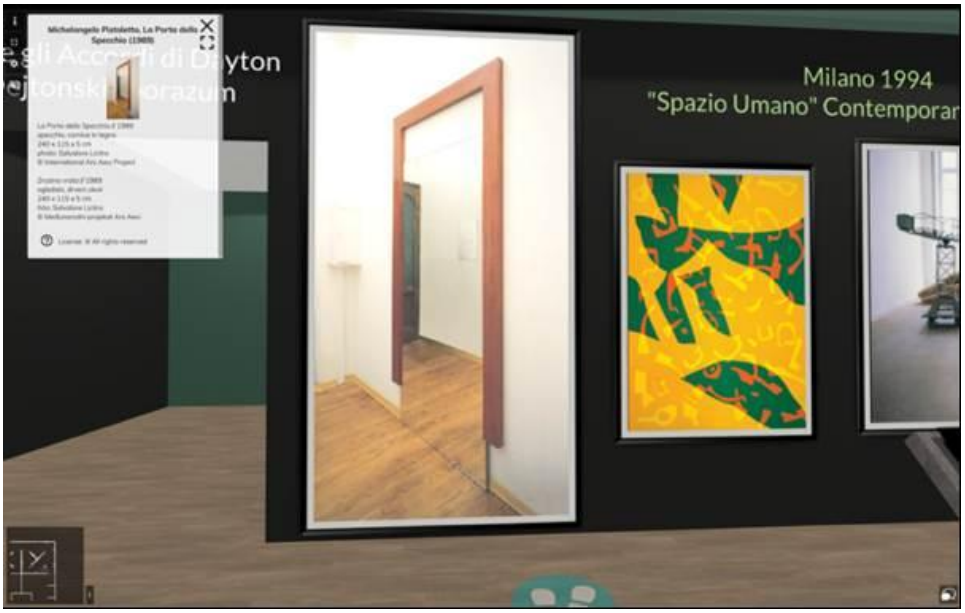


Figure 9: Sarajevo 1995-2025 VR exhibition on ArtSteps. Michelangelo Pistoletto's "Porta dello Specchio", Milan Collection.



Figure 10: Sarajevo 1995-2025 VR exhibition on ArtSteps. A panorama of the virtual tour with the Sarajevo, the Wien and the Bolognano collections.

4 Conclusions

The *Sarajevo 1995-2025 VR exhibition* is a demonstration of how these virtual spaces are open to creativity and design, a place where Digital art-historians and Digital curators could develop their new digital and virtual skills, by curating virtual exhibition and itineraries, as real curated pathways (De Vincentis 2023). This virtual project, created through the digitalization of analog contents and the use of AI tools, has its true core in the participation in telling stories, in reading newspaper articles and letters, trying to return, in a digital and virtual way, the same collaborative spirit that both the *Ars Aevi* initiative had, for the world of art, and the *Sarajevo calls Puglia* one, from an humanitarian point of view.

5 Acknowledgements

We would like to thank Franco and Enrica Giuliano for their collaboration in identifying the archive and photographic material that could be reused for the physical and virtual exhibition; Nicola Barbuti, Maurizio De Bari and the DABIMUS staff for the digitization of all the material provided, for the transcription and translation of the articles of the *Gazzetta del Mezzogiorno* and the letters of the Bosnian and Italian children; Senka Ibrišimbegović and her staff from the Ars Aevi project, for having accepted the proposal of a virtual collaboration at a distance to give visibility to the contemporary art collection of Sarajevo; PierLuigi Mirizzi and the Media Division Group to let us reuse archival content from Gazzetta del Mezzogiorno; Alessia Cioce for the graphic design of the exhibition; the group of the Department of Audiovisual, music and performance disciplines of the University of Bari (Federico Zecca, Angela Saponari, Francesco Dongiovanni) for their collaboration in editing the video interviews; the nuns and students of the Catholic School of Sarajevo for collaborating in the revision of the translations and the voice-over of the texts in Bosnian; the students of the Digital Valorization of Museum Collections course at the University of Bari.

6 Ethics declaration

The writer has been authorized by the Ars Aevi museum, partner of the project, for the publication of the images on ArtSteps.

7 AI declaration

No AI tool have been used in developing this paper.

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The Human in the Loop: Artificial Intelligence as a Co-Pilot in the Creative Process of the Artists. A Critical Analysis in Visual Arts

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Abstract

The rise of Artificial Intelligence (AI) in the visual arts represents a significant shift in contemporary creative practices, prompting urgent questions about the nature of art, the role of the artist, and the boundaries of human-machine collaboration (Cetinic & She, 2023; Rooij, 2024). This paper investigates how generative AI technologies are reshaping the visual arts, with a particular focus on their influence on the creative process (Miller 2019), the attribution of authorship, and audience perception.

Adopting a thematic literature review methodology within an interdisciplinary framework—spanning art theory, media studies, and cognitive science—the research synthesizes key developments from 1975 to 2024. The literature covers a temporal span from the earliest seminal explorations of computer-aided art (Molnar, 1975) to the most recent advances in generative AI technologies and critical discourse (Chiodo, 2024; Messer, 2024). This diachronic range enables a comprehensive understanding of both the historical evolution and the contemporary debates surrounding AI's role in the visual arts.

This research identifies and analyses three core conceptual themes emerging in the discourse. First, the ontology of AI-generated art interrogates the core concepts that address the definition of art, AI, and the links between them. Following a logical progression, the second theme that emerged presents the critical debates revolving around three central issues: authorship, originality, and intentionality (Floridi, 2021; Hertzmann, 2018; Chiodo, 2024). Finally, the review addresses the issue of audience perception, with particular attention to the cognitive bias that emerges when individuals evaluate artworks produced by AI (de Roji, 2024). This final theme is crucial for understanding not only how AI artworks are judged aesthetically but also how deep-rooted expectations about human creativity influence the reception of machine-generated art.

By drawing a historical parallel to the initial resistance faced by photography in the 19th century (Hertzmann, 2001), the paper contextualizes the current scepticism toward AI art as part of a broader cultural negotiation of new media. The findings suggest that AI is not displacing human creativity but rather expanding its modalities—offering novel pathways for artistic exploration and expression.

This study contributes to the academic debate by moving beyond polarized narratives of celebration or rejection, and instead, provides a nuanced, evidence-based reflection on the evolving dynamics between artists, machines, and audiences.

Keywords: Artificial Intelligence; Visual Arts; Creative Process; Human-Machine Collaboration; Audience Perception

Paper type: Academic Research Paper

1 Introduction

Nowadays, Artificial Intelligence (AI) is embedded in our lives, is set to profoundly influence sectors such as healthcare, education, commerce, finance, security and welfare (Ford, 2021; Lee and Qiufan, 2021). AI can be defined as intelligence performed by machines (McCarthy, 2007) and has received extensive academic attention. With the advent of AI, the field of arts and creativity faces new opportunities and challenges (Vinchon et al., 2023). Recent advancements in Generative AI (GenAI), such as ChatGPT, Midjourney, and DALL-E, have introduced unprecedented opportunities for producing content and ideas (Sestino and De Mauro, 2022).

AI is transforming how artists create, experiment, and interact with artworks. While AI's influence on music composition, design, digital media and creativity process has been widely studied (Carnovalini & Rodà, 2020; Anantrasirichai & Bull, 2022; Guo et al., 2023), scholars have only recently begun to critically examine the implications of AI-generated imagery and its role in visual arts (Cetinic & She, 2023; Rooij, 2024). AI is no longer merely a tool for automation; it is emerging as a co-pilot in the artistic process, engaging with human creators in complex, collaborative, and sometimes unpredictable ways. AI has become an integral part of many visual art practices (Rooij, 2024). AI, which mimics human thinking and behaviour, can give artists new tools and possibilities to create art in innovative ways.

The visual arts are important to society and culture. It spreads beauty and inspires new ideas. It also challenges what is normal. So, when we start using AI in art, we need to take a step back and think about what it means to create art. The research posits that the integration of generative AI in visual art is not merely a

technological advancement but a significant cultural shift, which necessitates a revaluation of our understanding of art and the artist (Garcia, 2024).

This study seeks to explore the intersection between AI and artistic creativity, addressing the following fundamental key research questions:

- How is AI influencing the creative process in visual arts?
- Can AI be considered a co-creator or merely an advanced tool for artists?

Through an interdisciplinary lens, this research aims to investigate how AI-assisted artistic creation challenges traditional notions of authorship, artistic agency (Zembylas & Niederauer, 2018), and creative decision-making (Sternberg, 2003).

This research contributes to the growing discourse on AI and creativity by systematically analysing the role of AI in visual art through an interdisciplinary lens. While literature has two points of analysis: either celebrate AI as a revolutionary creative force or dismiss it as mere automation, this study highlights the interactive and collaborative nature of AI-assisted art.

The paper is structured as follows. Section 2 traces AI's journey in visual arts, from early computational experiments to modern generative tools. It also draws a parallel to the introduction of photography, which initially disrupted traditional artistic methods but later expanded creative possibilities. Section 3 outlines the methodology, detailing the criteria and process for conducting a thematic literature review. Section 4 presents the findings, organised around three central themes: the ontology of AI-generated art, debates around authorship and intentionality, and audience perception of AI-created works. Section 5 discusses the implications of these findings for artistic practices and cultural theory. Finally, Section 6 offers concluding reflections on the future role of AI in the visual arts and its potential to reshape our understanding of creativity.

2 Background: AI's journey in visual arts

The background section unfolds around two main themes: (1) the evolution of AI in visual arts and (2) a historical parallel with the advent of photography. The selection of literature aimed to provide a critical and informed perspective on the impact of AI in contemporary artistic practice, while also situating it within a broader historical and cultural context. Overall, the reviewed literature provides an overview of the current state of AI in visual arts and help to draw connections with past experiences to enlighten the ongoing debate.

2.1 AI in Visual Arts: History and Evolution

The early experiments in AI and visual art are often linked to Harold Cohen, who began developing the drawing system AARON in the late 1960s. Initially, AARON was designed to generate basic abstract shapes, but over time it evolved to make independent artistic decisions (Miller, 2019; du Sautoy, 2019). Visual artists have been integrating digital technology into their creative processes for decades. For example, Vera Molnár (Molnàr, 1975) used geometric plotter drawings, while Sim explored AI-generated animations (Sims, 1991). More recently, the development of advanced AI image generation tools such as Midjourney (2022) and DALL-E 2 (2022) has significantly expanded the role of digital technology in image creation. These advancements have raised important questions and concerns about the role and relevance of visual artists in a rapidly changing technological landscape. This early exploration laid the groundwork for further developments in machine-generated creativity. Decades later, the emergence of Generative Adversarial Networks (GANs) marked a significant turning point (Mazzone & Elgammal, 2019) in the process of creating visual art (Goodfellow et al., 2014). GANs entered the AI conversation in 2014 when researcher Ian Goodfellow published an article theorizing that GANs represented a significant step forward in the capabilities of neural networks. In fact, Goodfellow theorized that unlike earlier AI art tools such as Google DeepDream, which modified pre-existing images in often predictable ways, GANs had the potential to generate original, high-quality images from scratch (Schneider & Rea, 2018). So, basically GANs is divided into two neural networks: one acts like an "artist" and the other like a "critic." The artist network tries to create new images based on patterns that finds in the data, while the critic network evaluates these images by comparing them to real ones (Still & d'Inverno, 2019).

GANs came to the attention of the public in October 2018 when, despite an estimated sale price of between $7,000 to $10,000, a portrait entitled Edmund de Belamy, from La Famille de Belamy, was sold at Christie's in New York for $432.500 (Christie, 2018; Notaro, 2020). The name "Belamy" was a reference to the creator's name of GANs, Ian Goodfellow, that roughly translate to "Bel ami" in French. The authors of the portrait were Obvious, *"a Paris based collective of artists, machine learning researchers and friends interested in AI for Art"* (Obvious 2018). The sale raised criticism from both art critics and AI artists due to several factors: the image's low resolution, the use of a pre-existing GAN model developed by Robbie Barrat in 2014 (with no proper attribution to him). Additionally, the work was presented and signed with a line of algorithmic code, reinforcing a machine-

centred narrative (Notaro, 2020). Adding to the controversy, the promotional material for the sale featured the group's slogan, "creativity isn't just for humans". As Vincent (2018) notes, this motto reflected Obvious deliberate embrace of a narrative that attributed creative agency to the algorithm itself, thereby intensifying debates around authorship and authenticity in AI-generated art.

However, since the boost of AI Art popularity triggered by Christie's auction, the number of artists involved in making AI Art is rising worldwide. The fact that AI Art gained momentum in the last years is reflected in the growing number of online platforms featuring AI Art such as AIArtists.org, as well as exhibitions, conferences, competitions and discussion panels dedicated to AI Art.

Figure 1 shows several examples of contemporary AI artworks.



Figure 1: Examples of AI art. 1) Obvious, Portrait of Belamy; 2) Mario Klingemann, Memories of Passersby; 3) Sofia Crespo, Neural Zoo

In recent years GenAI has become increasingly influential in the field of visual arts. In fact, diverse categories of AI tools are available to artists for producing their works (Braguez, 2023) through text-to-image platforms such as DALL·E, MidJourney, and Runway ML.

The fist, developed by Open AI in 2021 (Kang & Yi, 2023; Leivada et al, 2023), uses text prompts to generate imaginative images, allowing artist to visualize abstract concepts and incorporate AI-generated designs into their work (Jain et al., 2022). On the other hand, MidJourney (Borji, 2022; Hanna, 2023; Huang et al., 2023) released in 2022, enables artists to explore different styles and techniques, offering a dynamic way to apply stylistic transformations to existing or AI-generated images (Johnson et al., 2008). The capabilities of Midjourney have been investigated by other researchers in areas such as graphic design (Mansour, 2023), architecture (Jaruga-Rozdolska, 2022), industrial design (Yin et al., 2023).

The latter, Runway ML (Othman, 2023) was launched in 2018 by Runway AI Inc; this platform forms a variety of applications, but the one that interest us is exploring its capabilities in text-to-image.

These tools use sophisticated machine learning models, often trained on datasets of text-image pairs, to produce original visual content from simple textual prompts (Jain et al., 2022). Their emergence is transforming the role of the artist, the creative process, and the broader cultural understanding of image-making.

Table 1 show some of the different tools available in this moment for visual arts, following the work of Braguez (2023); while figure 2 show a timeline view of the most important technological milestones that led to the current AI Art production based on the research of Cetinic & She (2021).

Table 1: AI tools to create images (Braguez, 2023)

AI Tools	**Source**	**Input**
Dall-E	https://labs.openai.com	Text-to-image
Deep Dream Generator	https://deepdreamgenerator.com	Text-to-image, image-to-image, choose style
Deep AI	https://deepai.org	Text-to-image, choose style
Fotor	https://www.fotor.com/features/ ai-art-generator	Text-to-image, image-to-image, choose style
Hotpot	https://hotpot.ai	Text-to-image, other tools as restoring damaged photos and colorizing old photos
MidJourney	https://www.midjourney.com	Text-to-image, choose style, add edits
NightCafe	https://nightcafe.studio	Text-to-image, choose style and algorithm
RunwayML	https://runwayml.com	Text-to-image, image-to-image, video, 3d and more



Figure 2: Illustration of the current of technological AI Art production (Cetinic & She, 2021)

2.2 The Historical Parallel: The Advent of Photography

When looking to the past for insights into the relationship between AI and art, few inventions offer a more significant parallel than the emergence of photography in the 19th century (Hertzmann, 2001). This parallel has been widely explored in existing literature by Hertzmann (2018) and Aguera y Arcas (2017), so it will be shortly addressed here. The photography initially faced resistance from traditional painters who perceived it as a threat to established artistic practices. However, rather than rendering painting obsolete, photography catalysed new artistic movements, such as Impressionism, which shifted focus from representational accuracy to explorations of light and perception. A promising precedent for AI-generated art lies in the eventual acceptance of photography as a legitimate art form. This acceptance emerged through a dynamic exchange between photography and painting: photographers began adopting the formal and aesthetic sensibilities of painting, such as refined approaches to lighting and composition, while painters responded to photography's unique qualities, including its compositional flatness and the ability to capture movement. This mutual influence created a positive feedback loop, where each medium evolved by engaging with the other. Yet, as Hertzmann (2018) argues that it will be possible that a similar dialogue could develop between AI and traditional forms like painting, prompting artists across both domains to rethink and expand their creative perspectives.

3 Methodology: A thematic Literature review

Several fields of research have explored the ontological value of the artwork as both output and artifact, as discussed by Floridi (2021), while others have examined the artistic process and its moral dimensions (Fioravante & Vaccaro, 2024; Chiodo, 2024) Additional scholars have focused on the innovative processes related to decision-making, often referred to as "design". Traditionally, decisions within innovation processes have been made by humans; however, what happens when machines begin to assume that role? This question lies at the core of recent reflections, such as those by Verganti (2020).

The selection of authors in this literature review is driven by the inherently interdisciplinary nature of the topic. Given that the intersection of AI and art spans multiple research domains, the analysis draws upon scholars from both the humanities and socio-economic fields. Although the debate itself remains relatively niche, it is fundamentally interdisciplinary, involving contributions from diverse array of research backgrounds.

This study seeks to explore the intersection between AI and artistic creativity by addressing the following key research questions:

- How is AI influencing the creative process in visual arts?
- Can AI be considered a co-creator or merely an advanced tool for artists?

3.1 The protocol of the thematic literature review

This research employs a thematic literature review methodology to explore the field of visual arts in relation to AI. Relevant literature was identified using keywords across academic database such as Google Scholar. In fact, Google Scholar was selected for its comprehensive coverage of scholarly publications. This database was also implemented with a search on ResearchGate to discover recent research not yet published.

Selection criteria included highly cited publications in English between 1975 to 2024 that explicitly examine the intersection between visual art and artificial intelligence. The literature covers a temporal span from the earliest seminal explorations of computer-aided art (Molnar, 1975) to the most recent advances in generative

AI technologies and critical discourse (Chiodo, 2024; Messer, 2024). This diachronic range enables a comprehensive understanding of both the historical evolution and the contemporary debates surrounding AI's role in the visual arts. Keywords employed in the literature search are coherent with the paper's RQ such as "AI and visual art", or "AI and creative process of artists".

Sources were selected according to specific inclusion criteria: publications needed to engage directly with the application of AI in visual artistic practices. Works primarily focused on AI applications in unrelated fields- such as education, healthcare or philosophical reasoning- were systematically excluded. This rigorous screening process resulted in a final selection of 32 references directly pertinent to the intersection of AI and visual art.

To this end, a thematic literature analysis was conducted to examine practices combining art and artificial intelligence. This step provides an in-depth understanding of the field and identifies critical aspects requiring further research.

Based on the above-mentioned logic, we identified the principal papers on which our thematic literature review is grounded. Table 2 provides examples of some of these key sources that form the foundation of this review, organized according to four criteria: citation reference, main thematic focus, publication outlet and the academic field to which each work contributes. This organization highlights the multidisciplinary nature of the research landscape, spanning art theory, media studies, machine learning and digital humanities.

In the following sections, based on our protocol of exclusion and inclusion, the review will examine key concepts and current debates, focusing on:

- The ontology of AI Art
- Current Debate on AI-generated art
- The Cognitive Bias Toward AI Art (i.e., audience perception)

The first theme is fundamental for defining the core concepts that address the definition of art, AI, and the links between them. Following a logical progression, the second theme that emerged presents the critical debates revolving around three central issues: authorship, originality, and intentionality. Finally, the review addresses the issue of audience perception, with particular attention to the cognitive bias that emerges when individuals evaluate artworks produced by AI. This final theme is crucial for understanding not only how AI artworks are judged aesthetically but also how deep-rooted expectations about human creativity influence the reception of machine-generated art.

Table 2: Example of Papers Included in Our Thematic Literature Review

Paper References listed on the base of quotations	**Main Themes of the paper**	**Journal name**	**Journal's academic field**
Elgammal et al. (2017) (859 citations)	Creative Adversarial Networks (CAN) and AI art generation	Conference paper published on the eighth International Conference on Computational Creativity (ICCC)	Computational Creativity, Machine Learning
Hertzmann (2018) (291 citations)	Philosophical question: can computers create art?	Arts (MDPI)	Computational Aesthetics
Miller (2019) (363 citations)	Exploration of AI-powered creativity	The MIT Press	Cognitive Science, Creativity Studies
Daniele & Song (2019) (76 citations)	Human-AI collaboration in art creation	*Proceedings of the 2019 AAAI/ACM Conference on AI, Ethics, and Society*	AI Ethics and Creativity
Verganti, R., Vendraminelli, L., and Iansiti, M. (2020) (808 citations)	Innovation and AI-driven design processes	Journal of Product Innovation Management	Innovation Management, Design Studies, AI Integration
Goenaga (2020) (50 citations)	Critique of Edmond de Belamy and AI authorship	*AusArt*	Art Criticism
Floridi, 2021 (216 citations)	Ethics of AI-generated synthetic images (deepfakes, ectypes)	Ethics, Governance, and Policies in AI	Ethics, AI Policy, Philosophy
Cetinic & She (2022) (577 citations)	Review and future of AI art	*Transactions on Multimedia Computing, Communications, and Applications (TOMM)*	Multimedia Systems, AI Art
Sartori, L., and Bocca, G. (2023) (139 citations)	Public perceptions and socio-technical imaginaries of AI	AI & Society	AI Ethics, Sociology of Technology

4 Findings

The thematic literature review conducted in this study revealed three major conceptual areas that critically shape the current discourse on AI and visual arts: the ontology of AI-generated art; issues of authorship, originality, and artistic agency, and audience perception and cognitive biases toward AI-generated artworks.

Each theme is outlined below in detail.

4.1 The Ontology of AI Art: Defining Art, AI and the links between them

A significant body of literature interrogates the fundamental question: *Can AI-generated outputs be considered true art?*

Traditional theories of art, such as those of Plato (1955), Tolstoy (1995), and Croce (1920), emphasize human emotional experience, intentional expression, and cultural transmission as essential to artistic creation.

What is particularly interesting is the definition of Croce (1904), he stated that art is a "is a higher form of intuition, therefore a higher type of knowledge reached through expression"; also, interesting is that of Altieri (1987) which described artistic expressivity as a creative and profound manifestation of human agency. Furthermore, a more pragmatic approach is proposed by Dickie (1969) who poses two conditions for art to exist: 1) to be an artifact; 2) some society or sub-group needs to confer the status of "candidate for appreciation".

Equally important for human evolution is technology. As proposed by Leroi-Gourhan (2012), technical tools are a manifestation of the "milieu interieur", the ensemble of cultural and mental traditions of a group, including art. In this research, we adopt one of the most widely accepted definitions of AI, commonly attributed to Marvin Minsky (Wiggins, 2006): *"The performance of tasks, which, if performed by a human, would be deemed to require intelligence"*. Based on this definition, AI can take many forms, from simple rule-based systems to more advanced models. According to Song and Daniele (2019), there are generally two types of AI:

- AI that tries to replicate human cognition (thinking, learning, decision-making),
- AI that doesn't try to mimic humans but still performs intelligent tasks in other ways.

If an AI system can create art or showing signs of creativity, it belongs to the first group, under the field of Computational Creativity, which studies how machines can simulate or support creative processes like those of humans.

4.2 Authorship, originality, and intentionality of AI-generated art

The current debate on AI-generated art evolves around three key aspects: authorship, originality, and intentionality. Different scholars offer different perspectives on whether AI can create true art or if it is merely a tool that assists artists: Floridi (2021) argues that digital artwork is an *ectype*, a copy based on data models, raising questions about AI art originality; Verganti (2020) argues about innovative processes related to decision-making, which many researchers and professionals refer to as "design". Hertzmann (2018) states that art is a social process, and that AI lacks artistic intentionality. Instead, AI-generated artworks result from mathematical optimizations rather than personal expression (Hertzmann, 2018, p. 3). Chiodo (2024) explores AI art as a cultural phenomenon that challenges traditional definitions of authorship and creativity. By blurring the boundaries between artist, tool, and audience, AI forces a rethinking of what constitutes artistic agency (Chiodo, 2024, p. 6). Rather than focusing on AI's limitations, Chiodo explores how AI expands artistic possibilities, raising questions about whether AI should be seen as a co-creator rather than just a tool.

The perspectives of Floridi, Hertzmann, and Chiodo illustrate the complex and evolving nature of AI in art. Floridi and Hertzmann emphasize AI's dependence on human input and its lack of true creativity, while Chiodo highlights its potential to redefine artistic authorship. This raises fundamental questions:

- Is AI-generated art a new artistic medium or simply a computational tool?
- Does artistic intentionality define art, or is aesthetic value alone sufficient?

These discussions remain central to understanding the future role of AI in the creative process.

4.3 The Cognitive Bias Toward AI Art

How people react and deal with AI outcomes has become an interesting issue in recent years (Peeters et al., 2021; Pelau et al., 2021). A crucial aspect in analysing the impact of AI on visual arts concerns the public's perception and biases toward works generated using this technology. The recent literature suggest that people show both positive and negative bias towards AI (Fietta et al., 2021; Sartori & Bocca, 2022). Experimental studies such as Di Dio et al. (2023) state that when audiences are informed that a visual artwork was creating using AI, this diminishes emotion, appreciation and valuation of the work. This highlight the fact that audience might have

a bias against AI in visual art; in fact, informing audiences that AI was used in art creation can influence their aesthetic experience, independently if the objective qualities of an artwork (de Rooij, 2024).

A recent meta-analysis conducted by de Rooij (2024) highlights a significant trend: audiences tend to perceive AI-generated art as "less authentic" compared to art created by human hands. This finding fits into a broader context that could be described as the "AI Creativity Paradox" (de Rooij, 2024). This paradox is evident in the fact that, although the public may express admiration or interest in artworks produced by AI, they often reject the idea that a machine can be truly creative.

Up until now, artistic creativity has been intended exclusively as a human product and typically assumed to belong of human beings (Sawyer, 2011). However, we are nowadays facing a new era in which AI shows creative abilities (Miller, 2019) in painting visual artworks (Elgammal et al., 2017) sold by international auction houses and exhibited in important museums (Goenaga, 2020). This dichotomy suggests an important distinction in the minds of observers: while AI-generated art can be appreciated for its aesthetic or conceptual qualities, the lack of genuine human "intent" and a creative process like that of humans seems to undermine the perception of its inherent authenticity.

5 Discussions

The thematic analysis reveals that the incorporation of AI into visual arts represents a profound and multifaceted transformation, rather than a mere technological enhancement.

The findings illustrate that the integration of AI into visual arts constitutes a disruptive yet generative force in the evolution of creative practices. The discussion around the ontology of AI-generated art (Floridi, 2021) proves particularly relevant. While works created with AI may possess aesthetic and conceptual value, the question of their originality and their status as ectypes (copies based on data models) remains open.

The issue of cognitive bias towards AI-generated art (de Rooij, 2024; Di Dio et al., 2023) is another crucial aspect. In fact, persistent audience biases suggest that the full cultural acceptance of AI art remains contingent upon broader societal shifts in how creativity itself is conceptualized.

Drawing a historical comparison, the early rejection of photography in the 19th century provides an important precedent for understanding the current debates around AI in art (Hertzmann, 2018). Initially, photography was criticized as a purely mechanical process that lacked artistic value. However, rather than replacing traditional art forms, photography eventually inspired new movements such as Impressionism. In the same way, although AI-generated art is currently viewed with scepticism, it may, over time, gain broader acceptance. However, this shift will require a redefinition of artistic standards and cultural values.

The growing presence of AI-generated artworks in prominent artistic contexts (Elgammal et al., 2017; Goenaga, 2020) suggests an evolution in public perception and a potential overcoming of these initial prejudices.

Rather than replacing human creativity, AI acts as an *amplifier*, offering new aesthetic possibilities while exposing fundamental tensions about intentionality and authenticity. Artists engaging with AI in their creative process could suggest us that AI is not merely a tool, but rather an evolving partner or a co-pilot. Its role varies depending on the artist's approach, artistic goals, and the specific AI technology employed. While in some contexts AI primarily acts as an enhancer of human capabilities, in others it emerges as a form of co-creation, where AI actively contributes to the generation of ideas and the realization of the artwork. This dynamic prompt a reconsideration of our understanding of art, the artist, and the creative process in the age of AI

6 Conclusion

This study critically explored the intersection between AI and the visual arts, emphasizing how AI is reshaping the creative process and challenging established concepts of authorship, originality, and artistic agency. Through a thematic literature review, the paper identified and analysed three key areas of debate: the ontology of AI-generated art, the attribution of authorship and intentionality in AI-assisted creation, and the audience's cognitive responses to AI-produced artworks.

The findings indicate that the integration of AI into artistic practice represents more than a technical innovation—it reflects a broader cultural transformation. While generative AI tools expand the possibilities for artistic production, they also raise fundamental questions about what constitutes art and who—or what—can be considered an artist. AI does not replace human creativity but enhances it, offering artists new tools and opportunities for expression. However, public scepticism remains, largely due to the perception that AI lacks human intention or emotional depth.

This mirrors the initial resistance to photography in the 19th century, highlighting how new technologies, initially perceived as threats to artistic authenticity, can eventually lead to new forms of creative expression and legitimacy within the art world. Similarly, AI-generated art may follow this trajectory as cultural attitudes evolve

and definitions of creativity expand. In response to the research questions, it can be concluded that AI is profoundly influencing the creative process in the visual arts, offering artists new possibilities for experimentation, conceptualization, and production.

In conclusion, AI should not be viewed as a replacement for human creativity but as an evolving partner in the creative process. Its role varies depending on the artist's intentions, the context of use, and the interpretive frameworks of the audience. As generative AI will continue to develop, it becomes increasingly important to examine its implications for artistic practices, cultural institutions, and our broader understanding of creativity in the digital age.

7 Ethics declaration

Ethical clearance was not required for the research

8 AI Declaration

Use of DeepL Translate contributed to the refinement of the English language in the preparation of this manuscript. The tool was utilized exclusively for language enhancement. The authors remain fully responsible for the originality and accuracy of the research content.

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AI for Start-up Decision-Making and Knowledge Management: Evidence from an Innovation Ecosystem

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Abstract

The increasing integration of artificial intelligence (AI) into decision-making processes represents a fundamental lever for competitive positioning, especially for start-ups operating in innovative ecosystems such as Rome Technopole (RT). This paper analyzes whether and how RT startups adopt AI to support decision-making and knowledge management processes, basing these processes on ethical and human-centric principles.

After the preliminary reconstruction of the conceptual framework, using a qualitative-quantitative approach based on semi-structured interviews and questionnaires aimed at innovative startups and SMEs, the study shows that AI solutions are used for big data analysis, simulation of future scenarios and optimization of business strategies. Technologies, in fact, enhance the effectiveness of decisions through predictive analysis and automation, without ever replacing the critical contribution of the human element, which remains guaranteed through feedback, periodic meetings and mentorship sessions. At the same time, transparent and secure data management is essential to establish a climate of trust with stakeholders.

In addition, the adoption of AI is integrated with economic, social, and environmental sustainability criteria, directing innovation towards ethical and responsible business models, in line with the 17 Sustainable Development Goals and Environmental, Social, and Governance (ESG) standards.

The results indicate that, while still in its infancy, the use of AI in RT startups offers significant opportunities for growth and competitiveness, if the integration between advanced technology and human resources is strengthened.

Keywords: Artificial Intelligence, Knowledge Management, Decision-making process, Innovation Ecosystem, Start-up

Paper type: Academic Research Paper

1 Introduction

The integration of AI into business decision-making has become a critical element for business success, especially in innovative ecosystems (Adner, 2017; Granstrand and Holgersson, 2020) in the era of Industry 5.0 (Carayannis et al., 2024), as well as in the emerging innovative ecosystem (Dedayir et al. 2018) Rome Technopole (RT), the subject of this paper.

Start-ups active in innovation ecosystems can leverage AI to: i) analyze data sets and information, ii) identify market trends and iii) define competitive business strategies (Burström et al. 2021). Given that the early years of startups are often marked by uncertainty, resource constraints and high bankruptcy rates (Cantamessa et al., 2018), AI support is strategic. At the same time failures and constraints provide valuable learning experiences to access and/or develop new skills, abilities and outline innovative strategic orientations (Corvello et al., 2024). However, the integration of AI into decision-making and strategic processes raises concerns about ethical compliance and the need to preserve the central role of human judgment in decision-making processes (Eapen et al., 2023).

This paper aims to analyze whether and how start-ups operating within the RT innovation ecosystem use AI to support decision-making and strategic processes and how these can be grounded in humanistic and ethical principles. In this regard, the Knowledge Management (KM) framework (Edwards et al., 2003; Venkitachalam and Willmott, 2015) plays a fundamental role in ensuring that AI is used not only to improve the efficiency and effectiveness of business processes, but also to support decisions that respect ethical values (Vaccaro, 2022).

The start-ups of the RT innovative ecosystem serve as a paradigmatic example of how the collaboration between AI and human decision-making capabilities can positively influence their strategies and evolutionary paths. It is therefore considered necessary to explore how the KM framework can effectively integrate AI in an ethical way, while ensuring the autonomy of decision-makers.

At this aim, the paper is structured as follows: i) definition of the conceptual framework deriving from the analysis of the main theoretical contributions about Knowledge Management, AI and ethical implications; ii) quali-quantitative analysis of the strategic behavior of RT start-ups through the administration of semi-structured interviews and questionnaire; and finally, iii) comparison of the approaches adopted.

2 Conceptual framework

The integration of AI is a key factor in creating competitive advantages (Krakowski et al. 2023) and supporting the digital transformation of enterprises. In fact, AI supports companies in value creation processes (Porter and Kramer, 2018) especially in B2B markets by promoting virtuous iterative cycles that significantly enhance the ability to co-generate value (Leone et al. 2021). The ways in which AI can create value can be divided into four dimensions (Borges et al. 2021): i) decision support - AI as a tool to support and improve decision-making processes; ii) customer and employee engagement -AI to improve the interaction and experience of both customers and employees; iii) automation -AI to automate processes and increase operational efficiency; and finally, iv) new products and services – AI to enable new product and service offerings.

Figure 1 offers a conceptual representation that highlights how business strategy intersects in a dynamic and integrated way with information technologies, highlighting some key aspects. Business strategy and information technology (IT) no longer operate in isolation (Chari et al. 2025; Gamboa, 2024); on the contrary, they develop in a process of continuous alignment, in which IT strategy is integrated into the planning and pursuit of business strategies (decision making) (De Bem Machado et al. 2022). At the heart of the diagram is the interconnection between IT infrastructures, organizational processes, and human resources. It is highlighted how these elements must work together in a synergistic way to create an effective digital strategy, which is not limited to the implementation of technologies alone but also promotes cultural change and the transformation of business processes. Technological resources, in this perspective, become fundamental levers for innovating the business model and creating new market opportunities. Finally, the dynamic nature of the relationship between IT and strategy emerges, highlighting that alignment requires constant adaptability to market developments and technological innovations.

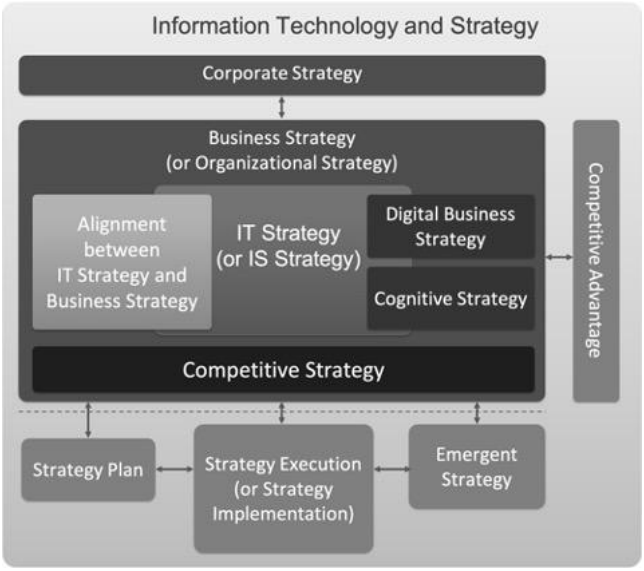


Figure 1. Integration between IT and strategy
Source: Borges et al. 2022

The study conducted by Leoni et al. (2024) highlights how the integration of AI into Knowledge Management (KM) processes improves the quality, timeliness and accuracy of decisions within the organization. The role of AI in KM processes is appreciated in terms of automation and data management, operational functions and generative AI. The latter aspect is particularly important because generative AI tools are revolutionizing KM as they can generate content that facilitates the creation and dissemination of knowledge (Oppioli et al., 2023). The adoption of AI tools within KM processes leads to a significant improvement in decision-making, thanks to more efficient data management and a greater ability to generate insights useful for strategic decisions (Nazeer et al., 2023).

The relationship between AI, KM, and decision-making emphasizes the importance of successful AI integration into KM processes, as it directly influences decision outcomes, and the need to evaluate AI's effectiveness in achieving desired outcomes, as perceptions of its benefits or disadvantages can influence future adoption decisions (figure 2).

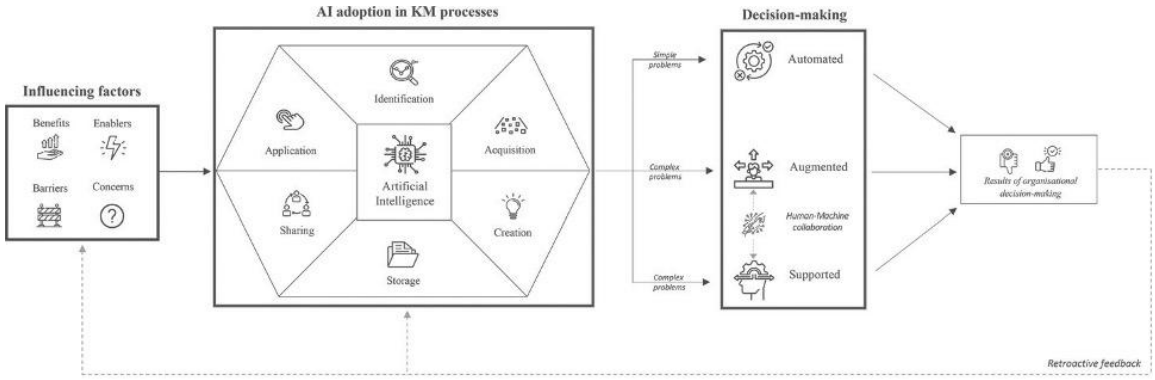


Figure 2. AI, Knowledge Management and decision making
Source: Leoni et al. 2024

Figure 2 shows that KM and decision-making are interconnected and mutually influence, in line with previous contributions that consider firms as complex systems, in which decisions are formed based on the interactions between multiple factors and actors (Parasuraman et al., 2000). In this perspective, interactions are made even more complex by human-AI interaction (Di Vaio et al., 2022). In this perspective, the framework suggests that AI mainly plays a complementary rather than competitive role with humans (Budhwar et al., 2022), identifying three specific types of decision-making (i.e., automated, augmented, and supported) based on the problem that needs to be solved and its complexity.

Adopting AI within KM processes enhances an organization's decision-making capabilities by rendering them more effective, accurate, and flexible (Agrawal et al., 2017a; Duan et al., 2019; Metcalf et al., 2019). It should be emphasized that the implementation of AI technologies alone does not guarantee a positive impact on performance; only the combination with systems that promote knowledge sharing creates an environment in which existing and new information can be adequately valorized, contributing to a sustainable improvement in business performance (Olan et al. 2022).

An interesting evolution is represented by the introduction of the concept of knowledge warehouse which refers to an integrated architecture that is not limited to collecting and processing data, but also aims to capture, codify, organize and share the knowledge (explicit and tacit) present within the company. This approach expands the role of decision support systems (DSS), directing them towards improving the knowledge and mental model of decision-makers, to make decisions more informed and effective (Nemati et al. 2002).

Figure 2 helps to identify factors that influence the adoption of AI in KM processes that can be categorized into: benefits, enablers, and barriers. Adopting AI in KM processes significantly reduces operational time and costs by enhancing real-time data collection and analysis, and spurring creativity and innovation for more informed decisions. Enabling factors include commitment from managers, an agile organization, and a strong customer base. However, cultural resistance to change, fear of replacing humans, shortage of skilled personnel, and high upfront costs are major barriers that can limit the effectiveness and integration of AI tools into KM processes. Added to these are also the lack of trust in automated decision-making processes and an inadequate level of commitment on the part of those in leadership positions in the company (Kar et al. 2021).

The topic of human-AI interaction has drawn the attention of academia to the idea that careful design of decision-making structures that integrate AI and human decisions can improve the quality, efficiency, and fairness of organizational choices. Human-AI interaction, if well designed, makes it possible to exploit the speed and accuracy of AI together with human interpretative capacity and flexibility, ensuring a balance between technological innovation and managerial responsibility (Shrestha et al. 2019). The contribution of Jarrahi et al. (2023) highlights how the partnership between humans and AI represents a turning point in the way companies create, store, share, and apply knowledge. Building on earlier reflections on organizational knowledge dynamics, the integration of AI into decision-making and KM processes recalls the foundational work of Ciborra (2002), who emphasized the importance of situated practice and mindfulness in technology adoption. Rather than viewing AI purely as a rational optimizer, it is essential to consider how human improvisation and organizational culture shape the actual use of digital tools. This perspective aligns with recent developments on human-AI symbiosis and dynamic capability.

The symbiotic approach (humane-AI symbiosis) makes it possible to exploit the speed and efficiency of AI, without losing the critical and contextual element that only humans can provide. In addition, the strategic interaction between humans and AI fosters positive impacts that can be seen in terms of business performance. Effective collaboration between AI and Human Intelligence (HI) contributes to the development of the

company's dynamic capability, i.e. the ability to adapt, be agile and respond effectively to a volatile and ever-changing competitive environment (Chowdhury et al. 2022). If employees trust technology and know exactly how their role integrates with it, the company tends to gain competitive advantages. In turn, skills in using AI positively influence business performance, with effects mediated by dynamic capability: an environment in which companies can quickly reconfigure processes and optimize resources leads to greater efficiency and a faster response to the challenges of the competitive environment.

The integration of AI, while offering significant advantages, raises complex issues, so it should be accompanied, at the same time, by a profound ethical reflection, which considers not only economic efficiency, but above all the protection of the rights and dignity of employees (Rodgers et al. 2023) and which considers the plurality of values and democratic participation. The real challenge for companies lies in balancing the benefits of automation with ethically responsible management, which places the human being at the centre (Varma et al. 2023) by promoting participatory and transparent processes in contemporary society.

The construction of the conceptual framework, albeit synthetic, underlines how adopting an integrated strategy in which AI and human intelligence collaborate synergistically not only facilitates innovation and digital transformation, but also produces concrete benefits in terms of competitiveness, effectiveness, efficiency and value creation.

3 Methodology

The paper adopts an empirical qualitative-quantitative approach based on the collection and analysis of data and information through the administration of a semi-structured interview with the founders and decision-makers of a sample of start-ups selected within the emerging innovation ecosystem RT (table 1). The start-ups were selected among those that participated in the Technè acceleration project of Spoke 2 of the Tecnopolo of Rome (see section 3.1) dedicated to digital startups and spin-offs of the Lazio Region and the Regions of Southern Italy.

Table 1. Sample of interviewed start-ups

Start-up	Sector	Core product or service
1	Health & Bio-pharma	Service for assessing the degree of reliability of research articles.
2	Digital transition	Digital platform for optimizing economic-financial reporting systems.
3	Energetic transition	Service for assessing the degree of sustainability (algorithm), including social and environmental, of tourism companies.
4	Digital transition	Management of coaching services, events, tournaments and E-sports team management.
5	Digital transition	Automation of collaborative projects.
6	Digital transition	Virtual assistance for tourism services.
7	Health & Bio-pharma	Research, development, marketing of phytoderivative products.

Source: own elaboration

Among the start-ups mentioned (table 1), 4 accepted the invitation to participate in the interviews and belong to the digital transition (3) and energy transition (1) sectors.

The semi-structured interview explored in depth the following thematic areas: human-centric and sustainable business models; support and collaboration within the RT; AI-Based platform for the simulation of business models and possible future scenarios.

Before proceeding with the analysis of the results (section 4), it is considered appropriate to illustrate the articulation in terms of actors, relationships and objectives of the emerging innovation ecosystem RT (section 3.1), since it represents the most appropriate strategic and organizational context for the development of the qualitative study.

3.1 Rome Technopole (RT) emergent Innovation Ecosystem

RT is an ambitious strategic project to create an innovation ecosystem (Adner, 2017) in Italy's Lazio region, integrating research, technology transfer, and education to drive regional and national economic transformation. Funded by the National Recovery and Resilience Plan (PNRR) 2021–2027, RT is designed as a strategic system (Oh et al., 2016) where each actor plays a specific role in generating sustainable value (Chandler, 2022). RT generates shared value (Porter & Kramer, 2018) by: i) strengthening Lazio's technological and economic fabric through collaboration among universities, businesses, and local governance; ii) establishing a

hub for cutting-edge research in energy and digital transition and in health and biopharmaceuticals; iii) enhancing STEM education and research capacities in Central and Southern Italy toward international excellence. These dynamic, multi-actor ecosystems are characterized by interdependence, and co-specialization and include actors, activities, and artifacts that shape innovation performance (Granstrand & Holgersson, 2020).

RT currently displays characteristics of an emerging innovative ecosystem (Dedehayir et al., 2018) in a hub-and-spoke configuration. Mapping identified five stakeholder categories (Freeman, 2023): seven public and private universities, four research centers, fourteen private companies, six institutions, and eight associations and start-ups. RT manages relationships, resources, and skills across the system (Valkokari et al., 2016). This arrangement promotes agility and resilience in adapting to emerging technologies and market shifts.

Actors collaborate and compete (Bacon, Williams & Davies, 2020) vertically, horizontally, and cross sectorally, adopting integrated innovation strategies and multiple roles. RT's six strategic spokes are: (1) applied research, (2) technology transfer, (3) advanced education, (4) vocational training, (5) industrial partnerships, and (6) shared research infrastructure and joint laboratories (RIPI). RT leads eight flagship projects addressing green energy, digital transition, AI in aerospace, health technologies, and human-centered AI. These projects aim to drive sectoral innovation and translate research into marketable solutions.

Participants drive four macro strategic activities—research, education, technology transfer, and community involvement—through specific projects. RT's competitive advantage stems from fostering collaboration, innovation, and new market opportunities, manifested through: i) differentiation and resource diversification; ii) facilitated access to innovations; iii) economies of scale and scope; iv) risk reduction; v) continuous innovation and organizational learning; vi) speed to market; and vii) sustainable development. By managing strategic interdependencies among stakeholders, RT fosters continuous co-evolution in response to technology shifts, market demand, and participants' actions aligned with future growth objectives. This continuous co-evolution aligns development with stakeholder's initiatives and strategic growth targets. RT aspires to be a regional, national, and European reference point, supporting long-term economic and social progress.

4 Results

The analysis of the semi-structured interviews highlights a path of integration of AI in the early stages, characterized by a certain heterogeneity in terms of infrastructure and organizational maturity.

The startups analyzed integrate digital tools as strategic levers and not just isolated technologies. First, AI and Machine Learning (ML) act as a decision support engine: a start-up uses predictive and deductive algorithms to guide the entrepreneur in governance choices, preventing e.g. crisis situations, while another start-up implemented AI digital assistants to automate customer relations processes (e.g. acceptance), freeing up Human Resources time for higher value-added activities. Another start-up addresses the issue of sustainability through a scoring algorithm, developed which assigns a score of 0–100 to accommodation facilities. This real-time reporting system supports operational decisions to reduce carbon footprint and improve ESG performance.

The blockchain, used by one of the start-ups interviewed, guarantees immutability and transparency in network agreements, offering a trust layer on which to develop future ethical AI applications. The adoption of smart contracts, the digital rights of stakeholders are protected, and regulatory compliance is promoted.

It emerges, therefore, that each technology does not remain isolated, but becomes an integral part of the business model:

- AI and ML power dashboards and decision-making scenarios;
- scoring algorithms translate sustainability metrics into concrete actions;
- blockchain serves as a secure infrastructure for smart contracts and governance;
- digital interfaces (QR-codes) streamline the provision of services.

In addition, these results are also confirmed by a study conducted by the RT AI Observatory (2025) on a sample of 60 companies, of which 32 are SMEs and start-ups. That study shows a diversified infrastructure adoption within RT: about a third use only cloud solutions, another part operates on hybrid infrastructures (on-premise and cloud), and many remain tied to local systems, while a small group is migrating to more integrated platforms. At the AI level, this mix reflects an experimental phase, with transitions to more modern models. Regarding decision-making processes, many companies have partially or well-structured procedures for AI adoption, but a significant share signals the need to formalize and strengthen these processes. However, organizational gaps remain: only 8 out of 32 companies have a dedicated AI team, 4 plan to hire, and as many as 20 do not have specialized in-house skills, which affects the effectiveness of digital integration. Operational experience is also still limited: the majority have implemented 1–5 AI projects, a large group have not yet started any, and very few companies have more than 6 projects.

In our study, the interviewees are implementing advanced platforms that, through machine learning algorithms, simulate strategic scenarios, evaluate business models, monitor cash flows, and assign sustainability scores (0–100). Some of these algorithms are already protected as intellectual property. Automation facilitates data-driven decision-making and optimizes both operational management and strategic planning.

On the innovation front, a collaborative model is emerging: humanized AI platforms are being developed through mentoring and R&D sessions, integrated with internal expertise, allowing for more flexible and critical decision-making. Digital solutions enhance human input through recurring feedback and discussions, while ensuring secure and transparent data management. The focus on sustainability is reflected in the adoption of the 2030 Agenda and ESG principles as strategic frameworks, promoting fair and inclusive internal policies.In conclusion, although SMEs and start-ups show a strong propensity for innovation and AI exploration, there are areas for improvement, especially in terms of structuring internal processes, creating dedicated teams and consolidating skills, which are key elements for transitioning from an experimental phase to full digital integration.

5 Limitations and future research directions

A limitation of the analysis lies in the small and diverse sample: many of the start-ups examined do not have teams specialized in AI, which compromises the generalizability of the results and limits an objective assessment of the actual impact of AI in decision-making processes.

In addition, despite the presence of numerous conceptual models, many applications of AI in the strategic and governance fields remain in the preliminary or theoretical phase, highlighting the need for further empirical studies to validate the expected benefits and deepen the interaction between AI and knowledge management. In addition, it would be appropriate to extend the validation of the analyses also to innovative start-up SMEs already operating in sustainable businesses at an economic, social, environmental and ethical level to contribute to overcoming the strategic, organizational, cultural and financial barriers that characterize the digital transition.

6 Conclusions

The analysis conducted in this paper highlights how AI-based models can significantly improve business decisions, providing predictive information and optimizing investments in IT infrastructure and business strategies. In fact, AI is configured as a strategic lever that contributes to the creation of competitive advantage thanks to the automation of processes and the extraction of new knowledge from big data.

The transformation of business models emerges as a complex and long process, which can be supported by the development of interactions that are not only competitive, but also collaborative between the players in the innovation ecosystem. In fact, the integration of AI in RT start-ups, despite being in its early phase and characterized by organizational heterogeneity, represents a strategic lever that enhances the interdependencies between advanced technology and human know-how in an ethical and sustainable way, while requiring further investments to consolidate dedicated processes and teams. Belonging to the RT has favored matchmaking with universities and other key stakeholders in the digital transition processes, although no real dedicated partnerships have been born. In this regard, a project of the RT Spoke 2 is engaged in the development of an AI-based platform conceived as a hub for simulations, feedback and networking, a powerful value multiplier for all startups.

The proposed conceptual models offer start-ups a framework to integrate AI into knowledge management processes, thus optimizing decision-making. AI supports the activation of a virtuous circle of learning that underlies decision-making processes and that favors innovation processes, therefore the creation of economic, social, environmental and ethical value of companies. These elements outline a perspective in which technological innovation is not an end in itself but is closely intertwined with values that aim at responsible and sustainable business management. The integration of a human-centric approach, data protection and integrated sustainability creates a business system in which technologies are a strategic ally at the service of informed, ethical and responsible choices.

Therefore, entrepreneurs and managers are invited to invest in the involvement and training of staff, as well as in the adoption of strategic-organizational choices (e.g. re-design of work processes) that allow them to fully exploit the potential of AI by ensuring ethical and sustainable human-AI integration.

7 Acknowledgements

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8 Ethics declarations

Ethical clearance was not required for the research.

7 AI declaration

AI tools were used to enhance the clarity and accuracy of the English language in this document.

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Managing in the AI Era: A Systematic Literature Review on the Evolution of Managerial Roles and Competencies

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Abstract

This study explores how Artificial Intelligence is reshaping managerial competencies in modern organizations. While much of the literature emphasizes technological capabilities, we adopt a human-centric perspective to map the evolving competencies, skills, knowledge, and responsibilities that managers must acquire to navigate the evolving technological landscape. The analysis is grounded in a Systematic Literature Review conducted in accordance with the PRISMA framework. A total of 92 peer-reviewed academic articles were examined using a hybrid methodology that combines Large Language Model-assisted content extraction with structured human coding. The resulting taxonomy groups these competencies into four macro-areas: (1) strategic and decision-making competencies, (2) technical and analytical skills, (3) ethical and legal regulatory knowledge, and (4) leadership and change management. Each category includes specific sub-competencies reflecting the complex, interdisciplinary nature of AI adoption. The findings reveal a predominance of studies focused on tertiary industries and a strong reliance on qualitative research designs. A fit score was applied to assess each contribution's alignment with the review's objectives. By mapping the evolving skillset required for AI readiness, the study offers both theoretical insights and practical orientation for managers, educators, and policymakers seeking to navigate digital transformation responsibly and effectively.

Keywords – Managerial Competencies; Artificial Intelligence; Large Language Models; Systematic Literature Review; Human Resource Management

Paper type - Academic Research Paper

1 Introduction

Artificial Intelligence (AI) is transforming the dynamics of business management by introducing new ways of automating decisions and reshaping work structures. Far from being merely a technical shift, the diffusion of AI represents a socio-organizational transformation that affects the nature of managerial work (Haesevoets et al., 2021; Wilson & Daugherty, 2018). As AI systems become increasingly embedded in operational and strategic processes, managers are expected not only to oversee technological integration but also to exercise judgment in complex hybrid environments where human and machine intelligence coexist and interact (Kolbjørnsrud, 2024).

The concept of competence has been widely debated across educational, psychological, and managerial domains, yet its theoretical foundations remain fragmented. Hoffmann (1999) highlights the distinction between input-based and output-based approaches to competence: the former defines competence as a set of knowledge, skills, and abilities, while the latter emphasizes observable performance and behavior within a specific context. Wong (2020) further stresses that the literature frequently conflates related terms such as skill, ability, and capability, creating conceptual ambiguity. This lack of clarity becomes particularly problematic when attempting to define the competencies needed in dynamic and technologically evolving environments, such as those shaped by AI. Despite such definitional challenges, the managerial literature has produced a range of frameworks aimed at identifying the competencies required for effective leadership. A notable point of agreement across the literature is the centrality of certain competency domains: leadership ability and communication skills repeatedly emerge as critical factors for managers in almost every context; similarly, strategic or analytical thinking competencies are consistently emphasized, reflecting the importance of cognitive skills in managerial roles (Asumeng, 2014; Bolzan De Rezende & Blackwell, 2019; Hawi et al., 2015; Khoshouei et al., 2013). While some models are generic and cross-sectoral, others are tailored to specific industries, highlighting domain-specific competencies such as customer focus or project-based coordination (Bolzan De Rezende & Blackwell, 2019; Hawi et al., 2015). Overall, a widely accepted core set of managerial competencies appears to exist, although often enriched or recontextualized depending on organizational role or environment. However, most of these frameworks were developed before the widespread adoption of AI, and few explicitly incorporate the challenges posed by data-driven and algorithmically mediated decision-making.

The urgency of updating these frameworks has grown in light of the transformations triggered by the increasing diffusion of AI technologies. According to the Future of Jobs Report (2025) by the World Economic Forum, by 2030 only one-third of work-related tasks will be performed exclusively by humans, down from 47% in 2025. Although 92 million jobs are expected to be displaced, approximately 170 million new positions will be created globally, resulting in a net employment gain of 78 million. Simultaneously, 39% of current core competencies are projected to become obsolete or significantly altered. In response, more than half of the global workforce will require reskilling, and 85% of companies plan to invest in workforce development initiatives to close emerging skill gaps (WEF, 2025). Beyond its effect on specific competencies, AI is increasingly recognized as a transformational force that redefines how organizations operate. The concept of AI readiness has emerged to describe an organization's ability to absorb and implement AI in a sustainable manner. It encompasses dimensions such as strategic alignment, resources, knowledge, culture, and data (Jöhnk et al., 2021). This transformation unfolds on multiple levels, influencing organizational processes, group dynamics such as collaboration with algorithms, and individual perceptions including attitudes toward AI, perceived fairness, and concerns over skill obsolescence (Bankins et al., 2024). At the managerial level, this transformation prompts a redefinition of responsibilities and decision-making roles. Rather than being displaced, managers are increasingly positioned as coordinators of hybrid systems where human judgment and algorithmic insight must be integrated. Augmented decision-making models, where AI supports but does not replace human input, are more widely accepted and more effective than full automation (Haesevoets et al., 2021). This view aligns with the emerging concept of collaborative intelligence, whereby new managerial functions are introduced to ensure ethical, strategic, and operational alignment between humans and machines (Wilson & Daugherty, 2018). These insights highlight the growing disconnect between existing models and the evolving managerial reality, reinforcing the need for a structured synthesis of the academic literature to identify and classify AI-related competencies within a coherent and transferable framework.

Recent studies have introduced novel managerial roles such as AI translators, ethical ambassadors, and algorithmic brokers (Lippert & Dresden, 2024), suggesting a shift in the capabilities required by contemporary managers. Yet, the existing research is often fragmented, and theoretical contributions vary in how they define and frame competencies; more specifically, there is a significant lack of systematization regarding the specific managerial competencies required to govern such transformations (Aziz et al., 2024; Bevilacqua et al., 2025). Furthermore, foundational ambiguities persist around key terms such as competence, skill, and ability (Hoffmann, 1999; Wong, 2020), complicating attempts at building a shared taxonomy. This paper seeks to address this gap by conducting a Systematic Literature Review on managerial competencies in the context of AI adoption. Following the PRISMA protocol for article selection and filtering, a curated corpus of peer-reviewed academic contributions was analyzed. Prompt engineering techniques were applied using Large Language Models to extract relevant content related to managerial knowledge, skills, and abilities. Subsequently, a Structured Content Analysis, performed by human judgment, was used to develop a taxonomy of competencies and to group them into coherent conceptual families. The study is guided by three main research questions:

- *RQ1*: Which AI-related competencies are essential for board members and corporate executives in the current technological landscape?
- *RQ2*: How are managerial roles evolving in response to the integration of AI into organizational processes?
- *RQ3*: What ethical and regulatory considerations should shape the competency profile of corporate leadership roles?

The subsequent sections of the article are structured as follows. Section 2 details the methodology employed, highlighting the selection criteria and analytical techniques. Section 3 provides an overview and discussion of the key findings, including the proposed taxonomy along with sectoral and methodological trends. Lastly, Section 4 concludes with reflections and suggestions for future research directions.

2 Methodology

This study employs a Systematic Literature Review as a structured, transparent, and replicable method for synthesizing existing knowledge, minimizing bias through rigorous protocols and standardized procedures (Nightingale, 2009). To ensure methodological transparency, the review process was aligned with the PRISMA framework (Moher et al., 2009), which provides a structured format for article identification, screening, eligibility assessment, and inclusion. The methodology was articulated in three main phases: (i) selection of the article corpus; (ii) AI-assisted extraction of articles' content; and (iii) analysis of managerial competencies through structured content analysis.

2.1 Article Selection Criteria

Regarding scientific literature, the research was conducted using major bibliographic databases, specifically Scopus and Web of Science, with a structured and articulated search strategy. The primary query was constructed by combining terms related to three key dimensions:

(TITLE-ABS("artificial intelligence") OR TITLE-ABS(AI) OR TITLE-ABS("machine learning") OR TITLE-ABS("ML"))
AND
(TITLE-ABS("competenc") OR TITLE-ABS("skill"))
AND
(TITLE-ABS("board of director") OR TITLE-ABS("board member") OR TITLE-ABS(boardroom) OR TITLE-ABS("C-suite") OR TITLE-ABS("C-level") OR TITLE-ABS("chief executive") OR TITLE-ABS(CEO) OR TITLE-ABS(CFO) OR TITLE-ABS(CTO) OR TITLE-ABS("top manage") OR TITLE-ABS("senior manage") OR TITLE-ABS("executive*") OR TITLE-ABS("corporate governance") OR TITLE-ABS("leaders*"))**

The search was further refined by applying filters related to document type (articles and review papers) and language (English), as well as by focusing on specific disciplinary areas (Business, Management, and Social Sciences). To ensure the relevance and quality of the analyzed articles, the following inclusion criteria were applied: (1) peer-reviewed articles and review papers in English; (2) papers focused on managerial skills in the AI era.

Concurrently, the following exclusion criteria were established: (1) purely technical AI studies without a managerial focus; (2) single case studies that are not generalizable; (3) studies focused exclusively on technological aspects without managerial implications; and (4) documents not accessible in full text.

In the first phase, a preliminary screening based on titles and abstracts was conducted to exclude documents clearly unrelated to the research objectives. Each contribution was assessed for its apparent relevance to the core research questions. This process identified 110 relevant documents out of an initial corpus of 189. Due to accessibility issues, only 95 articles were ultimately included in the review.

2.2 AI-assisted extraction through LLMs and prompt engineering

The categorization of the selected articles was conducted through an AI-assisted extraction process, leveraging the capabilities of the Gemini Flash 2.0 Large Language Model within a human-in-the-loop process. The use of LLMs in literature reviews has become increasingly consolidated, particularly for automating tasks such as article summarization and data synthesis (Antu et al., 2023). In line with recent empirical studies, the model was applied to systematically extract predefined content areas from each article: managerial competencies, sector of application (classified, where possible, according to ISIC codes revision 4), empirical results, managerial and theoretical implications, ethical considerations, best practices, methodological details, theoretical framework, limitations, future research directions and an interpretative fit score ranging from 1 to 5, indicating the degree of alignment between each paper and the objectives of the systematic review.

The effectiveness of this phase hinged on the design and iterative refinement of prompts, a technique widely recognized as critical to the success of LLMs' accuracy (Lin, 2024). Each prompt was structured according to a Role-Task-Expected Features-Example framework, which enabled the model to execute tasks with clarity and internal consistency. This approach aligns with established prompting methodologies, including the PARTS framework (Park & Choo, 2024), which emphasizes role specification, objective definition, and desired structure explanation as essential components to maximize output relevance. To reduce hallucinations, the temperature parameter was fixed at 0, which is in line with recent best practices that suggest low-temperature settings enhance determinism and consistency (Ekin, 2023). Furthermore, the application of negative prompting techniques was crucial: the model was explicitly instructed to return "NOT-DEFINED" when the content extracted from the article did not match the criteria of the specific query. This technique, documented as effective in minimizing speculative outputs (Lin, 2024), proved especially valuable in tasks such as competency identification, where semantic misalignment would compromise the validity of the output. The prompt engineering process followed an iterative refinement strategy, with multiple cycles of adjustment based on output evaluation conducted through human judgement. Where appropriate, few-shot prompting was employed using manually curated examples extracted from a subset of articles. This approach was particularly effective for enhancing model comprehension in extracting complex categories (Chen et al., 2023) such as managerial competencies, empirical findings, and managerial implications.

From a technical standpoint, the prompting system was operationalized through the integration of Langflow v1.2.0 and KNIME Analytics v5.4.0. Langflow enabled the visual design of prompt-response pipelines connected

to Gemini Flash 2.0, while KNIME was used to automate the parsing of article texts, generate input prompts, manage sequential requests, and aggregate the model outputs into a unified dataset. At the end of this stage, 3 out of 95 articles in the corpus were excluded because their text could not be extracted from the source file. Thus, the number of articles effectively analyzed corresponds to 92, as shown in Figure 1.

Following the extraction phase, a Structured Content Analysis was conducted to classify the managerial competencies identified across the reviewed articles. By leveraging a coding approach based on human expertise, all managerial competencies were grouped by the authors into recurring thematic patterns through an iterative categorization process. This method allowed for the construction of a coherent and replicable taxonomy, capturing the strategic, relational, and cognitive dimensions of managerial skills in AI-driven organizational contexts.

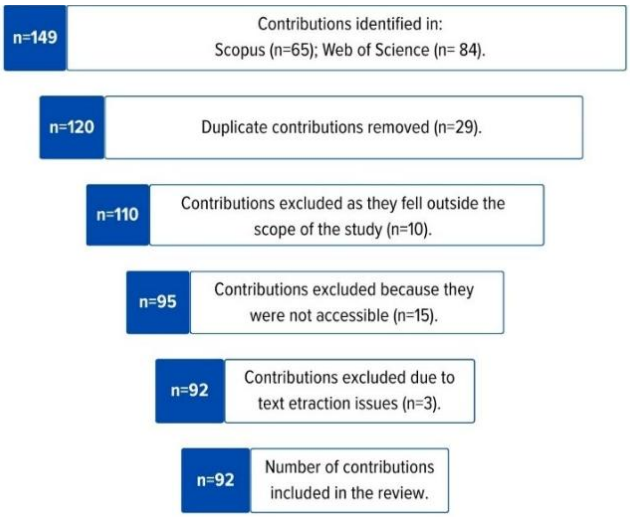


Figure 1: Diagram of the article selection process.

3 Results and discussion

The following sections present the results of this study, organized into two main areas: (i) managerial competencies, and (ii) numerical meta-analysis.

3.1 Managerial competencies

The main results are presented through a structured taxonomy of managerial competencies that emerged from the analysis of the reviewed articles. As shown in Figure 2, the taxonomy adopts a hierarchical structure articulated over two levels: four macro-competency families, each encompassing a set of sub-competencies that reflect distinct managerial competencies in AI-integrated contexts. The following discussion focuses on the four overarching dimensions identified through Structured Content Analysis: strategic and decision-making competencies, technical and analytical skills, ethical and regulatory knowledge, and leadership and change management capabilities.

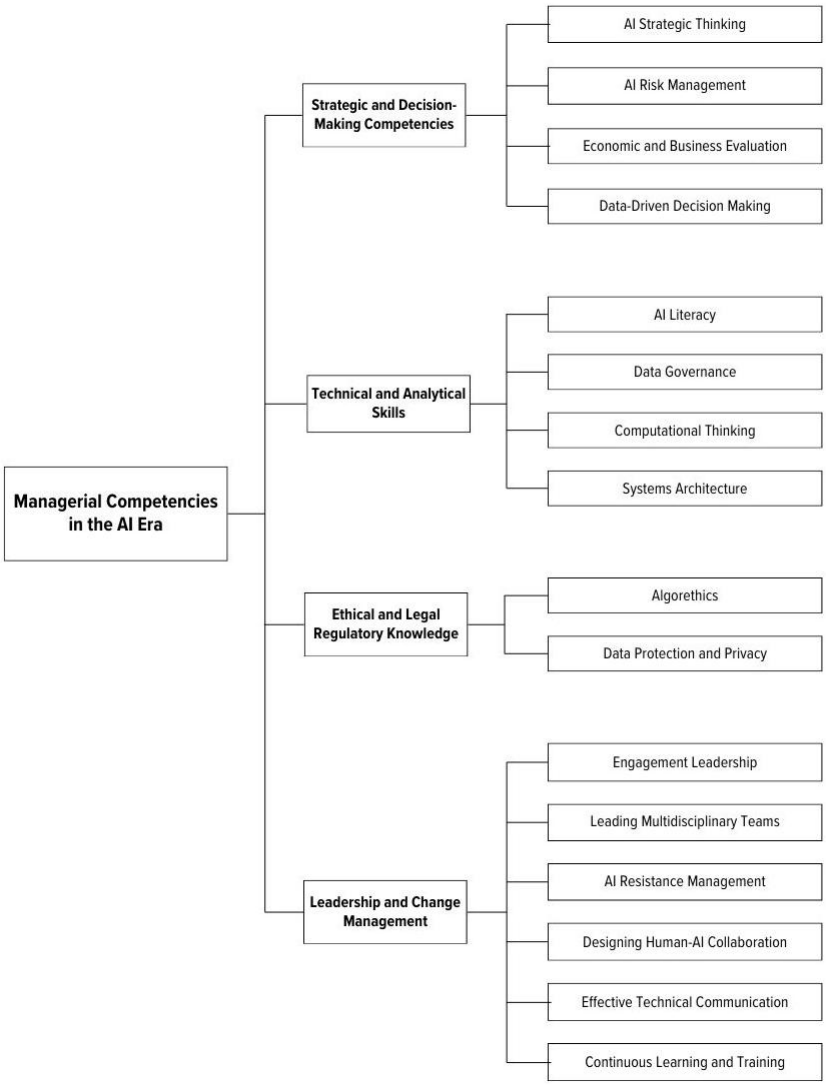


Figure 2: Two-level hierarchy diagram of managerial competencies

3.1.1 Strategic and Decision-making Competencies

The first family concerns strategic and decision-making competencies, which are recognized as paramount for managers operating in AI-driven environments. Strategic leadership capabilities and long-term vision are considered essential, particularly in contexts where shared orientations must be developed and perceptual divergences overcome in AI-based initiatives (Caro, 2008). The evaluation of AI from an economic and business standpoint is also frequently addressed, with a strong emphasis on the need for competencies that allow managers to assess its profitability and organizational impact (Baumgartner et al., 2024). Themes related to critical judgment and the ability to make decisions in complex and uncertain scenarios emerge as well, where a data-driven and experimentation-oriented mindset is often recommended as a managerial requirement (Jorzik et al., 2024). Moreover, a focus on data comprehension and familiarity with AI-supported decision-making processes is emphasized to ensure proper integration of algorithmic insights into managerial routines (Surbakti et al., 2024). Based on these contributions, four areas of competence were identified within this family: “AI Strategic Thinking”, which refers to the awareness of emerging technological trends and the ability to anticipate their impact and integrate AI into broader business goals; “AI Risk Management”, which involves understanding the risks associated with AI technologies and the ability to identify and assess such risks effectively; “Economic and Business Evaluation”, which concerns the ability to evaluate the financial and operational costs and benefits of AI adoption and to estimate the economic value of organizational data; and “Data-Driven Decision Making”, which relates to understanding how AI algorithms function, interpreting their outputs, and effectively integrating such insights into business processes.

3.1.2 Technical and analytical skills

The second family of managerial competencies focuses on technical and analytical AI-related skills, which are widely discussed across the reviewed literature. These competencies include the knowledge of AI applications, organizational data sources, and system interfaces (Baumgartner et al., 2024). AI literacy among top managers is also emphasized as a critical factor for effective AI adoption and business alignment (Pinski et al., 2024). Competencies related to data management play a prominent role, particularly in terms of the ability to handle both structured and unstructured data (Richthofen et al., 2022). Finally, technical skills related to the application of machine learning techniques are highlighted as essential for the operational implementation of AI solutions in organizational settings (Karki & Hadikusumo, 2023). Based on these contributions, four core subcategories were defined under the family of technical and analytical competencies. “AI Literacy” refers to the understanding of basic AI terminology, core functionalities, and the operational logic of AI applications, as well as the ability to evaluate performance metrics such as reliability and generalizability. “Data Governance” involves familiarity with the processes and tools for managing structured and unstructured data, including data quality procedures and metadata documentation practices at the enterprise level. “Computational Thinking” reflects the capacity to frame and solve complex problems using a structured and algorithmic approach. Finally, “Systems Architecture” relates to knowledge of enterprise digital infrastructures and the ability to integrate AI solutions with existing systems and platforms in a coherent and scalable way.

3.1.3 Ethical and regulatory knowledge

The ethical, legal, and governance aspects of AI represent central themes across a substantial portion of the reviewed literature. As AI technologies become increasingly embedded within organizational workflows, ensuring responsible and sustainable use requires structured competencies related to regulatory compliance and ethical decision-making. Organizational principles guiding AI implementation are seen as fundamental in promoting accountability and fostering trust (Fenwick et al., 2024). Ethical awareness is identified as a key managerial competency for AI governance, including the ability to anticipate, recognize, and mitigate ethical risks (Shahzad, 2024). Data protection and privacy also emerge as critical concerns, requiring managers to understand the implications of handling sensitive information in AI-driven systems (Baumgartner et al., 2024). In addition to privacy issues, effective governance must account for systemic vulnerabilities and emerging threats, calling for competencies in the design of robust control mechanisms (Almeida, 2025). Accordingly, two specific areas of competence were defined under this category: “Algorethics” refers to the awareness of the ethical dimensions of AI, the ability to recognize and mitigate algorithmic bias, and the capacity to translate moral values into computable principles. “Legal and Regulatory Knowledge”, on the other hand, concerns familiarity with relevant legal frameworks and policy landscapes, as well as with the principles of compliance, privacy, and data protection, which have become indispensable in contemporary management practices.

3.1.4 Leadership and change management

The successful adoption of AI requires strong leadership capable of managing organizational change and guiding teams through complex transformation processes. One crucial aspect of this competency area is the ability to coordinate interdisciplinary teams while actively involving end users in AI-related transitions to foster smoother integration and broader acceptance (Baumgartner et al., 2024). The concept of AI leadership often coincides with that of an “AI evangelist”, a figure able to inspire and motivate employees while promoting a comprehensive vision of AI implementation (Jorzik et al., 2024). Empathetic, inclusive, and adaptive communication practices are considered critical for ensuring employee alignment and overcoming resistance to AI-related change (Aldighrir, 2024). Considering these contributions, six sub-categories of competencies were identified. “Engagement Leadership” refers to the innovative mindset and openness to technology required to engage and motivate employees throughout AI adoption processes. “Leading Multidisciplinary Teams” concerns the capacity to assemble, coordinate, and manage cross-functional groups in AI projects, fostering collaboration, emotional intelligence, and effective integration between human and algorithmic components. “AI Resistance Management” highlights the ability to address and overcome cultural obstacles to AI adoption, providing both emotional and operational support during transitional phases. “Designing Human-AI Collaboration” relates to the definition of human and machine roles and the design of hybrid workflows. “Effective Technical Communication” involves the ability to translate AI-related concepts for non-technical audiences, ensuring organizational alignment and comprehension. Lastly, “Continuous Learning and Training” reflects the importance of cultivating a continuous learning mindset and of promoting upskilling initiatives among individuals unfamiliar with AI tools and processes.

3.2 Comparative overview

To contextualize the proposed taxonomy, Table 1 compares it with selected pre-AI competency frameworks.

Table 1: Overview of competency areas in existing frameworks and in the present AI-focused taxonomy

Model	Key competencies identified
(Hawi et al., 2015)	Leadership, problem solving, decision making, customer focus, strategic planning.
(Asumeng, 2014)	Intrapersonal skills (i.e., self-control, self-awareness, creativity), interpersonal skills (i.e., team building, networking), leadership, technical/business skills (i.e., business acumen, analytic thinking, decision-making), career skills (i.e., work commitment, work efficacy), mentoring skills (i.e., coaching, empathy, desire to help others).
(Khoshouei et al., 2013)	Value, analysis, decision-making, knowledge, adaptation, performance, leadership, communication.
Proposed taxonomy	AI strategic thinking, AI risk management, economic and business evaluation, data-driven decision making, AI literacy, data governance, computational thinking, systems architecture, algorethics, data protection and privacy, engagement leadership, leading multidisciplinary teams, AI resistance management, designing human-AI collaboration, effective technical communication, continuous learning and training.

3.3 Numerical meta-analysis

Alongside the qualitative taxonomy, a numerical meta-analysis was carried out to quantitatively assess the key characteristics of the reviewed articles. This approach offers complementary insights into the consistency and relevance of the contributions.

3.3.1 Application areas and sectors

Figure 3 illustrates the ranking of studies across ISIC-coded sectors. In cases where no specific application area was mentioned, the label “GENERAL” was applied. This category, together with “P – Education” and “M – Professional, scientific and technical activities”, accounts for the majority of cases.

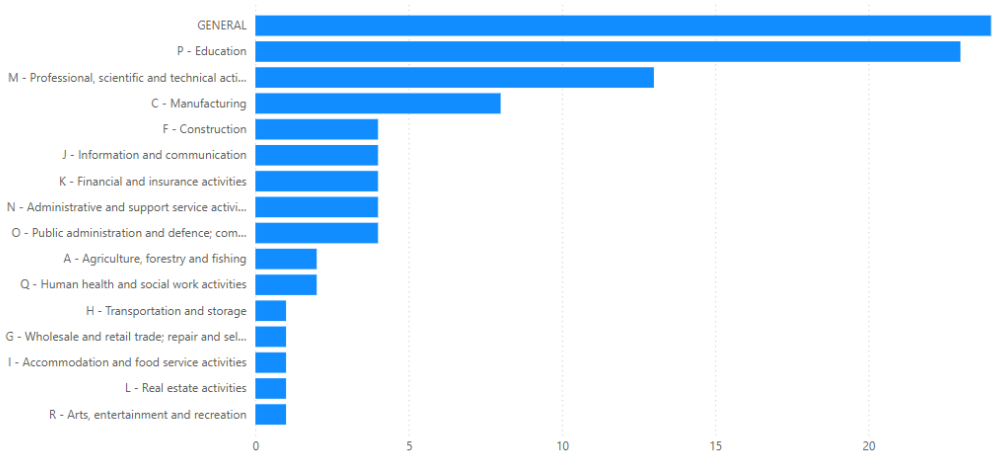


Figure 3: Horizontal bar chart showing the ranking of contributions by application area

These areas were then aggregated into macro-sectors according to ISIC Revision 4 classification. Records labeled as “GENERAL” were excluded. As shown in figure 4, most studies fall within the tertiary sector, with only a few contributions linked to secondary and primary sectors. This corroborates with Kataria & Devershi Mehta (2025), who found that AI adoption is notably higher in tertiary sectors.

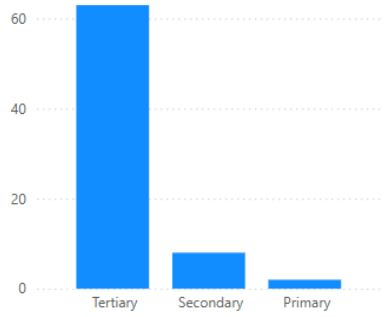


Figure 4: Vertical bar chart showing the ranking of contributions by sector.

3.3.2 Methodologies

As shown in Table 1, qualitative methods are the most represented, with content analysis and case studies as the dominant approaches. Quantitative designs follow, mainly through surveys and statistical analysis. Mixed methods and theoretical or conceptual papers are rare, and experimental designs appear only marginally.

Table 2: Absolute and relative frequencies of methodologies of the contributions

Methodology (Keyword)	Count	Relative Frequencies
QUALITATIVE - CONTENT ANALYSIS	26	28,3%
QUANTITATIVE - SURVEYS	14	15,2%
QUALITATIVE - CASE STUDIES	11	12,0%
QUANTITATIVE - STATISTICAL ANALYSIS	11	12,0%
QUALITATIVE - INTERVIEWS	9	9,8%
QUANTITATIVE - CROSS-SECTIONAL STUDIES	6	6,5%
MIXED - SEQUENTIAL EXPLANATORY DESIGN	3	3,3%
THEORETICAL	3	3,3%
CONCEPTUAL	2	2,2%
EXPERIMENTAL - FIELD EXPERIMENT	2	2,2%
MIXED - CONCURRENT TRIANGULATION DESIGN	2	2,2%
EXPERIMENTAL - QUASI-EXPERIMENTAL RESEARCH	1	1,1%
QUANTITATIVE - EXPERIMENTS	1	1,1%
QUANTITATIVE - LONGITUDINAL STUDIES	1	1,1%
Total	**92**	**100,0%**

3.3.3 Fit scores

The fit score measures how well each article aligns with the review's objectives. As shown in Figure 5, most studies scored between 3 and 5, with no article rated 1.

$$Average\ Fit\ Score = \frac{(2 * 9) + (3 * 28) + (4 * 39) + (5 * 16)}{92} = 3.7$$

The average score is 3.7 out of 5, confirming a generally strong thematic coherence across the contributions.

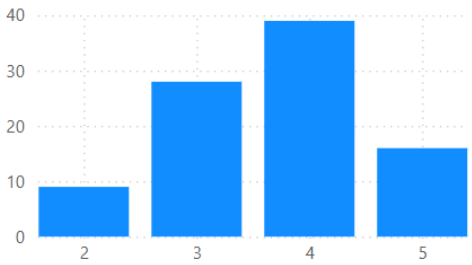


Figure 5: Histogram showing the distribution of fit scores among contributions.

4 Conclusions and future research

The proposed taxonomy offers a structured framework to understand how managerial roles evolve in AI-driven environments, where the integration of strategic, technical, ethical, and leadership competencies becomes increasingly essential. Beyond theoretical relevance, this framework holds practical value for organizations seeking to assess skill gaps, define targeted training initiatives, and align managerial development with technological transformation. In response to RQ1, the study identifies a structured set of AI-related competencies that are essential for corporate executives and managers operating in technologically advanced contexts. Regarding RQ2, the study suggests that the evolution of managerial roles in organizations is increasingly shaped by emerging demands such as the design of effective human–AI collaboration, the ability to govern algorithmic systems, and the capacity to lead interdisciplinary teams. These role transformations are reflected in the competencies required, which encompass strategic, technical, ethical, and change-oriented dimensions. Finally, addressing RQ3, the taxonomy includes a dedicated dimension on ethical and regulatory knowledge, highlighting the growing importance of governance, compliance, and algorithmic responsibility in leadership profiles.

From a theoretical perspective, the study contributes to the growing literature on AI and management by synthesizing fragmented insights into a coherent and operational taxonomy. It provides a useful reference for future empirical research aiming to validate, adapt, or extend the proposed framework in different contexts. However, some limitations must be acknowledged. The review only includes academic publications in English and covers literature published up to early 2025. Additionally, the taxonomy has not yet been tested in applied settings. Although LLM-assisted prompting ensured consistency and scalability, it may have introduced simplifications or overlooked implicit nuances in more interpretive articles. Future research could empirically test the framework across industries and managerial levels, examine the dynamic development of AI-related competencies over time, and explore their interplay with organizational culture, structure, and innovation strategies in real-world implementation scenarios. This framework can also serve as a practical roadmap for upskilling strategies and organizational readiness assessments in an AI-driven economy, offering concrete guidance to companies, training institutions, and policymakers involved in the digital transition.

5 Ethics declaration

No ethical approval was required for this study.

6 AI declaration

Large Language Models were employed to support content extraction and classification during the analysis phase, and to assist with language editing during the writing process. All substantive content, interpretations, and final editorial decisions were made by the authors.

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Advancing Holistic Heritage Impact Assessment through Human-Digital Collaboration

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Abstract

This paper explores the development and implementation of a digital knowledge-action platform designed to embed and translate the SoPHIA (Social Platform for Holistic Impact Assessment) method—a multidimensional framework for evaluating cultural heritage initiatives—into an accessible and participatory digital environment. Building on the Horizon 2020-funded SoPHIA project, the SoPHIA for CHANGES initiative, led by Roma Tre University and funded under Italy's Next Generation EU program, sought to address this gap by creating a digital platform grounded in the participatory ethos of the original SoPHIA method. The research employed a Participatory Action Research (PAR) approach, involving iterative cycles of collaboration between academic researchers, digital developers, and cultural heritage stakeholders. This methodology ensured that the platform was not merely a technical artefact but a co-created tool for reflexive learning, action, and knowledge transfer.
The research makes several significant contributions. Firstly, it enhances our understanding of how digital platforms function as socio-technical infrastructures for knowledge creation and dissemination within the cultural sector. It highlights a shift from static information repositories to dynamic, reflexive systems that actively engage and empower users. Secondly, the study introduces a process model for designing a comprehensive heritage impact assessment platform grounded in participatory knowledge management. This model offers valuable guidance for developing future knowledge-action platforms in cultural management and other complex, interdisciplinary domains. Ultimately, this project sheds light on how cultural heritage impact assessment can be disseminated and sustained through digital means without losing the critical reflexivity and human judgment that define meaningful heritage work. It demonstrates that digitalization, when rooted in participatory principles, can enhance—not replace—human creativity, sense-making, and collective action.

Keywords: Digital platform, Cutural Heritage, Impact Assessment, Knowledge Management, SoPHIA method

Paper type: Academic Research Paper

1 Introduction

Over the last two decades, literature on digital technologies and knowledge management has extensively addressed how new tools can reshape creativity, collaboration, and decision-making (Raisch & Krakowski, 2021; Eapen et al., 2023). Within the cultural sector, scholars have emphasized the disruptive and empowering potential of digitalization for heritage preservation (Zhou et al., 2012), cultural engagement (King et al., 2016; Doğan, 2022), art markets (Wang and Wang, 2021), and activities linked to creativity processes in arts (Ghosh and Fossas, 2022).

In particular, in the field of heritage management, there have been significant efforts at both European and country levels in digitizing and archiving historical data, artefacts and artworks to safeguard past knowledge (Macrì and Cristofaro, 2021) and share cultural heritage in a "phygital" (physical and digital) way (Del Vecchio et al., 2023).

However, despite these technological advances, there remains a notable gap in how methods for impact evaluation of cultural initiatives/projects may be operationalized and translated into accessible tools for practitioners, communities, and policymakers.

Addressing this gap, the H2020-funded SoPHIA project (Marchiori et al., 2021) developed a holistic heritage impact assessment framework, grounded in a multidimensional method. Inspired by the Faro Convention's people-centered approach to heritage, SoPHIA emphasized the need to assess the social, cultural, environmental, and economic impacts of cultural initiatives. Yet, while the method and toolkit of SoPHIA produced valuable knowledge on how to assess cultural heritage initiatives, the challenge of making this knowledge ready for use and broadly accessible persisted. In particular, questions remained around how to transfer this knowledge to diverse stakeholders through user-friendly digital means while maintaining the participatory ethos central to the original approach.

Building on this foundation, the Roma Tre University research team initiated the SoPHIA for CHANGES project, developing a digital knowledge-action platform (McIntosh et al., 2023), here defined as a digital tool that seeks to manage and organize knowledge, aiming at embedding and transferring the SoPHIA method within

a wider cultural heritage ecosystem. The project was funded through Italy's Next Generation EU investments under the CHANGES-*Cultural Heritage Active Innovation for Sustainable Society* partnership.

Against this background, this paper seeks to address the following research question: *How can the knowledge of the SoPHIA method be effectively translated and embedded into an interactive digital platform?*

To answer this research question, the project adopted a Participatory Action Research (PAR) methodology (Cornwall & Jewkes, 1995; Cornish et al., 2023). PAR offered a coherent epistemological and methodological framework to support co-creation, collective interpretation, and iterative learning processes during the platform's development. Unlike traditional top-down digitization projects, the platform design was grounded in cycles of problem identification, collaborative knowledge generation, reflection, and action with active involvement from researchers, technology partners, and representatives from the cultural heritage field. This methodology was fully aligned with the participatory nature of the SoPHIA model, ensuring that platform development was not merely a technical exercise, but rather a collective, critical, and creative endeavor. It was grounded in the logic of a boundary object (Leigh Star, 2010) —designed as a tool that is both comprehensible and accessible to academics and professionals across diverse fields of expertise.

The research made several key contributions. First, it advances knowledge on how digital platforms can act as socio-technical infrastructures for knowledge creation and transfer in the cultural sector (Dameri and Demartini, 2023), and moving beyond static information repositories towards dynamic, reflexive environments that empower users. Second, it provides a process model for developing a holistic heritage impact assessment platform based on participatory knowledge management principles, offering insights for future development of knowledge-action platforms in the cultural management field and other complex, interdisciplinary fields.

In practice, the SoPHIA for CHANGES platform represents a pioneering attempt to operationalize a holistic, people-centered impact evaluation framework through digital environments. It offers users a guided, interactive experience to evaluate cultural projects, selecting from sector-specific themes and indicators, learning from best practices, and adapting evaluations to local contexts. The platform integrates both academic and experiential knowledge, emphasizing collective ownership of the assessment process. Furthermore, by embedding mechanisms for continuous feedback and participatory updating, the platform embodies a knowledge ecosystem capable of evolving alongside its user communities.

Ultimately, this project sheds light on how cultural heritage impact assessment can be disseminated and sustained through digital means without losing the critical reflexivity and human judgment that define meaningful heritage work. It demonstrates that digitalization, when rooted in participatory principles, can enhance—not replace—human creativity, sense-making, and collective action.

The remainder of the paper details the background literature, methodology, key phases of the project, and broader implications for knowledge management theory and practice.

2 Background and research themes

In recent years, investments in the protection and enhancement of cultural heritage—both public and private—have grown significantly (Labadi et al., 2021). This trend reflects a broader acknowledgment of cultural heritage's role in driving social, cultural, and economic regeneration in contemporary societies (UNESCO, 2018). Despite an abundance of case studies and best practices (CHCfE, 2015), consensus remains limited regarding the core values and principles that should underpin such investments.Several landmark reports have sought to address this conceptual gap, including *Impact 08*, which evaluated Liverpool's tenure as European Capital of Culture (Garcia et al., 2010); *Cultural Heritage Counts for Europe* (CHCfE Consortium, 2015); and the *European Quality Principles for EU-funded Interventions* (ICOMOS, 2020). Each of these initiatives contributed to developing more structured approaches to assessing the value of cultural heritage projects.

Among the most recent and comprehensive contributions is the SoPHIA project, developed by a multidisciplinary team led by Roma Tre University (Marchiori et al., 2021). Grounded in the Faro Convention (Council of Europe, 2005), the project emphasizes shifting attention from the intrinsic value of heritage to its significance for individuals and communities. In doing so, it proposes a more dynamic and inclusive understanding of cultural heritage.

The SoPHIA Consortium aimed to construct a holistic evaluation framework to assess cultural heritage initiatives. This framework sought not only to identify intended outcomes and benefits but also to capture actual impacts across a range of dimensions (SoPHIA website).

At the core of the SoPHIA method are three analytical drivers:

People: This dimension includes stakeholders involved in decision-making or the use of cultural heritage. Understanding their perceptions and cognitive engagement is crucial to attributing meaning and value to cultural heritage.

Time: A temporal dimension guides investment decisions at different stages—ex-ante, ongoing, and ex-post—in project planning and execution.

Impact Domains: This perspective emphasizes a multidimensional evaluation framework that measures expected or realized impacts/changes from a multidisciplinary perspective. The SoPHIA impact domains emerged from discussions among over 200 European experts and encompasses six main themes of potential impact: social capital and governance; identity of place; quality of life; education, creativity, and innovation; work and prosperity; and protection (Marchiori et al., 2021; Baioni et al., 2021)

The SoPHIA project generated several outputs, including a conceptual method and a practical toolkit for implementation.

Upon completion of the project, the Roma Tre research team focused on two follow-up directions: applying the SoPHIA method to real-world case studies (Marchiori et al., 2024a, 2024b), and developing a digital platform to operationalize the method and facilitate its application through an automated, user-guided process (Demartini et al., 2025).

To this end, the team launched the *SoPHIA for CHANGES* project under the umbrella of the CHANGES partnership. This broader initiative involves 25 universities, research institutions, and businesses and aims to establish a national research infrastructure for the cultural heritage sector (CHANGES website).

The digital platform—conceived as a *knowledge-action* platform (McIntosh et al., 2023; Codagnone et al., 2016; Bonina et al., 2021)—is under development from April 2024 to November 2025. A joint team comprising Roma Tre researchers and a technology partner is collaboratively defining the platform's design, functionalities, and data processing mechanisms.

This effort is guided by a central research question: How can the knowledge developed in the H2020 SoPHIA project be effectively embedded into the digital platform *SoPHIA for CHANGES* and transferred to users?

Two interrelated research themes of knowledge management and practice underpin this research question:

Knowledge creation and transfer within cultural ecosystems:

The cultural sector has limited literature addressing how knowledge flows across academia and practitioners. Existing research suggests that, in a cultural ecosystem (Borin and Donato, 2015), collaboration among diverse yet complementary actors —rather than competition—creates a trust-based environment contributing to knowledge exchange and innovation. Such ecosystems encompass a wide range of stakeholders—including public institutions, private enterprises, artists, researchers, and citizens—whose interactions contribute to the production and consumption of culture. Within these systems, universities act as enablers and connectors, activating relationships and mobilizing talent (Florida, 1999) to generate cultural, economic, and social value (Dameri and Demartini, 2023).

Digital platforms as enablers of knowledge translation:

The study conducted by Baioni et al. (2021) revealed that digital social platforms are increasingly being employed in the cultural sector. Despite their relevance and diffusion, however, the degree of interaction with stakeholders is very low, and these platforms are mostly conceptualised as showcase websites. Building on the SoPHIA approach, this project aimed to go beyond and investigate how a knowledge-action platform can integrate automated processes with human-centered interpretation, opening new possibilities for participatory and reflexive evaluation in the cultural sector.

3 Methodology

To address our research question, it is important to fall back on the research approach that characterized the H2020 Sophia project.

The evaluation of the impacts generated by a cultural initiative, or project, implies the idea of a change — whether cultural, social, environmental, or economic — that can be produced within society (Rogers, 2014). These changes can be of multiple natures and require multidisciplinary knowledge to be identified, captured and evaluated. Moreover, in many cases, such changes can only be assessed by capturing the perceptions of those who, directly or indirectly, are the beneficiaries, recipients, or stakeholders involved in the cultural initiative.

Based on these premises, the SoPHIA research group adopted a Participatory Action Research (PAR) approach.

3.1 The Participatory Action Research

The Participatory Action Research (PAR) is a collaborative research methodological approach that actively involves participants (often community members or stakeholders) in the research process with the dual goal of generating knowledge (Cornwall and Jewkes, 1995; Cornish et al. 2023; Vaughn and Jacquez, 2020) and driving social change (Aguilera et al. 2007).

Unlike traditional research, where subjects are studied from a distance, PAR empowers individuals to become co-researchers—participating in the design, data collection, analysis, and even the implementation of solutions. As it has been defined:

"The key difference between PAR and conventional research lies not in methods, but in who defines problems, who owns the results, and who acts upon them." Cornwall & Jewkes (1995, p. 1669)

PAR is rooted in principles of democracy, equity, and social justice, aiming to address real-world problems through cycles of reflection, planning, action, and evaluation. It is particularly prevalent in fields like education, community development, healthcare, and social work. Its main features can be summarized in the display of a research design based on being: Collaborative: Involves researchers and participants equally. Action-oriented: Focuses on practical solutions. Reflective and iterative: Cycles of planning, acting, observing, and reflecting. Contextual: Rooted in the local, social, or cultural environment. Transformative: Seeks to empower and bring about systemic change. (Reason and Bradbury, 2001; Kindon et al. 2007).

According to Cornwall & Jewkes (1995), Participatory Action Research (PAR) involves a plurality of actors, each contributing distinct knowledge and roles within a shared process of inquiry and change. The actors engage in a dialogical and dialectical relationship. The goal is not extraction of information but co-production of knowledge and transformation (see table 1).

Table 1: PAR Actors

Involved actor(s)	**Role in PAR**
Community of practice / interested community	Central protagonists and co-researchers who identify problems, generate knowledge, and take action. Community of practice experiences and perspectives are the foundation of the research.
Researchers / Facilitators	Not neutral observers but engaged facilitators who support, catalyze, and co-analyze, aiming to reverse conventional power hierarchies. They contribute tools and theoretical frameworks, but relinquish control.
Inclusive perspective (involves all interested groups)	Minority groups are empowered through participation to address issues affecting their lives.
Institutions, NGOs and other intervening actors	Sometimes initiate or support PAR projects, but their agendas must be critically balanced to avoid co-opting community processes.
Change agents	Both internal (community-based) and external (e.g., researchers, NGOs), they help initiate and sustain cycles of reflection and action.

PAR revolves around a cyclical, action-oriented learning process where knowledge is built with and for those it concerns.

Here is how that unfolds:

1. Problem Identification

- Initiated by community members or jointly with facilitators.
- Based on lived experiences and local priorities, not imposed externally.
- Techniques include participatory mapping, storytelling, and visual tools.

2. Knowledge Generation and Interpretation

- Involves multiple epistemologies — blending scientific, experiential, and indigenous knowledge.
- Emphasis is on community-driven interpretation, not researcher-led.
- Researchers act as catalysts and learners, not authority figures.
- The process surfaces invisible structures, power relations, and assumptions.

3. Reflection & Mutual Learning

- Participants and researchers engage in collective reflection.
- This is not linear: learning evolves through the process ("praxis").
- Focus is on critical consciousness — recognizing problems and their structural roots.

Note that steps two and three are actually iterative moments that alternate multiple times

4. Action and knowledge translation/dissemination

- Knowledge leads to action, which provokes further reflection and learning.
- Solutions are driven by a people-centered perspective

3.2 The Participatory Action Research applied to our research project

As shown in the following table 2, the principles that underpin the H2020 SoPHIA project align closely with the PAR approach.

Table 1: SoPHIA core concepts that align with PAR

Sophia Principle	**PAR alignment**
Holistic impact	Community-driven, contextual insights
People-centered perspective	Co-Creation and shared interpretation
Integrated Policy-making	Action stage of PAR feeds into governance
Inclusive stakeholder voice	Central tenant of PAR

4 Findings

In the following, we will focus on the analysis of the processes of knowledge creation and transfer identified on the basis of the PAR approach and followed to design and implement the digital platform. Successive phases, actors involved, outcome and challenges encountered will be described.

4.1 Identification of the problem

The Problem Identification phase was crucial for ensuring the SoPHIA knowledge platform addressed the real needs of the cultural heritage sector.

This process can be summarized in two sub-phases, all grounded in a participatory action research (PAR) approach.

Phase I – Co-design of the SoPHIA method and Toolkit

The H2020 SoPHIA Consortium, together with diverse stakeholders such as local communities, heritage managers, NGOs, and policymakers, collaborated to identify crucial sector needs and define project goals. Among the key challenges were managing the multitude of disciplinary perspectives and ensuring that both the method and the toolkit would function as accessible, flexible tools across various professions and sectors.

Through open dialogue, several participatory workshops with stakeholders and discussions among the researchers, the Sophia method and its Toolkit were developed. These artifacts serve as ‘bridges’ or ‘boundary objects’, (Leigh Star, 2010) facilitating understanding among actors speaking different ‘languages’ within the cultural heritage ecosystem.

Phase II - Platform Concept Development

Within the Roma Tre CHANGES project team, debates were held to conceptualize the knowledge-action platform. This internal co-identification process focused on translating the SoPHIA method principles into a dynamic and participatory digital space capable of connecting research, action, and stakeholders. The objective was to define a platform that goes beyond static content, fostering real engagement and collaborative knowledge building.

Key outputs of this phase concern the identification of main problems. A critical point emerged around the choice between a window-website and a knowledge platform. The goal was to find a solution emphasizing user engagement and active enactment, ensuring the platform would not just inform but also empower stakeholders. Another criticality, researchers encountered, lay in the technological translation of the platform vision: it had to remain faithful to the participatory principle, stimulating active involvement in the evaluation process by the user while offering robust, user-friendly technology.

4.2 Knowledge Generation and Interpretation: from a method-model to a user-driven evaluative and learning process

The second phase, Knowledge Generation and Interpretation, emphasizes plural epistemologies and participatory engagement. Knowledge here is not the sole domain of scientists but emerges from integration of scientific and experiential knowledge.

Along with this approach, community-driven interpretation was central in the SoPHIA method. Instead of imposing external frameworks, knowledge production was collaboratively shaped by local stakeholders — communities, practitioners. Researchers no longer serve as authoritative knowledge-bearers but reposition themselves as catalysts and co-learners. Their role was to facilitate dialogue and create spaces for exchange.

Accordingly, customization of the digital platform was approached as a co-creative effort, aiming to embed in the digital tool sector-specific understandings of impact and brainstorming sessions were held internally within the core team of Roma Tre University.

Researchers collaboratively refined and summarised themes and sub-themes, anchoring them to indicators that were meaningful and recognizable to diverse users, including heritage managers, local communities, and policymakers. Special attention was given to the translation and simplification of SoPHIA guiding indicators for each original dimension, ensuring that these remained faithful to the original method and model, but were reformulated into accessible language and operational categories suited to the platform's diverse user communities.

A central aim during this step was to guarantee a blending of scientific, experiential, and sector-specific knowledge, ensuring that community perspectives guided interpretations rather than being researcher-imposed. To strengthen the relevance and applicability of the platform, case studies were integrated, enriching raw data with real-world examples. This allows users not only to engage with abstract models but also to connect with practical, lived experiences.

The process marked a deliberate transition from a general method-model to a user-driven evaluative and learning process, offering users concrete and actionable tools. By introducing best practices and tips, the platform moved beyond theoretical frameworks, proposing a dynamic, adaptive knowledge space capable of supporting reflexive learning and decision-making. This iterative approach aimed to enable users to recognize and validate their own knowledge systems within the platform environment.

4.3 Reflection and learning. Translating the SoPHIA method in the platform

The third phase, Reflection and Learning, based on shared interpretation and evaluation, was pivotal for translating the Sophia method framework into a practical and operational digital knowledge platform. This phase involved a continuous, participatory process of shared interpretation and evaluation carried out collaboratively by the Roma Tre University team and the technological partner team .

In a series of co-design workshops, wireframes and preliminary versions of the platform interface were collaboratively developed. These sessions included knowledge gathered by and from sector experts in cultural heritage, user experience, design, and data visualization. Together, the participants conceptualized key components such as the structure of the digital interface, navigation pathways, dashboard organization, and visualization tools (e.g., graphs, impact maps, progress trackers). The design process was dynamic, allowing the platform to evolve iteratively based on feedback and insights gathered during the workshops.

A central aim during this step was to ensure that the platform remained user-friendly while preserving the breadth, completeness, and depth of Sophia's rich conceptual framework. This required balancing the complexity of the original method with the need for clarity and accessibility for a wider range of users, including non-specialists in cultural heritage assessment. This translation preserved the theoretical rigor of the original method but made it operable through structured user workflows within the platform, ensuring users could navigate, input, and analyze information intuitively.

Key outputs of the process have been: a preliminary version of the digital platform was developed, aligned with user-centered design principles. A core set of evaluation indicators was established through collaborative refinement processes. Key lessons were integrated regarding how to communicate complex knowledge in a simplified yet rigorous manner. Researchers adopted an approach that combined specialist knowledge with engineering, aiming at user-centered design, through participatory validation, with the goal of making complex Sophia cultural heritage assessment method accessible, operational, and impactful within the platform environment.

4.4 Knowledge Translation and Dissemination: future steps

The fourth phase, Knowledge Translation and Dissemination, is a forward-looking phase, aimed at ensuring the long-term vitality, usability, and evolution of the digital platform developed from the Sophia method. Although still in the design stage, this phase outlines essential processes for operationalizing the platform in real-world contexts, enabling knowledge transfer across user communities, and establishing foreseen mechanisms for ongoing refinement

A critical action involves the deployment of trial versions of the platform among a selected group of pilot users representing the target audiences — including cultural heritage practitioners, policymakers, researchers, and community organizations. The trials aim to:

- Test the usability and intuitiveness of the interface to ensure a user-friendly experience
- Assess the applicability and relevance of the embedded indicators and dashboards
- Gather initial feedback on the user experience, interpretation of knowledge structures, and practical outcomes derived from using the platform

Structured trial protocols will be developed, including observation of user interactions, guided task completion exercises, and post-trial debriefing sessions.

Recognizing that the cultural heritage sector is dynamic and evolves in response to shifting societal, political, and technological contexts, the platform's sustainability depends on establishing continuous feedback mechanisms.

Future actions will include:

- Feedback channels embedded within the platform (e.g., user surveys, feedback forms, quick reporting buttons)
- Periodic focus groups and interviews with representative users
- Longitudinal monitoring of user engagement metrics and patterns
- Co-creation labs held at regular intervals to discuss new needs and adapt the platform accordingly

By institutionalizing a cyclical model of feedback, reflection, and redesign, the platform will remain aligned with emerging needs and retain its relevance over time.

This phase should yield: A set of validated methods for feedback collection and analysis; Guidelines for iterative redesign based on evolving user needs or policy changes; Definition of a sustainability plan ensuring the platform's active life and ongoing relevance; Fostering a vibrant, engaged user community that sees itself as co-owner of the platform's knowledge ecosystem.

Overall, phase 4 recognizes that the process of knowledge translation does not end with the launch of a digital platform and the embedding of Sophia method in the digital ecosystem, rather focusing on users as active participants in sustaining, adapting, and disseminating the embedded knowledge over time. Furthermore, it seeks to involve the community of practice further in continuous assessment and refinement of the platform itself.

To sum up, Figure 1 present a map of the processes followed by the team, which are the focus of reflection in this paper to answer our research question: How can the knowledge of the SoPHIA method be effectively translated and embedded into an interactive digital platform?

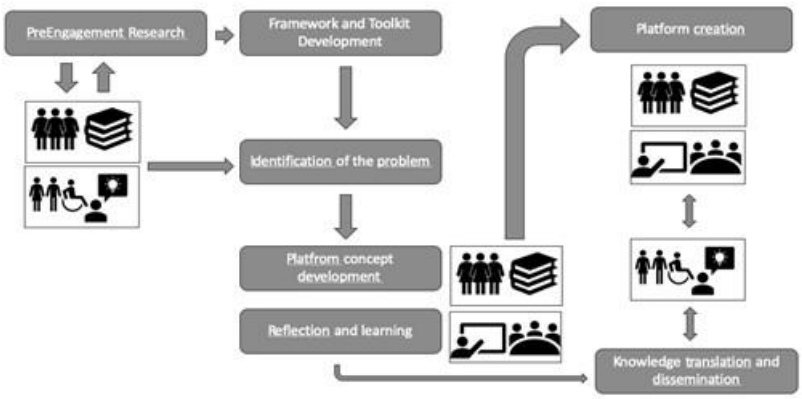


Figure 1: Participatory knowledge processes-SoPHIA digital platform

5 Conclusions

The findings of our research have enabled us to formulate the following main contributions.

Contributions to previous research

- Digital platforms exhibit three fundamental characteristics: technological mediation, task execution, and user interaction (Bonina et al., 2021). The *SoPHIA for CHANGES* platform embodies these traits by facilitating the transfer of knowledge on impact assessment—developed by researchers and experts of the cultural sector —to a wider audience. Through guided phases and interactive steps, users can adapt and apply the method within their specific contexts.
- The platform serves not only as a medium for knowledge transfer but also as a catalyst for new knowledge creation and its practical application. Its interactive design enables continuous updating through user-contributed case studies, fostering learning and inquiry. In this regard, our research contributes to the discourse on how academic research can support knowledge generation and translation in the cultural sector, particularly through the use of tailored digital tools (Dameri & Demartini, 2023).

Practical Contributions

- The platform represents a pioneering effort to archive knowledge and best practices from over 200 experts, serving as a valuable guide for investors, managers, policymakers, entrepreneurs, and citizens seeking evaluation insights in the cultural sector.
- The SoPHIA for CHANGES platform may contribute significantly to the fields of cultural heritage management, impact assessment, and digital technology integration. By offering an innovative and inclusive tool for evaluating cultural projects, the platform addresses critical knowledge gaps and supports stakeholders in making informed decisions. Ultimately, the project demonstrates that digital tools, when grounded in participatory principles, can facilitate the transfer of embedded knowledge through automated processes while preserving the essential roles of human judgment, creativity, and collective engagement.

Future research could further explore the user's perception of the balance between human and digital collaboration in practice and investigate how the platform evolves as new data and case studies are integrated.

The research also acknowledges certain limitations, particularly subjective biases. To enhance reliability, preliminary findings and interpretations were validated by organizational participants not involved in the initial data collection process. This validation provided an additional layer of objectivity and reduced the influence of researcher biases (Yin, 2018).

6 Acknowledgement

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7 Ethics declaration

No ethical clearance have been required for this study.

8 AI declaration

Generative AI tools (ChatGPT) have been used to proof read standard academic English of the paper.

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Digital Healthcare Technologies and the Co-Design of Healthcare Services: A Scoping Review

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Abstract

Healthcare today more than ever is supported by technological innovation that has allowed the improvement of the standards of diagnosis and treatment but also the enhancement of the collection of anamnestic information and monitoring of the treatment path. The new digital health technologies (DHT) and the use of algorithms based on machine learning and artificial intelligence have improved the integration and analysis of data from different sources, becoming a driving force for network collaborations both for research purposes and for healthcare. Moreover, the innovative solutions resulting from the integration between technology and healthcare, aiming at strengthening health services efficiency and patient outcomes, involve the need to integrate complex technologies and specific skills in the design of instruments, devices, specialized health care services. In this context, the theme of co-designing healthcare services comes into play, and it involves a due analysis of the challenges to be faced in implementing co-design architecture.

The aim of the paper is to identify and analyse the coverage of the body of literature on the implication of DHT implementation in the co-design of healthcare services and give a trustworthy indication of the bulk of studies available as well as an overview of the key issues analysed. A scoping review is carried out to map the research done in this field and to identify critical themes and challenges.

The results of this work allow us to outline a cognitive map of the "areas of involvement" and to understand which challenges have already been faced and which are rising. Several interesting theoretical and managerial implications emerge.

Keywords: Digital Health Technologies, healthcare services co-design, scoping review

Paper type: Academic Research Paper

1 Introduction

The integration of digital health technologies (DHT) in healthcare systems has transformed the landscape of medical diagnosis, treatment, and patient care. Developments in machine learning and artificial intelligence have enhanced the capture, analysis, and application of health data from different sources to facilitate enhanced decision-making and coordination in clinical practice and research (Zhang et al., 2025; Rocco et al., 2024). These innovations offer significant potential to improve healthcare efficiency, optimize resource allocation, and enhance patient outcomes. However, the successful implementation of DHT requires a structured approach that comprehends specialized knowledge, technological capability, and insight into healthcare complexities (Kasula, 2024; Adeghe, Okolo and Ojeyinka, 2024).

In this new digital landscape, co-design of healthcare services has emerged as a crucial strategy to ensure that technological innovations align with patient needs, clinical workflows, and organizational goals. Co-design, as an open process involving several stakeholders (including healthcare practioners, technology creators, and patients), aims to create solutions to advance service development and patient experience (Wilson et al., 2024). Despite the potential benefits, there are significant challenges to the use of co-design methods in healthcare, involving the combination of advanced technologies, cross-disciplinary collaboration, and regulatory concerns.

Although research on digital health technologies and co-design in healthcare has progressed, there is a gap in the literature regarding the intersection of these two fields. Studies mostly focus on the technological advancements in healthcare or design processes but rarely explore their combined implications.

This study seeks to fill this gap by investigating how DHT influences the co-design of healthcare services, identifying key themes and challenges, and offering an overall picture of the current literature. Our research questions are: *How do scholars address the topic of DHT in the co-design of health services? Are there emerging key themes and challenges in the use of DHT in the co-design process of health services?*

We explore these aspects via a scoping review based on PRISMA standards and guidelines revised for scoping review (Page et al., 2021; Arksey and O'Malley, 2005; Tricco et al., 2018). By mapping the existing body of literature, our study provides insights on the key themes, concerns, and implications of DHT-driven co-design in healthcare.

This paper is structured as follows. The next section proposes a theoretical background. Section 3 presents the methodology, search strategy, selection criteria and data analysis. Section 4 illustrates our main results. Discussion and conclusions in the last section with some managerial and theoretical implications.

2 Theoretical background

Our analysis of the theoretical background regards two main streams of research: the role of digital health technologies in healthcare, and co-design methods applied to healthcare services. An understanding of both these fields allows to examine their intersection and to assess how digital innovations can enhance healthcare service design.

2.1 Digital Health Technologies in Healthcare

Digital health technologies involve a broad range of innovations, like telemedicine, wearable health monitoring systems, electronic health records, and AI-based diagnostic tools. Such technologies facilitate real-time health monitoring, personalized treatment plans, and data-driven decision-making, thereby improving the overall productivity and effectiveness of healthcare services (Cure et al., 2025; Tian et al., 2025). Machine learning algorithms and AI models have enhanced data processing capabilities, enabling predictive analytics to be used, automated diagnosis, and supporting more accurate patient risk analysis. Their increased adoption underscores their potential in transforming healthcare delivery and improving network collaborations among healthcare institutions.

However, the application of digital health technologies should be guided by ethical considerations. According to Hanjahanja-Phiri et al. (2024), ethical concerns for data privacy, informed consent, and the digital gap should be properly managed to avoid health inequities, to ensure responsible technology rollout, and to facilitate inclusive healthcare service design

2.2 Co-Design in Healthcare Services

Co-design, or participatory design, refers to the active participation of different stakeholders in designing healthcare services and technologies; it ensures that solutions are context specific, user-based, and address the needs of patients and healthcare professionals (Kasula, 2024). Co-design fosters a culture of collaboration in which knowledge sharing and interdisciplinarity enhance the process of developing healthcare innovations. Nonetheless, the integration of co-design and healthcare is not challenge-free, with technical feasibility straddling against user demand, managing stakeholder expectations, and health regulations (Adeghe, Okolo and Ojeyinka, 2024).

The integration of DHT in co-design activities introduces both opportunities and challenges. A good example is the co-design of digital mental health applications to foster youth, as explored in Ezimora et al. (2025), which emphasized the importance to give priority to end-users' lived experiences when designing technology. Similarly, Australian First Nations community research stresses the need for culturally specific co-design approaches that address healthcare access challenges (Khanal, 2025). Stakeholder involvement is relevant for effective and sustainable healthcare innovations development.

Ethical concerns should be integrated into co-design practices (Hanjahanja-Phiri et al., 2024), to ensure equitable and transparent public health surveillance and data-driven healthcare practices. On the one hand, digital tools enable efficient data collection, real-time feedback, adaptability of services and personalization. On the other hand, challenges such as data security concerns, need to be addressed to ensure the successful implementation of DHT-driven co-design frameworks (Wilson et al., 2024).

3 Methodology

As mentioned above, our research questions are: *How do scholars address the topic of DHT in the co-design of health services? Are there emerging key themes and challenges in the use of DHT in the co-design process of health services?*

To address these questions, the present study undertakes a scoping review methodology using the original Arksey and O'Malley framework (2005), further enhanced by Levac, Colquhoun and O'Brien (2010) and Tricco et al. (2018). A scoping review or scoping study is a form of knowledge synthesis that addresses an exploratory research question with the aim of mapping key notions, kinds of evidence, and gaps in research related to a defined area or field by systematically searching, selecting and synthesising existing knowledge (Colquhoun et al., 2014).

3.1 Search strategy and eligibility criteria

We conducted a literature search of relevant articles from Scopus, Web of Science and PubMed databases, with any limitation in the range of years of publication, in the language or the type of publication. This choice was made because the intention was to include all peer reviewed publications that, since the beginning of the implementation of DHT in the healthcare sector, have dealt with the topic, regardless of the use of a lingua franca. No screening was performed also regarding research areas, as health and technology are fields that are enriched also by studies from other disciplines. No exclusions were made based on the type of documents, as each contribution supports the formation of the scientific panorama.

This wide approach is also maintained in the string of search and in including in the selected record also the secondary sources of Scopus database. The database search terms included digital health* technolog* OR “dht” AND “co-design*” and the search strategy was adapted to suit each database.

The search results (as of April 2025) produced: 468 entries on Scopus, plus 5 secondary records; 344 entries on WoS and 327 on PubMed. The results from each database were exported to Zotero and duplicates were removed.

At the end of this first screening, the sample resulted in 621 publications.

3.2 Data charting

In the second step of our work, we used VosViewer (Van Eck and Waltman, 2010, 2017) to visualise the network of authors and co-occurrences. In this step, publications with a maximum of 25 authors were extracted and, among them, the connections between authors were identified. The total number of identified authors is n.3,505. Among them, 295 authors present at least two documents on the topic, and 28 present co-authorship links. This criterion has been used to identify the main themes harbingers of connections and, therefore, synergies between researchers. Figure 1 highlights that the set of publications is formed by a constellation of research groups, with often no connections.

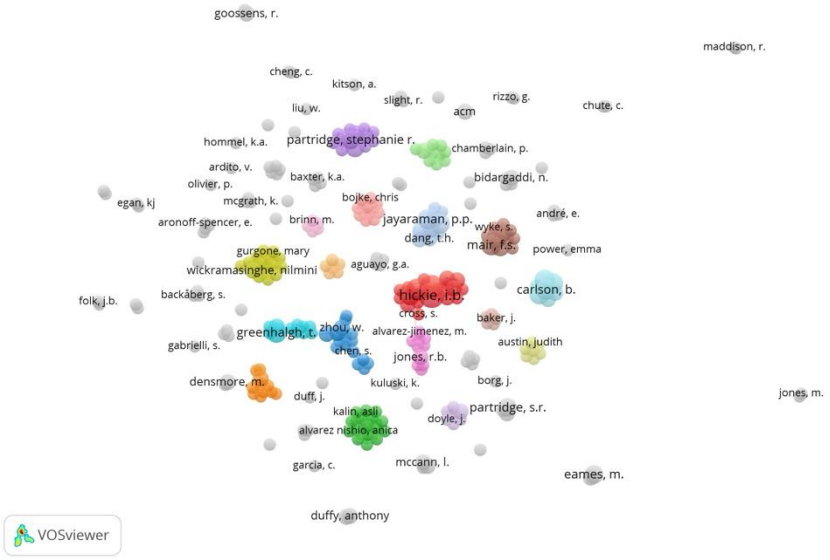


Figure 1 Constellation of authors (items:295; weight: documents; documents per author:2)

Regarding the main themes, an analysis of the co-occurrences in the titles and abstracts was carried out on the same sample. Out of 17,835 terms, those co-occurring at least 10 times were identified, i.e. 664 and, among them, those with greater relevance (60%) were 398. Of these, 46 generic terms were excluded that provide very little information and decrease the usefulness of the map, such as names of some months, and terms such as *journal, research, academic, paper, peer, period* and so on. The result is presented in figure 2, which also highlights in yellow the keywords of the most recent publications.

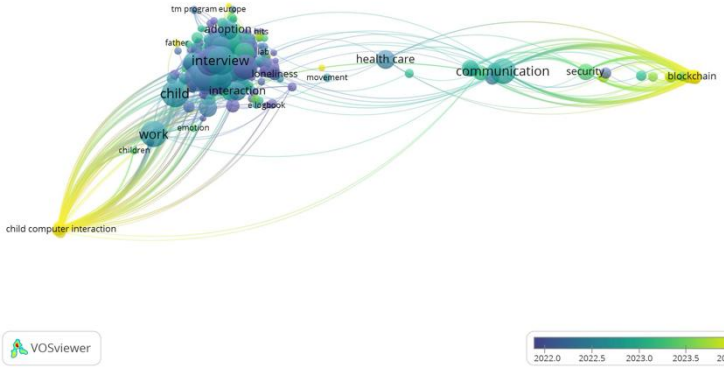


Figure 2 Overlay map of key terms (items:352; score: average publication year)

We can identify two distinct clusters: the first is focused on technological evolution and the related themes of communication and data security (figure 3); the second is focused on child and family health with particular focus on computer interaction (figure 4).

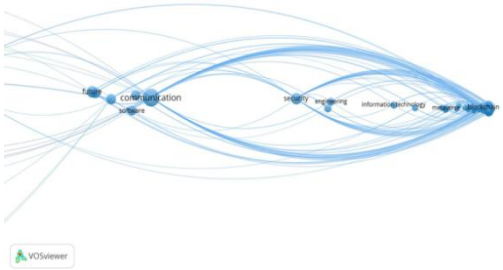


Figure 3: Cluster 1

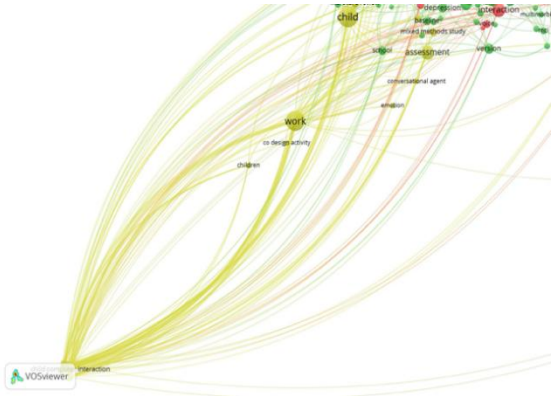


Figure 4: Cluster 2

Two other clusters, however, are strongly connected to each other and concern issues of management of healthcare processes, roles and specific diseases (figure 5)

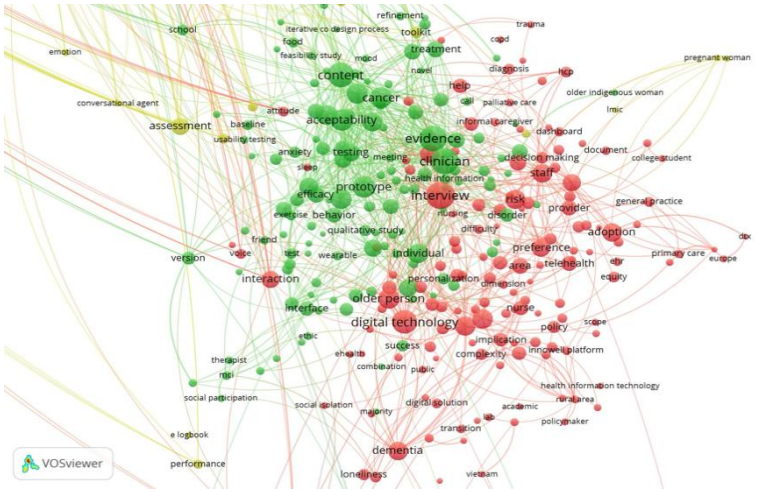


Figure 5 Cluster 3 and 4: The cohesion is based on the proximity of the keywords to each other.

4 Results

The analysis carried out has allowed us to understand how much the analysis of the implementation of DHT in healthcare co-design processes is still at an early stage. The studies that have proliferated in recent years seem strongly connected to the reference context and this is evident both from the presence of not linked constellations of scholars, and from the predominant choice of qualitative analyses (see table 1) which tend to deepen the understanding of behaviours, motivations and reactions, but have the limitation of producing results that are difficult to generalise and therefore not exportable.

Table 1: Used method, occurrence and relevance

Id	term	occurrences	relevance score	Id	term2	occurrences	relevance score2
1	interview	131	0.4227	**21**	preferred reporting item	10	24.643
2	review	86	0.5253	**22**	qualitative analysis	9	0.2986
3	focus group	60	0.3883	**23**	interview data	9	11.102
4	questionnaire	36	0.7004	**24**	mixed methods design	8	0.9009
5	qualitative study	32	0.1223	**25**	meta-analysis	8	25.676
6	systematic review	30	11.983	**26**	prisma	7	2.79
7	qualitative data	28	0.2432	**27**	implementation research	7	0.4557
8	mixed methods study	24	0.11	**28**	focus group discussion	7	0.3898
9	observation	22	0.3303	**29**	descriptive statistic	7	12.916
10	depth analysis	20	0	**30**	individual interview	7	10.981
11	scoping review	19	13.344	**31**	systematic search	7	2.116
12	pilot study	18	0.4842	**32**	participatory research	6	0.3713
13	qualitative interview	18	0.4096	**33**	interview transcript	6	19.016
14	participatory approach	14	0.7861	**34**	narrative synthesis	6	17.493
15	semistructured interview	14	0.5666	**35**	qualitative approach	6	12.668
16	mixed methods approach	14	0.222	**36**	quantitative method	5	0.6561
17	randomized controlled trial	13	0.3857	**37**	participatory design method	5	39.578
18	mixed method	12	0.138	**38**	participatory method	5	14.937
19	quantitative data	11	0.8441	**39**	qualitative feedback	5	13.743
20	narrative	11	0.5497	**40**	exploratory	5	1.985

Regarding the topics explored by the different groups, the following are of great relevance: mental health especially in young people and children (Bevan Jones et al., 2020; Hammond et al., 2021; Jones et al., 2020; Lipson-Smith et al., 2019); the health of an entire community (Henson, Chapman, et al., 2022; Henson et al., 2023a, 2023b, 2024; Henson, Rambaldini, et al., 2022); the care of older people (Bally et al., 2023; Darley and Carroll, 2022); support patients before and after surgery (Robinson et al., 2021, 2022); the support to selfcare and caregivers of cancer patient and people with dementia (Dang et al., 2021, 2023; Dang, Ludlow, et al., 2024; Dang, Wickramasinghe, Forkan, et al., 2024; Dang, Wickramasinghe, Jayaraman, et al., 2024).

Some of these topics represent strong challenges for today's society. Challenges that the correct co-design of interventions and the use of digital technologies can help to face and overcome.

5 Discussion and Conclusion

Our research develops a cognitive map of the "areas of involvement" concerning the role of DHT in healthcare and co-design methods applied to healthcare services. At the same time, some key themes, challenges and implications emerge in this field.

The mapping approach of our study highlights that in this new contest the traditional top-down decision making needs to evolve towards more network-based stakeholder interactions, with a patient-centered model and new forms of stakeholder engagement. Managers need to be flexible and collaborative with stakeholders,

invest in training approaches to develop digital skills for the successful implementation of healthcare policies. Moreover, with the increasing involvement of patients and caregivers, healthcare companies need to develop engagement strategies and implement ethical guidelines to ensure responsible DHT adoption in co-design, avoiding data privacy concerns.

Particularly, “taking a look at home”, this study can be useful for healthcare managers and policy makers to understand and act on the dynamics that are being activated in Italy with the application of the DM 77/22 for the development of proximity healthcare, which requires healthcare managers and policy makers to become increasingly familiar with the use of DHT, AI and machine-based learning in the management of interorganizational relations and partnerships for the co-design, co-management and co-monitoring of healthcare services and procedures.

In summary, the cultural and technological evolution of recent years led to an increasingly active involvement of patients, caregivers but also policy makers and suppliers of tools and devices in the care process.

6 Ethics declaration

The authors state that ethical approval was not required for this research.

7 AI declaration

The authors state that AI was not used in this research.

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Leveraging the Metaverse: A Multidimensional Approach to Knowledge Management in Project-Oriented Settings

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Abstract

Over time, the evolution of digital technologies has enabled a new perspective on knowledge as a collaborative and dynamic process, shaped through interactions among multiple stakeholders. These technologies facilitate real-time information sharing and support continuous knowledge creation and management in flexible, adaptive ways. Organizations increasingly rely on these digital tools to harness internal and external collective intelligence, fostering innovative knowledge practices. Particularly in project-oriented environments—characterized by complexity and constant change—digital platforms are essential to centralize information, promote collaboration, and enhance knowledge traceability and adaptability.
In this context, emerging platforms such as the metaverse reshape how work and collaboration occur. No longer limited to science fiction, the metaverse now provides immersive, interactive, and collaborative environments enabled by Virtual, Augmented, and Mixed Reality technologies. These digital spaces allow human resources to engage in work, learning, and social interaction in new ways. The metaverse, therefore, offers a promising environment for supporting knowledge management (KM) processes across organizations.
Despite growing interest in virtual environments for learning and communication, the implications of the metaverse for knowledge management remain underexplored. In particular, little attention has been given to how the metaverse affects the various dimensions of knowledge—from tacit to explicit, individual to collective, and from creation to application—especially in project-driven settings. This study addresses this gap by investigating the metaverse as a platform for KM, with a focus on how it facilitates the conversion of knowledge across these dimensions.
Using a qualitative methodology based on multiple case studies, the research examines how immersive virtual environments can enhance knowledge sharing, visualization, and decision-making in complex projects. Findings reveal that the metaverse enables the transition between tacit and explicit knowledge, supports real-time collaboration across distributed teams, and creates value at both individual and organizational levels. Features such as virtual prototyping, scenario planning, and real-time interaction with data and workflows improve communication, alignment, and coordination in project teams.
In conclusion, the metaverse offers a transformative opportunity to address the challenges of knowledge management in dynamic, project-based environments. This study provides insights that could be relevant to both scholars and practitioners in the fields of Human Resource Management and Information Technology.

Keywords: Knowledge Management; Human Resource Management; Digital Technologies; Metaverse; Case study

Paper type: Academic Research Paper

1 Introduction

Over the years, the widespread adoption of digital technologies has fostered a reconceptualization of knowledge as a co-created asset emerging from interactions among diverse stakeholders. Digital tools, by enabling rapid and continuous information exchange, support knowledge creation and management in dynamic and fluid forms. These technologies empower organizations to harness collective intelligence both internally and externally, facilitating novel approaches to knowledge development within organizational ecosystems. In such a context, knowledge must be effectively managed and integrated to ensure mutual understanding and practical relevance, particularly within project-oriented environments characterized by complexity, interconnection, and dynamism (Canonico and Söderlund, 2010). Getting control of multi-project organizations: Combining contingent control mechanisms. International Journal of Project Management, 28(8), 796-806.. The effective use of digital tools becomes essential to centralize information, foster collaboration, guarantee traceability, and mitigate knowledge fragmentation. Among the emerging technological frontiers, the metaverse is gaining recognition as a transformative environment where the dynamics of work and collaboration are evolving (Carter, 2022). Enabled by Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (XR)—collectively referred to as Web3—the metaverse offers a virtual, interactive, immersive, and collaborative space that can be accessed by Human Resource functions across organizations to perform tasks, engage in social activities, and facilitate

learning. Concrete implementations of metaverse-based practices are already evident in the corporate world. For example, Coty launched a virtual "Coty Campus" to upskill its 11,000 employees in digital competencies using immersive technologies (Vogue Business, 2022). Similarly, Accenture introduced the "Nth Floor," a corporate metaverse used for onboarding 150,000 employees, each equipped with VR headsets (Axios, 2022). Pfizer has also integrated metaverse solutions for internal training and team-building activities (Immersive Learning News, 2024). These examples demonstrate the metaverse's potential to transform knowledge sharing and learning processes within complex organizational settings.

Despite the growing relevance of such applications, the implications of the metaverse for knowledge management (KM) remain underexplored. In particular, a comprehensive understanding of how the metaverse affects various knowledge dimensions—such as the transition from tacit to explicit, the movement from individual to collective knowledge, and the process from creation to application—remains insufficiently addressed, especially in project-oriented contexts.

To investigate this gap, this study adopts a qualitative research design based on the multiple case study methodology (Stake, 1995; Tellis, 1997). This approach is well-suited to examining emerging and complex phenomena, as it facilitates the collection and interpretation of rich, contextual, non-numerical data (Hennink et al., 2020). It also allows researchers to capture subtle organizational dynamics, test new hypotheses, and generate novel research questions—particularly in areas such as digital transformation and the intersection of KM and immersive technologies. Through the analysis of case studies, this research explores how the metaverse facilitates knowledge management processes in project-oriented environments by enhancing collaboration, promoting the flow of information, supporting knowledge conversion, and improving organizational adaptability.

2 Theoretical background: Exploring knowledge management in the metaverse leveraging on project-oriented environments

In recent years, the organizational landscape has been profoundly transformed by the rise and widespread use of digital technologies. This shift has led to a reconceptualization of knowledge, no longer perceived as a static entity but as a dynamic and relational process, resulting from the co-creation among multiple organizational and inter-organizational actors (Piccolo et al., 2022; Iandolo et al., 2021; Schiuma et al., 2022). In this regard, knowledge is increasingly understood as articulating three fundamental dimensions (Ammann, 2009) for understanding and managing knowledge within organizations. It classifies knowledge according to its location (internal, explicit, or external), its kind (such as factual, procedural, or strategic), and its quality (including depth, structure, and modality). This model helps identify how knowledge is stored, expressed, and applied, offering a more nuanced view than traditional binary distinctions like tacit versus explicit. The literature has highlighted how digital technologies support the creation, sharing, and application of knowledge by enabling real-time and large-scale collaboration and communication (Fulk & DeSanctis, 1995; Argyres, 1999). Specifically, the integration of collaborative tools and digital platforms has enabled organizations to better leverage collective intelligence, both internally and within broader ecosystems (Bonabeau, 2009; Armenia & Loia, 2022). These technologies integrate data and knowledge from heterogeneous sources, enhancing organizational responsiveness to environmental complexity and supporting continuous learning (Yang et al., 2023). Nevertheless, KM practices face significant challenges in project-oriented contexts (Canonico et al., 2022), where temporary structures, complex stakeholder interactions, and uncertain outcomes make knowledge sharing and integration particularly difficult (Carlile & Rebentisch, 2003). In these environments, traditional hierarchical models of information management often prove ineffective due to the fragmentation of knowledge flows and the difficulty in ensuring traceability and operational coherence across teams (Waardenburg et al., 2022). Therefore, digital tools that can centralize information, enhance collaboration, ensure transparency, and facilitate adaptive work processes become essential (Muller et al., 2024).

Amid this backdrop, growing interest has emerged around the metaverse—a set of persistent, interactive, and immersive virtual environments enabled by technologies such as Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (XR), collectively referred to as "Web3" (Carter, 2022). Although originally conceived in science fiction literature, the metaverse is increasingly seen as a relevant space for interaction, learning, and collaboration within organizations (Hirsch, 2022). Several studies have acknowledged the potential of the metaverse to foster immersive and engaging experiences that support experiential learning and the co-construction of knowledge (Duan et al., 2021; Truong et al., 2021; Siyaev & Jo, 2021).

The metaverse can thus be seen as an effective platform to support conversions between different knowledge forms and to encourage individual and collective learning in complex and dynamic contexts (Loia et al., 2025). By leveraging immersive virtual environments, organizations can simulate scenarios, test operational

alternatives, and foster a deeper understanding of project goals. This leads to stronger coherence across organizational levels, reduced communication barriers, and improved alignment on deadlines and objectives (Siyaev & Jo, 2021). Furthermore, the metaverse proves especially useful for KM in processes such as onboarding, continuous training, and performance management, as it allows for the creation of contextualized and experiential learning paths (Duan et al., 2021). Furthermore, the metaverse introduces novel possibilities for developing organizational memory through immersive simulations and virtual archives. By embedding knowledge in interactive digital environments, organizations can preserve critical insights and lessons learned, enhancing long-term knowledge retention and reuse. This is particularly relevant in project-oriented contexts, where the cyclical nature of teams and tasks often hinders continuity (Argyres, 1999; Kirkman et al., 2004). As such, the metaverse can function not only as a space for real-time collaboration but also as a strategic repository of organizational intelligence, facilitating seamless knowledge transfer across projects and generations of employees (Hirsch, 2022; Fjeldstad et al., 2012).

However, the specific implications of the metaverse for KM remain relatively underexplored in academic research. Existing studies often focus on technological or experiential aspects (Loia et al., 2025) without providing a comprehensive analysis of their impact on different dimensions of knowledge and their management within organizational settings. Research is limited on using the metaverse in volatile, multi-stakeholder, project-oriented environments with temporary goals. These settings require tools and models that are highly adaptive while ensuring continuity in knowledge processes and organizational learning (Kirkman et al., 2004).

In conclusion, recent literature suggests that the metaverse represents a promising frontier for KM, particularly in project-oriented contexts. However, further theoretical and empirical work is needed to fully understand its strategic and operational implications. The main challenge lies in integrating technological potential with organizational needs by developing KM models that are flexible, scalable, and sustainable in the long term. Future studies could study integrating the metaverse into organizational processes can generate tangible benefits for KM, particularly by facilitating transitions between tacit and explicit knowledge, and by creating virtual environments where information is easily shared and contextualized (Ammann, 2009).

Table 1. From digital transformation to the metaverse from KM processes

Category	**Description**	**Key Concepts**	**Implications for KM**	**References**
Digital Transformation Tools for Knowledge Management	The integration of digital tools in organizational processes to facilitate knowledge creation, sharing, and application.	- **Collaboration Tools**: Software for teamwork and communication. - **Digital Platforms**: CRM, ERP, intranet. - **Knowledge Sharing Systems**: Document management, real-time communication tools.	- Facilitates faster sharing and access to knowledge. - Supports large-scale collaboration across teams. - Enables continuous learning and adaptation to changing environments.	Fulk & DeSanctis (1995); Argyres (1999); Bonabeau (2009); Armenia & Loia (2022); Yang, Zhang, & Pei (2023)
The Metaverse for Knowledge Management	The use of immersive virtual environments (VR, AR, XR) to enhance the management of knowledge in organizations.	- **Immersive Virtual Spaces**: Virtual environments where users interact and collaborate. - **Virtual Prototyping**: Simulating operational scenarios. - **Knowledge Co-Creation**: Collaborative, experiential learning and knowledge building.	- Facilitates transitions between tacit and explicit knowledge. - Enhances collaboration, onboarding, training, and performance management. - Develops organizational memory through virtual simulations and immersive experiences.	Carter (2022); Hirsch (2022); Duan et al. (2021); Truong, Chernova, & Batra (2021); Siyaev & Jo (2021); Loia et al. (2025)

Category	Description	Key Concepts	Implications for KM	References
Metaverse for Knowledge Management in Project-Oriented Environments	The adoption of the metaverse for knowledge management in project-driven environments characterized by temporary teams and multiple stakeholders.	- **Project-Specific Knowledge**: Knowledge is often fragmented due to the temporary nature of teams and projects. - **Dynamic, Multi-Stakeholder Environments**: Projects require high adaptability and flexibility.	- **Adaptive KM Tools**: The metaverse enables seamless integration and sharing of knowledge in complex and dynamic settings. - **Knowledge Continuity**: The metaverse can preserve and share knowledge across project lifecycles, overcoming team transitions. - **Simulated Environments**: Supports scenario-based learning and virtual prototyping for project success.	Kirkman et al. (2004); Canonico and Söderlund, (2010); Carter (2022); Canonico et al. (2022); Duan et al. (2021); Siyaev & Jo (2021); Hirsch (2022); Fjeldstad et al. (2012); Carlile & Rebentisch (2003)

Source: Authors' elaboration

3 Methodology

We employed a qualitative case study approach (Yin, 1994, 2003) to thoroughly examine the core characteristics of the phenomena under investigation. The objective of this study was to gain a comprehensive understanding of the subject matter and to clarify its complexities. The case study methodology, as defined by Eisenhardt (1989) as a research strategy focused on understanding the dynamics within specific contexts, prioritizes qualitative approaches and ongoing research (action research) to describe, explain, and illuminate the evolving aspects of organizational phenomena. This methodology is particularly well-suited for investigating phenomena that involve multi-dimensional constructs, which are not easily operationalized through quantitative variables and are not fully defined semantically in the existing body of literature. According to Yin (2009) case studies are valuable for explaining, describing, or exploring events or phenomena in their real-life contexts, particularly when exploring causal relationships and pathways, such as those associated with the organizational adoption of new technologies. Unlike other research methodologies, the case study approach is particularly effective for addressing 'how' and 'what' questions, which can, in turn, contribute to theory development or refinement. This is especially pertinent to advancing theoretical insights on the adoption of the metaverse within organizations, an area that has gained growing attention in recent academic discourse.

While the Single Case Study approach is typically employed to observe and analyze unique, specific events, this study adopts a Multiple Case Study design to investigate recurring processes and phenomena through the comparative analysis of several similar cases. The Multiple Case Study approach facilitates a direct comparison of the similarities and differences in implementation practices across various contexts and it allows for more generalizable conclusions (Eisenhardt & Graebner, 2007). Adopting a qualitative and exploratory research approach, this study analyzes three international companies that are actively applying metaverse-based technologies. To maintain confidentiality, the names of the organizations and their CEOs were anonymized. The first CEO interviewed leads a recently established startup whose explicit mission is to support companies and brands in entering the metaverse. This Italian-based metaverse agency specializes in developing immersive experiences, services, and content through Virtual Reality, Augmented Reality, and NFTs. The second CEO represents an American company composed of a team of uniquely skilled professionals with decades of experience in the design, production, and application of immersive virtual reality solutions. With deep expertise in creative design, camera technology, software engineering, and hardware integration, the company delivers high-impact VR content and applications across a wide range of sectors, including advertising, sports, education, tourism, and entertainment. The third CEO leads an Italian metaverse studio based in Northern Italy, focused on developing immersive experiences that connect people, foster learning, and enhance organizational performance. This company offers consulting, tailor-made immersive projects, and a comprehensive training and education program aligned with corporate needs.

The interviews conducted played a crucial role in supporting the analysis of the case studies and enhancing the understanding of the benefits of implementing metaverse approaches. Specifically, within five months (from November 2024 to March 2025), two researchers conducted interviews with the CEOs of selected innovative companies in the metaverse domain, aiming to explore the use of these advanced technologies in the higher education context. The interviews averaged 60 minutes in length and were structured around open-ended questions. During each interview, the primary objectives of the research were introduced and discussed with the key informants. Subsequently, the researchers posed questions relevant to the research topic. While the

interview protocol was followed, experts were encouraged to engage in a conversational exchange. To ensure consistent transcription, interviews were recorded, and notes were taken. The interview transcripts underwent a two-pass verification process. Data coding was initially conducted separately by two researchers, and then the researchers shared and integrated their analyses to ensure the highest level of reliability (Gilmore & Coviello, 1999).

Table 2. Data collection and analysis

Data collection and analysis	Description	Main contribution
Set of semi-structured interviews	Initial data gathering	Preliminary characterization
Archival analysis	Additional information concerning both the technologies and the initiatives are gathered from sources such as reports and external communication	Further characterization and categorization of the metaverse towards the organizational environment
Data analysis, reduction, display and identification of interpretation patterns	Data are put into tables, and also analyzed in light of the theoretical constructs originated from the literature review. The data analysis is conducted through a combination of sessions where each of the authors works individually and then shares his/her result with the other researchers. Interpretation patterns emerged from this process	Key analytical concepts and findings are identified
Iteration with the literature	The review of key literature allows for better grounding the theoretical foundations of our investigation into current scholarly work	Key propositions about the contribution of design-based learning in open innovation

Source: Authors' elaboration

4 Results and discussion: The metaverse as a transformative enabler of knowledge management in project-oriented contexts: a knowledge cube perspective

In analyzing the data collected, certain key aspects related to knowledge management and organizational learning within the metaverse emerged. Specifically, the analysis revealed that the metaverse plays a crucial role in reshaping organizational processes, particularly in project-oriented environments. Emerging as an integrated, immersive ecosystem built on Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (XR), the metaverse offers a new frontier for knowledge management (KM). In particular, the study found that the metaverse's impact on knowledge integration and adaptation is essential for achieving project goals, especially within environments characterized by complexity, fluidity, and innovation. This analysis utilizes the Knowledge Cube model to examine the metaverse's influence on the type, kind, and quality of knowledge in organizations engaged in complex, temporary, and multi-stakeholder projects. The results highlight how the metaverse facilitates the exchange and application of knowledge, contributing to more effective organizational learning and project success.

4.1 Type or location dimension: integrating internal and external knowledge

The Type dimension distinguishes between internal (organizational, experiential) and external (market, stakeholder) sources of knowledge. In project-oriented contexts, the ability to combine these sources in real time is critical.

In terms of the location dimension, the metaverse enables real-time externalization of internal knowledge by allowing participants to embody avatars and interact in immersive environments, effectively bridging tacit and explicit knowledge through simulations and embodied communication. This supports internalization as well, as individuals can experience knowledge-rich contexts that mirror real project scenarios, promoting deeper personal assimilation. Furthermore, the metaverse provides a collaborative virtual ecosystem that bridges internal expertise and external information. In the three multinational case studies analyzed, CEOs reported that metaverse platforms can contribute to codify tacit knowledge (e.g., expert routines, lessons learned) into visual models and immersive simulations, which could then be augmented with external regulatory data, client inputs, and competitive intelligence. This integration ensures that project teams align their decisions not only with internal goals but also with dynamic environmental requirements.

By enabling a fluid exchange between internal and external knowledge reservoirs, the metaverse supports holistic, up-to-date understanding across project stakeholders—thus enhancing agility and coordination.

4.2 Kind or content dimension: bridging propositional and procedural knowledge

This dimension refers to the differentiation between propositional knowledge ("know-what") and procedural knowledge ("know-how"), both of which are essential in executing complex projects.

Along the content (kind) dimension, thus, the metaverse fosters a convergence of propositional, procedural, and strategic knowledge. Project team members can collaboratively engage with dynamic data, perform virtual tasks, and strategize within shared virtual spaces, blending declarative facts with hands-on practice and high-level planning in a unified context. Moreover, acquaintance-based knowledge is enriched through continuous exposure to simulated project environments that replicate complex, real-world dynamics.

In the three organizations studied, metaverse-based environments were used to transform abstract guidelines into interactive simulations, allowing team members to collaboratively test procedures, rehearse operational tasks, and revise workflows in response to live project needs. These platforms fostered contextualized learning by embedding knowledge into simulated environments where it could be experienced, rather than simply documented.

As a result, knowledge transfer became more experiential, intuitive, and scalable, especially for onboarding, role adaptation, and inter-team coordination. This transformation is particularly valuable in project-oriented settings where team compositions shift frequently and procedural continuity must be maintained.

4.3 Quality dimension: enhancing validity, reliability, and relevance

The Quality dimension evaluates knowledge based on its validity, reliability, and relevance to decision-making and operational success.

The metaverse improves these aspects by enabling real-time testing of hypotheses, simulation of multiple project scenarios, and experiential validation of project strategies. In the cases examined, organizations used immersive tools to validate design assumptions, conduct virtual inspections, and evaluate stakeholder feedback within interactive 3D environments. These practices reduced ambiguity, minimized rework, and accelerated consensus-building.

Thus, regarding the quality dimension, the metaverse enhances the structure and automation of knowledge by integrating multimodal representations—visual, auditory, spatial—within cohesive virtual frameworks. It supports deeper levels of knowledge by enabling layered interactions and feedback, while also increasing generality through scalable, cross-domain applications. Consequently, the metaverse acts as both a container and a catalyst for high-quality knowledge processes, supporting reflective and collaborative practices that are critical in complex project-oriented work.

Furthermore, by logging actions and decisions in persistent virtual spaces, the metaverse allows organizations to build a traceable, auditable organizational memory—essential for learning across projects and institutionalizing best practices.

4.4 Final reflections

Viewed through the lens of the Knowledge Cube, the metaverse emerges as a strategic enabler of advanced KM practices in project-oriented contexts. Its immersive, persistent, and collaborative nature facilitates the integration of internal and external knowledge (Type), enables the transfer of both declarative and procedural knowledge (Kind), and enhances the trustworthiness and applicability of knowledge assets (Quality). As shown through the three multinational case studies, the metaverse is not simply a digital novelty but a socio-technical architecture with the capacity to transform knowledge dynamics, sustain learning, and improve project outcomes in volatile, high-stakes environments.

5 Conclusion, limitations, and future research directions

This study provides a first attempt to stimulate an understanding of how the metaverse can serve as a transformative infrastructure for knowledge management (KM) in project-oriented environments. By analyzing three case studies, the research demonstrates how immersive virtual environments support the integration, codification, and dissemination of knowledge across distributed, cross-functional teams. Interpreting the findings through the lens of the Knowledge Cube model, the metaverse is shown to impact the type, kind, and quality of knowledge by enabling experiential learning, enhancing procedural transfer, and strengthening the validity and relevance of shared knowledge assets. As project contexts become increasingly volatile, dynamic,

and collaborative, the metaverse emerges not only as a technological innovation but as a socio-technical system that reconfigures how knowledge is produced, mobilized, and retained within organizations.

From a theoretical standpoint, this research contributes to the growing body of literature on digital transformation and KM by situating the metaverse within a well-established conceptual framework—the Knowledge Cube. It offers an original perspective on how immersive technologies affect the epistemological dimensions of knowledge creation and transfer in project settings. Moreover, the study extends the discourse on knowledge management in project-based organizations by highlighting how new technologies enable not only storage and retrieval, but also contextualized understanding and tacit-to-explicit conversion. This aligns with and advances theories of socio-technical systems, organizational learning, and dynamic capabilities.

For practitioners, the findings underscore the strategic potential of adopting metaverse technologies to enhance knowledge-intensive processes in project-based work. Managers are encouraged to explore immersive environments as collaborative knowledge spaces that can enhance team alignment, decision-making quality, and project agility. Specifically, the metaverse can facilitate onboarding, cross-functional collaboration, prototyping, and experiential training—activities that are essential for maintaining project momentum and innovation. Investing in these platforms may yield long-term benefits in terms of organizational learning, memory retention, and responsiveness to change, especially in complex, multi-stakeholder project ecosystems.

This research is not without limitations. First, the qualitative, multiple-case study design, while rich in depth, limits the generalizability of the findings across all industries and organizational types. Second, the analysis is based on early adopters of metaverse technologies, which may not reflect the experiences of less technologically mature organizations. Another limitation of this study lies in its exclusive reliance on in-depth interviews with the CEOs of the selected organizations. While these perspectives provide valuable strategic insights, they do not capture the views and experiences of other key professional roles—particularly project managers—whose operational involvement and practical knowledge could offer a more nuanced understanding of how the metaverse impacts project execution and knowledge practices on the ground.

Future research could address this gap by exploring the impact of the metaverse in smaller organizations or in varying organizational contexts, providing a more comprehensive understanding of its potential across a wider range of industries and company sizes. Future research should seek to expand the empirical base by conducting longitudinal and comparative studies across different industries and cultural contexts. Quantitative investigations could also be employed to validate the effects of metaverse-based KM on project performance, innovation rates, and team effectiveness. Additionally, further exploration is needed to examine the ethical, psychological, and organizational challenges associated with immersive technologies—such as user fatigue, data privacy, and virtual behavior norms. Finally, integrating the metaverse with emerging technologies such as artificial intelligence and blockchain presents fertile ground for advancing both theory and practice in digital knowledge ecosystems.

6 Ethics declaration

Ethics approval was not required for this study.

7 AI declaration

No AI tools were used in the development of this paper.

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Knowledge Ecosystem in a Hybrid Context: Insights From a Consultancy Project

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Abstract

This paper explores the concept of knowledge ecosystem created by Treedom, a pioneering B-Lab certified startup at the intersection of technology and environmental conservation. This research aims to provide a comprehensive understanding of how organizational dimensions play a role in a knowledge ecosystem settings where multiple logics coexist. In particular, we adopt the experience of a consultancy project carried out by ALTIS Advisory[1], a consultancy spin-off of Università Cattolica del Sacro Cuore devoted to promoting sustainability in established organizations and new entrepreneurial initiatives. This empirical study was based on a qualitative investigation. We carried out the analysis iteratively using a semi-grounded approach, and our data informed the selection of theories. Three data collection techniques were used: documentary analysis, participant observation and semi-structured interviews (one of the authors was part of the consultancy team during the project). The combination of social purpose and commercial strength equips Treedom to sustain, scale, and amplify the benefits generated throughout the ecosystem. Within this ecosystem, knowledge operates as a strategic asset that underpins the shared objectives of Treedom and its stakeholders. The social-impact assessment carried out by ALTIS Advisory thus became a collective learning exercise, enabling every actor to acquire deeper insight into their own capabilities, those of their counterparts, and the project as a whole.

Keywords – Knowledge creation, Hybrid organization, Consultancy project

Paper type: Academic Research Paper

1 Introduction

This paper explores the concept of knowledge ecosystem created by Treedom, a pioneering B-Lab certified startup at the intersection of technology and environmental conservation. This research aims to provide a comprehensive understanding of how organizational dimensions play a role in a knowledge ecosystem settings where multiple logics coexist. In particular, we adopt the experience of a consultancy project carried out by ALTIS Advisory, a consultancy spin-off of Università Cattolica del Sacro Cuore devoted to promoting sustainability in established organizations and new entrepreneurial initiatives.

The main goal of the project was to realize a path aimed at establishing a model for monitoring and measuring the impact of Treedom's agroforestry projects in the world. We decided to analyse this single case study due to its market success and given the replicability of the business model, as well as its adherence to the different environmental and sociocultural contexts of the countries in which Treedom operates. Assessing and measuring impact from a holistic perspective carries several conceptual ad operational consequences (Cerchione et al., 2025). Specifically, for this startup meant changing the mainstream paradigm, thus abandoning the financial performance assessment alone in favour of a more integrated and multidimensional system of evaluating the firms' outcomes (Liute & De Giacomo, 2022). What draws attention is the need to measure how an organization's activities affect the local area and community by quantifying the importance stakeholders assign to the changes they have experienced in their own lives (e.g., Adib et al., 2021; Xie et al., 2024). The context where the consultancy project was carried out is a classical example of hybrid area, where profit and nonprofit organizations cooperate in order to put together public (or common) and private goals. Treedom as B-Corp is a typical example of hybrid organization and the consultancy projects involves different actors that could be considered as part of a hybrid context (ONG, consultancy firm, local communities, etc). Though still in its infancy—and therefore marked by a degree of conceptual fluidity—this emerging field is rapidly gaining traction and holds exceptional promise, positioning hybrid organizations as one compelling arenas for future research (e.g., Cornelissen et al., 2o21; Vakkuri et al., 2021). Our aim is to give an insight from a knowledge ecosystem perspective. The rest of the paper is organized as follows: in the next section we introduce the

[1] *For more information on the consultancy firm, please visit the following website: https://www.altisadvisory.com/home/*

concepts of hybrid context. After a methodological section we present the case study; the last section discusses the main results and conclusions.

2 The hybrid context

The topic of hybrid organisations has been receiving renewed attention and research recently, due to the escalating social, environmental and economic challenges that organisations worldwide are facing (e.g., Stubbs, 2017). Therefore, there are several sources claiming that the number of hybrid organisations is growing (e.g. Haigh et al., 2015; Ratinho & Bruneel, 2024). Hybrid organizations are a compelling subject of study—not only for the distinctive structures they adopt, but also for their capacity to forge relationships and build collaborative networks that underpin their survival and entrepreneurial success (e.g., Cantele et al., 2023; She & Michelon, 2023). They offer an important contribution to society by fostering new models of local development and by nurturing multi-stakeholder organisations that drive territorial transformation through innovative, participatory, and adaptable solutions (e.g., Esposito et al., 2025; Wang et al., 2020). From this point of view, therefore, the boundaries between the profit and non-profit, public and private, work and voluntary dimensions appear increasingly blurred, in the face of the emergence of 'hybrid' actors, in which value is created, retained and shared through new and multiple forms of production by traditional businesses, non-profit organisations and public administrations (Boni et al., 2025). Therefore, the need to bring together the social and entrepreneurial perspectives requires the adoption of a 'hybrid' approach, capable of reconciling two visions that are only apparently different, the social and non-profit and the entrepreneurial and profit-driven business (Riso et al., 2024). The social, environmental and economic challenges open up new spaces of opportunity for the hybrid model (Holt & Littlewood, 2015), whose rise in contemporary society is explained by scholars with reference to an increasing prevalence of pluralistic and complex institutional environments (Pache & Santos, 2010; 2013; Thornton & Ocasio, 2008). A key aspect of this process is the involvement of actors from civil society and the third sector. These actors act as catalysts for new local initiatives and bottom-up experimentation, contributing to the transformation of social protection systems by providing more adaptable and contextualised responses than traditional public policies. Private actors and so-called social entrepreneurs also play an important role, introducing new ideas and investments that can support social innovation initiatives (Ghisellini et al., 2024). B-Corps are a classical example of hybrid organizations, as stated by Boni et al., 2025: 4440): "*…organizations part of the B Corp movement adopt a positioning in the hybrid spectrum that is closer to fully commercial for-profit organizations. B Corps are purely for-profit firms, which adopt a hybrid structure given by their social or environmental mission, having no legal obligation of profit retentions (Cao and Gehman 2021)*".

3 Methodology

This empirical study was based on a qualitative investigation (Yin, 2003). We carried out the analysis iteratively using a semi-grounded approach, and our data informed the selection of theories (Van Maanen et al., 2007). Three data collection techniques were used: documentary analysis, participant observation and semi-structured interviews (one of the authors was part of the consultancy team during the project).

Management scholars have increasingly adopted action research as a methodology to validate various research outcomes (Eden & Huxham, 1996). The capacity of action research to establish connections between theory and practice renders the results of action research potentially pertinent, comprehensible, and compelling to both practitioners and academic audiences (Baskerville, 1997). The methodology of action research is characterized by its dual objective of engaging in action and generating knowledge and theory pertaining to action (Coughlan & Coghlan, 2002; Erro-Garcés & Alfaro-Tanco, 2020). The involvement of the (client) organization in the study enhances the trustworthiness and reliability of the findings due to the collaborative nature of the analysis (Argyris & Schön, 1991).

4 The Treedom case: main findings

Founded in Florence in 2010, Treedom is the first organisation that allows people to plant trees from a distance and follow online the story of the project they will contribute to. Thanks to its business model, Treedom is a Benefit Corporation and has been a member of the Certified B-Corp since 2014. Since its foundation, more than 4,000,000 trees have been planted in Africa, Latin America, Asia and Italy, directly involving local organisations and farmers who, in their daily work on the individual seedlings, virtually connect with businesses and people globally through the 'adoption' system. All trees are planted directly by local farmers and help to produce environmental, social and economic benefits in full adherence to all dimensions of sustainability and fostering the 17 SDGs of the United Nation 2030 Agenda. By planting trees alone, Treedom contributes to the

achievement of 9 of the 17 Sustainable Development Goals. Treedom has chosen to undertake, with the scientific and methodological support of ALTIS Advisory, a path aimed at creating a model for monitoring and measuring the impact of its agroforestry projects in the world. A model that is characterised by its replicability over time and its adherence to the different environmental and socio-cultural contexts of all the countries in which Treedom operates. The results are therefore in line with the positive outcomes demonstrated by similar case studied on hybrid organizations, thus fostering the idea of the improvement of social and environmental impacts through its operations (e.g., Ghisellini et al., 2024; Boni et al., 2025). On top of the substantial impacts, measuring them means changing the financial- performance-led assessment paradigm, in favour of a more holistic system of evaluating firms' managerial practices and outcomes. Emerging evidence suggests that attention is now turning—cautiously—to measuring how an organisation's activities influence its territory and reference community, while also estimating, with due care, the weight each salient stakeholder group places on the changes it perceives in its own daily life (Riso et al., 2024). Measuring impact is tantamount to activating a dialogue: it is a choral work that combines expertise and scientific method with knowledge and experience of the specific context (Adib et al., 2021; Xie et al., 2024).

In line with the principles of Social Value's social impact assessment (Esteves et al., 2012), the methodology adopted mainly refers to the Theory of Change (Rajagopalan & Spreitzer, 1997) and follows a stakeholder-driven approach, with several successive steps. The fundamental characteristic of this methodological process lies in the fact that, through the involvement of relevant stakeholders, it is possible to collect their opinions and experiences regarding the pathways of change, determining the outcome dimensions to be attributed to Treedom's different activities, in an attempt to curb bias and self-referentiality that could arise from questions selected in desk mode. The theoretical framework of the Theory of Change is based on the observation that the construction of impact is realised through causal links and gradual and successive changes over time: thanks to the activities provided, the beneficiary at first expands his or her theoretical knowledge, subsequently increases his or her skills or begins to plan the implementation of previously developed theoretical knowledge and finally implements change through a modification of his or her behaviour (Rajagopalan & Spreitzer, 1997). Consequently, the indicators are defined around these elements of change: in some cases, they seek to assess the theoretical knowledge arising from the satisfaction generated by the intervention; in others, the skills developed within relationships; and in still others, the behavioural shifts and the resulting enhancement of the beneficiary's psychosocial well-being. Selecting the impact stakeholders constitutes the first necessary step in initiating the evaluation process and underscores its collective character, since it involves, from the very outset, the active participation of Treedom's representatives. The representatives were invited to fill out a structured questionnaire with the aim of identifying that specific subgroup of stakeholders on which it is possible to detect and measure the actual change that occurred between before and after the activation of agroforestry projects. The measurement process therefore advances along this dialogic track, blending desk research with the direct engagement of the heads of local organisations in Kenya, Madagascar, and Nepal through open-ended interviews. These meetings sought to explore how Treedom's projects relate to - and affect - each stakeholder group, with the specific aim of identifying:

- distinctive features of Treedom's activities and relationships;
- perception of the effects generated by Treedom's activities;
- possible contribution of parties external to Treedom to the generation of the effects identified above;
- potential risks and negative impacts.

The data that emerged from the survey phase made it possible to outline the impact dimensions, i.e. the areas in which Treedom's activity generates a change in stakeholders, declined in one or more impact indicators/themes.

5 Discussion and conclusions

Treedom's philosophy is to build sustainable ecosystems by directly engaging thousands of farmers worldwide. By covering the upfront costs of tree-planting, it enables them to develop resources that, over time, both safeguard the local environment and create ongoing income streams. The approach goes well beyond a simple financial transfer: it becomes an opportunity to share knowledge, establish production methods and processes, heighten awareness of local resources, and plan medium- to long-term programmes for growth and stewardship. The impact assessment is configured as an essential strategic tool for analysis and planning available to the organisation since it allows to deepen the knowledge of its ecosystem, identify projects related to its mission and business vision and make their management efficient in terms of resources, improve its accountability and structure an effective flow of communication to stakeholders in terms of enhancing the results achieved. The impact assessment conducted with Treedom therefore aims to determine how and to what

extent the agroforestry projects represent, for all stakeholders involved. Treedom finances projects in rural communities in the south of the world and also carries out projects with a strong social value in Italy. The first step is the training and financing of the communities involved in the projects, obtaining extraordinary results in terms of their own empowerment. The trees and their fruits belong to the farmers, allowing them to diversify and supplement their income and in some cases to launch micro-entrepreneurship initiatives. Financing the planting of new trees with Treedom serves to support the trees' care in the first years of their life, when they are not yet productive in terms of fruit.

In this sense, Treedom and all the stakeholders involved could represent a peculiar example of knowledge ecosystem. As stated by Öberg and Lundberg (2022; 293) "The concept of knowledge ecosystems has gained traction in recent research, with such ecosystems focusing on the knowledge-enhancing activities (knowledge sharing, knowledge development) rather than business interactions of a defined number of parties organised around a specified knowledge search or practice." Van der Borgh et al. (2012) describe the traditional knowledge ecosystem as a network of knowledge intensive firms and other interdependent actors whose effectiveness and efficiency rely on being geographically close to one another. More recent work argues that, while proximity can still facilitate knowledge creation, modern digital coordination tools now enable such ecosystems to operate across substantial distances, so co location is no longer indispensable (Still et al., 2014). In fact, Treedom demonstrates that spatial proximity has become largely incidental: its stakeholder constellation spans multiple continents, yet effective coordination and oversight are secured through sophisticated digital platforms, illustrating the expanding strategic reach of technology in sustainability-oriented, tech-enabled enterprises (Leitão et al., 2024). Although knowledge ecosystems were once dominated by universities and public research institutions, recent scholarship recognises that profit-seeking organisations also make substantive contributions to knowledge generation and diffusion (van der Borgh et al., 2012). The present case extends this insight, showing that a distinctive hybrid, for-profit enterprise such as Treedom can assume a central orchestrating function within the ecosystem, mobilising dispersed capabilities and aligning heterogeneous stakeholders around shared innovation trajectories. The ecosystem derives its cohesion from a clearly shared mission and values. One local partner remarked:

"Treedom is our main partner; its goals are identical to ours. Because it is both our principal collaborator and funder, we dedicate roughly 90 percent of our efforts to working with Treedom."

Beyond this strategic alignment, Treedom and its stakeholders explicitly view education as a pivotal lever for enhancing local livelihoods. As a representative of another partner organisation explained:

"What Treedom is a taking care and we talk many times and they also did training to us is first of all the importance of the nursery. The importance of doing the training to the farmers and the importance to do the follow up of the plantation. This is this is what we agree with Treedom".

Although Treedom's social mission remains paramount, its profit orientation is equally instrumental to the initiative's overall success. As a certified B-Corp that operates for profit, Treedom brings both a disciplined, professional approach to project management and the financial capacity that allows local partners to expand. The resulting growth is evident in the figures reported across the network. As one partner observed:

"This year we are increasing the number of trees we plant, reaching many more farmers, and expanding into additional districts."

In short, the combination of social purpose and commercial strength equips Treedom to sustain, scale, and amplify the benefits generated throughout the ecosystem. Within this ecosystem, knowledge operates as a strategic asset that underpins the shared objectives of Treedom and its stakeholders. Among the six overarching goals Treedom articulates—promoting education, cultivating awareness of social and environmental sustainability, disseminating sustainable agronomic practices, and investing in research and development—each is fundamentally knowledge-based. This orientation is reflected in key performance indicators reported in the social report, such as "variety of new cultivation tools and technologies introduced and adopted" and "extent of farmers' understanding of the environmental effects of their agricultural activities." The interviews conducted during the project reinforce this centrality: local partners see themselves as primary conduits for transferring knowledge to their communities, and all of them run tailored training programmes. The social-impact assessment carried out by ALTIS Advisory thus became a collective learning exercise, enabling every actor to acquire deeper insight into their own capabilities, those of their counterparts, and the project as a whole. Ultimately, Treedom's hybrid status - as a profit-making B-Corp with a pronounced social mission - creates the conditions for a robust knowledge ecosystem: commercial resources fund continuous capacity-building, while socio-environmental commitments keep knowledge creation and diffusion squarely focused on community development. Knowledge is a specific dimension of the system, because it is considered a fundamental "asset" to get Treedom and stakeholders' goals.

6 Ethics declaration

The authors confirm that this study has been conducted in compliance with ethical standards.

7 AI declaration

The authors did not use artificial intelligence tools to develop the article.

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Digital Transformation and Organizational Change in the Public Sector: Evidence from a Case Study

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Abstract

In the management of public sector, digital transformation is supposed to lead to new and better service delivery by increasing efficiency and transparency, and by improving accountability. The complexity of the transformation process increases, in terms of actors involved and effects on working practice and way of interacting and offering services. The pressure is more and more on the response to the changing needs and aspirations of the society, supporting self-governance for local communities to be able to govern themselves with no or little interference from government. This process is still ongoing, requiring a great effort from academics and practitioners to understand different dynamics. This paper copes with a case of organizational change "triggered" by a process of digital transformation. We are specifically engaged in the change management of INPS concerning the potential development of a technological application for managing disputes under the jurisdiction of the Court of Auditors, with the objective of monitoring the recovery of state damages caused by the fraudulent actions of public employees.

In this setting, the focus is on the analysis of the reengineered business process in the effort to analyse jointly the digital transformation project and the organizational change. The paper may be located within emergent digital transformation literature.

Keywords: digital transformation, organizational change, public administration

Paper type: Academic Research Paper

1 Digital transformation in a public context

Digital Transformation (DT) is an expression related to a variety of organizational contexts and perspectives, both private and public, and it often used interchangeably with terms such as digitization, digitalization (Mergel et al, 2019). According to Otia and Bracci (2022), concepts such as digitization and digitalization underline technology, while DT is more concerned with strategy and the overall business model.

A stream of the literature has analysed the opportunity to deploy new technologies to stay competitive, in order to improve the efficiency through standardization (see, for example, Andal-Ancion et. al, 2003). A different stream has defined digital transformation as a way to rebuild business models following the needs of customers, by using new technologies. In this sense, digital transformation is a process of change that concerns innovation, the way in which it is implemented in the organization, and how people involved react to it. According to Luna-Reyes and Gil-Garcia (2014) in the public sector it is possible to identify two different transformations: (1) the transformation of internal processes, and (2) the transformation of the relationships between governments and other social and political actors (institutional transformation).

In the public domain, the concept of digital transformation seems more and more controversial, due to different kind of technological initiatives taken to overall the typical weakness of public administrations. According to Denhardt and Denhardt (2015), the processes of digital transformation in public administration are "complex" phenomena that involve the redesign and management of organizational structures, dynamics, processes, practices, tools and organizational and inter-organizational relations of the stakeholders involved.

Moreover, in the public sector arena, another expression is adopted to represent the digital transformation process. Many scholars refer to digital government or digital governance (Eom and Lee, 2022) as the way governments are trying to find innovative digital solutions to social, economic, political and other pressures, and how they transform themselves in the process (Janowski, 2015:221). What is interesting is the way to look at digital government as a process in action and in continuous evolution. Janowsky (2015:221) identified four different steps: Digitization (Technology in Government), Transformation (Electronic Government), Engagement (Electronic Governance) and Contextualization (Policy-Driven Electronic Governance).

The four-stage model is defined on whether the transformation has an internal or external impact and if transformation is or not related to a specific context in terms of sector or geographical space (country or city).

Moving from a step to another, the complexity of the transformation process increases, in terms of actors involved and effects on working practice and way of interacting and offering services. While in the first step the main focus is on technology, in the fourth step the pressure is on the response to the changing needs and aspirations of the society, supporting self-governance for local communities to be able to govern themselves with no or little interference from government Janowsky (2015:232).

This process is still ongoing, requiring a great effort from academics and practitioners to understand different dynamics.

As stated by Andersson et al. (2022:2) "digital technologies come with a logic of standardisation, rationalisation, efficiency, text-based communication and quantitative judgements (Petrakaki and Kornelakis, 2016); a logic that fits work that is purely calculative rather well. Other types of public sector work, for example social work, comes with a logic of situation specific practices, care, knowledge creation, qualitative judgements, and involves the careful and slow interaction with citizens, that embody and to some extent negotiate, the formal rules of the bureaucracy".

Even if it is not clear at all what digital transformation is and what it is not, the analysis of the allows the understanding that is a process that involves strategical and organizational dimensions and that is characterized by change.

In our perspective, such process is dynamic and context specific, so our approach is not finding the way fails or gets success, but understanding which organizational dynamics take place in a digital transformation experience. As stated by Andersson et al. (2022:2) "*The dynamics of how these changes come about in practice is however not known, and there is thus a need to look more carefully at how the work of public administrators is transformed though the development and implementation of automated technologies*".

Managerial literature, in fact, has mostly focused on understanding what are the critical success factor enabling digital transformation in the public sector (Gideon Mekonnen, 2019), and, except for a few of contributions (Mergel et al., 2019), has not yet investigated the different practices adopted in diverse public administrations following an interpretative perspective. In public administrations, practices are different because take place in specific settings, cultures, and legal frameworks. In this perspective, our work aims to investigate how to implement a digital transformation process in a unique context of public administration.

This article examines a case of an organizational change hypothesis initiated by a digital transformation process. We concentrate on overseeing the initial phase of the transformation launched at Inps, specifically the development of a technology application for managing public accounting loss litigation, which is intended to monitor the recovery of the State's credit.

In this setting, the focus is on the analysis of the reengineered business process in the effort to analyse jointly the digital transformation project and the organizational change. The paper may be located within emergent digital transformation literature.

In the remaining part of the contribution, after an analysis of the concepts of digital transformation, and a brief description of the intervention of digital transformation, we will analyse the methodologies of intervention designed and being implemented for the management of this complex case of organizational change.

2 Research method

This empirical study is grounded in a qualitative research design, employing an iterative and semi-grounded approach to data collection and theory building. Theoretical constructs were progressively developed and refined in the light of the empirical material, following a predominantly inductive logic. The investigation is based on a single-case study, selected purposefully for its relevance in illustrating the complexities of organizational transformation and digital innovation within a public administration setting (Yin, 1994). As Dyer and Wilkins (1991:614) emphasize, the in-depth examination of a single case may serve to uncover novel theoretical relationships and challenge established assumptions.

The selected case involves Italian National Social Security Institute (INPS), Italy's primary public social security institution, which administers a wide range of welfare programs including pensions, unemployment benefits, and income support. With a workforce of over 25,000 employees and a highly decentralized organizational structure, INPS represents one of the largest public institutions in the country and serves as a paradigmatic context to explore public sector digitalization initiatives. The case is situated within a broader organizational change program undertaken by INPS, aiming to modernize its internal processes and service delivery through digital transformation strategies.

This case study examines a specific intervention proposal inside INPS, in which a mid-level public employee recognized significant deficiencies in the ICT dimension of the overall process of overseeing and reclaiming fines related to convictions levied by the Court of Auditors on personnel accountable for administrative offences.

The data were collected through a triangulated methodology incorporating document analysis, participant observation, and semi-structured interviews. The documentary corpus included strategic plans, organizational charts, internal reports, and digital transformation roadmaps. These materials allowed for a comprehensive understanding of the structural and procedural aspects of the change initiative, including timelines and change management tools. Participant observation constituted the principal source of data. It was conducted over a six-month period, with the embedded researcher attending regular project meetings, and intra-departmental coordination sessions, to analyze all administrative, legal, economic, and technical complexities associated with the management and oversight of the phenomenon.

Observations were recorded in the form of detailed field notes, which captured both formal decision-making processes and informal interactions among project stakeholders. In the six months (October 2023 - March 2024) in which the data collection phase was carried out. During the data collection phase, approximately 30 comprehensive interviews were conducted with key informants, including several employees from the Directorate of Information Technology and Innovation (DCTII) and public officials directly engaged in the pilot phases of the digital services redesign.

The analysis of the current situation was essential, involving the mapping of primary and support processes, the identification of the requisite legal framework that must be adhered to and serves as the legal prerequisite for transformation, the recognition of critical issues or areas for improvement, the exploration of solutions, and the subsequent organic redesign of the process utilizing enabling digital technologies. The presence of elevated critical metrics indicated the need and opportunity to enhance the overall effectiveness and efficiency of the operation. The comprehensive effort aimed to discover operational criticalities, thereby determining the essential functionalities of the application and its practical feasibility, particularly regarding interoperability. The endogenous factors (internal context) and exogenous variables (external context) were delineated. The analysis of several variables has facilitated the formulation of an IT strategy conducive to attaining the established objectives. The meetings discussed the technical design intervention, which may encompass both a phase of mere digital transition and a following one of genuine transformation.

The analysis proceeded in multiple iterative stages. Initial memos were produced based on preliminary coding of interview transcripts and observational notes by the proficient regional team, which proposed the investigation and identification of key concerns to formulate the change plan.

The study team deliberated on these documents to develop common interpretative frameworks. The current process was subsequently built using a combination of inductive and deductive coding strategies based on the recommendations generated by the Team, highlighting essential characteristics such as coordination mechanisms, interpretative challenges, and technical affordances.

Triangulation was systematically applied, comparing the insights from interview data with field observations and documentary evidence. Particular attention was paid to the discursive and practical manifestations of knowledge sharing across professional boundaries—e.g., between IT personnel and frontline administrators—emphasizing how new tools and routines were localized, adapted, or resisted. The analytical approach has been informed by theoretical frameworks from organizational change and public sector innovation studies: the proposed digital transformation seeks to enhance the performance of both individual and collective processes, in accordance with the objectives established by the legislator.

In the final phase, the data were synthesized into a narrative that elucidates the unfolding of the transformation process at INPS, highlighting the critical tensions and enabling factors that shaped its trajectory.

3 Case study

3.1 The INPS "Co.Ded" Platform Initiative

In Italian National Social Security Institute (INPS), digital transformation is of paramount importance for achieving organizational efficiency and reinstating citizens' confidence in institutions. Conte and Solari (2023) emphasized that the INPS scenario exemplifies not merely a technology advancement but also a fundamental transformation in organizational structure, propelled by the integration of three strategic pillars: digital innovation, technological modernization, and human capital enhancement. The axes of change are located within wider theoretical frameworks, including the New Public Management paradigm (Pollitt et al., 2007), the digital-era governance model (Dunleavy et al., 2006), and the developing concept of public value creation, which

collectively necessitate a reconfiguration of bureaucratic models towards participatory, adaptive, and user-centric governance forms.

In this context, INPS serves as a distinctive area of study for understanding how digital transformation, combined with a strategic initiative to engage internal stakeholders via viral and distributed change mechanisms (Solari, 2016), can enhance both the operational efficiency of a public institution and its ability to create value within intricate socio-technical systems.

The digital transformation at INPS was not only a technological replacement, but a purposeful and systematic organizational redesign based on participative principles and underpinned by a cohesive change management framework. Understanding that the efficacy of digital tools is influenced by organizational culture and human behaviour, INPS implemented its transformation through four interconnected workstreams: (1) articulating vision and strategic intent, (2) cultivating strategic human capital, (3) systematizing institutional knowledge, and (4) innovating work modalities, including the structural integration of smart working (Solari, 2023).

The comprehensive digital transformation initiative of INPS in our case study primarily centers on the creation of a technological application for overseeing public accounting loss litigation, intended to track the restitution of State damages arising from the fraudulent actions of public employees.

3.2 The assessment of the as-is system

The current process of public accounting loss is characterized by high procedural complexity, low technological support, and a reliance on manual tasks. Activities span multiple organizational levels (territorial, regional, central) and involve several functional domains (disciplinary offices, legal services, accounting units).

The administration of fiscal damage (“danno erariale”) recovery at INPS is fragmented across several dimensions:

- procedural dimension: the process is delineated into distinct phases—reporting misconduct, commencing disciplinary proceedings, escalating legally to the Corte dei Conti, and ultimately enforcing financial recovery—each managed by a separate organizational unit without centralized coordination;
- technological dimension: diverse software environments (e.g., SAP, ARCA, "Recupero Indebiti," S.G.D. platform - document management, RIAF, Reduced and Disjoint Payments, PUNTO FISCO, PDND) operate in isolation, lacking systematic interoperability. Essential data elements, like case status, recovery amounts, and regulatory deadlines, necessitate manual extraction and re-entry across systems, thereby amplifying inefficiencies and heightening the organization's vulnerability to data loss or misreporting.
- geographical dispersion: accountability for implementation is distributed across regional, central, and local offices, each possessing varied competencies and interpretative latitude regarding defined protocols.

The as-is situation reported an organizational misalignment, in which structure, processes, and information systems are not cohesively arranged.

A significant aspect of the status quo is the excessive dependence on human interaction. The complete workflow, encompassing damage assessment and the commencement of recovery operations, is conducted manually by individuals possessing extensive tacit knowledge. The lack of process automation implies that: the precision of data is contingent upon the specific competencies and diligence of personnel; employee turnover, subjective judgment, and knowledge silos compromise process consistency; compliance risk escalates, when legally mandated deadlines (e.g., annual reporting to the Corte dei Conti) may be overlooked due to excessive workload or coordination deficiencies.

The impetus for transformation is not only efficiency-driven but normative: INPS, as a major national welfare institution, operates under increasing scrutiny regarding public value, equity, and digital maturity. The proposed transformation—conceptualized as both a technological intervention and an organizational redesign—therefore becomes essential not only for performance improvement but for institutional accountability and resilience.

3.3 Business process reengineering and digital enablement (to be)

The digital transformation program implemented by INPS was based on the foundation of Business Process Reengineering (BPR) (Hammer and Champy, 1993). The program sought to completely rethink the process for executing and monitoring financial recovery associated with public employee wrongdoing, rather than simply digitizing current procedures. The transition involved a fundamental shift from a disjointed, manual, and human-reliant process to a cohesive, automated, and digitally traceable system.

In the development phase of the digital transformation proposal, the goals and project objectives were delineated, with the latter being more explicit and specific, as they concentrate on the precise final outcomes

to be attained upon project completion. The work under review was assessed for adherence to the S.M.A.R.T. methodology (Specific, Measurable, Achievable, Realistic, and Time-bound).

The Process Card – Critical Process Profile was employed to elucidate the purpose of the process, defined as its final output. This tool facilitated a concise and detailed identification of the service recipients, the expectations to be fulfilled, the functions to be executed, the reference standards, and the contribution to the internal customer.

The subsequent phase involved the hierarchical decomposition of the process, progressing from macro-activities to elementary activities, which represent the optimal level of disaggregation necessary for a comprehensive description of the process activities, following a top-down methodology; the selected instrument for this decomposition was the Work Breakdown Structure (WBS).

The Work Breakdown Structure (WBS) for elementary activities was developed, delineating the precise level 2 activities to which I allocated each process actors, specifying their related roles, responsibilities, and qualities.

The access control model matrix delineates access rights for each role, facilitating access regulation and restricting information knowledge to only what is essential for executing requisite job responsibilities.

This ensures a high level of security and protection for the information and data entered in the INPS application.

The shift from the "as-is" to the "to-be" configuration was formulated within a holistic framework. The newly developed digital infrastructure, termed "*Contenzioso Danno Erariale Dipendenti (Co.Ded*)", aims to replace the existing fragmented and document-centric methodology with a platform that can manage the complete end-to-end procedure. The architectural redesign was guided by principles of modularity, interoperability, data integrity, and role-based access control, along with the core elements of the Italian Codice dell'Amministrazione Digitale and the European Interoperability Framework (2017). The system was conceptualized to act as a centralized, secure, and interoperable application for managing litigation-related procedures at INPS.

The objectives were mainly to enable automatic assignment of recovery procedures based on territorial jurisdiction, ensuring real-time traceability, integrating access controls and role-based functionalities to produce automated reports for both internal governance and external judicial authorities.

The use of a process-oriented methodology will facilitate a distinct delineation of process boundaries, identifying the initiating and concluding events (i.e., receipt of the final ruling by the Corte dei Conti and closure of the recovery file), the principal responsible entities (notably the Disciplinary Proceedings Unit—UPd) and regional teams, and the essential outputs (such as official notifications, structured reports, and procedural updates to oversight bodies). Internal stakeholders anticipated enhanced timeliness, procedural transparency, data accessibility, and the eradication of superfluous manual activities.

The platform architecture was designed in accordance with the concepts of platform thinking, as defined by Gawer and Cusumano (2014). The Co.Ded will serve as a digital nexus that connects with established corporate systems, including SAP for payments, RIAF for preventive enforcement actions, and the S.G.D. document management platform, facilitating semantic and procedural interoperability across functions. This integrative architecture will enable real-time data synchronization, timely state credit recovery efforts, automatic task distribution based on jurisdictional criteria, and a cohesive audit trail that complies with cybersecurity norms and public accountability.

A key characteristic of the Co.Ded platform proposal is its ability for sophisticated automation. The system independently will produce procedural documentation, including official warnings, responsibility assignments, and annual reports for the Corte dei Conti. It will also encompasse a notification engine that detects procedural bottlenecks and dispatches notifications to the accountable units. In subsequent generations, the platform may integrate artificial intelligence modules—such as chatbots for user support or case-based reasoning systems that suggest actions based on past data—thereby evolving into a more intelligent and adaptive process architecture.

The project, upon implementation, should be organized into several phases: initial feasibility assessment, system design and prototype, pilot implementation, nationwide rollout. The allocation of roles among functional units was identified, thus ensuring project governance and reducing role ambiguity—termed "accountability vacuums" by Scott and Davis (2007) in complex bureaucracies.

Importantly, the design of Co.Ded was not solely focused on technical capabilities but sought to augment institutional capability. By integrating decision logic into the system, INPS can institutionalize implicit knowledge, diminish reliance on individual expertise, and enhance resilience against people turnover, regulatory changes, or procedure intricacy.

Moreover, the platform will guarantee complete adherence to legal regulations pertaining to administrative processes, privacy, and public financing. The platform will provide strong safeguards against data loss, unwanted access, and information imbalances that have traditionally affected document-heavy public sector settings.

The Co.Ded platform will signify a technological advancement of the procedural and institutional framework overseeing a vital function inside INPS. It indicates a transition from human-centered coordination to digitally mediated governance, providing an exemplary framework for other public administrations aiming to synchronize digital transformation with organizational efficacy and legal responsibility.

The Co.Ded platform aims to significantly enhance the operational performance of INPS in managing financial damage recovery. Expected benefits include reduced processing times, increased transparency, higher legal compliance, and improved coordination among departments. Moreover, the system's modular structure allows for scalability and potential reuse in other public agencies facing similar challenges.

The platform is designed not only as a technical solution but also as a driver of an olistic organizational change, fostering a culture of digital innovation, interdepartmental collaboration, and data-driven decision-making. Its implementation aligns with broader policy goals of modernization, accountability, and digital sovereignty in the Italian public sector.

4 Discussion and conclusion

The deployment of the Co.Ded platform at INPS signifies not merely a technology enhancement; it embodies a significant shift in organizational culture and the institutional frameworks that dictate public sector operations. Although the platform will enhance efficiency and automates processes, its most profound effects lie in the symbolic and cognitive transformations it initiates within the business. The project serves as a model for how strategically integrated digital technologies can transform the normative frameworks, practices, and identities that define bureaucratic systems.

Historically, public administrations have exhibited a culture of procedural formalism, wherein legitimacy is rooted in rigorous compliance with defined regulations rather than in output-oriented or value-driven reasoning. The implementation of a platform such as Co.Ded, which reconfigures responsibilities, automates compliance functions, and links remote organizational units, breaks this balance and fosters a more procedural, integrated methodology to administrative chores. Employees are now accountable for contributing to a comprehensive process regulated by common metrics, digital traceability, and procedural transparency. The platform will implement a transition from task-oriented to process-oriented thinking, as articulated by McCormack and Johnson (2001). The transition necessitates a significant cognitive restructuring of work processes. Prior to the digital intervention, staff workers were indoctrinated into a segmented perspective of their duties, frequently restricted to the boundaries of their administrative silo. The new system requires them to align their actions with a comprehensive organizational framework, acknowledging the interdependencies that govern the entire damage recovery process.

The digital transition has also engendered new professional jobs and hybrid competencies. With the blurring of lines between legal-administrative functions and digital system management, new roles have evolved, including digital process coordinators, data integrity officers, and compliance analysts possessing digital proficiency. These roles function at the intersection between conventional knowledge and the demands of platform governance, necessitating both technical skill and the ability to manage organizational complexity. The organizational structure progressed towards more horizontal coordination, collaborative decision-making, and distributed responsibility—characteristics linked to the post-bureaucratic organizational paradigm (Heckscher & Donnellon, 1994).

The Co.Ded platform will enhance internal trust and external credibility by rendering processes visible, verifiable, and legally valid, particularly in the eyes of jurisdictional and supervisory entities like the Corte dei Conti. The digital transformation serves as a catalyst for institutional renovation, allowing the organization to align its bureaucratic responsibilities with modern demands for efficiency, transparency, and responsiveness.

Recent contributions to the study of organizational change in the public sector have emphasized the centrality of participation, trust, and symbolic alignment in sustaining digital transformation. Solari (2023), drawing on his experience with INPS, conceptualizes transformation as a participatory process grounded in the co-construction of meaning among internal stakeholders. His account shifts the analytical focus away from purely technical or top-down approaches, suggesting that durable change arises through the legitimization of new practices within the cultural and narrative fabric of the institution. In this view, digital infrastructures—while necessary—do not themselves generate transformation unless embedded within a broader context of relational trust, and adaptive learning.

The INPS and Co.Ded platform case may will provide a useful empirical contribution to the literature on digital transformation in public administration, especially when analysed through strategic and sociotechnical frameworks. Digital transformation, as posited in recent research (Vial, 2019; Verhoef et al., 2021), beyond the mere implementation of new technologies; it constitutes a significant and systemic alteration that redefines an

organization's value proposition, operational capabilities, and institutional logic. The change inside INPS signifies a major transition from technology serving as a supportive tool to technology acting as a catalyst for structural reconfiguration.

The proposal corresponds with the fundamental principles of digital transformation—customer focus, data-informed decision-making, cross-functional integration, and modular platforms—while tailoring them to the specific limitations and responsibilities of a public sector environment. By substituting disjointed, paper-based methods with a digitally connected system, the organization will transform the focus of value creation from isolated administrative tasks to collective, traceable results contained inside a unified technical framework.

This case exemplifies how public organizations can strategically orchestrate digital transformation to resolve structural inefficiencies and enhance public value creation.

By aligning technological interventions with organizational restructuring, regulatory frameworks, and user requirements, the INPS will establish a foundation for a reproducible model of process innovation inside the Italian public administration.

5 Ethics declaration

Authors did not need ethical clearance for the research referred to in this paper.

6 AI declaration

Authors did not use AI tools in developing the paper.

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Untangling Proof-of-Concept Projects: A Systematic Literature Review

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Abstract

The past decades have witnessed a surge of research interest in academic engagement, largely focusing on academic entrepreneurship. However, academics also engage through other forms of knowledge application, broadly referred to as academic engagement. Drawing on the domain of academic engagement, in the last years arise an innovative form named Proof-of-concept (PoC) characterized by the interaction between many actors coming from different contexts, as researchers, professionals, managers and entrepreneurs.

This paper aims to review and analyze organizational mechanisms in proof-of-concept projects (PoCP). It develops the theoretical literature on PoC, particularly in the context of university-industry relations in academic engagement. Through a systematic literature review (SLR), the paper examines 85 published articles.

Findings show that literature on PoC is fragmented; various definitions of PoC are used and different typologies of PoC need the adoption of different organizational mechanisms. The research identifies areas that are currently underdeveloped. While the knowledge management framework is lacking in the reviewed literature, our findings highlight a growing interest in this area.

Recent studies reveal a call from the literature to identify knowledge integration issues and mechanisms for successful PoCP in academic engagement field. This paper provides an overview of the current state of research on PoCP and outlines new research opportunities, focusing on underexplored areas within the academic engagement field.

Keywords: Academic Engagement, University-Industry relations, Proof-of-concept, Project, Knowledge integration, Digital transformation

Paper type: Academic Research Paper

1 Introduction

Over the past decades, research into academic engagement increased. Most of this research studied academic entrepreneurship (Agrawal, 2001), which includes patenting, licensing, joint ventures, spin-offs and so forth. However, there are other ways for academics to ensure application of their knowledge. These forms of interaction have been referred to as academic engagement (Perkmann et al., 2013; Perkmann et al., 2021).

Considering this assumption, we will focus on the form of Proof-of-Concept Projects (PoCP) characterized by the interaction between many actors coming from different contexts, as researchers, professionals, managers and entrepreneurs (Maia and Claro, 2013; Hayter and Link, 2015; Battaglia et al., 2021; Tolin and Piccaluga, 2024).

The starting point is that most of the studies in this field have so far concentrated on project inputs – such as funding – and project outputs – such as number of spin off or licensing. However, the key fact that collaboration in PoCP is a practical application of knowledge is early stage. Though research shows that the need of integrate specialized but complementary knowledge is a major topic in project environment (Tell, 2011), moreover in interdisciplinary setting as PoCP.

The paper aims to contribute to the theoretical development in the field PoCP as privileged observation point of university-industry relations in academic engagement.

In this light, we are leaded a systematic literature review (SLR) on this specific topic as part of an ongoing research project targeting *"Open the black box of proof-of-concept projects: challenges and opportunities"*.

Drawing on previous works that offer a theoretical conceptualization of PoCP process (Zaitsava et al., 2024; Tolin and Piccaluga, 2024; Battaglia et al., 2021), we asked *what PoCP is, how PoCP unfolds, and which organizational conditions affect the knowledge integration process in PoCP*. We focused on these research questions because they matched the impressions gained from our initial reading and because they fit with the aspired review scope (Snyder, 2019).

The structure of our paper is as follows. We first briefly describe the current state of the literature on proof-of-concept, to provide central concepts, search terms and definitions. Next, we present our systematic literature review on PoCP and knowledge integration in academic engagement domain. Finally, we discuss the emerging themes and derive conclusions, limitations and suggestions for future research.

2 Background

According to Perkmann and Walsh, academic engagement processes are based on "high relational involvement in situations where individuals and teams from academic and industrial contexts work together on specific projects and produce common outputs" (Perkmann and Walsh, 2007, p. 263).

In order of this, a growing number of universities have recently introduced Proof-of-Concept Project (PoCP) with the goal to bring research-based inventions (RBI) close enough to a commercialization point or raise interest of investor to growth a spin off. PoCPs support the commercialization of emerging technologies enhancing the creation of synergies between university and industry.

2.1 PoC as a U-I research project: characteristics and mechanisms

A Proof of Concept (PoC) is generally understood as a test or a preliminary demonstration aimed at validating the feasibility of an idea or technology during the early stages of development or adoption. More in-depth, particularly when integrated into formal pathways, PoC have an operational nature that compels universities institutions and research groups to transfer knowledge concretely both within and outside organizations.

Therefore, we can refer to PoC as a project, specifically U-I research project.

Projects are comprised of teams consisting of diverse specialists with varying skill sets, brought together to achieve a specific goal or complete a defined task within established constraints of cost and time (Canonico et al., 2013; Canonico et al., 2017). As temporary systems, projects have a transient and multidisciplinary nature, features that fundamentally contribute to shaping the possibilities as well as the obstacles for generating knowledge and accumulation of learning (Sydow et al., 2004).

In light of this, on one side PoCP can act as a platform capable of facilitating collaboration opportunities between academic institutions and the external world, promoting the sharing of knowledge, research partnerships, and mutual enrichment through the exchange of innovative ideas (Battaglia et al., 2021).

On the other, PoCP requires an heterogenous background of specialist expertise that is essential to achieve outcomes but needs to integrate complementary knowledge and often very different approaches to work. This tool tackles these dimensions by integrating knowledge from different scientific disciplines, on the one hand, and from research and practice, on the other hand.

2.2 Knowledge integration processes in U-I research project

Knowledge integration is particularly challenging in context as project where individuals deal with multiple ideas, values, and perceptions (Gugerell et al., 2023).

The theory of knowledge integration emphasizes the economic value of specialization and the effectiveness of integration. In other words, competitiveness depends on the diversity and strategic value of specialized knowledge, as well as an organization's capacity to integrate the knowledge in an effective manner. Therefore, knowledge integration focuses on "combining specialized but complementary knowledge" (Tell, 2011, p.27) with the purpose of taking advantage of actors' differentiated knowledge bases and complementarities.

The different forms of knowledge present within a PoCP represent an important resource for problem-solving. However, this raises the question of how – in spite of or because of these differences – knowledge can be exchanged and ultimately integrated in such a manner as to achieve common goals. This challenge calls for the use of appropriate mechanisms such as innovative and emergent technologies that can facilitate knowledge integration practices.

Understanding how knowledge is integrated across disciplinary boundaries in a PoCP context is a pressing issue within the area of management and organizations (Battaglia et al., 2021; Tolin and Piccaluga, 2024). The process of knowledge integration is key to the added value of PoCP. Therefore, in PoCP context, a focus on understanding the organizational conditions affect the knowledge integration and the strategies and mechanisms to achieve this, also taking in the account the impact of digital transformation, becomes relevant (Canonico et al, 2017).

Starting from this background and from the main contributions of the managerial literature on PoCP (Battaglia et al., 2021; Zaitsava et al., 2024; Tolin and Piccaluga, 2024), our paper aims to highlight a literature research gap and provide valuable insight for scholars for further exploration of undersized topics, such as the knowledge integration process in PoCP.

3 Methodology

As the research background revealed the novelty of the PoCP phenomenon is observed, the methodological solution is to explore the phenomenon adopting a literature review choosing a systematic approach.

Systematic literature review (SLR) begins by (1) establishing the search question and determining the parameters for a literature search, then (2) conduct the search using keyword searches and screening to produce the "content" to be analyzed, then (3) analyse and synthesize the content, and (4) report and discuss the results (Tranfield et al., 2003; Snyder, 2019). To explores the growth of the topic, we performed a search using SCOPUS database that was particularly chosen for its comprehensive coverage across the area of management research (Williams et al., 2021). Systematic reviews improve the quality of the review process and outcome by employing a transparent, reproducible procedure.

We followed the steps outlined in the latest *Preferred Reporting Items for Systematic Reviews and Meta-Analyses* - PRISMA statement, a guideline designed to help authors transparently report why the review is done, what the authors do and what the authors find (Mishra and Mishra, 2024). PRISMA statement are widely accepted guidelines for performing SLR in healthcare research (Cook et al., 1997) but in recent years its wide use in management research is debated among scholars (e.g. Mishra and Mishra, 2023). In recent years some authors agree with the use of a protocol as PRISMA extending it to specific objectives reviews of management literature (e.g., Fan et al., 2021; Crawford and Jabbour, 2023; Graessler et al., 2024).

3.1 Data collection and inclusion criteria

The first step was to identify studies focused specifically on proof-of-concept. To do so, we conducted a search in the SCOPUS database using the keyword "proof-of-concept" and its variations such as "proof of concept" and "proof of concepts". The initial search was conducted without any limitations or restrictions on publications, with the first phase of the database search conducted on data (112.642 items).

The second step involved focusing on the concept of university-industry relations. Selecting search terms proved to be more complex because of the variety of terms used for describing these collaborations.

We initially established a search string with the term "industry", "business", "academic", "university" to capture any variations of the keywords (5908 items).

We then narrowed down the review by using three specific search terms.

The first was "project", a valuable tool for understanding how the university-industry relations happen.

The second term was "program", a precise description of the domain in which these collaborations emerged.

The third term was "process", a term that allow us to identify works describing this iterative dimension of this relations.

In addition, the names of researchers who had published a substantial amount of work in the field and were frequently cited by other authors were also used as keywords in the search (e.g Battaglia D., Zaitsava M., Tolin, G.)

Records (2618 items) were included in our final set if they met four inclusion criteria:

1. Language: only studies published in English were included.
2. Year of publication: we selected records published in the period > 1999 and < 2025
3. Document type: we selected records limited to articles
4. Subject area: we selected records limited to Business, management and accounting and Economics, econometrics and financing areas

After the screening stage, paper abstracts and contents were fully analysed, to exclude any articles that did not consider proof-of-concept from the managerial perspective. This left a total of 139 articles that were selected and coded along predefined themes on university-industry relations in PoCP common themes drawn from literature (Battaglia et al., 2021; Tolin and Piccaluga, 2024).

The literature review identified the scarcity of research on applying knowledge management to the context of PoCP (85 items).

This process is detailed in the Figure 1.

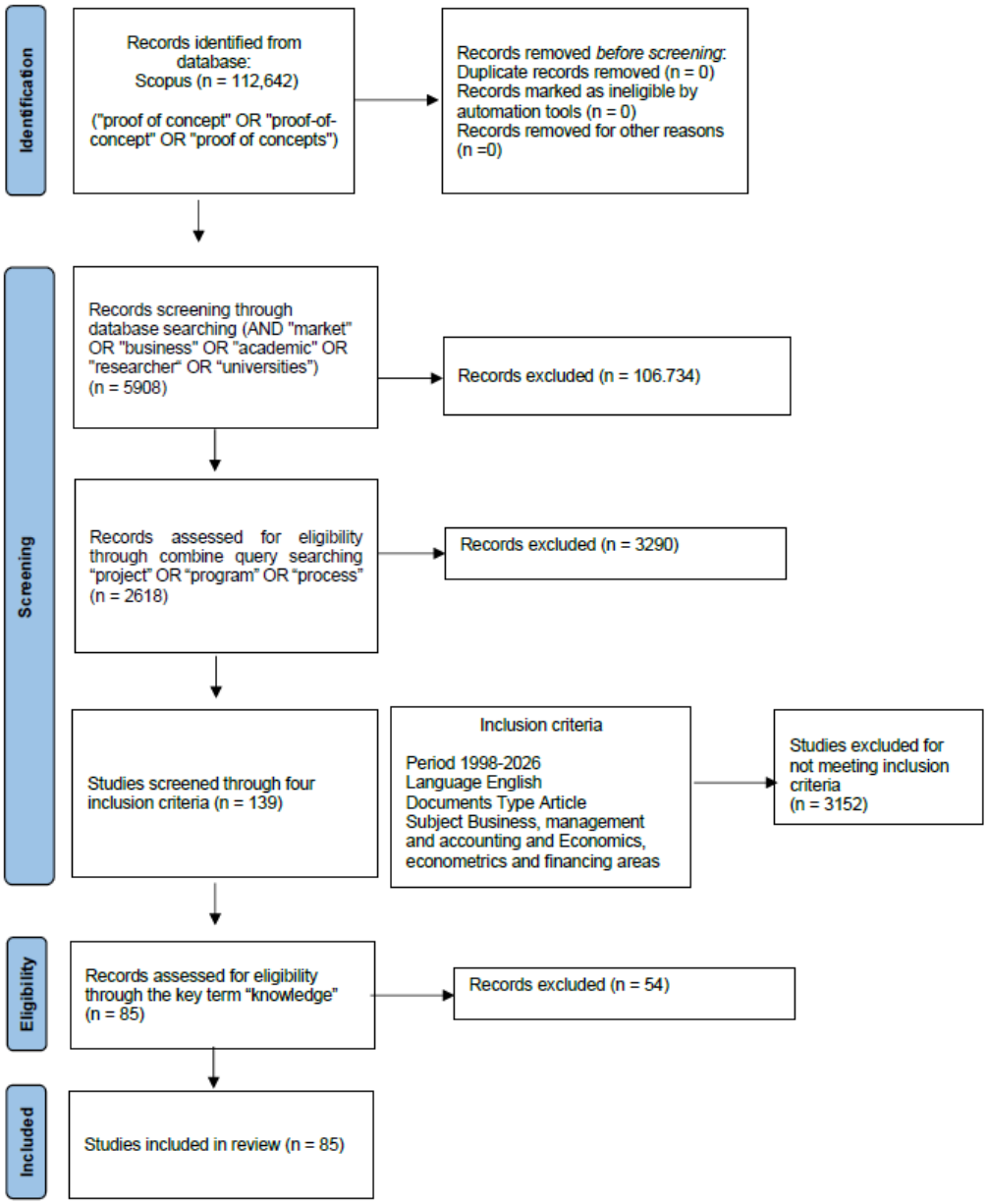


Figure 1 – PRISMA-chart of the literature selection procedure
Source: authors' elaboration

4 Overall findings

The next section explores the evolution trend of publications, the author demographics regions of research and the focus subject area of the studies.

4.1 Descriptive characteristics of the studies

In Figure 2 we presented the trend of publications analyzed over the two past decades and in the Table 1 the annual distribution of articles.

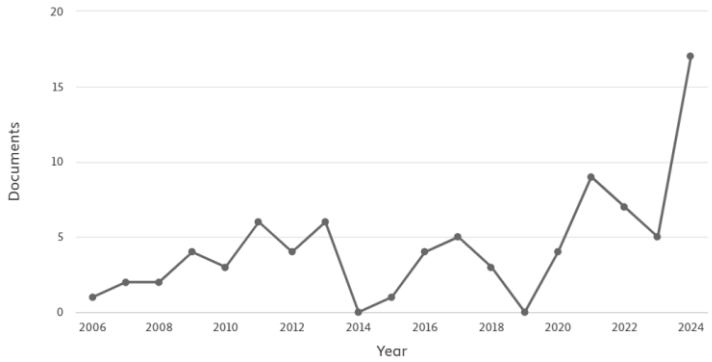


Figure 2 – Evolution in the number of articles
Source: own study based on data retrieved from Scopus database as of 20 February 2025

Table 1 – Annual distribution of publications

Year	Documents
2025	2
2024	25
2023	8
2022	14
2021	13
2020	7
2019	2
2018	7
2017	5
2016	5
2015	2
2014	2
2013	7
2012	4
2011	8
2010	5
2009	6
2008	8
2007	3
1999-2006	6

Source: own study based on data retrieved from Scopus database as of 20 February 2025

In the Figure 3 and 4 we presented respectively the subdivision by geographical area of the authors and by subject field.

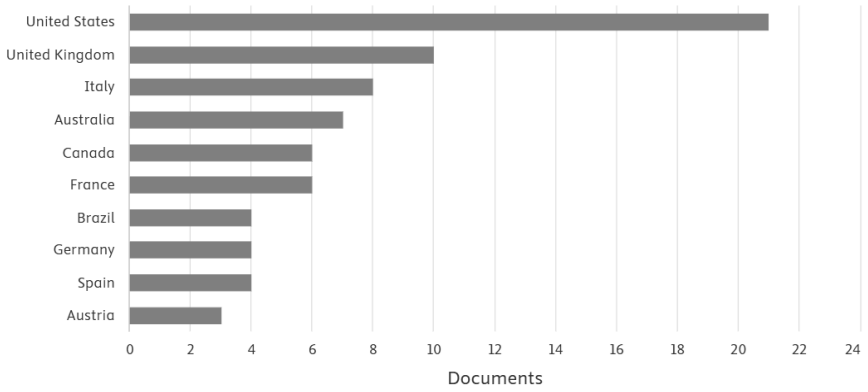


Figure 3 – Documents by country
Source: own study based on data retrieved from Scopus database as of 20 February 2025

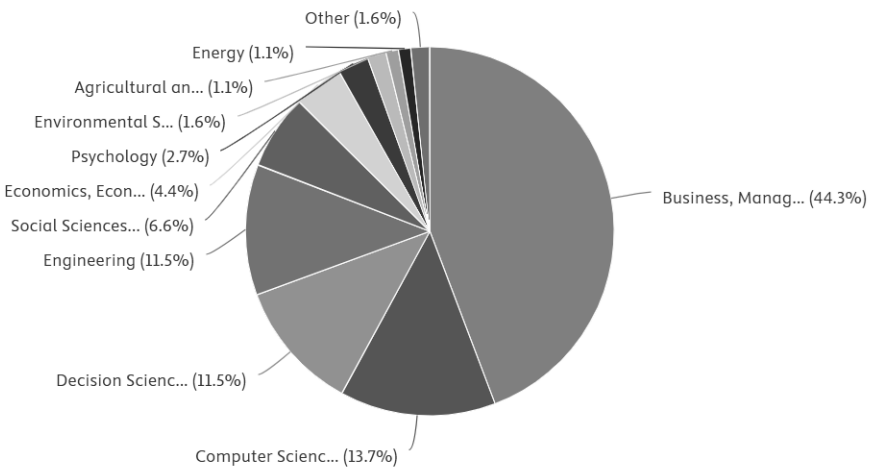


Figure 4 – Documents by subject area of the authors
Source: own study based on data retrieved from Scopus database as of 20 February 2025

4.2 Insight from the studies

This section aims to discuss the main findings to answer *what PoCP is* and *how PoCP unfolds* analysing frameworks used and definitions of PoC studies.

To conduct this second phase of analysis, we used keywords' co-occurence analysis to identify how articles related to each other through a visual relatedness. The processes of (1) creating keywords network and (2) clustering keywords was supported with the use of the VOSviewer application, developed by the Centre for Science and Technology Studies of the University of Leiden, the Netherlands (Van Eck and Waltman, 2009).

(1) Regard the keywords network, once the file was uploaded to VOSviewer, a threshold was set relating to the minimum number of citations for the keywords equal to 5, identifying 60 keywords reported within the co-occurence map.

Figure 5 shows a network map that visualized both the frequency of keyword occurrence and patterns of co-occurrence.

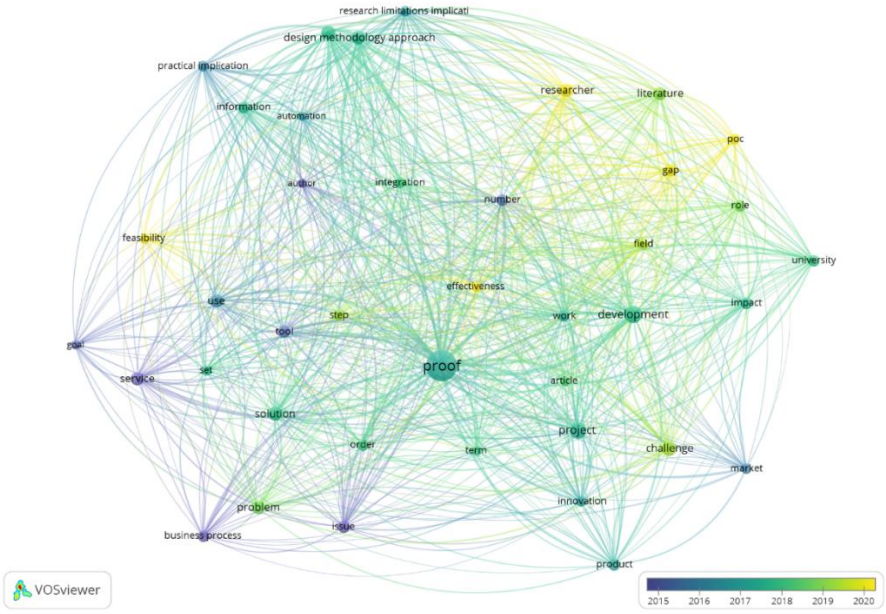


Figure 5 – Emerging themes from network map
Source: own study based on data retrieved from Scopus database as of 20 February 2025
and analysed with the use of VOSviewer

The creation of the map was functional to the analysis of the cluster of documents identified by the search in SCOPUS, which cover a time horizon from 1999 to 2024 but as can be seen from the map the keywords that meet the 5-citation threshold are included in documents between 2012 and 2024.

(2) Regard clustering keywords, as can be seen from the Fig. 6, scientific research in recent years has touched on various themes and topics and it is particularly simple to identify the trend it has followed. The papers comprising the research sample provide 1242 keywords. The co-occurrence should include 59 high-frequency keywords with the minimum number of occurrences equal to 3. However, in the sample there are 59 keywords meeting this threshold. In the map, the size of nodes manifests the frequency of keywords' occurrence, while lines show relationship among keywords.

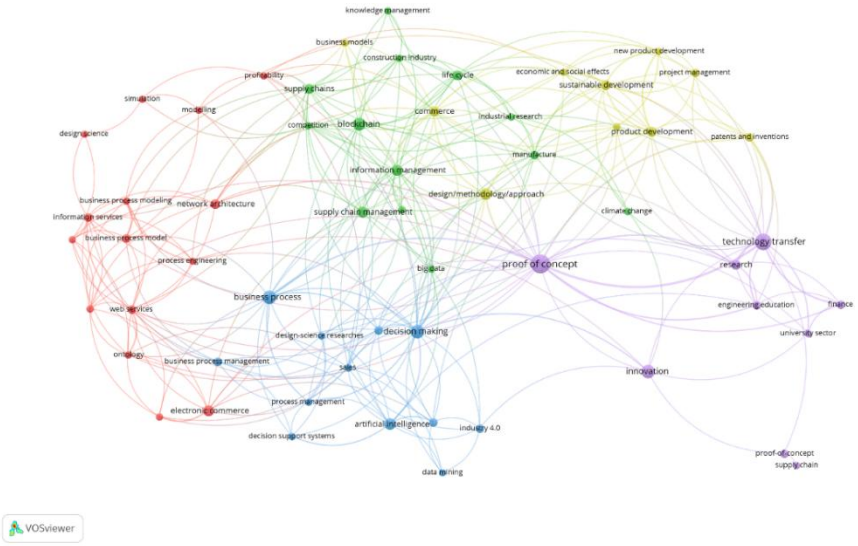


Figure 6 – Co-occurrence of high-frequency keywords
Source: own study based on data retrieved from Scopus database as of 20 February 2025 and analysed with the use of VOSviewer

With the use of this method, identified high-frequency keywords can be categorized into 5 clusters corresponding to the areas of research interest in the field.

Cluster analysis of high-frequency keywords is presented in Table 2.

Table 2 – Clusters of high-frequency keywords related to a PoCP

Cluster	Items	High-frequency keywords	Issue
C1	15	web services (15), information services (12), business process model (10), electronic commerce (10), network architecture (10), ontology (11), user interfaces (11), e-business (9), profitability (9), service-oriented architecture (9), business process modelling (8), process engineering (8), modelling (7), simulation (4), design science (3)	Business process management
C2	13	supply chains (18), manufacture (17), life cycle (16), blockchain (15), information management (14), competition (13), supply chain management (12), construction industry (11), big data (9), industrial research (9), maintenance (9), knowledge management (5), climate change (5)	Knowledge and information management
C3	12	decision making (25), business process (18), automation (16), sales (15), artificial intelligence (13), design-science research (9), machine learning (9), process management (8), business process managing (8), decision support system (6), data mining (5), industry 4.0 (7)	Decision making management
C4	10	business models (6), commerce (16),design/methodology/approach (14), economic and social effect (11), new product development (10), patents and inventions (9), product design (10), product development (15), project management (7), sustainable development (12)	Project management
C5	9	proof-of-concept (27), technology transfer (16), research (10), innovation (8), engineering education (6), finance (5), proof of concept (3), university sector (5), supply chain (1)	Innovation management

Source: own study based on data retrieved from Scopus database as of 20 February 2025 and analysed with the use of VOSviewer

The emerging topics within the research field dealing with the issues related to a PoCP were identified also with the use of VOSviewer. The findings from the analysis are presented in Figure 7 that shows the temporal keyword co-occurrence analysis tracking the frequency of occurrence of keywords in conjunction with the publication dates of the documents.

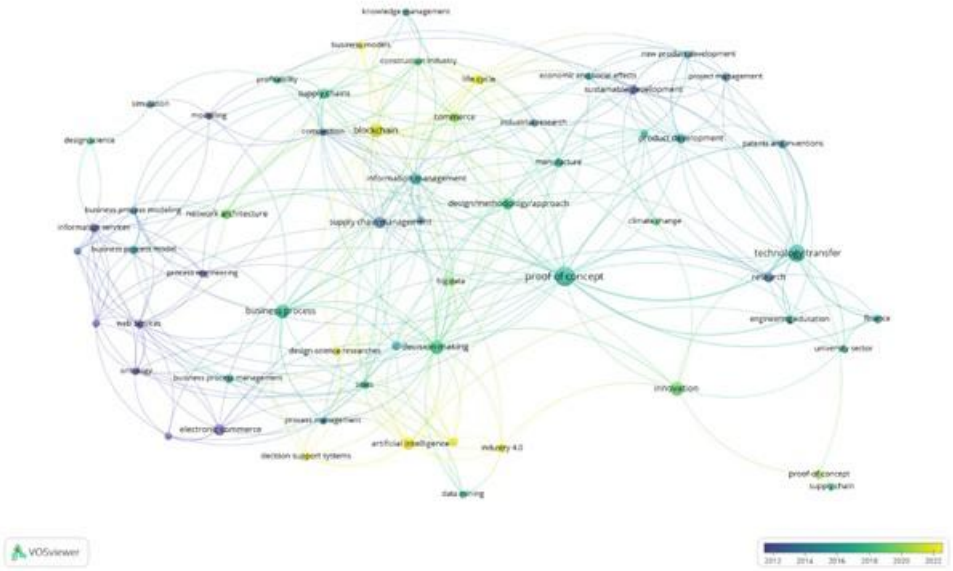


Figure 7 – Emerging keywords (overlay visualization)
Source: own study based on data retrieved from Scopus database as of 20 February 2025
and analysed with the use of VOSviewer

The analysis indicates the keyword on the yellow points and arcs representing hot topics attracting a growing attention of the research community in recent years as the zoom of the overlay visualization show in Figure 8.

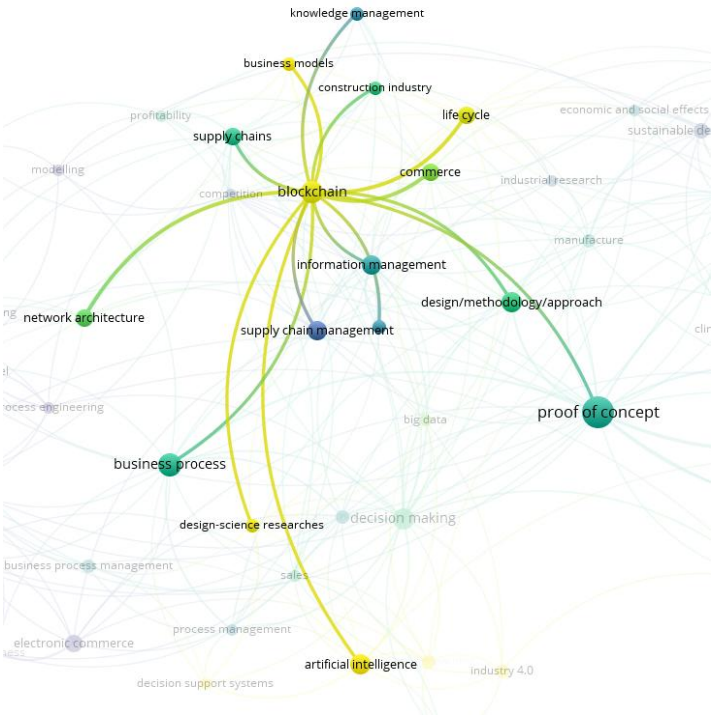


Figure 8 – Emerging keywords in the 2021-2024
Source: own study based on data retrieved from Scopus database as of 20 February 2025
and analysed with the use of VOSviewer

Summing up, the study has identified and discussed five key frameworks associated with the concept of a PoCP: (1) business process management, (2) knowledge and information management, (3) decision making management, (4) project management, (5) innovation management.

Moreover, emerging, three areas attracting a growing attention of the research community in recent years have been enumerated:

1. tool area, as blockchain, artificial intelligence and life cycle of new technologies and innovation product;
2. process/project area, as information management, knowledge management, business process management;
3. method area, as design/approach/methodology and design-science researchers.

This section improves the analysis of the areas of implication of the findings.

5 Discussion

This section aims to discuss the overall findings to answer *which organizational conditions affect the knowledge integration process in PoCP* addressing several implications in the following sub-sections.

5.1 Implication 1: what is PoC? All sets are not equal

According to Battaglia et al. (2021), PoC is described as a "black box", a process that is clearly in terms of input and potential output, without knowledge of its internal mechanisms. In terms of definitions, on one hand, PoC is widely used as tool to test a new concept at early stage of innovation; on the other hand, PoC is also a research and methodological approach used to develop knowledge.

In this sense, a PoC can be identified as a "project", and these perspectives may open many possibilities of future research avenues.

5.2 Implication 2: only some aspects are investigated

The review highlighted that almost all papers are about innovation management. Though the major issue in PoC is the integration of many types of data from many different sources. There are significant technical and cultural obstacles to the practical realisation of data integration which is a prerequisite for collaboration projects as a PoC. They, by definition, bring together multiple university and industry communities, who are most often not familiar with the data handling conventions of their counterparts.

This challenge open to investigate how to train young researchers to address the specific challenges of collaborative projects, including effective communication across disciplines, engagement with non-academic stakeholders, and complex project and knowledge management.

5.3 Implication 3: there is a lack of a common definition of PoCP as a knowledge integration process

The review has revealed a lack of a knowledge management perspective in the framework models of the papers. While most articles touch on topics and variables related to knowledge mechanisms, the recurring frameworks often focus on open innovation and digital transformation.

This gap suggests that exploring knowledge processes in PoC could pave the way for future research opportunities.

5.4 Implication 4: common elements that affect the integration of knowledge in PoCP

The most insightful papers, from a knowledge perspective, highlight that conducting PoCP involves overcoming various barriers inherent in the setting. There are often tensions between disciplines, also terminology differences between sectors are a barrier. Often integration between more related disciplines can be more difficult than between more widely separated disciplines, both because of approaches and expectations and because of institutional barriers.

Moreover, a co-production of knowledge is required, and different actors develop characteristic language, criteria and ways of working that demand integration of project activities.

The Table 3 summarizes the details emerging from the review linked to the focus topics of knowledge literature (e.g. Grant, 1996; Enberg et al., 2006; Foss et al., 2010) to open issues for a future research agenda on PoCP.

Table 3 – PoCP as KI process: focus topics and main variables analysed of the *implication 3* and *4*

PoCP as KI process: focus topics and main variables analysed		
Focus	***Details***	***Quotations***
Interaction to support PoCP	Social interaction to support/influence the knowledge process	Passarelli et al., 2018, 2020
	Governance to support/influence the knowledge process	Rasmussen and Sørheim 2012 Brem and Radziwon, 2017
	Methods and strategies of interaction	McAdam 2006; McAdam 2010 Jones et al., 2023
	Interaction barriers	Passarelli et al., 2018, 2020
Human factors that affect the PoCP	Personal motivation, skills and absorptive capacity, personal knowledge, decision-making capabilities	Battaglia et al., 2021 Posillico and Edwards, 2024
	Individual barriers	Battaglia et al., 2021 Pacheco et al., 2024
Organisational factors that affect the PoCP	Management support	Hoang et al. 2022 Rochon et al., 2010
	Organisational culture	Paget et al., 2024
	Internal resources: financial, technological, rewards	Munari et al. Nicholls-Nixon et al. 2022
	Organisational barriers	Pacheco et al., 2024 Tolin and Piccaluga, 2024
External factors that affect PoCP	Customers, suppliers, competitors	Zaitsava et al. 2024 Swamidass 2013
	Financial programme, coaching, time	McAdam 2010

Source: authors' elaboration

5.5 Implication 5: bridging the gap and identifying tools to support knowledge integration in PoCP

Understanding the processes of knowledge integration can reveal new enablers and techniques. From this perspective, fostering dialogue between academics and practitioners becomes crucial to achieving the most impactful outcomes.

In this regard, it would be important starting empirical research on PoCP members using interviews to conduct an in-depth analysis of many aspects related to knowledge integration

6 Conclusion remarks

The study makes two specific contributions to the existing literature, developing a comprehensive conceptualization of the PoCP process from a knowledge integration perspective and outlining an agenda for future research that can explore this emerging area of research more deeply with empirical evidence.

Our review addressed two central research objectives.

First, given the emerging and fragmented nature of PoCP, we asked what PoCP is and how it can be described in a more uniform way. In this light, we provide a stronger conceptual foundation for scholars and practitioners to build on. The review succeeded in broadening the understanding of PoC in two respects. On the one hand, only a few studies have previously investigated PoC as a project environment; on the other hand, the review served as a starting point for exploratory research hypotheses in future theoretical and empirical work, linking the characteristics of relationships in U-I projects with the development of PoC activity.

Second, we aim to identify the underlying principles and organizational conditions that influence the PoCP process and the existing mutual knowledge barriers that may hinder the achievement of the desired outcomes. This aspect of the findings could be useful both theoretically and practically. Building on previous work by Battaglia et al. (2021), Zaitsava et al. (2024), and Tolin and Piccaluga (2024), we observe that there are important underlying organizational mechanisms that influence the PoCP process. Our review aims to advance the research by opening new lines of research on how these mechanisms operate, with a particular focus on the relationship between university actors and external stakeholders in relation to activity levels, roles, and responsibilities in the PoCP.

Our study also had several limitations.

First, we encountered difficulties in developing an optimal search string. The term “proof of concept” is widely used, with different meanings across different disciplines and fields, making it difficult to narrow down the selection of articles.

Second, our review does not provide a comprehensive overview of all the literature in the context of open innovation or digital transformation. There is a vast literature in related fields. However, our primary goal was to consolidate knowledge in the social sciences, particularly in the management and organizational literature.

Although considerable effort was invested in the development of this study, it is essential to recognize some limitations inherent to SLR method. Our review protocol used a recognized database, Scopus, but we may have overlooked relevant research older than the timeline of our protocol or included it only in other databases, introducing potential publication bias or incomplete coverage. This is despite extensive backward and forward searches. Finally, human judgment was required at various stages of this search, which introduced potential subjectivity. However, this systematic literature review has made several efforts to ensure intersubjective verifiability and replicability, following international standards for transparent and rigorous academic practice.

Beyond these limitations, according to Massaro et al. (2016), a systematic literature review “is not the end of the road, but the beginning of new journeys.” Combining both theoretical insights and practical implications, this research has advanced the understanding of PoC and contributed to enriching organizational studies by opening the “black box” of the PoCP process.

7 Ethic declaration

This research did not required an ethical clearance.

8 AI declaration

This research did not involve use of artificial intelligence tools.

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Preliminary Study on the Impact of Artificial Intelligence in ESG Practices: A Multi-Case Approach in the Italian Market

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Abstract

The integration of Environmental, Social, and Governance (ESG) principles into corporate strategy has emerged as a global imperative, catalyzed by regulatory frameworks, investor pressure, and increasing stakeholder expectations. However, the complexity of ESG data collection, analysis, and reporting poses significant challenges for organizations. Recent advances in Artificial Intelligence (AI) have led to the development of AI-enabled platforms, such as PlaNet, CliMax, and Choral, which promise to transform ESG management. This paper presents a comprehensive analysis of the adoption and impact of these platforms across a diverse set of Italian companies, drawing upon more than twenty real-world case studies from sectors including finance, consulting, manufacturing, events, and digital. Through a mixed-methods approach combining document analysis, platform review, and cross-case synthesis, we examine how AI supports ESG data management, stakeholder engagement, decarbonization strategies, and organizational learning. Our findings reveal sector-specific adoption patterns, highlight operational improvements, and document the emergence of new forms of transparency and cultural engagement. The study concludes with actionable recommendations for organizations seeking to leverage AI for sustainable business transformation and outlines avenues for future research on the digitalization of ESG.

Keywords: artificial intelligence, knowledge management, sustainability, ESG, innovation

Paper type: Academic Research Paper

1 Introduction

In recent years, the strategic importance of Environmental, Social, and Governance (ESG) criteria has grown exponentially on a global scale. The combined pressures of regulatory change—such as the European Union's Corporate Sustainability Reporting Directive (CSRD), the United States' Securities and Exchange Commission (SEC) proposals, and the Sustainable Finance Disclosure Regulation (SFDR)—alongside shifting consumer preferences and investor demands, have made ESG integration a business necessity rather than a choice. Across all sectors, organizations are under increasing scrutiny to provide transparent, standardized, and measurable evidence of their sustainability efforts and social responsibility (Davenport & Prusak, 1998; Davenport et al., 2020).

Despite the growing consensus on the importance of ESG, companies face a daunting array of challenges in managing ESG data, metrics, and reporting. The process typically involves multiple actors—ranging from sustainability managers and financial controllers to IT departments and external consultants—and spans diverse information systems, business units, and regulatory environments. Traditional approaches, often reliant on manual data entry and fragmented spreadsheets, have proven inadequate to manage the increasing complexity and volume of ESG-related information. This can lead to inconsistencies, inefficiencies, and even reputational risks due to reporting errors or delays.

The emergence of Artificial Intelligence (AI) as a transformative force in corporate sustainability marks a pivotal shift in how organizations approach ESG challenges. AI-enabled platforms—such as PlaNet, CliMax, and Choral—offer the prospect of automating repetitive tasks, extracting actionable insights from unstructured data, and fundamentally rethinking stakeholder engagement. By leveraging predictive analytics, natural language processing, and machine learning, these technologies promise to increase the efficiency, accuracy, and impact of ESG management, while also fostering a culture of continuous learning and improvement.

This paper seeks to systematically review the application and outcomes of AI for ESG in a broad set of Italian companies. Rather than focusing solely on theoretical potential, we draw upon an empirically rich, multi-case study approach, offering insights that are both contextually grounded and transferable to other markets. Our aim is to provide a robust foundation for understanding the transformative potential of AI in sustainability management, and to inform both practitioners and scholars of best practices and key challenges.

2 Literature Review

2.1 The Evolution of ESG Reporting and Knowledge Management

The field of ESG has evolved rapidly, with the proliferation of reporting frameworks such as the Global Reporting Initiative (GRI), the Sustainability Accounting Standards Board (SASB), the Task Force on Climate-Related Financial Disclosures (TCFD), and, more recently, the European Sustainability Reporting Standards (ESRS). These frameworks provide guidelines for companies to report on a broad range of environmental, social, and governance indicators, but also increase the complexity of compliance.

Knowledge management (KM) systems have long been recognized as critical enablers for effective ESG strategies. As Davenport and Prusak (1998) argue, KM supports the acquisition, organization, and dissemination of data, facilitating both internal learning and external reporting. In the context of ESG, effective KM enables organizations to break down silos, ensure data consistency, and drive continuous improvement. However, traditional KM approaches—centered on manual processes and static repositories—often fall short in addressing the dynamic, multidimensional nature of ESG information.

2.2 Artificial Intelligence in ESG: Opportunities and Barriers

AI technologies, including machine learning, natural language processing, and large language models (LLMs), have demonstrated their value across a wide range of business domains (El-Kassar & Singh, 2019). In the ESG context, AI can:

- Automate data collection and validation, reducing human error and increasing speed;
- Analyze complex datasets, including carbon footprints and decarbonization pathways;
- Generate and personalize sustainability reports in alignment with international standards;
- Engage employees and stakeholders through innovative formats such as gamification, serious games, and interactive learning modules.

Several studies have highlighted the potential of AI to revolutionize ESG management (Smith et al., 2021; World Economic Forum., 2025; Wamba-Taguimdje, S. et al, 2020). However, barriers remain. These include technical challenges (data harmonization, system integration), organizational resistance (digital skills gaps, change management), and hical considerations (data privacy, algorithmic transparency). Empirical research on the real-world implementation of AI in ESG, particularly in multi-sectoral contexts, remains limited.

2.3 The Italian Context and Research Gap

Italy offers a particularly interesting context for studying the digitalization of ESG. The country is home to a diverse industrial base, ranging from large multinational corporations to innovative small and medium-sized enterprises (SMEs). Recent years have seen a surge in ESG reporting and sustainability initiatives, driven both by regulatory compliance and a growing recognition of the business value of sustainability. Yet, as in other markets, companies face significant challenges in scaling up their ESG efforts and ensuring data quality.

This study addresses the research gap by analyzing the adoption and impact of AI-enabled ESG platforms (PlaNet, CliMax, Choral) in a representative sample of Italian companies, spanning banking, finance, consulting, manufacturing, events, and digital sectors.

3 Methodology

3.1 The Italian Context and Research Gap

This research adopts a mixed-methods approach, combining qualitative and quantitative techniques to deliver a comprehensive analysis of AI adoption in ESG practices. The study is structured around three core components:

- Document Analysis: Over twenty case studies, white papers, and official reports are systematically reviewed. These documents, sourced from company disclosures, platform vendors, and academic publications, provide detailed accounts of ESG initiatives, AI-enabled solutions, and organizational outcomes.
- Platform Review: Official documentation and product pages for PlaNet, CliMax, and Choral are analyzed to map technical functionalities, innovation drivers, and sectoral applications. Special attention is paid to features such as data automation, real-time monitoring, user engagement, and compliance alignment.

- Cross-Case Synthesis: A thematic synthesis is conducted across all cases to identify sectoral adoption patterns, functional outcomes, user feedback, and best practices. Where available, quantitative metrics (e.g., time saved, error reduction, engagement rates) are extracted to support qualitative findings.

3.2 Case Selection Criteria

Cases were purposively sampled to maximize diversity in sector, organizational size, ESG maturity, and stage of digital transformation. The sample includes both large corporations and SMEs, with representation from finance, consulting, manufacturing, event management, digital services, and more. Priority was given to companies with documented experience in adopting at least one AI-enabled ESG platform.

3.3 Data Collection and Analysis

Data were collected through a combination of document analysis, review of public disclosures, and where possible, semi-structured interviews with company representatives and platform providers. Thematic analysis was used to code and categorize findings, with cross-validation against public data and third-party audits where available. Analytical rigor was ensured through iterative coding, peer review, and triangulation of multiple sources.

3.4 Research Limitations

While the multi-case approach provides rich insights, several limitations should be noted. First, the sample is limited to Italian companies, which may affect generalizability. Second, access to primary data (e.g., interviews) was limited for some cases, necessitating reliance on secondary sources. Finally, the evolving nature of AI platforms means that findings reflect a specific moment in time and may not capture future developments.

4 Results

4.1 AI-Enabled Platforms: Functional Overview

4.1.1 Planet

PlaNet is Up2You's flagship platform for ESG education and employee engagement. Designed to leverage the motivational power of gamification, PlaNet offers a suite of interactive tools—including quizzes, video lessons ("video pills"), team challenges, leaderboards, and unique rewards—to foster knowledge, engagement, and behavioral change around sustainability. The platform is fully customizable, allowing organizations to tailor content, branding, and learning pathways to their specific needs. PlaNet's scalability and intuitive design have driven its adoption by over 450 companies across finance, consulting, manufacturing, and events. Key features include real-time progress tracking, personalized feedback, and integration with broader ESG strategies.

4.1.2 Climax

CliMax is an AI-powered platform dedicated to carbon management and decarbonization strategy. It centralizes carbon data from multiple organizational sites and products, automates the calculation of Scope 1, 2, and 3 emissions, and provides real-time monitoring of emission trends. The platform supports the design and execution of decarbonization strategies, integrating certified offsetting projects (e.g., Verra, Gold Standard) and producing audit-ready reports validated by third-party certifiers such as RINA. CliMax's data automation features minimize manual entry errors and allow for granular analysis by location, business unit, or product line, making it especially valuable for manufacturing and multi-site organizations.

4.1.3 Choral

Choral is designed to streamline the creation of sustainability reports, ensuring alignment with international standards such as GRI, ESRS, and VSME. The platform uses AI to automate data collection, facilitate real-time collaboration among multiple users, and enhance stakeholder engagement through targeted communications and feedback loops. Choral's customizable branding features enable organizations to produce visually distinctive reports, while its compliance tools facilitate independent assurance by accredited auditors. By reducing reporting time and minimizing errors, Choral has become a preferred solution across finance, consulting, and services.

4.2 Case Study Synthesis

The study analyzed a diverse sample of Italian organizations, including:

- Finance/Asset Management: Azimut, Banco Azzoaglio
- Consulting: BakerMcKenzie, Randstad, Colliers
- Manufacturing: Aeffe, IB Chem, Sodai, Italtel, Talea Group
- Events & Services: TEDXMilano, OIC Group, Caribe Bay, Panino Giusto, Xenia, Team Emirates, Gattinoni, Yocabè
- Digital & Tech: Kotuko, Mimosa Milano, Atlantic, Edison

Table 1- AI Platform Adoption Across Case Studies

Company	**Sector**	**Main Platform(s)**	**Core AI-Enabled ESG Functions**
Azimut	Finance	Choral, CliMax	Carbon emission (Scopes 1/2), data validation, reporting, employee engagement
Banco Azzoaglio	Banking	Choral	GHG data collection (20+ branches), reporting, training, data consistency
BakerMcKenzie	Consulting	Choral	Data collection, multi-site reporting, stakeholder engagement
Randstad	Consulting	Choral	Stakeholder engagement, ESG reporting, data validation
Colliers	Consulting	Choral	Emission tracking, ESG data, reporting
Kotuko	Digital	Choral, PlaNet	Gamified ESG education, data collection, reporting, employee engagement
Aeffe, IB Chem, etc.	Manufacturing	CliMax, Choral	Carbon footprint, decarbonization, data automation, reporting
TEDXMilano, OIC, etc.	Events/Serv.	PlaNet	ESG training, employee engagement, gamification

Many companies employ more than one platform for complementary ESG needs.

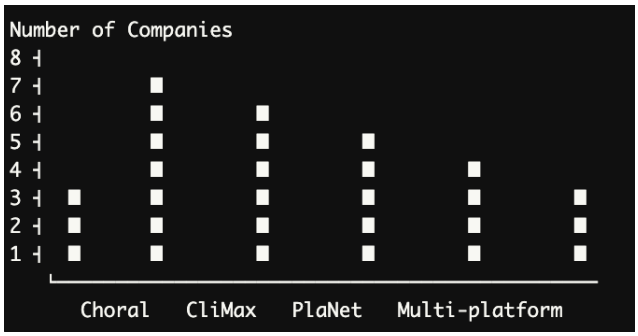


Figure 1 - Adoption of AI-Enabled ESG Platforms by Sector

Legend:

- Choral: most widely adopted for ESG reporting and stakeholder engagement across sectors.
- CliMax: leading for carbon management in manufacturing and finance.
- PlaNet: focused on gamified education, primarily in digital, events, and services.
- Multi-platform: several companies use two or all three for integrated ESG management.

ESG Functionality	**Choral**	**CliMax**	**PlaNet**
Data Collection	✓	✓	✓
Data Consistency Check	✓	✓	
Carbon Footprint		✓	
Reporting Automation	✓	✓	
Stakeholder Engagement	✓		✓
Gamification/Training			✓

Figure 2 - AI Functionalities Adopted Across Case Studies

4.3 Case Highlights

Azimut

Azimut, a major asset management group, implemented Choral for multi-site carbon data collection (Scopes 1 and 2). The adoption enabled automated data validation, streamlined GRI/ESRS-compliant reporting, and generated actionable insights for decarbonization. In parallel, CliMax was leveraged for scenario-based decarbonization strategy and real-time emission monitoring, while PlaNet supported employee ESG training and engagement through gamified modules.

Banco Azzoaglio

Banco Azzoaglio is a regional bank employing Choral for automated and accurate ESG data collection from over 20 branches, verification of data consistency, and management training on sustainability. The implementation led to increased reporting accuracy, a measurable reduction in reporting cycle time, and a more engaged workforce. Feedback from internal stakeholders indicated that the platform's user-friendly interface and automated notifications facilitated cross-departmental collaboration.

Consulting and Services

Firms such as BakerMcKenzie, Randstad, and Colliers adopted Choral for coordinating data collection from multiple offices, automating sustainability reports, and engaging a diverse range of stakeholders. These organizations reported significant reductions in manual workload, improved data reliability, and higher response rates from stakeholders, attributed to Choral's integrated communication tools.

Digital, Events, and Manufacturing

Companies in the digital and event sectors, including Kotuko, TEDXMilano, OIC, and Panino Giusto, utilized PlaNet for ESG education and employee engagement. By integrating gamified content, these organizations fostered a culture of sustainability, as evidenced by increased participation in ESG initiatives and improved knowledge scores in post-training assessments. Manufacturing firms (Aeffe, IB Chem, Sodai, Talea Group, etc.) employed CliMax for systematic carbon footprint calculations (Scopes 1, 2, and 3), real-time emission monitoring, and decarbonization scenario planning, resulting in improved audit outcomes and compliance.

4.4 Cross-Case Findings

- **Sectoral Preferences:** finance and consulting sectors favor Choral for robust reporting and collaboration features. Manufacturing and industry prioritize CliMax for carbon management and emissions tracking. Events, services, and digital companies adopt PlaNet for staff engagement and ESG education.
- **Multi-Platform Integration:** leading organizations often combine platforms—PlaNet for engagement, Choral for reporting, and CliMax for emissions—achieving holistic ESG management.
- **AI Value Drivers:**
    - Time and error reduction in data collection and reporting.
    - Improved data consistency and auditability.
    - Increased stakeholder participation and trust.
    - Enhanced employee ESG culture through interactive learning.
- **Quantitative Outcomes:** across cases, organizations reported reductions in reporting cycle times (up to 40%), increased stakeholder engagement rates (by over 30%), and improved audit scores, demonstrating tangible benefits of AI integration.

5 Discussion

5.1 Relating Findings to Existing Literature

The findings from this multi-case analysis resonate with and extend the current body of literature on AI and ESG. As highlighted by El-Kassar & Singh (2019), the integration of AI into sustainability management is not only a technological upgrade but also a catalyst for organizational transformation. The Italian cases confirm that AI-enabled platforms are crucial for overcoming the limitations of traditional knowledge management (KM) systems, as theorized by Davenport & Prusak (1998). The adoption of tools like Choral, CliMax, and PlaNet has facilitated a shift from siloed, manual processes to integrated, automated ESG management, enabling companies to respond more dynamically to regulatory and stakeholder demands.

Additionally, the sector-specific adoption patterns observed in the Italian context mirror global trends. For example, manufacturing firms' emphasis on carbon management (via CliMax) aligns with international pressures on heavy industry to decarbonize, while finance and consulting's adoption of advanced reporting platforms (like Choral) reflects the growing importance of transparency and compliance in these sectors (*World Economic Forum., 2025*).

5.2 Sectoral Nuances and Organizational Change

The case studies reveal that the effectiveness of AI-enabled ESG platforms depends not only on technological capabilities but also on organizational readiness. In manufacturing, the complexity of Scope 3 emissions and the need for granular, plant-level data make platforms like CliMax indispensable—yet their success hinges on strong internal data governance and sustained training. In banking and consulting, where ESG data is often dispersed across multiple branches or client accounts, Choral's collaborative features and AI-driven consistency checks have been especially valued.

Change management emerges as a critical factor. Companies that invested in comprehensive onboarding, ongoing training, and cross-functional ESG teams reported higher engagement rates and smoother platform adoption. This supports the notion, found in recent research (Wamba-Taguimdje, S. L. et al,

2020), that technology adoption in ESG must be accompanied by parallel investments in people and processes.

5.3 New Opportunities and Emerging Risks

While AI platforms have yielded clear efficiencies—reducing reporting cycle times and improving data quality—they also introduce new challenges. Over-reliance on automated recommendations can lead to "black box" decision-making, where the rationale for certain ESG actions is not fully transparent to users. Some interviewees expressed concerns about data privacy, especially in relation to sensitive HR or supply chain information processed by AI systems.

Moreover, the gamification of ESG education (as seen with PlaNet) has proven highly effective in boosting engagement, but it also requires careful calibration to ensure that learning outcomes are substantive and not merely competitive. Companies must balance the motivational benefits of gamification with the need for rigorous, impactful ESG training.

5.4 Scalability and Internationalization

The platforms studied are designed to be scalable, supporting organizations ranging from SMEs to multinational groups. Their multi-language support and customizable features make them suitable for international rollouts, a point of strategic importance as ESG regulations become increasingly harmonized across the EU and beyond. However, the degree of customization required to align with local regulations and cultural expectations can be significant, underlining the need for vendor support and flexible implementation strategies.

5.5 Limitations and Critical Assessment

Despite the positive outcomes, several limitations should be acknowledged. The reliance on secondary data in some case studies may introduce reporting bias. The pace of technological change means that platform functionalities and user experiences are continually evolving, potentially limiting the long-term generalizability of findings. Furthermore, empirical evidence on the direct impact of AI-enabled ESG platforms on financial performance remains scarce and warrants further investigation.

6 Managerial Implications and Recommendations

6.1 Choosing and Implementing AI-Enabled ESG Platforms

Organizations should carefully assess their ESG maturity, sector-specific needs, and internal capabilities before selecting an AI platform. For instance, manufacturing firms with complex supply chains may prioritize platforms with advanced carbon tracking and scenario analysis, while consulting and financial services may focus on robust reporting and stakeholder engagement features. A phased implementation—starting with pilot projects and progressively scaling up—can help manage risks and optimize learning.

6.2 Integrating Multi-Platform Solutions

The evidence suggests that combining multiple platforms (PlaNet for engagement, Choral for reporting, CliMax for emissions management) yields the most comprehensive results. Integration across platforms should be prioritized to avoid data silos and maximize the value of AI-driven insights. IT departments play a key role in ensuring seamless data flows and maintaining cyber-security standards.

6.3 Fostering an ESG Culture through Engagement

Gamification and interactive learning modules, as offered by PlaNet, can be powerful tools for embedding sustainability values across all levels of the organization. HR departments should collaborate with ESG managers to design engaging, contextually relevant training programs and to recognize and reward ESG-related achievements.

6.4 Ensuring Data Quality and Compliance

Automated data validation and audit trails, as provided by Choral and CliMax, are essential for meeting increasingly stringent regulatory requirements. Companies should establish clear data governance policies and regularly review platform outputs for accuracy and completeness. Third-party assurance and certification can further enhance credibility and stakeholder trust.

6.5 Managing Change and Building Capacity

Successful adoption of AI in ESG requires dedicated change management efforts. This includes clear communication of the benefits and expectations, regular training, and the creation of cross-functional ESG teams. Leadership commitment is crucial: C-suite executives must champion digital transformation and allocate resources for continuous improvement.

6.6 Addressing Risks and Ethical Considerations

Organizations must remain vigilant about potential risks, including data privacy, algorithmic bias, and over-automation. Transparent AI models, regular audits, and clear ethical guidelines should be established to mitigate these risks and ensure that technology supports, rather than undermines, corporate responsibility.

7 Conclusion

This preliminary study demonstrates that AI-enabled platforms are rapidly transforming ESG practices in Italian companies, delivering measurable improvements in efficiency, transparency, and stakeholder engagement. Through the adoption of innovative solutions such as PlaNet, CliMax, and Choral, organizations have not only automated and improved the accuracy of ESG data management but also fostered a culture of sustainability and collaboration. Sectoral nuances reveal that a one-size-fits-all approach is insufficient; instead, organizations benefit most from integrating multiple platforms tailored to their specific needs.

The findings contribute to the growing body of knowledge on the intersection of AI, knowledge management, and ESG, offering both practical guidance for practitioners and a foundation for future academic inquiry. However, the study also highlights emerging challenges—ranging from data privacy concerns to the need for explainable AI—and underscores the importance of human-centered change management.

Future research should expand the analysis to include more industries, longitudinal impact assessments, and cross-country comparisons. Quantitative studies assessing the financial and reputational returns of AI-driven ESG innovation will be particularly valuable. As regulatory expectations and stakeholder demands continue to evolve, the strategic integration of AI into ESG will remain a critical differentiator for organizations seeking to lead in sustainable business.

8 Acknowledgements

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9 Ethics declaration

The research presented in this paper did not require the collection of sensitive data, nor the direct involvement of human or animal subjects; therefore, no approval from an ethics committee was necessary. All

data used derive from public sources, corporate documentation, and already available scientific literature. Should the collection of primary data become necessary in the future, the procedure established by current regulations and the affiliated institutions will be followed.

9 AI declaration

During the drafting of this paper, Artificial Intelligence (AI) tools were used exclusively to support language revision and for stylistic suggestions, without any substantial part of the scientific content being automatically generated. All ideas, analyses, and conclusions are the result of the authors' work. The use of AI was therefore limited to editing and spelling/grammar checking functions.

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Optimizing ESG Risk Assessment Processes with AI-Driven Process Mining: A Framework for Proactive Sustainability Management

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Abstract

The growing focus on sustainability and mitigation of environmental risks has made the ESG (Environmental, Social and Governance) framework a central element in the strategic and operational management of modern organizations. In a context marked by increasingly stringent regulatory pressures – such as the Corporate Sustainability Reporting Directive (CSRD) and the recommendations of the Task Force on Climate-related Financial Disclosures (TCFD) – companies are now called upon to integrate ESG metrics into their decision-making processes, in order to address global challenges such as climate change, biodiversity loss and the necessary ecological transition. However, the fragmentation of available data and the lack of adequate predictive tools continue to hinder truly effective and future-oriented ESG management. This study proposes an innovative operating model based on the synergistic integration between Artificial Intelligence (AI) and Process Mining, with the aim of improving monitoring, automation and transparency in ESG processes. AI allows the processing of large volumes of heterogeneous and unstructured data, while Process Mining allows you to map and optimize business flows, detecting inefficiencies and ensuring traceability. The model proves to be particularly effective for financial institutions and companies operating in sectors with high climate exposure, providing concrete answers to the needs of regulatory compliance and strategic sustainability. The adoption of this approach makes it possible not only to anticipate environmental risks, but also to strengthen organizational resilience and support the transition to a "sustainability-first" paradigm. The study highlights the transformative potential of AI-driven Process Mining in ESG management, offering scalable and replicable solutions for sustainable innovation that combines efficiency, responsibility and competitiveness in the long term.

Keywords: Artificial Intelligence, ESG, Process Mining, Environmental Risk Assessment, Climate Change

Paper type: Academic Research Paper

1 Introduction

Climate change represents one of the most complex and pervasive challenges for the global economic and financial system. The incessant expansion of human activities has led to a significant increase in greenhouse gas emissions, aggravating global warming and generating negative consequences such as extreme weather events, sea level rise and destruction of ecosystems (Di Bella, 2020). These phenomena have significant impacts not only on the environment, but also on the stability of firms, on the security of investments and on economic competitiveness (Engel et al., 2015).

At the regulatory level, the United Nations 2030 Agenda and the European Green Deal have strengthened the centrality of climate sustainability in political and industrial agendas. However, despite growing awareness, many companies are still unprepared to identify and manage climate risks (Ai & Gao, 2023). According to Omar et al. (2020), strengthening climate resilience requires companies to develop capacities to assess and absorb risk information, translating this knowledge into strategic actions. In this context, the ESG (Environmental, Social and Governance) framework is established as an essential tool for guiding organizations towards sustainable, transparent and resilient business models. The integration of ESG metrics into risk management is now critical not only for regulatory compliance, but also for long-term value creation (Leoni, 2024). The growing focus on sustainability has prompted supranational institutions and regulators, such as the European Union with the Corporate Sustainability Reporting Directive (CSRD) and the Task Force on Climate-related Financial Disclosures (TCFD), to adopt increasingly stringent and detailed regulations (Brende & Sternfels, 2022; Zhao et al., 2024).

Alongside the regulatory component, a crucial role is played by the ability of companies to integrate digital tools for predictive analysis, reporting automation and proactive sustainability management. Emerging technologies, such as Artificial Intelligence (AI), Process Mining and Natural Language Processing (NLP), offer new possibilities to transform ESG assessment from a manual and reactive process to an intelligent, automated and strategic system (Amiri et al., 2024; Minz & Khattar, 2024). The joint use of AI and Process Mining makes it possible to improve traceability, identify anomalies in ESG flows and support timely decisions (Gerassis et al., 2021).

Despite the growing importance of ESG principles, many organizations struggle to implement them effectively. The difficulties stem from structural factors such as data fragmentation, the absence of standardized

methodologies and the reliance on outdated assessment tools (Kalogiannidis et al., 2024). In the face of these critical issues, this study proposes the integration of two synergistic approaches: on the one hand, a structured methodology for the self-assessment of climate-related and environmental risks, in accordance with the ECB Guidelines (2020) and the expectations of the Bank of Italy; on the other hand, an innovative digital framework based on Artificial Intelligence (AI) and Process Mining, to optimize the analysis and reporting of ESG risks (Amiri et al., 2024; Minz & Khattar, 2024).

The aim is to provide a theoretical and operational basis to support companies in the adoption of intelligent and integrated tools, capable of addressing environmental and regulatory challenges with proactive and data-driven approaches.

2 Theoretical framework

2.1 The strategic role of ESG in corporate governance

The integration of ESG principles into corporate governance models is now recognized as a necessary condition for effective risk management and for strengthening organizational resilience. Environmental risks, particularly those related to climate change, are increasingly being transformed drivers for business models. They impact not only economic aspects, but also social and environmental ones, triggering changes in value chains, operational management and stakeholder relations (Di Bella, 2020; Ai & Gao, 2023). Climate change manifests itself through direct effects, such as extreme weather events and sea level rise, but also through indirect impacts, such as fluctuations in demand, price volatility and rising insurance costs (Engel et al., 2015). Numerous studies underline that companies are not yet fully aware or ready to face these risks. According to Omar et al. (2020), it is crucial for companies to improve their capacity to absorb and transform climate-related information in order to maintain competitiveness and business continuity. Failure to prepare can result in financial losses, reputational damage and reduced access to credit.

To promote a resilient and sustainable economy, companies must adopt a systemic view of ESG risks, capable of integrating technological tools, business strategies and regulatory compliance. A multidimensional approach allows to simultaneously consider physical risks (e.g. floods, droughts, heat waves), transition risks (e.g. new regulations, carbon taxes, technological innovation) and liability risks, such as legal claims arising from environmental damage caused by business activities (FSB, 2015; ECB, 2020). In this context, the ECB Guidelines (2020) and the EBA take on a central role, setting out precise expectations for the banking system in terms of identifying, managing and communicating climate-related and environmental risks. These documents clearly indicate that financial institutions must incorporate ESG risks into their strategic models and risk management mechanisms. In particular, it is required to identify the most exposed sectors and geographical areas, assess the impact on products and services and define climate and environmental risk reduction objectives in business plans (Pasquini, 2020).

ESG risks are reflected in all traditionally monitored risk categories: credit, market, operational, reputational, strategic and liquidity risk. Acute climate change, such as the increase in scorching days, has already been associated with a decline in business performance and increased fragility of supply chains (Pankratz et al., 2023). In addition, the adaptation to a low-carbon economy has impacts on operating margins, demand for goods and asset valuation, triggering an overall reorganisation of business models, especially in emission-intensive sectors. Within this paradigm, the "E" (environmental) component is the one on which the most attention is focused by companies, supervisors and investors (Naeem et al., 2022). Initiatives such as the United Nations 2030 Agenda and the Network for Greening the Financial System (NGFS) have pushed for greater harmonization in the classification and management of environmental risks. The NGFS has introduced a detailed classification table that distinguishes the main components of physical and transition risks, thus providing a useful tool for financial institutions in the risk identification and assessment phase (Pasquini, 2020).

2.2 Regulatory and technological integration in ESG management

The growing awareness of the importance of climate risk management has also led to greater attention to the role of technological innovation, with particular reference to Artificial Intelligence (AI) and Process Mining. The integration of these technologies makes it possible to overcome the inefficiencies of traditional ESG models, which are often manual and not very dynamic, improving the quality and timeliness of the information available. Technologies such as Natural Language Processing (NLP), deep learning and predictive analytics make it possible to analyze large amounts of ESG data from heterogeneous sources (regulatory reports, media, social networks), thus supporting proactive and data-driven risk management (Amiri et al., 2024; Gerassis et al., 2021).

Process Mining allows you to visualize and monitor operational processes in real time, mapping any deviations from ESG standards and identifying inefficiencies or bottlenecks in the reporting chain (Schreiber, 2020). This synergy between AI and Process Mining translates into greater transparency and traceability of corporate ESG flows, facilitating regulatory compliance and improving communication with stakeholders. Empirical evidence shows how the adoption of advanced digital tools can facilitate a shift from a reactive to a proactive logic in risk management. According to Burnaev et al. (2023) and Kim & Lee (2022), the automation of ESG processes not only reduces manual workload, but also allows for hidden patterns in data and predictive scenarios useful for strategic planning. In addition, the application of sentiment analysis techniques makes it possible to detect the external perception of the company in real time, providing an additional tool for reputation management (Kiriu & Nozaki, 2020).

The adoption of a theoretical framework based on the integration of regulatory requirements, digital innovation and a long-term strategic vision is the main way to effectively address the challenges of climate change. Companies that are able to systematically integrate ESG tools into their decision-making models will not only strengthen their resilience, but will gain a competitive advantage in terms of reputation, attractiveness for investors and sustainability in the long term. A central reference point is the ECB Guidelines (2020) and the EBA Recommendations, which outline the obligation for banks to integrate environmental risks into their business models and business strategy. In particular, two main types of climate risk are defined: physical risk, deriving from extreme climatic events or gradual environmental changes, and transition risk, linked to regulatory, technological and reputational adaptation towards a sustainable economy (Pasquini, 2020; Caldecott et al., 2021).

Physical risk can manifest itself in direct damage to structures and assets, disruptions in the supply chain, or reduced productivity, with concrete impacts on revenues, cash flows, and business value (Pankratz et al., 2023). Transition risk, on the other hand, is expressed through costs related to regulatory compliance, market loss for carbon-intensive sectors, and possible legal disputes for environmental liabilities (EBA, 2020). In addition to these, there is a third level of risk that is often less considered: "liability risk", i.e. legal and reputational liability linked to environmental damage caused by corporate activities, as highlighted in the most recent European regulatory consultations (FSB, 2015; EBA, 2020). Alongside the regulatory dimension, contemporary literature emphasizes the role of technological innovation in ESG management. In particular, Artificial Intelligence (AI) and Process Mining are establishing themselves as enabling tools to overcome the limitations of traditional evaluation models. Natural Language Processing (NLP), predictive analytics, and deep neural networks enable meaningful insights to be extracted from large volumes of unstructured data, such as business reports, social media, and regulations (Amiri et al., 2024; Gerassis et al., 2021). In addition, deep learning finds application in areas such as agriculture and natural resource management, making it possible to predict emissions, deforestation, and biodiversity loss more accurately and in a timely manner (Ezenkwu et al., 2024).

2.3 Synergies between AI and Process Mining for ESG Transformation

Process Mining, on the other hand, makes it possible to map and optimize sustainability-related business processes, improving the traceability of ESG flows, detecting inefficiencies and facilitating regulatory compliance in real time (Schreiber, 2020; Minz & Khattar, 2024). This technological integration is particularly relevant in regulated and information-intensive sectors, such as banking, insurance and energy, where transparency and accountability are critical.

The review of the literature (Kim & Lee, 2022; Burnaev et al., 2023) suggests that the AI–Process Mining combination is divided into three main directions:

1. Advanced ESG data analytics: With the support of AI, you can improve the quality and consistency of your data by spotting anomalies and emerging trends.
2. Optimization of ESG processes: Process mining enables continuous tracking of compliance and the identification of bottlenecks.
3. Automation and decision support: thanks to the digitization of reporting processes, errors and time are reduced, improving the timeliness and quality of strategic decisions (Yaseen, 2023; Sokolov & Abramova, 2023).

In addition, several studies underline that the adoption of these digital tools allows not only a faster reaction to emerging risks, but also the construction of moral and reputational capital useful for dealing with future crises (Lins et al., 2017; Deng et al., 2013). This dynamic approach allows companies to adopt a resilience-oriented mindset, capable of integrating sustainability within the corporate culture and core decision-making processes. The evolution of governance models, which increasingly incorporate stakeholder engagement practices and transparency in the disclosure of ESG data, should also be considered. In this context, AI can also support

sentiment analysis on social media and the assessment of public perception, providing real-time feedback on corporate reputation and the effectiveness of environmental and social strategies (Kiriu & Nozaki, 2020). Finally, ESG-based technologies are also showing an increasing impact on sustainable investing. The growing interest from institutional investors in robust and documented ESG practices is driving companies to structure digital and measurable strategies to improve their ESG rating (Naeem et al., 2022; Popescu & Yu, 2024). The traceability offered by Process Mining, combined with the predictive capacity of AI, is a key element in attracting capital and strengthening stakeholder trust. The proposed theoretical framework is based on a twofold innovation: on the one hand, the standardized structuring and classification of ESG risks, in line with current regulations; on the other, the adoption of intelligent technologies that allow predictive and adaptive management of sustainability. This integrated vision represents a game-changer for companies that want to address climate change not only as a threat, but as an opportunity for transformation and sustainable growth.

3 Methodology of approach and proposed solutions

3.1 High-level process

The present work has developed an operating model based on the digitization of business processes and the synergistic use of technologies such as Artificial Intelligence (AI), Robotic Process Automation (RPA) and Machine Learning (ML). The approach adopted resulted in the construction of a Business Process Model and Notation (BPMN) (Mahdi et al, 2024) that describes, in detail, the phases that lead to the definition of risk. This scheme, which represents the skeleton of the theoretical model, has been developed with the aim of identifying for each process area the value-added activities and those that are repetitive or standardizable, in order to optimize the entire path through automation. The mapping of the processes has made it possible to highlight numerous critical areas, often linked to manual or untraceable operations, which slow down the risk analysis and reduce its effectiveness.

In the first phase of the model, the analysis focuses on the definition of operating environments and the identification of internal processes that do not generate value. In this phase, Process Mining (Aalst 2022) was used, an advanced tool that makes it possible to reconstruct the real flows of the organization starting from the information systems, highlighting inefficiencies and redundancies. The output of this analysis provided the basis for a targeted redefinition of processes through the design of RPA solutions (Tripathi et al, 2025), capable of automating recurring and operationally intensive tasks.

Considering the high-level process, the BPMN model (figure 1) has been divided into different operational areas, where the first macro area is dedicated to risk calculation. In this first phase, a questionnaire that can be adapted for each company is used, aimed at defining the reference environments, KPIs, weights associated with each risk category, and assessing the current risk through a scoring system. The second macro area concerns strategic planning, which is responsible for representing the results obtained, organizing them into risk clusters by importance, and illustrating the mitigation plan with the corrective actions to be taken. The third macro area concludes the process with the definition of a managerial action plan, focused on monitoring deviations and continuously updating strategies based on the results of the analysis.



Figure 1. High level BPMN of the process. Our elaboration.

Once the different steps had been defined, a careful analysis was launched aimed at identifying the most suitable algorithms for their automation. The choice fell on the use of multiple and integrated models, which collaborate with each other in a modular way (Wang et al, 2024). This solution has proven to be more efficient than using a single monolithic model, as it allows performance to be optimized with less information usage. In addition, the adoption of intermediate outputs along the various stages of the process allows constant and timely monitoring, improving control and operational transparency (Stern et al, 2023 and Wu et al., 2021).

3.2 Risk Assessment Process

More specifically, in the macro area of Risk assessment, the final goal is to divide customers into clusters to identify a level of gross risk for the company. This action allows for the breakdown according to the risk that they pose to the business. To achieve this, several steps are carried out in the process.

Going into the details of the model, the study of the same has shown the presence of a risk analysis based on static elements and repetitive manual tasks of information exchange. The development opportunity identified in the study proposes the use of machine learning algorithms, the training of which is aimed not only at risk classification, but also at its evaluation with a view to minimizing losses.

In fact, the risk definition process is divided into several steps with different levels of manual skill and analysis.

The first step of the macro area of the Risk assessment involves the use of two separate questionnaires to identify risk categories. The first questionnaire is aimed at identifying the presence of risks generated by customers; the second is aimed at measuring the severity of the risk in individuals identified as suffering from potential criticalities. It was therefore decided to automate the generation of these questionnaires through the use of Robotic Process Automation (RPA), developing a bot capable of producing a standardized checklist. According to the framework developed by Wellmann et al. (2020), repetitive and standardised activities, such as the production of questionnaires, fully fall within the technical feasibility criteria. Introducing RPA in this operational phase helps reduce the risk of human error and ensure consistency in information collection.

Furthermore, the sole limitation to the administration of questionnaires is partially efficient although perfectly manageable by humans. This dimension can be broadened by introducing more in-depth analysis techniques (Kelley-Quon LI., 2018).

Therefore, in parallel with the automation of the generation of checklists for corporate risk assessment through RPA, an additional component based on Web Scraping techniques has been introduced, with the aim of enriching the decision-making process through the automatic and systematic collection of data from both internal sources (company documentation, management reports, digital archives) and external sources (institutional sites, financial indicators, regulatory portals and sectoral databases). This technique allows to automatically aggregate data from multiple sources, structuring them into consistent outputs that can be integrated with internal company systems (Ferrara et al., 2012). In addition, according to Wellmann et al. (2020), to validate all the criteria provided by RPA, it is necessary to use applications to support the model. This activity is part of a broader logic of business intelligence, where the ability to access and analyze distributed and not always structured information is essential to build a dynamic and updated representation of the operating context and potential risks.

This process translates into a double advantage: on the one hand, it improves the ability to identify weak signals or anomalies in the external context, and on the other hand, it allows the internal parameters used in risk assessment models to be kept up to date. Furthermore, thanks to the ability to access structured content in real time, Web Scraping helps to automatically populate risk indicators (KPIs), strengthening the reliability of the analysis model (Ferrara et al., 2012).

The second step relating to the Risk assessment is the definition of the weights for each of the risk categories identified in the first step. In our case, the approach adopted is oriented towards a logic of minimizing losses, focusing on a central concept: the protection and monitoring of a minimum company assets, understood as a critical threshold below which the integrity and operational continuity of the company could be compromised. The deterioration of company assets becomes the metric through which the severity of the risk is measured: the more significant the expected damage, the greater the weight assigned to the detected risk.

In this case, the process involves the search for information and data from authoritative sources such as the European Union or the Italian Government for a qualitative attribution of weights supported as much as possible by objective criteria. However, this system has a subjective component that can affect the comparability and objectivity of the results (Koradecka et al., 2010).

In fact, in this case, a structured analysis of the sources has been provided. Three machine learning techniques have been identified that can make the assignment of weights objective. The three techniques selected are respectively Random Forest, Gradient Boosting Machine and Logistic Regression. These solutions are comparable and can be integrated with each other.

The first model, the Random Forest, proves to be particularly suitable for its robustness and flexibility in business contexts where it is necessary to assign weights to risk variables starting from complex, heterogeneous and sometimes redundant datasets. The main advantage of this algorithm lies in its ability to identify the most relevant variables for risk prediction, through internal selection mechanisms based on measures of importance (Speiser et al., 2019). However, the Random Forest technique is known to be a "black box" model. This reduces

the transparency of decisions, which is crucial for the application of this study as already highlighted. Furthermore, if not properly optimized, the model can involve high processing times, especially in the training phase, in the presence of very large or complex datasets, so its use is recommended in small business contexts.

The second model, the Gradient Boosting Machine (GBM) algorithm, is an ensemble learning technique (combination of multiple predictive models) based on sequential optimization of weak models. This method is able to build highly accurate models through an iterative process that aims to correct, step by step, the errors made by previous predictions. Unlike the Random Forest, which works in parallel on independent trees, the GBM builds the model sequentially, which makes it particularly sensitive to parameter adjustment, but also very powerful from a predictive point of view (Tian et al., 2020). However, this system can be subject to overfitting especially in the presence of large datasets (Tian et al., 2020).

The third model, Logistic Regression, is a well-established technique widely used in risk modeling. Second, Logistic Regression represents an extremely effective tool to analyze binary variables, such as in the case of risk events, while allowing to include multiple explanatory variables in the model and to estimate the probability of occurrence of an event that can also be interpreted in the decision-making field. One of the main strengths of this model is its transparency and simplicity of interpretation, which makes it particularly useful when it is necessary to explain the modeling choices to non-technical stakeholders (Sperandei, 2014).

Therefore, the power of the first two models and the transparency of the results of the third can be combined to provide an accurate weight definition that is understandable to outside observers.

Once the risk categories and the weights associated with them have been defined, the process continues in the mapping of the business processes that are put in the matrix with the risk areas to understand their probability and impact, thus defining the gross risk. This process is totally discretionary and is based on the collection of information carried out up to that moment. The calculation of probability and impact, then, are exclusively linked to a current calculation without considering historical trends. Furthermore, in the specific context of the company in question, the result is extremely influenced by the characteristics of the customers of the process who must be clustered in order to be evaluated. This work is carried out manually through an initial skimming of the riskiest subjects and an in-depth investigation exclusively on them. This approach is effective, although limiting, if carried out by a person. The approach we suggest is a wide-ranging analysis of the basic information of all customers and a model capable of reconstructing the historicity of the subjects to include the forecast within the considerations.

In this context, it was decided to integrate Artificial Intelligence as a tool to support these activities. Flammini et al. (2023) proposes a methodological approach to risk management through AI systems. This model is not limited to data collection or technical automation alone, but aims to generate operational intelligence through the continuous processing of performance and risk indicators. This strengthens the organization's ability to respond promptly to potential critical events. It suggests an AI tool capable of carrying out an in-depth and structured analysis capable of generating a dynamic clustering of customers.

3.3 Strategic definition and creation of the action plan

Once the level of risk has been defined, the process continues with strategic planning in which the most critical areas are identified and priorities are set. This plan defines both the monitoring and implementation times of the measures envisaged, with the aim of arriving at an objective assessment of the degree of mitigation obtained. Finally, the last step of the process involves the construction of an action master plan. In the creation of the latter, targeted interventions are identified and developed through a structured analysis. Given the high interconnection between the second and third macro areas of the model, the decision was made to adopt a single automated approach for both phases.

In the current process we find a definition of priority levels based on brainstorming and analysis approaches with experts to determine priorities together with forecasting future impacts and monitoring actions. Also in this case, discretion plays a decisive role in the result.

To limit the discretionary contribution, the framework of Flammini et al. (2023) was again considered, which with its power of analysis is able to provide objective elements to the decision-making process. Therefore, the final steps of the process can be grouped and simplified by having the tool produce several intermediate outputs that can help decision-makers to have the correct guidelines.

4 Conclusions

In conclusion, the model developed in this work is configured as an integrated ecosystem of intelligent technologies applied to risk management, capable of combining automation, predictive analysis and decision support in a single operational architecture. The adoption of tools such as RPA, AI and Machine Learning,

supported by a solid mapping of processes through BPMN, has made it possible to outline a systemic path oriented towards efficiency, the reduction of human error and the enhancement of company data.

A key aspect of the model is the ability to segment customers based on the risk they bring to the business. Using clustering techniques, customers can be grouped into homogeneous clusters, making it easier to identify high-risk customers and take targeted corrective measures.

The innovative contribution of this model lies in the ability to transform risk management into a modular, adaptive and proactive process, overcoming the traditional static and fragmented approach. The integration of Web Scraping techniques and Business Intelligence tools has also significantly expanded the scope of information available, enriching assessments with dynamic and contextual elements from inside and outside the organization.

These developments have opened the door to higher investigations and considerations. Among the most interesting ones, certainly, is the opportunity to integrate the results of risk assessment into predictive models that convey the same results into mathematical optimization models. This would provide decision-makers with a clear guideline in the field of short- and long-term strategic planning that has never been addressed before. The introduction of machine learning algorithms such as Random Forest, Gradient Boosting Machine and Logistic Regression could open the door to better reliability of forecasts and to refine the definition of weights in risk categories, adapting modeling choices according to the complexity and transparency required in the different operational areas. The synergistic use of these models has proven to be more efficient than monolithic solutions, favoring incremental data processing and constant monitoring of outputs.

Looking ahead, the framework outlined can also be extended to other business decision-making areas, where the complexity of data and the need for rapid responses require the adoption of flexible, intelligent and automated models. At the same time, the approach remains open to subsequent evolutions, including the introduction of emerging technologies, such as Large Language Models or generative AI systems to further enrich risk analysis, forecasting and simulation capabilities.

Ultimately, this work intends to contribute to the development of a new vision of corporate risk management, based on the integration of organizational know-how and technological potential, capable of enabling increasingly timely and sustainable decision-making models.

5 Ethics declaration

The present research did not require the approval of an ethics committee, as it does not involve human subjects, sensitive personal data or experimentation on living beings. All the information used comes from publicly accessible sources and scientific literature.

6 AI declaration

Generative Artificial Intelligence tools have not been used for the drafting or processing of the contents of this document. All sections of the paper were developed independently by the authors, without the aid of generative AI applications.

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Exploring the Synergy: AI-Driven Knowledge Management, ESG Performance, and Stakeholder Perceptions in the Energy Sector

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Abstract
The global imperative for sustainable development is compelling industries to reassess operations, emphasizing Environmental, Social, and Governance (ESG) criteria. The energy sector, pivotal yet environmentally impactful, faces intense pressure to innovate sustainably. Artificial Intelligence (AI) offers transformative potential, particularly its application in Knowledge Management (KM) systems to enhance information handling for superior ESG performance. However, a literature gap exists concerning the interplay between AI-driven KM, ESG outcomes, stakeholder perceptions, and corporate competitiveness in this sector. This proposal outlines a study to investigate these dynamics: how AI-driven KM influences ESG outcomes, how stakeholders perceive these innovations, and how such practices might bolster energy companies' competitive advantage. A mixed-methods design is planned (literature review, three Italian energy sector case studies, a survey of ~150 stakeholders). Findings are expected to show a positive AI-KM impact on ESG metrics, multifaceted stakeholder perceptions (more positive externally, varied internally with concerns like job displacement), and enhanced competitiveness through innovation and efficiency. The study aims for theoretical contributions to the AI-KM-ESG nexus and practical insights for energy executives.

Keywords: artificial intelligence, knowledge management, ESG performance, stakeholder perception, energy sector, mixed-methods research, sustainability, digital transformation

Paper type: Academic Research Paper

1 Introduction

The 21st century demands sustainable development, pushing Environmental, Social, and Governance (ESG) criteria to the forefront of corporate strategy (Eccles et al., 2014). The energy sector, vital yet a major environmental contributor (York & Bell, 2019), must transition to cleaner models while ensuring energy security and affordability. Artificial Intelligence (AI) is a key enabler, with its capacity to optimize operations, enhance efficiency, and improve ESG reporting (Duan et al., 2019). A promising AI application is in Knowledge Management (KM), crucial for innovation and achieving ESG targets (Nonaka & Takeuchi, 1995). AI-powered KM can help energy companies understand their ESG footprint and embed sustainability.

Despite interest in AI, KM, and ESG, their intersection in the energy sector is under-researched. Empirical studies are lacking on:

- How specific AI-driven KM practices influence ESG performance indicators.
- How diverse internal and external stakeholders perceive these technological adoptions.
- The mechanisms through which these initiatives affect corporate competitiveness.

Stakeholder perceptions are critical (Freeman, 1984), as AI introduction is a socio-technical shift evoking varied reactions (Brynjolfsson & McAfee, 2014). This research aims to understand the interplay between AI-driven KM, ESG performance, stakeholder perceptions, and competitiveness in the energy sector. Specific objectives are:

- Assess how AI-driven KM influences ESG metrics in selected energy companies.
- Analyze stakeholder perceptions of AI in KM for sustainability.
- Evaluate how AI-driven KM, mediated by ESG performance and stakeholder perceptions, could enhance corporate competitiveness.

A mixed-methods approach (qualitative case studies, quantitative survey) is proposed. Anticipated outcomes include empirically grounded insights for theory and practice, aiding energy sector navigation of digital transformation and sustainability.

2 Theoretical background and research motivation

This research integrates four domains: Knowledge Management (KM), AI's role in KM, ESG frameworks in the energy sector, and Stakeholder Theory.

2.1 Knowledge management (KM):

KM involves managing organizational knowledge for competitive advantage (Drucker, 1993). It distinguishes tacit (personal, hard to codify) and explicit (formal, communicable) knowledge (Polanyi, 1966), with models like SECI (Nonaka & Takeuchi, 1995) explaining their conversion. Effective KM improves decision-making and efficiency (Davenport & Prusak, 1998). In ESG, KM is vital for managing complex data (emissions, compliance) and integrating sustainability (Ling, 2013), though traditional systems struggle with Big Data.

2.2 Artificial intelligence (AI) as an enabler of advanced KM

AI can transform KM by overcoming traditional limitations (Jarrahi, 2018). Key AI technologies include Machine Learning (ML) for pattern identification and prediction (e.g., predictive maintenance), Natural Language Processing (NLP) for analyzing unstructured text (e.g., stakeholder feedback), expert systems, Robotic Process Automation (RPA), and Knowledge Graphs for intuitive knowledge discovery (Hogan et al., 2021). AI enhances all KM stages but faces challenges like data quality, algorithmic opacity, ethics, and employee resistance (Dwivedi et al., 2021). Human-AI synergy is a promising path (Batista et al., 2022).

2.3 Environmental, social, and governance (ESG) in the energy sector

ESG criteria evaluate a company's societal impact (Gillan et al., 2021). Environmental aspects (emissions, resource use) are critical for the energy sector's low-carbon transition (IPCC, 2023). Social factors include health/safety, DEI, and just transition (Heffron et al., 2021). Governance covers leadership, ethics, and risk management (Bebchuk & Tallarita, 2020). ESG reporting standards (GRI, SASB, TCFD) are evolving, with investor pressure driving improvements. AI can automate ESG data collection, monitoring, risk analytics, and reporting.

2.4 Stakeholder theory and perceptions

Stakeholder Theory (Freeman, 1984) emphasizes managing relationships with all affected parties. AI adoption for sustainability impacts diverse stakeholders differently. Internal stakeholders (employees, management) may see benefits but also fear job loss or de-skilling (Autor, 2015). External stakeholders (investors, regulators) might view AI positively for ESG but have concerns about data governance or accountability. Navigating these perceptions requires engagement and ethical AI principles (Rawlins, 2008).

2.5 Synthesis and justification

While literature exists on KM, AI, ESG, and Stakeholder Theory individually, their integrated empirical study in the energy sector is lacking. This research addresses this gap by investigating how AI-KM influences ESG, how stakeholders perceive these changes, and the net effect on competitiveness.

3 Methodology

A mixed-methods sequential explanatory design (QUAL -> quan) is proposed, grounded in a pragmatist paradigm (Morgan, 2014). Qualitative findings will inform the quantitative phase.

3.1 Phase 1: Qualitative case study research

Case Study Selection

Three energy companies in Italy will be purposively selected based on: active AI-driven KM for ESG, explicit ESG focus, varied profile (desirable), and accessibility. Anonymity will be ensured.

Data Collection

- Semi-structured Interviews: ~15-20 per company (45-60 total) with diverse internal (executives, managers, technical staff, employees) and potentially select external stakeholders (investors, regulators). Themes: AI-KM motivations for ESG, tools/processes, perceived impacts, benefits/challenges, effects on KM, perceptions (job roles, ethics), and competitiveness. Interviews (60-90 min) will be recorded and transcribed.
- Document Analysis: Corporate ESG/sustainability reports, strategic plans, AI-KM system documentation, communications, and public ESG data.
- Observational Data: Non-participant observation of AI-KM system use.

3.2 Phase 2: Quantitative survey research

Instrument Development: A structured questionnaire based on qualitative findings and validated scales (adapted for AI-KM for ESG context, e.g., from Davis, 1989 for TAM; Kock et al., 2021 for AI anxiety). Sections: demographics, AI-KM awareness/use for ESG, perceived ESG impact, AI attitudes/concerns (job security, transparency), organizational support, and perceived KM/competitiveness impact. Likert scales will be used. Pilot testing and translation (if needed) will be conducted.

Sampling and Administration: ~150 stakeholders, primarily from the case study companies (stratified sampling considered). Online administration via platforms like Qualtrics. Anonymity guaranteed.

3.3 Data analysis plan

Qualitative: Thematic analysis (Braun & Clarke, 2006, 2019) of interview transcripts and documents using CAQDAS (e.g., NVivo). Within-case then cross-case analysis.

Quantitative: Statistical software (SPSS/R). Descriptive statistics, correlation analysis, comparative analysis (t-tests, ANOVA), and potentially exploratory regression analysis.

Integration: Qualitative findings will explain and contextualize quantitative results.

3.4 Ethical considerations

Strict adherence to ethical principles. IRB/Ethics Committee approval from Mercatorum University will be obtained. Key aspects: informed consent, anonymity/confidentiality, voluntary participation, secure data management, risk/benefit assessment, and potential feedback to companies.

4 Expected results and hypotheses

This study anticipates findings on AI-KM's impact on ESG, stakeholder perceptions, and competitiveness.

4.1 Expected impact on ESG performance

Hypothesis 1a (Environmental): it is hypothesized that the implementation of AI-driven KM systems will be positively correlated with measurable improvements in environmental performance indicators.

Expected Findings: AI applications (predictive maintenance, grid optimization) leading to tangible benefits, supported by KM for data capture and best practice dissemination.

Hypothesis 1b (Social): AI-driven KM initiatives will associate with positive social outcomes (e.g., enhanced OHS, better training) but may reveal nuanced challenges (e.g., employee anxiety).

Expected Findings: KM facilitating safety protocol tracking and stakeholder feedback management.

Hypothesis 1c (Governance): AI-driven KM will enhance governance (transparency, compliance, risk management).

Expected Findings: AI tools improving ESG reporting accuracy and timeliness, AI analytics aiding ESG risk identification.

4.2 Expected stakeholder perceptions

Hypothesis 2a: External stakeholders (investors, regulators) will generally hold more uniformly positive perceptions of AI-driven KM for ESG than internal stakeholders.

Expected Findings: Externals viewing initiatives as signals of innovation and proactive ESG management.

Hypothesis 2b: Internal stakeholders will exhibit more heterogeneous perceptions, with significant concerns (job security, skill gaps, algorithmic transparency, privacy) alongside recognized benefits.

Expected Findings: Survey quantifying these concerns

Hypothesis 2c: Perceived adequacy of organizational change management (communication, training) will significantly moderate internal stakeholders' perceptions and acceptance of AI-driven KM.

Expected Findings: Effective change management correlating with lower concerns and higher acceptance.

4.3 Expected impact on KM processes and corporate competitiveness

Hypothesis 3a: AI-driven KM will lead to demonstrable improvements in KM capabilities (knowledge capture, sharing, application, innovation).

Expected Findings: AI tools enhancing knowledge accessibility and fostering a learning culture.

Hypothesis 3b: Enhanced ESG performance, facilitated by AI-driven KM, will positively associate with perceived/actual improvements in corporate competitiveness (reputation, investor confidence, efficiencies, innovation).

Hypothesis 3c: Positive stakeholder perceptions of AI-driven KM and ESG initiatives will further amplify competitive advantages.

Exemplary Tables of Anticipated Survey Data Constructs

To provide a clearer picture of the quantitative aspect, the tables below illustrate the type of constructs that it is planned to measure via the survey and the general format of the results it is expected to obtain.

Table 1 - Examples of Key Constructs and Planned Measurement Approaches for the Stakeholder Survey

Construct Category	**Example Construct**	**Potential Measurement Approach (Illustrative)**
Perceptions of AI-KM System	Perceived Usefulness of AI-KM for ESG Tasks	5-item scale adapted from Davis (1989) (e.g., "Using the AI-KM system improves my performance in ESG-related tasks.") - Likert 1-7
	Perceived Ease of Use of AI-KM	4-item scale adapted from Davis (1989) (e.g., "Learning to operate the AI-KM system is easy for me.") - Likert 1-7
Impact on ESG Performance	Perceived Contribution of AI-KM to Environmental Perf.	3-item scale developed for study (e.g., "AI-KM has significantly helped our company reduce its carbon footprint.") - Likert 1-7
	Perceived Contribution of AI-KM to Social Perf.	3-item scale (e.g., "AI-KM has improved workplace safety in our company.") - Likert 1-7
Stakeholder Concerns	AI-related Job Insecurity	4-item scale adapted from Kock et al. (2021) (e.g., "I am worried that AI might make my job redundant.") - Likert 1-7
	Algorithmic Transparency Concerns	3-item scale (e.g., "I often don't understand how the AI-KM system arrives at its recommendations.") - Likert 1-7
Organizational Factors	Adequacy of AI-related Training	3-item scale (e.g., "The company has provided sufficient training for using the new AI-KM tools.") - Likert 1-7
	Quality of Communication about AI Changes	3-item scale (e.g., "Management has clearly communicated the reasons for implementing AI-KM systems.") - Likert 1-7
Impact on KM & Competitiveness	Improvement in Knowledge Sharing	3-item scale (e.g., "AI-KM has made it easier to share relevant knowledge with my colleagues.") - Likert 1-7
	Perceived Impact on Company Competitiveness	4-item scale (e.g., "Our company's use of AI for ESG and KM strengthens its competitive position in the market.") - Likert 1-7

Note: This table illustrates examples of constructs and potential measurement approaches planned for the survey. Actual scales will be finalized after the qualitative phase and pilot testing.

Table 2 - Illustrative Format of Expected Aggregate Quantitative Survey Results

Key Indicator Measured	***Expected* General Finding (Illustrative Format)**
Mean Score: Perceived Usefulness of AI-KM for ESG Tasks	Expected: Moderately high to high (e.g., Mean > 5.0 on a 7-point scale), varying by user role.
Percentage of Employees Expressing High Job Insecurity due to AI	Expected: A notable minority (e.g., 20-30%) expressing high levels of concern.
Correlation: Adequacy of Training vs. Perceived Ease of Use of AI-KM	Expected: Strong, positive, and statistically significant correlation.
Difference in Perceptions: Managers vs. Non-Managerial Employees	Expected: Managers to report significantly more positive perceptions of AI-KM benefits and lower concerns compared to non-managerial staff.
Relationship: Perceived ESG Improvement vs. Perceived Competitiveness	Expected: A significant positive association, suggesting that stakeholders link better ESG outcomes (via AI-KM) to stronger competitiveness.

Note: This table illustrates the type of aggregate results and relationships the study aims to uncover through the quantitative survey analysis.

By systematically testing these hypotheses and exploring the expected findings through a mixed-methods approach, this research aims to provide a comprehensive, empirically grounded understanding of the pivotal role AI-driven KM can play in advancing ESG agendas and shaping competitive dynamics in the energy sector, while also highlighting the critical importance of managing stakeholder perceptions effectively.

5 Discussion of potential implications

This research is poised to offer significant theoretical and practical implications.

5.1 Potential Theoretical Implications

The anticipated findings are expected to offer highly relevant and actionable insights for managers, policymakers, and other practitioners:

- Advancing AI-KM-ESG Nexus Understanding: Providing empirical investigation of this tripartite linkage, potentially offering a more granular theoretical model.
- Refining Stakeholder Theory: Demonstrating diverse stakeholder perceptions of AI-driven sustainability, adding nuance for transformative technologies.
- Contributing to Socio-Technical Systems Theory: Reinforcing STS tenets by showing AI success depends on co-adaptation of social and technical elements.
- Informing Competitive Advantage Theories: Suggesting AI-KM for ESG as a potential valuable resource (RBV) or dynamic capability.
- Methodological Contribution: Offering a mixed-methods exemplar for AI and sustainability research.

5.1 Potential Practical Implications

- Guidance for Strategic AI Implementation for ESG: Offering energy executives clearer understanding of impactful AI-KM applications and integration roadmaps.
- Framework for Proactive Stakeholder Engagement: Equipping managers to design effective communication, training, and change management, mitigating resistance.
- Informing Ethical AI Governance: Aiding development of ethical AI frameworks within companies.
- Optimizing KM for Sustainability: Revealing best practices for AI-driven KM to enhance organizational learning in ESG.
- Enhancing ESG Reporting and Investor Relations: Helping companies meet investor demands and improve access to capital.
- Benchmarking and Performance Improvement: Providing a basis for companies to benchmark their AI-KM-ESG efforts.
- Policy Recommendations: Offering insights for policymakers on fostering beneficial AI adoption for sustainability.
- Applicability to Other Sectors: Findings likely relevant for other industries facing similar digital and sustainability transformations.

6 Conclusion

This research proposal outlines an empirical investigation into the AI-KM, ESG performance, and stakeholder perception nexus in the Italian energy sector, addressing a key literature gap. A sequential explanatory mixed-methods design (qualitative case studies followed by a quantitative survey) is proposed.

It is anticipated that AI-driven KM can enhance ESG performance, but stakeholder perceptions will be complex, with internal stakeholders expressing concerns (job security, transparency) alongside benefits. Effective change management is crucial. Improved ESG and positive stakeholder engagement via AI-KM are expected to boost competitiveness.

Potential contributions are significant: theoretically advancing understanding of the AI-KM-ESG linkage and Stakeholder Theory; practically offering actionable insights for executives on AI deployment, stakeholder management, and ethical governance.

Acknowledged limitations include qualitative generalizability, data access, survey cross-sectional nature, potential researcher bias, and causal inference complexity. Mitigation strategies are planned. Future research could include longitudinal studies, cross-cultural comparisons, and deeper dives into specific AI technologies or mitigation strategies.

This research is timely and relevant, aspiring to contribute valuable knowledge for guiding industries towards a technologically advanced, economically competitive, environmentally sound, socially equitable, and ethically governed future.

7 Acknowledgements

The conceptualization of this research proposal has been developed within the framework of the PhD program in Sustainability and ESG at Mercatorum University of Rome. The proposing authors are grateful for the institutional support and intellectual environment that has facilitated this endeavor.

8 Ethics declaration

This research will strictly adhere to ethical principles, with prior IRB/Ethics Committee approval. Informed consent will be obtained, ensuring voluntary participation and the right to withdraw. Confidentiality and anonymity of participants and organizations will be rigorously protected throughout the study. Data will be managed securely, minimizing risks and upholding research integrity.

9 AI declaration

This study investigates AI-driven Knowledge Management as its subject, not developing new AI. Ethical implications of the studied AI systems, including bias, transparency, and job impact, are central to the research. Standard data analysis software (CAQDAS, SPSS/R) is planned; any use of generative AI tools by researchers in manuscript preparation will be transparently acknowledged. The focus is on AI's real-world application and societal impact in the energy sector's ESG efforts.

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Artificial Intelligence, Knowledge Management and Reduced Work Time: Rethinking Organizational Competitiveness

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Abstract

Business success is no longer defined solely by financial performance or the quality of goods and services provided. It is imperative for companies to embed sustainability into their strategic frameworks, embracing socially and environmentally responsible practices. Businesses must now prioritize aligning profit with ethical and sustainable practices that enhance lives, protect the environment, and foster inclusive communities.

In this new mindset, work focuses on growth as well as output, redefining productivity around well-being and sustainability in a people-centered "productive revolution."

Emerging technologies such as artificial intelligence (AI) offer new ways of organizing work, helping companies use their resources more effectively. It is through intelligent automation that many repetitive, low-value tasks can be eliminated, freeing up time for more strategic and creative activities. This makes it possible to reduce working hours without compromising, and indeed improving, both productivity and competitiveness.

At the same time, AI plays a fundamental role in knowledge management (KM), due to its ability to collect, analyze, and organize large volumes of data, enabling the creation, sharing, and preservation of knowledge within companies.

The reduction of working hours is increasingly central to the debate on the future of work, closely linked to the issue of work-life balance. Improving the balance between private and professional life has become a priority for many companies. What experiences such as the "4 Days Week" have demonstrated in various European countries is that they can bring tangible benefits: greater well-being, motivation, productivity, and improved talent retention.

The present study aims to explore the role of AI in transforming work models, focusing in particular on the effects of reducing working hours on productivity and knowledge management. The analysis will be carried out through a theoretical-documentary research approach, based on an integrated review of scientific literature, institutional reports, and national and international business cases, with particular reference to the themes of artificial intelligence, productivity, and knowledge management.

Keywords: Artificial Intelligence, Productivity, Worktime Reduction, Knowledge Management, Well-being

Paper type: Academic research paper

1 Introduction

In the era of digital transformation and increasing focus on sustainability, companies are facing a crucial challenge: reconciling the adoption of new technologies with employee well-being and organizational competitiveness. In this context, artificial intelligence (AI) is not merely a tool to enhance efficiency—it is a strategic lever for fundamentally rethinking how work is organized and experienced.

AI enables the automation of repetitive and low-value tasks, thereby freeing up time and cognitive resources for activities with greater human significance. This development contributes to a broader redefinition of productivity, one that takes into account not only economic output but also the quality of working life. In this context, Work Time Reduction (WTR), already piloted in several countries, emerges as a tangible strategy for improving work-life balance (WLB), supported in part by AI's transformative potential.

At the same time, the role of Knowledge Management (KM) is gaining strength: intelligent technologies not only facilitate access to and sharing of knowledge, but also enable a more flexible and sustainable reorganization of business processes.

This study explores how AI can transform workplace structures by enhancing efficiency, knowledge management, and employee well-being, positioning knowledge, motivation, and innovation as key pillars of new organizational models.

The central research question is as follows: How can artificial intelligence contribute to a sustainable reduction in working hours without compromising, and indeed, while strengthening, business competitiveness, through more effective knowledge management?

The analysis will focus on the relationship between AI, KM and WTR, identifying the organizational conditions that enable a virtuous transformation of work. Based on a theoretical and documentary review of recent literature, the paper aims to build a conceptual model capable of guiding companies toward a more human, efficient, and sustainable future.

2 Theoretical framework

2.1 Industry 5.0: AI, automation, and productivity

With Industry 5.0, technology is no longer focused just on increasing output, but on creating value for people, society, and the environment. Unlike Industry 4.0, which focused primarily on automation and efficiency, Industry 5.0 places the human being at the center and promotes sustainability, resilience, and well-being at work (Breque, De Nul & Petridis, 2021).

In this context, intelligent technologies can enhance worker well-being, offer greater flexibility, and improve collaboration between humans and machines, promoting a cultural transformation based on participation and shared responsibility (Nirupama et al., 2024). AI thus becomes a strategic ally in building more inclusive, flexible, and human-centered workplaces.

Today, AI is one of the main drivers of productivity transformation. It goes beyond the limits of traditional automation by enabling systems to handle not only mechanical or repetitive tasks but also complex ones (Muro et al., 2019). Industry 5.0 therefore promotes a cultural shift in which technology serves people and society. The aim is to create a more ethical, sustainable, and future-oriented work model.

AI-driven automation, especially generative AI (GenAI), is reshaping operational processes, making them more efficient, accurate, and faster. By automating repetitive tasks, GenAI reduces human error and frees up time for more strategic activities, thereby improving the quality of work (WEF, 2024).

Recent studies (Rožman et al., 2023) highlight that AI can reduce perceived workload, increasing engagement and performance. However, to fully benefit, organizations need proper training and a flexible, tech-integrative culture (WEF, 2024). Productivity gains depend on accessible technology, alignment with human skills, and strong leadership. The most significant advantages currently favor early adopters with an innovation-oriented mindset, adequate resources, and rapid AI integration capabilities (Filippucci et al., 2024).

2.2 Knowledge management, competitiveness, and AI

Knowledge, as a key intangible asset for competitiveness, emerges from a collective, dynamic process involving experience, values, and context. KM plays a strategic role in fostering learning, innovation, and adaptability. Davenport and Prusak (1998) define knowledge as a fluid mix of contextual information, experience, and intuition, embedded not only in systems but also in practices and culture. KM, therefore, must be approached as a holistic system integrating people, technology, and management. The SECI model by Nonaka and Takeuchi (1995) frames knowledge creation as an ongoing cycle, socialization, externalization, combination, and internalization, that drives innovation through the "knowledge spiral".

This dynamic can only function effectively within an enabling environment. The workplace must encourage the sharing, organization, and enhancement of knowledge. Without a culture oriented toward KM, this process risks stagnation, and knowledge may become dispersed. Wiig (1997) argues that business success depends on the ability to manage knowledge in a structured way, through activities such as monitoring, developing appropriate infrastructures, and transforming and enhancing intellectual resources.

The idea of the knowledge-based firm is now well-established in the literature. Grant (1996) emphasizes that competitive advantage stems from the ability to integrate individual knowledge, while Nonaka, Toyama, and Hirata (2008) highlight the importance of continuous circulation and renewal of knowledge within the organization.

Today, knowledge can be managed in a more structured way thanks to systematic processes for collecting, organizing, and enhancing knowledge, processes made more effective by digital technologies, particularly AI (Berryhill et al., 2019; Agostino, Arnaboldi, & Busco, 2021).

Corporate experiences such as those of E80 Group and Pfizer show that AI can transform complex archives into intelligent hubs (E80 Group, 2023; AWS & Pfizer, 2023). These tools support decision-making and improve operational efficiency. Knowledge management becomes faster, more accessible, and user-oriented. Time is freed up for higher-value activities, opening the door to a potential sustainable reduction in working hours.

2.3 Work life balance and work time reduction

Work-Life Balance (WLB) is becoming increasingly important for building sustainable organizations that prioritize employee well-being, with technology playing a key role in helping individuals maintain a healthy balance between professional and personal life (Cookey, 2025).

In response to technological change and evolving employee needs, many companies are rethinking how work is structured. Solutions such as reduced working hours and remote work offer greater flexibility and improve quality of life while maintaining high levels of productivity (Trougakos et al., 2024; Corso et al., 2023).

The "4-Day Week" model, reducing the workweek to four days without salary cuts, has been trialed in various countries with promising results. Empirical evidence highlights benefits for both employees and organizations, including higher job satisfaction, lower burnout rates, improved work-life balance, increased productivity, and reduced turnover (Campbell, 2024).

These outcomes are also supported by theory, particularly Self-Determination Theory (Deci & Ryan, 1985; 2000), which argues that motivation and well-being stem from the fulfillment of three core psychological needs: autonomy, competence, and relatedness. When the work environment supports these needs, employees tend to show higher levels of energy, engagement, creativity, and performance (Van den Broeck et al., 2008; Gagné & Deci, 2005). Conversely, rigid and controlling structures may undermine motivation and increase stress.

From this perspective, what truly makes a difference is not merely the reduction of working hours as a conciliatory measure, but its role as a strategic lever to enhance engagement and improve the quality of professional life. Organizations that embrace such approaches are better positioned to innovate, attract talent, and adapt to change, while promoting a culture based on well-being, trust, and the appreciation of people.

AI is reshaping organizational models, influencing productivity, KM, and employee well-being. However, a key area of inquiry remains: how can artificial intelligence contribute to a sustainable reduction in working hours without compromising, and indeed, while strengthening, business competitiveness, through more effective knowledge management?

To address this issue, the study proposes breaking it down into two more specific research questions, allowing for a clearer and more structured analysis:

- How can the integration of AI into knowledge management contribute to a sustainable reduction in working hours within organizations? This question focuses on the role of AI-enhanced KM as a lever for freeing up time and reorganizing work processes.
- How can a reduction in working hours, enabled by AI, maintain or even enhance business competitiveness? Here, the emphasis is on the impact of work time reduction (WTR) on organizational performance when supported by AI.

While these two questions address different dimensions, they ultimately converge in the development of an integrated model in which AI acts as a driving force for organizational transformation aimed at long-term well-being and competitiveness.

3 Methodology

This study adopts a theoretical-documentary approach aimed at exploring the role of artificial intelligence in transforming organizational models, with particular focus on the reduction of working hours and knowledge management. The methodology is based on an integrated analysis of secondary sources, scientific, institutional, and corporate, selected for their relevance, timeliness, and credibility.

Specifically, the analysis includes: articles published in international peer-reviewed scientific journals; reports and white papers from institutions such as the OECD, European Commission, Aspen Institute, and McKinsey & Company; and documented corporate case studies (e.g., Pfizer, E80 Group, Microsoft Japan, Shopify).

The documentary research was conducted using keywords such as: Artificial Intelligence, Work Time Reduction, Knowledge Management, Productivity, and Work-Life Balance. The selected sources cover the period from 2019 to 2025, with priority given to the most recent publications and empirical evidence related to real-world experiments (e.g., the "4-Day Week").

The analysis was guided by a sequential logic model, AI → Knowledge Management → Work Time Reduction → Competitiveness, which served to interpret the collected data in light of the central research question. Materials were examined from both a comparative and conceptual perspective, identifying recurring patterns, organizational implications, and enabling conditions.

Although no primary data were collected, the chosen methodology makes it possible to outline an integrated conceptual model that can support future empirical research and strategic reflections in the context of digital transformation in the workplace.

4 Discussion and findings

4.1 AI, knowledge management and work time reduction

How can the integration of AI into knowledge management contribute to a sustainable reduction in working hours within organizations?

Integrating AI into knowledge management is a strategic lever for optimizing working time and enabling sustainable work hour reduction (Morandini et al., 2023). AI represents a new form of knowledge investment, enhancing intangible capital and increasing capital deepening—key as much corporate value now stems from knowledge, innovation, and human capital (Filippucci et al., 2024; Corrado et al., 2022). AI streamlines knowledge discovery by analyzing large datasets, identifying patterns, and organizing information efficiently. A notable example is E80 Group S.p.A., where AI transformed unstructured data into a semantic knowledge graph, evolving into a Knowledge Hub that improved access to information, collaboration, and operational continuity (E80 Group, 2023).

In other sectors, such as pharmaceuticals, intelligent systems have shown similar impact. Pfizer, for example, implemented AI-driven solutions to extract, categorize, and recommend relevant scientific content from massive datasets, significantly reducing research time and improving overall efficiency. This accelerated the acquisition and dissemination of scientific knowledge within R&D processes (AWS & Pfizer, 2023). As a result, the time saved could be reinvested in higher-value activities, contributing to a more sustainable use of working time.

In the hospitality industry, the knowledge concierge concept offers another effective application. Here, intelligent virtual assistants accompany guests throughout their stay, automating repetitive tasks such as reservations, check-in/check-out, FAQ responses, and handling of personalized requests.

These systems provide timely, relevant, and updated responses, improving the user experience (McDowell, 2024). At the same time, they allow human staff to focus on tasks requiring empathy, creativity, and problem-solving, easing operational stress and improving shift organization.

AI also enables access to and activation of latent knowledge, such as dark knowledge (Zhang et al., 2025): information not easily codified or immediately identifiable by humans but present within large organizational datasets. This type of knowledge can be critical for solving complex problems, anticipating risks, and improving processes. It also helps reduce uncertainty and response times, further supporting smarter use of working hours.

A notable example is Microsoft Japan's 2019 trial of a four-day workweek, launched under the Work Life Choice Challenge program. The results were significant: a 40% increase in productivity, a 23% drop in energy costs, and a sharp reduction in average meeting duration. Although this initiative was not directly AI-driven, it produced similar effects: streamlined workflows, elimination of non-essential activities, and a redefinition of operational priorities (Microsoft Japan, 2019).

These cases demonstrate that the integration of AI into KM systems can become a powerful lever for achieving a sustainable reduction in working hours. By automating repetitive and low-cognitive tasks, AI improves knowledge access and management, freeing up both time and mental resources.

This enhanced efficiency allows for a more intelligent distribution of working time, with tangible benefits in terms of both productivity and well-being. As emphasized by the IA2 Observatory, the benefits of AI emerge when it is embedded in organizational models that emphasize continuous learning and the development of human capital (Aspen Institute Italia, 2024).

In this context, AI does not replace people, it amplifies their contribution, enabling a more human and dynamic form of knowledge management (Farrell et al., 2023). According to the OECD, this can lead to more sustainable and resilient organizations, where reduced working hours are matched by greater value creation (OECD, 2025).

4.2 AI and work time reduction as a lever for competitiveness

The authors inquire how the reduction in working hours, enabled by the use of AI, can maintain or even enhance business competitiveness.

Work-Life Balance (WLB) has become key to workplace well-being, as more free time improves psychosocial health, focus, and performance. Organizations implementing WLB measures, like flexible schedules or non-monetary benefits, report reduced stress, higher job satisfaction, better performance, and lower absenteeism (Halpern, 2005; Abid & Barech, 2017; Rodríguez-Sánchez et al., 2020).

Beyond individual and organizational benefits, WLB practices make companies more attractive to young talent. This, in turn, helps recruit qualified, motivated individuals, contributing to a more stable work environment (Rodríguez-Sánchez et al., 2020).

Work Time Reduction (WTR) is an increasingly relevant WLB strategy involving fewer weekly hours without cutting pay or raising workload (Trougakos et al., 2024). Unlike part-time work, it restructures schedules across the organization and is seen as a strategic investment in human capital, as shown by international cases (Van Rossum, 2025). WTR builds on the WLB concept, aiming to boost well-being, motivation, productivity, and overall performance.

A large-scale trial in Iceland between 2015 and 2019 showed that reducing the workweek to 35-36 hours maintained or even improved both productivity and service quality. Following its success, 86% of Icelandic workers secured the right to a shorter workweek through collective agreements (Haraldsson & Kellam, 2021).

European pilot programs demonstrate the benefits of a four-day workweek, with UK companies reporting a 35% revenue increase and reductions in stress and turnover (Lewis et al., 2023), Portuguese workers citing improved motivation and WLB (Gomes & Fontinha, 2024), and 73% of German firms continuing trials due to better work quality (Backmann et al., 2024). Though not AI-led, these cases show how technology and process optimization support successful WTR.

AI is widely seen as a tool to improve task allocation and time management (European Commission, 2024), making reduced workweeks more feasible and scalable. A U.S. survey found that 59% of AI users reported higher job satisfaction, 30% saw improved efficiency, and 90% of AI-using companies supported WTR, compared to only 41% among non-users (Tech.co, 2024). This suggests that AI adoption enhances productivity and fosters openness to new work models.

Effective AI integration requires rethinking organizational structures, guided by clear governance separating strategic oversight (often by senior leaders) from functional implementation, typically through hybrid models (McKinsey & Co., 2025). CEO involvement, as in Shopify's AI-first hiring policy (Lütke, 2024), is crucial for aligning innovation with company goals.

Adoption is rising: 73% of organizations recognize AI's value in accelerating tasks and 66% in automating low-value work (European Commission, 2024). Generative AI, now used by 63% of firms, is increasingly embedded in workflows (McKinsey & Co., 2025). Leading companies apply systemic approaches using roadmaps, KPIs, training, and communication to align AI with strategy.

However, realizing WTR through AI also requires cultural change, greater team autonomy and accountability. AI doesn't replace work but redefines it, elevating human skills and fostering well-being-centered, inclusive workplaces (Bankins et al., 2024). Ultimately, AI-driven efficiency supports reduced working hours while enhancing well-being, motivation, and competitiveness, positioning WTR as a strategic path to sustainable innovation.

4.3 Conceptual model proposal

In light of theoretical and practical evidence, a conceptual model of organizational innovation is proposed, summarizing the relationships between Artificial Intelligence (AI), Knowledge Management (KM), Work Time Reduction (WTR), and Business Competitiveness. The model consists of six main components:

Based on both theoretical insights and practical observations, we propose a conceptual model of organizational innovation that highlights the interplay between six key components:

- Artificial Intelligence (AI) as a driver for intelligent automation;
- enhanced Knowledge Management (KM);
- Work Time Reduction (WTR) as an organizational strategy;
- improved Productivity and Well-being;
- renewed Business Competitiveness;
- reinvestment in AI for continuous improvement.

These elements form a circular, self-reinforcing structure, where each component supports and amplifies the others in a virtuous cycle of innovation.

AI is the foundation of the model, enhancing efficiency and work quality by automating low-value tasks and transforming data into structured knowledge, thus enabling a smarter allocation of time to strategic and creative activities.

The second pillar, Knowledge Management (KM), is a dynamic, AI-powered ecosystem that enhances knowledge sharing, supports continuous learning, and improves access to information, enabling better collaboration and reducing repetitive cognitive work.

The synergy between AI and KM enables time optimization, making work time reduction (WTR) both feasible and productive. Through smarter workflows and task redistribution, organizations can reduce working hours while maintaining or even improving performance, fostering a culture of trust, autonomy, and goal-oriented work.

When supported by smart technologies, reducing working hours enhances well-being and work-life balance, lowering stress and boosting motivation. At the same time, clearer goals and streamlined tasks increase productivity, proving that well-being and performance can grow together.

This virtuous cycle leads to a new enterprise model focused not on work intensity, but on balancing technological efficiency, human development, and sustainability—making well-being, team stability, and talent retention central to organizational growth

Ultimately, the model fosters continuous improvement by reinvesting gains in efficiency, well-being, and development into AI solutions, employee training, process innovation, and a stronger organizational culture.

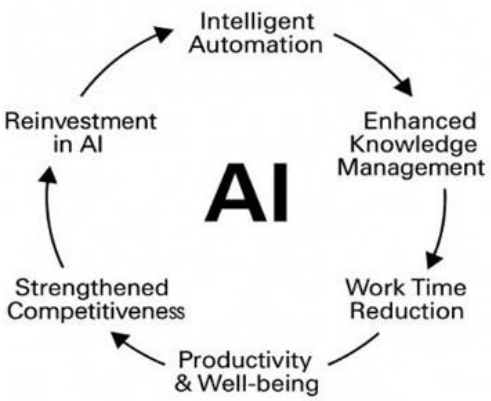


Figure 1. AI, KM and WTR virtuous cycle

In summary, a virtuous path of innovation has been outlined, represented by a circular model (Figure 1) in which each component supports and reinforces the others, giving rise to a continuous and integrated evolutionary dynamic.

The proposed model is based on the idea that the adoption of AI, when integrated into an advanced KM system and accompanied by organizational rethinking, can generate simultaneous benefits in productivity, well-being, and competitive sustainability.

This approach reflects a vision aligned with the principles of Industry 5.0, promoting a cultural and organizational evolution where reduced working hours are not a concession, but a strategic outcome enabled by the intelligent and systemic use of technological innovation.

5 Critical analysis

This article leads to the presentation of a conceptual model that links Artificial Intelligence (AI), Knowledge Management (KM), Work Time Reduction (WTR), and corporate competitiveness. The model offers a perspective on technological change that highlights the transformative potential of AI, not as a threat, but as an opportunity to rethink work patterns and timing in terms of well-being and sustainability. The inclusion of concrete examples enhances accessibility, even for non-specialist audiences, while references to recent sources lend relevance to current dynamics in the world of work and technological innovation.

However, the text presents some limitations that merit further examination. First, the study is based entirely on a theoretical-documentary analysis: it lacks original data, interviews, or field observations. These elements could have strengthened the validity and practical applicability of the arguments.

Moreover, the model overlooks several critical issues related to AI. These include implications for the labor market, psychological impacts, risks resulting from algorithmic biases, and inequalities in access to technology. Additional concerns involve the proper management of data and the protection of privacy.

The optimistic view of the virtuous cycle risks oversimplifying the real challenges of applying AI in productive contexts, as the positive outcomes of shorter workweek trials mainly concern SMEs operating in digital or flexible sectors—quite different from the well-structured, capital- and knowledge-intensive firms that typically succeed in adopting AI (Filippucci et al., 2024; ISTAT, 2024).

Furthermore, the diffusion of AI remains uneven. SMEs are often hindered by a lack of financial resources, technical skills, and adequate infrastructure. These difficulties are even more pronounced in rural or less-developed areas, where infrastructure gaps and a weaker innovation ecosystem are prevalent.

Finally, the real-world implementation of the "4 Day Week" has revealed several challenges, such as increased workload on active days, coordination difficulties, reorganization costs, and the complexity of evaluating productivity outcomes.

To promote AI as a driver for reducing working hours, it's crucial to test the model across different companies to ensure broad, fair, and sustainable adoption. An empirical study should support this by identifying key organizational factors and ethical implications in AI integration.

6 Ethics declaration

This research did not involve human or animal subjects, nor did it collect any sensitive data; therefore, approval from an ethics committee was not required.

7 AI declaration

No Artificial Intelligence (AI) tools were used in the creation or editing of this work. However, online translation tools such as Google Translate were used only to assist with language translation. All ideas, structure, and final content are the original work of the authors, and full responsibility for the accuracy and integrity of the work remains with the authors.

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Artificial Intelligence as a Driver for Educational Inclusion: Developing a Generative AI Chatbot to Support Professors and Students

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Abstract

Social sustainability is a fundamental pillar for the balanced and inclusive development of contemporary societies. It embodies the commitment to social equity, inclusion, respect for human rights, and the promotion of collective well-being. Artificial intelligence (AI), with its increasing deployment, is emerging as a key tool for addressing social challenges and promoting sustainability goals, which, to date, also involve education, following the provisions of Sustainable Development Goal 4 (SDGs 4) of the UN 2030 Agenda. The integration of artificial intelligence (AI) technology into education has introduced many possibilities. However, it also raises ethical issues that require careful consideration. This paper aims to highlight the importance of considering AI as a driver for educational inclusion, starting with an analysis of its potential. The study delves into the benefits and challenges of the introduction of a generative AI chatbot by Multiversity Group, Italy's largest group operating in the Digital Education sector and Europe's second largest group, which, driven by its vision of AI-enhanced education, collaborated with strategic consulting firm Bain & Company to build such a generative chatbot, leveraging OpenAI technology, to provide a better learning experience for students by fostering engagement and interaction with professors, and to combine didactic delivery and interactive assistance to learners. This paper aims to explore the emerging contribution of AI in education to promote innovative and inclusive educational delivery to reduce possible educational inequalities, considering the benefits, challenges and ethical implications of implementing the technology. AI can be an enabler for social progress, but it requires attention relative to the risks of discrimination and risks related to privacy and data security. The paper analyzes the high-impact challenges faced in developing the generative AI project to ensure that student data is securely managed in compliance with legal standards, such as GDPR 2016/679, the qualitative value of responses, the need for continuous monitoring, and overcoming any technological limitations.

Keywords - Artificial intelligence, social sustainability, inclusive education, digital education, role of AI in education

Paper Type: Practical Paper

1 Introduction

Artificial intelligence is revolutionizing the educational sector, offering innovative tools for personalized learning and accessibility. Educational inclusion is a central challenge in the modern school and academic system. Emerging technologies, particularly AI, offer innovative tools to foster more accessible and personalized education. Chatbots based on generative AI can provide assistance to students, contributing to the reduction of educational barriers. This paper aims to explore the emerging role of AI to promote innovative and inclusive educational provision, reducing possible educational inequalities, and analyze the benefits, challenges, and ethical implications related to implementing the tool. Inclusive education is a central element of social sustainability, aimed at ensuring equal educational opportunities for all, regardless of economic, geographic, or personal barriers. However, structural inequalities persist that limit access to quality education. *Ad hoc* public policies that promote universal access to AI technologies and educational resources and are aimed at bridging the digital divide between geographic areas and social groups are crucial on this point. AI offers significant opportunities to overcome multiple types of barriers, improving accessibility by implementing online learning systems that can reach remote or disadvantaged communities, providing access to high-quality content, personalizing learning pathways and bridging existing gaps. It is possible, then, to consider AI as a driver for educational inclusion, starting with an analysis of its potential. Driven by the vision of AI-enhanced education, Multiversity Group collaborated with strategy consulting firm Bain & Company to build a generative, 24/7 responsive chatbot, leveraging OpenAI technology, to provide a better learning experience for students by fostering engagement and interaction with professors. The pilot project also included the introduction of a customized tool that would enable faculty to complete administrative tasks 90 percent faster, allowing them to focus more on higher-value teaching activities. The goal of the project was to elevate continuous interactive learning experiences, becoming a benchmark for AI-powered instruction across all of its programs. This innovative new service will complement student lectures and regular tutoring provided by the academic cohort

and university services, providing better understanding of complex concepts, important clarifications, additional insights and reference sources. This assistance tool will also provide students with instant feedback. AI is evolving rapidly, and companies need to identify real-world applications that generate sustainable value in their respective industries to secure a competitive advantage. The launch of this AI assistance tool represents a real game changer for the online experience of students and professors

2 The role of artificial intelligence in education

The introduction of AI education is exponential growth. Many areas of education can benefit greatly from the application of artificial intelligence, which improves administrative management and school learning. Intelligent tutoring systems, adaptive learning platforms, natural language processing, data analytics and virtual bot assistants all fall under the umbrella of new technologies anchored by AI. Indeed, AI is being used in various educational fields, leading to a number of benefits. Firstly, AI algorithms can analyze individual student performance to create tailored study paths and structure so-called "*adaptive learning.*" These tools ensure that each student receives the appropriate support based on his or her own pace and learning style. In addition, AI can detect educational difficulties or gaps early, offering targeted interventions to prevent school or even academic dropout through a process of prior identification of needs. Artificial intelligence systems evaluate huge amounts of data to personalize learning paths based on each student's strengths, weaknesses and detected deficiencies. In fact, technologies related to the use of AI make it possible to assess student data to determine which students are at risk of failing a course or are having difficulty with a particular subject. Data on student achievement and detected behavior can be analyzed by predictive analytics algorithms to help educators and teachers identify possible critical issues. Such a model allows preemptive analysis of specific issues to be carried out, enabling teachers to act promptly to resolve them. Artificial intelligence, therefore, enhances "targeted" learning experiences, motivating and retaining students. AI-based analytics systems enable real-time assessment of student performance and the effectiveness of instructional programs, ensuring progress monitoring and accommodating the individual needs of students with learning difficulties or special needs. The use of such technologies improves accessibility through digital platforms and virtual assistants, such as intelligent tutors, who can provide individualized assistance to students. One of the most innovative tools developed for educational inclusion is the generative AI chatbot. Advanced Natural Language Processing (NLP) algorithms enable chatbots to intelligently understand and respond to students' questions, adapting content to their needs, thus making educational processes more accessible and personalized. Personalized learning for each individual student is one of the main benefits using artificial intelligence in digital education. Artificial intelligence algorithms can personalize instruction by assessing information about students' learning preferences, interests and progress. The OECD-OECD report “The potential impact of Artificial Intelligence on equity and inclusion in education” highlights how artificial intelligence can prevent dropout by identifiyng at risk students early through personalized tools that enhance learning. The World Economic Forum’s “Shaping the Future of Learning: the Role of AI in Education 4.0” report also emphasizes the fact that AI makes personalized teaching sustainable, improves learning 98 percent of the time, overcoming the limitations of large-scale application. Artificial intelligence is a key tool for addressing the major challenges in digital education, overcoming traditional barriers and redefining the educational experience to make it more equitable, inclusive and innovative. The true potential of AI lies in its ability to store and analyze huge amounts of data about students, with the purpose of personalizing instruction for each learner. There is a branch of machine learning called "deep learning," a subset of Machine Learning, based on artificial neural networks with multiple layers. It is used to analyze large amounts of complex data with high accuracy. The world of education is going through a period of radical transition, driven by technological evolution, changes in labor market needs and the intensifying need for continuous learning. The World Economic Forum (WEF), moreover, stressed the importance of synergistic collaboration among educational institutions, businesses and governments in order to build a learning system that is more inclusive, adaptive and aligned with the skills of the future.

Below we present two diagrams illustrating a typical model of AI-based digital learning in academia: (1) a process flow diagram and (2) a layered architectural diagram. Both highlight the key elements of the technology-based Digital Learning Model: student data collection, AI/ML analysis, content personalization, delivery via digital platforms, continuous monitoring/feedback and iterative cycle of improvement.

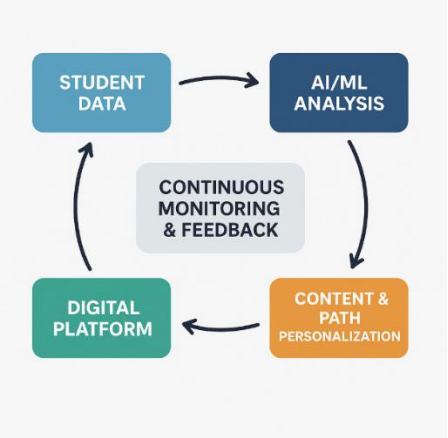


Figure 1: Adaptive model for AI enabled Digital learning

The flowchart shows the sequential steps (in circular form) of the AI-based adaptive learning model. It starts with the acquisition of student data: the system collects information on the performance (e.g., grades, quiz results) and online behaviors (e.g., response times, participation in activities) of each student. This raw data forms the basis on which the AI will operate, providing the informational "fuel" for the model to learn and generate insights. In the AI/ML analysis phase, *machine learning* algorithms and *Natural Language Processing* techniques process the collected information to identify recurring patterns and predict future performance: for example, the strengths and weaknesses of each student are identified, analyzing outcomes and interactions over time. Such analyses produce useful knowledge about the individual learning profile (e.g., specific knowledge gaps, cognitive style, level of engagement). Based on these insights, customization of content and pathways follows: the AI system builds a tailored training pathway, adapting the level of difficulty, the pace of progression, and selecting the most appropriate learning materials for a specific student. Essentially, AI decides what to offer and *how to* offer it, so that each student receives “the right content at the right time" based on his or her progress. The delivery phase takes place through digital platforms: typically a web-accessible Learning Management System (LMS) or mobile app that delivers this personalized content to the student, presenting the learning activities through a user-friendly interactive interface. The digital educational platform then acts as a conduit between the AI and the student, providing the adaptive educational resources while recording new user interactions. During the course execution, continuous monitoring with immediate feedback takes place: the system tracks the student's progress in real time and provides instant automatic feedback on exercises, quizzes, and activities performed. For example, AI can flag errors made in a quiz and offer tailored explanations or suggestions, allowing the student to correct their deficiencies immediately. In parallel, teachers have access to control panels (dashboards) through which they can track student progress, treat it as "human monitoring" and provide additional qualitative feedback or motivational support when needed. Finally, the model incorporates an iterative cycle of improvement: all data collected during activities (results, times, clicks, paths followed) continuously feed the AI system. Through repeated cycles of learning from new data and feedback, the AI progressively refines its algorithms, increasing the accuracy of predictions and the quality of recommendations with each iteration. This closed feedback *loop* ensures that the system gradually becomes "smarter" and more effective as more and more students use it, creating continuous improvement for both student performance and the instructional strategies employed. The model is dynamic and self-regulating. The AI learns from real behaviors, adapts content, observes learning effectiveness, and constantly updates itself, providing a personalized, effective, and constantly evolving learning experience.

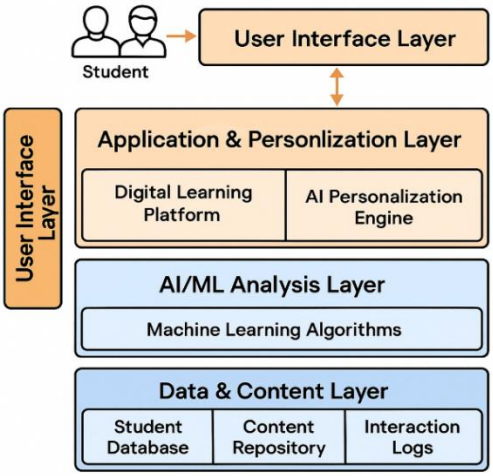


Figure 2 Layered architecture of the adaptive model for artificial intelligence-enhanced digital learning

The architecture of an adaptive model for artificial intelligence (AI)-enhanced digital learning is structured into multiple layers, each with a specific role, which together enable a personalized learning experience for the student. The student is the starting point: he or she interacts with the system through a digital user interface. The second diagram represents the layered architecture (layered architecture) of an AI-based digital learning system, highlighting the main functional components arranged in layers. User Interface Layer: at the top layer are the interfaces through which human actors interact. On one side is the learner, who accesses content and activities through a web or mobile application (the front-end LMS); on the other side is the teacher, who uses a monitoring dashboard to track student progress and intervene as needed. This layer provides user-friendly access to the platform's features, enabling learning anywhere, anytime. Application & Personalization layer: immediately below the user interface resides the actual e-learning platform (LMS backend) along with the business logic and AI modules that orchestrate the personalized experience. This is where the management of courses, learning materials, and adaptivity rules takes place: for example, an AI personalization engine processes requests from the user interface (e.g., "student X has completed unit Y") and, based on learned patterns, determines what content to offer next to the student. This level serves as the "brain" of the application, where AI techniques are applied in real time to adapt the training path. AI/ML Analysis layer: in some architectural models, a layer dedicated to intelligent analysis is distinguished, where Machine Learning algorithms and predictive models trained on educational data reside. This analytical layer processes collected data (student performance, interaction logs, etc.) in the background using methods such as neural networks, data mining algorithms, and NLP in order to extract useful knowledge. The results of the analysis (e.g., the degree of mastery of a certain topic or the prediction of future difficulties) are then passed to the higher application level, which translates them into concrete instructional actions (e.g., proposing a remedial exercise on a topic in which the student has shown deficiencies). Data and Content Layer: at the base of the architecture we find the data layer, which includes the databases and archives that are essential to the functioning of the system. Here reside the student database (containing profiles, results, activity history), the repository of learning content (lessons, exercises, videos, documents available for delivery), and interaction logs (detailed traces of every action taken on the platform). This layer feeds the upper layers by providing the information needed for both AI analysis and content presentation: in other words, the raw data stored in the repositories is what enables AI to make informed decisions. Importantly, a bidirectional flow of information takes place in the architecture: from the low levels upward, data and analysis feed into instructional decisions (data -> AI -> personalization -> user), while from the high levels downward, feedback and newly acquired information flows (e.g., user interactions and teacher-given ratings return to the data layer). Specifically, monitoring results (student performance, automatic AI-generated feedback, and teacher observations) are returned to the database in the form of new data, closing the learning loop of the system. This modular and layered architecture ensures scalability and clarity: each layer plays a distinct but interconnected role, contributing overall to an adaptive and continuously improving learning experience. On the basis of the above, while AI analyzes data to provide personalized recommendations, teachers can focus on high-value-added activities (mentoring, emotional support), leveraging the insights provided by the system. In summary, the presented model combines data collection, intelligent algorithms and human intervention in a virtuous cycle: this enables the university student to be offered a tailor-made educational pathway delivered through modern digital platforms and to continuously improve both teaching

effectiveness and learning success. The ultimate goal is to offer **personalized, adaptive, interactive, data-driven learning** that supports the student on his or her journey in a continuous and dynamic way.

3 Generative AI chatbots for educational support: the case of Multiversity Group

The Multiversity Group, a leader in Digital Education in Italy and second in Europe, in collaboration with strategic consulting firm Bain & Company, has developed a chatbot based on OpenAI technology to support students belonging to the Group's Digital Universities. The collaboration between OpenAI and Multiversity has created an environment of innovation in the educational landscape. Such technological integration is changing the way students and faculty interact. One of the most innovative aspects of the AI chatbot is its ability to interact in real time with learners, who in this way receive support in the study and deepening of complex concepts, getting immediate answers, as if they were interacting with a personal tutor. The more than two hundred thousand students at the group's universities already had the opportunity to take classes flexibly, benefiting from tutoring and university services, but with this innovation they had additional ways to personalize the educational experience and improve exam preparation. In addition, the chatbot, developed and tested with the cooperation of professors and with an accuracy of more than 99 percent, will be useful for the lecturers themselves, refining the interactivity of teaching. The implementation of this AI assistant represents a significant step toward the education of the future. The current version of the chatbot not only provides information, but has the potential to transform into a more advanced assessment system. It itself becomes an analytical tool that identifies areas where students can improve. This ability to personalize not only makes learning more accessible, but also creates an inclusive educational pathway. This approach could, in the long run, revolutionize the way we learn, enabling more and more students to address their gaps and enhance their skills. Multiversity's project represents an ambitious educational vision that integrates technology and learning. The synergy between artificial intelligence and humanity in education is gaining increasing relevance. Potentially, the use of these technologies makes it possible to redefine the role of educators, who will no longer be mere transmitters of information and knowledge, but valuable guides in the learning experience. The world of education is constantly evolving; the inclusion of artificial intelligence tools such as the Multiversity Group's is a significant step in this direction. The implementation of such technologies could not only improve the effectiveness of teaching, but we could see a real process of "democratizing" access to education, opening up new opportunities for students from diverse backgrounds. The future of education looks promising and full of opportunities because of this radical change. The increased demand for flexible and personalized educational solutions necessitates the need to develop tools such as the one implemented by Multiversity, which are critical to meeting the needs of modern students. This technology not only enhances the learning experience, but also prepares students for the challenges of an increasingly digitized and innovative world. The chatbot has helped elevate learning experiences by providing insights and clarification of complex concepts. The goal is to transform digital education, making it more inclusive and effective. The pilot project also included the introduction of a customized tool that would enable teaching staff to complete administrative tasks 90 percent faster, allowing them to focus more on higher-value teaching activities and streamline paperwork. The goal of the project was to aim to elevate continuous interactive learning experiences, becoming a benchmark for artificial intelligence-powered education in all its programs. This innovative new service complements student lectures and regular tutoring provided by the academic cohort and university services, ensuring a better understanding of complex concepts by supplying necessary clarifications, additional insights and reference sources. AI is evolving rapidly, companies need to identify real-world applications that generate sustainable value in their respective industries to secure a competitive advantage. The launch of this AI assistance tool represents a real game changer for the digital learning experience of students and professors.

4 Challenges, ethical implications and future prospects

The integration of artificial intelligence (AI) in education represents a momentous transformation, but it also poses relevant and complex challenges. The introduction of AI into teaching and research practices raises fundamental issues related to algorithmic transparency, protection of personal data, equity of access and prevention of systemic bias. On the ethical side, one of the main risks is algorithmic bias: the use of unrepresentative datasets can generate discriminatory responses or perpetuate pre-existing inequalities. Smart tutors must be trained on diverse data to avoid discrimination. Continuous monitoring is essential in order to ensure the production of accurate and appropriate content. One of the biggest critical elements lies in the fact that AI chatbots can provide false, misleading, harmful, and biased information. It is, therefore, critical that algorithms be designed in a transparent, auditable and equity-oriented manner. Equally important is the need for students to learn to critically examine the production, distribution, ownership, design, and use of these tools

to make informed decisions about their use in their field of study and in their future careers. Another crucial aspect is the issue of privacy: the collection and processing of sensitive student data requires strict security protocols, informed consent, and full compliance with current regulations, think GDPR 2016/679. In addition, there is a need to work hard on continuing education to foster the adoption and use of AI technology by teachers and students. It is important for teachers to develop digital skills by participating in professional development opportunities in order to experiment with innovative teaching methods that can make use of AI-enhanced tools to analyze and address the specific learning needs of each student. Educational and educational institutions must be at the forefront of the use of AI because of its enormous impact on learning and future job requirements. The widespread adoption of AI tools in school and college settings, however, risks exacerbating the digital divide among students with different access to devices, connections and digital skills. Addressing these additional issues related to AI use requires taking a multifaceted approach involving technological innovations, ethical guidelines, legal regulations and educational efforts aimed at promoting the integrity and responsible use of AI. The term "digital ethics" refers to a set of values and principles for the proper use of technology in relationships among individuals, groups and entities. Digital ethics represents a crucial aspect in the implementation of artificial intelligence (AI) in education and academia, requiring critical reflection on how such technologies are developed, adopted and used. There is a need to ensure that AI-based tools respect the principles of inclusiveness, student autonomy, and academic integrity, while preventing automation from compromising educational quality or accentuating pre-existing inequalities. In addition, the responsible integration of AI requires the adoption of shared ethical guidelines and constant monitoring of social and cognitive impacts in order to promote informed and sustainable use of technology within educational and research settings. AI has a significant and disruptive impact on society. Many organizations have launched a wide range of initiatives to establish ethical principles for the adoption of socially useful AI. In the context of artificial intelligence (AI) implementation in educational and academic settings, digital ethics not only imposes standards of transparency, fairness and accountability, but also raises the need to guard against *ethical bluewashing* phenomena. This term describes the practice through which institutions and companies exhibit a formal commitment to ethical principles without such statements being translated into substantive changes in operational practices. In education, the risk of ethical bluewashing is manifested when AI integration is presented as inherently respectful of students' rights or promoting inclusivity, without any real control over the algorithms used, real stakeholder participation, or independent evaluation of impacts. Therefore, critical reflection on digital ethics must necessarily include analysis of the dynamics of bluewashing, so that AI adoption occurs in a genuinely virtuous and collectively welfare-oriented manner. It is incumbent on academic and administrative leaders to reflect on and assess the existence of bluewashing problems in the use and advancement of AI among university students. To manage these critical issues, it will be essential to develop ethical and inclusive public policies, introduce specific regulations, enhance technological infrastructure and promote digital literacy. Indeed, maximizing the positive impact of AI in education requires concrete actions. The future prospects of AI in education are, however, promising: if implemented ethically and responsibly, it can contribute to more personalized teaching, adaptive and continuous learning and a more accessible, equitable, sustainable education system. The adoption of intelligent chatbots that are active 24 hours a day every day, as evidenced by recent experiments in the university context and the case study regarding the Multiversity Group, is a concrete example of how AI can improve the student experience, foster autonomy, and optimize educational resources. The future will see an evolution of chatbots with increasingly advanced capabilities for personalized student support. For an ethical implementation of AI in education, it is essential to ensure transparency in algorithms, equity in access to technology and continuous monitoring of the effectiveness of AI tools. Transparency, accountability and close monitoring are key to mitigating the risks associated with the use of AI in academia. Although AI has the potential to revolutionize education for all economies around the world, its implementation must be guided by the principles of transparency, fairness, equity and responsible use to ensure positive impacts for the benefit of all stakeholders.

5 Conclusions

Generative AI represents a revolutionary opportunity for educational inclusion by improving access to and personalization of learning. The case of Multiversity Group's chatbot demonstrates the potential of these technologies in supporting both students and teachers. However, to ensure ethical and effective implementation, it is critical to address technical, regulatory and educational challenges. Artificial intelligence represents a tremendous resource for promoting social sustainability through inclusive education. In order to fully realize this potential, it is critical to ensure that AI is designed and implemented with a user-centered approach, within guidelines, ethical standards, and regulatory dictate. Through responsible, cross-sectoral

engagement, it will be possible to transform AI into a concrete driver of sustainable social progress for the benefit of the community. To date, structural inequalities persist that limit access to education. A sustainable and effective AI-powered educational landscape requires vigilance, collaboration, and commitment to high-quality education for all. Artificial intelligence, if implemented with an ethical and user-centered approach and supported by appropriate public policies to ensure its safe and equitable use, can help overcome these barriers, reduce the education gap and improve the overall education system.

6 Ethics declaration

The authors declare that this study was conducted in accordance with the ethical standards generally accepted for scientific research. Where applicable, all experimental procedures were approved by the appropriate ethics committees and comply with national and international regulations. The authors declare no conflicts of interest.

7 AI declaration

During the preparation of this manuscript, generative Artificial Intelligence tools were used to assist with writing and editing. Specifically, the language model ChatGPT developed by OpenAI (GPT-4 version) was employed to improve textual clarity, harmonize linguistic style, and provide suggestions for rephrasing complex sections, under the direct supervision and final approval of the human authors. No part of the content was generated autonomously by AI without human oversight. The authors take full responsibility for the scientific content and conclusions presented.

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The Role of Artificial Intelligence in Social Sustainability: A Socio-Technical Systems Perspective

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Abstract

This paper examines the role of Artificial Intelligence (AI) in advancing sustainability, focusing on the intersection of AI and social sustainability. Given the substantial body of research in this field, a systematic review of over 2,000 articles was conducted. The sample was first analysed descriptively, followed by a thematic grouping based on sustainability dimensions. Notably, the social dimension of sustainability was underrepresented, prompting a more detailed exploration of AI's role in addressing social sustainability. To explore AI's role in advancing social sustainability, this study uses the Socio-Technical Systems (STS) framework. STS, developed by Emery and Trist (1960), examines the interplay between technology and social systems, focusing on five elements: technology, work processes, people, organizational structures, and the external environment. These elements guide the analysis of AI's effects across sectors such as healthcare, education, and governance. The study highlights AI's role in reshaping workflows, skill development, organizational hierarchies, and societal systems, while addressing global challenges like climate action and economic resilience.The study contributes to the field by integrating STS into AI and social sustainability, providing a structured lens to assess AI's impact. It offers actionable insights for policymakers, organizations, and researchers on how to leverage AI responsibly, ensuring ethical governance, fairness, and inclusivity. The study emphasizes the need for frameworks that balance AI's opportunities with potential risks, promoting responsible AI deployment across sectors.

Keywords: Artificial Intelligence**;** Socio-Technical Systems Perspective; Social; Sustainability; Thematic Analysis.

Paper type: Academic Research Paper

1 Introduction

From its inception, expectations for Artificial Intelligence (AI) have been exceptionally high, and today, experts increasingly view AI as a potential ally in addressing global challenges (Goralski & Tan, 2020; Kulkov et al., 2024; Nishant et al., 2020). However, the significant dual influence of AI—both enabling and inhibiting—requires careful examination. This critical issue has been explored by institutions such as the KTH Royal Institute of Technology, the AI Sustainability Centre, and the Massachusetts Institute of Technology (MIT), which jointly organised a roundtable discussion. Insights from this event are captured in the document *"Assessing whether artificial intelligence is an enabler or an inhibitor of sustainability at indicator level"*. It is essential to thoroughly analyse both the opportunities and challenges that AI presents for sustainable development. The Social Sustainability Goals provide a valuable framework for assessing AI's impact across various sectors. According to Vinuesa et al., (2020), AI has the potential to positively impact 79% of the Sustainable Development Goals (SDGs). However, when these results are examined by pillar, significant variations emerge. Environmental sustainability demonstrates the highest potential for positive influence from AI, with a remarkable 93% impact, while social sustainability records the highest rate of distrust towards AI, with a negative impact value of 38% (Gupta et al., 2021). Some of the positive effects of AI align with SDG 8 (Decent Work and Economic Growth) and SDG 9 (Industry, Innovation, and Infrastructure), where AI-enabled technologies can generate new employment opportunities and boost productivity. Similarly, SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action) may benefit from the more efficient use of energy and the development of tools to predict and manage urban pollution. Further contributions extend to SDG 14 (Life Below Water) and SDG 15 (Life on Land), where AI can support the conservation and management of biodiversity and natural resources. However, a comprehensive understanding of this phenomenon requires an exploration of AI's potential negative effects. Notably, AI poses risks to achieving several SDG applications in the domains of economy and society. For instance, AI could lead to job displacement, exacerbate inequality in access to computing resources, or polarise societies through biased algorithms, thus undermining SDG 10 (Reduced Inequalities). These inequalities could also negatively impact SDG 4 (Quality Education). Another concern involves the growing energy demands of information and communication technologies (ICT), which are projected to increase from 1% to 20% of global electricity consumption by 2030. In conclusion, artificial intelligence represents a double-edged sword for sustainability.

Given the critical role of AI's influence on sustainability, this study aims to explore its role in advancing social sustainability by addressing two central research questions:

- **RQ1)** What are the key thematic areas where AI exerts the most significant influence on social sustainability?
- **RQ2)** How does Artificial Intelligence influence these thematic areas when analyzed through the lens of the Socio-Technical Systems (STS) framework?

To answer the second research question, this study adopts Socio-Technical Systems Theory (STS) as its theoretical framework. STS, originally developed by Emery and Trist (1960), provides a robust lens for analyzing the interaction between technological systems and social systems. The theory highlights the interdependence of technology, people, organizational structures, and the broader societal context. Later developments, particularly those by Baxter and Sommerville (2011), identify five interconnected elements critical to understanding technology's impact: technology, work processes and activities, people, organizational structures, and the external environment. These elements offer a comprehensive means to evaluate how AI is transforming specific domains of social sustainability.

2 Methodology

The methodology adopted to examine the interaction between AI and sustainability is a systematic literature review. A literature review serves two primary purposes: (a) to summarise the existing body of research on a topic, identifying key themes and issues while proposing directions for future investigation; and (b) to situate any new scholarly contributions within the context of established knowledge and theories (Maditati et al., 2018). The advancement of knowledge must build on prior work, and to push the frontiers of understanding, it is crucial to determine the current state of the field. By reviewing the relevant literature, one can grasp the breadth and depth of the existing research corpus and identify gaps that merit further exploration (Xiao & Watson, 2019). Given the substantial volume of publications on this topic, a hybrid approach combining traditional and bibliometric analysis was selected. This approach is outlined in the diagram below, detailing the steps of *Material Collection and Selection*, *Descriptive Analysis, and Content Analysis.*

2.1 Material Collection and Selection

The data collection process began in October 2024 and lasted approximately one month. The primary source used was Scopus, a database that provides abstracts, citations, and full-text articles. Owned by Elsevier, the world's largest publisher in the medical and scientific fields by the number of publications and journals, Scopus is described as a source-neutral database. It is curated and managed by an international and independent committee of researchers and experts known as the Scopus Content Selection & Advisory Board (CSAB). In addition to Scopus, the commonly used search engine Google also supported the data collection process.

The Scopus database facilitated the search and selection of articles using a variety of keywords, including *"artificial intelligence," "sustainability,"* and *"AI."* Below the query used for the database search:

("Artificial Intelligence" OR "AI") AND ("Sustainability")

Scopus returned a significant number of results more than 8.000 documents. Therefore, search filters were applied to refine and narrow down the selection.

The following criteria were implemented:

1. **Language:** English was chosen as it is universally accepted within the scientific community and is the language in which the vast majority of scholarly work is published.
2. **Timeframe:** Publications from 2010 to 2024 were considered. The period from 2010 to 2024 was chosen to ensure that the review captures both foundational works and recent advancements in the field. This timeframe reflects the emergence and rapid development of artificial intelligence (AI) technologies and their applications in sustainability-related domains. Beginning the analysis in 2010 allows for the inclusion of the foundational studies in AI and its early integration into sustainability initiatives. The endpoint of 2024 ensures the inclusion of the most current and up-to-date research, providing a comprehensive overview of the topic's evolution.
3. **Relevant Fields:** Scientific domains relevant to the research objectives were identified, including Environmental Science, Engineering, Social Sciences, Medicine, Psychology, Multidisciplinary, Health Professions, Decision Sciences, Earth and Planetary Sciences, Arts and Humanities, Economics, Econometrics, and Finance. The selection of scientific domains was guided by the interdisciplinary nature of the interaction between AI and sustainability. Fields such as Environmental Science and Engineering were included to capture studies on ecological applications and technological innovations. Social Sciences, Medicine, and Psychology address the societal and human-centric implications of AI in

sustainable practices. Other areas, such as Economics and Decision Sciences, were incorporated to explore the economic impact and strategic applications of AI. This diverse selection ensures a holistic understanding of the topic, reflecting the multifaceted nature of sustainability.

4. **Document Types:** Only *Articles* and *Reviews* were selected for this literature review. Articles and reviews were chosen as they represent the most rigorous and in-depth forms of academic literature. Articles provide original research findings, offering insights into novel methodologies, experiments, and case studies. Reviews, on the other hand, synthesize existing knowledge, identifying trends, gaps, and future research directions. This combination ensures that the literature review is both comprehensive and grounded in high-quality, peer-reviewed sources, supporting robust and reliable conclusions.

Following the application of the aforementioned filters, the sample of documents was significantly reduced, decreasing to *2431* documents, aligning with the first phase of our research.

2.2 Descriptive Analysis

The aim of this analysis is to provide a comprehensive and detailed overview of the selected document sample. The distinctive characteristics of the documents were examined, particularly their temporal distribution, to understand the evolution of research over the years and to identify periods of higher or lower concentrations of publications, which may indicate trends or seasonality. This analysis serves to carefully assess the quality and relevance of the extracted sample, ensuring that it constitutes a valuable and meaningful resource for the subsequent research. From the total sample, an initial analysis was conducted to categorise the documents based on the year of publication and number of citations, allowing for an evaluation of the trends in this area of study over time.

To delve deeper into the topic, the title and abstracts of 2431 documents were reviewed—a process that took approximately 40 days—and the documents were classified. This classification focused on the three pillars of sustainability: environmental, social, and economic. This approach was adopted to explore how artificial intelligence has been studied in relation to each of these dimensions of sustainability. Figure 1 illustrates the temporal distribution of articles and citations related to the AI and sustainability from 2010 to 2024. The bar graph (green bars) represents the annual number of articles published, while the line graph (grey line) shows the corresponding total number of citations per year. The number of articles published remained relatively low and stable, indicating limited research activity on the intersection of AI and sustainability during this period. A noticeable increase in publications occurred, suggesting growing awareness of the potential role of AI in addressing sustainability challenges. From 2020 onwards, there was a sharp rise in the number of articles, peaking in 2024 with the highest volume of publications. This period reflects heightened academic interest and research efforts in the field. Citations increased significantly starting in 2018, peaking in 2020. However, despite the highest number of articles in 2024, citations show a slight decline, likely due to the lag effect in citation accumulation for recent publications. The convergence of increased publications and citations highlights the growing recognition of AI and sustainability as a critical research domain.

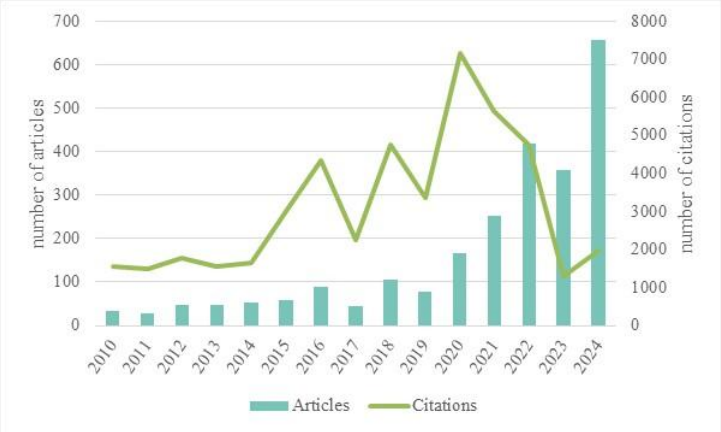


Figure 1 Temporal distribution of articles and citations

The prior descriptive analysis confirmed the suitability of the selected sample, paving the way for a more in-depth investigation. Given this results, the abstracts were classified into three categories of sustainability: social, environmental, and economic. Additionally, a fourth category, “non-relevant,” was introduced to catalog documents that were neither useful nor pertinent to this research. This classification provides a deeper

understanding of how AI aligns with each aspect of sustainability, highlighting areas of strength and weakness as well as potential challenges and opportunities AI presents in this complex domain. The classification process was carried out with meticulous attention to detail. Each abstract from the 2431 documents was carefully read and analyzed to determine if a predominant or exclusive category could be assigned among the three considered: environmental sustainability, economic sustainability, and social sustainability. During this process, each abstract was reviewed for clear and relevant indications that would allow it to be assigned to one of the categories. If the abstract lacked sufficient information for precise classification or was deemed non-relevant to the categories of interest, the document was categorized as "non-relevant." This methodical approach ensured an accurate organization of the documents, creating a solid and reliable foundation for further analyses. Figure 2 summarizes the distribution of articles based on their alignment with different dimensions of sustainability in the context of artificial intelligence (AI).

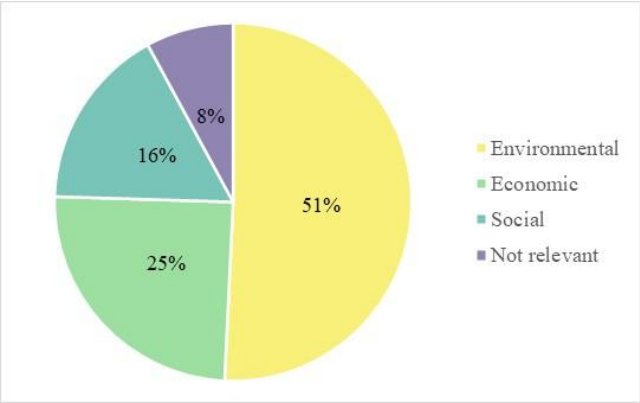


Figure 2 Articles per sustainability dimensions

Regarding the relevant documents, which constitute 92% of the total, the analysis reveals that 1234 of these discuss Artificial Intelligence (AI) in relation to environmental sustainability. This accounts for 51% of the total documents and over 55% when considering only the relevant ones.

This finding leads to a significant initial observation: among the various dimensions of sustainability, environmental sustainability is clearly the most discussed and explored. The predominance of this topic can be attributed to the growing global awareness of environmental issues and the urgent need for innovative technological solutions to address these challenges. Environmental sustainability has become a priority for many organisations, governments, and scientific communities, reflecting a collective commitment to safeguarding the planet. AI, with its vast applicative potential, emerges as a crucial tool for developing effective strategies for climate change mitigation and adaptation, natural resource management, and the reduction of environmental impacts.

The emphasis placed on environmental sustainability in the analysed documents also highlights the key role AI can play in this domain, fostering innovations ranging from energy consumption optimisation to advanced monitoring systems for pollution control. This prevalence of studies on AI and environmental sustainability therefore reflects not only a thematic priority but also an orientation towards the search for practical, immediately applicable solutions to tackle global environmental crises.

After environmental sustainability, the second most addressed topic in the relevant documents is economic sustainability, with 601 studies exploring AI in this context. This represents 25% of the total documents and 27% when considering only the relevant ones.

This figure suggests that, alongside the global environmental crisis, the scientific community and researchers are also strongly focused on economic challenges. Economic sustainability encompasses a wide range of topics, including operational efficiency, cost reduction, innovation in business models, and resource optimisation in businesses and industries. AI provides powerful tools to address these challenges, offering advanced solutions for financial management, economic data analysis, and market trend forecasting.

The significant number of studies centred on economic sustainability highlights the essential importance of creating resilient and sustainable economic systems. AI can support this adaptation by automating processes, optimising supply chains, and creating new business models that promote sustainable growth. Moreover, the global economic crisis, exacerbated by events such as the COVID-19 pandemic and wars, has heightened awareness of the importance of developing economies that are not only resilient but also capable of thriving under adverse conditions. Thus, the prominence of economic sustainability in the analysed documents reflects

a direct response to these urgent needs. This prioritisation of economic sustainability, following closely behind environmental sustainability, underscores the interconnectedness of the environment and economy, recognising that long-term economic prosperity is inextricably linked to the responsible and sustainable management of natural resources.

Finally, only 403 documents address the topic of AI in relation to social sustainability, representing 16% of the total documents and 18% when considering only the relevant ones.

This figure clearly indicates that among the dimensions of sustainability, social sustainability is the least explored. The reasons for this disparity may be manifold. Firstly, the impact of social sustainability is often more challenging to quantify compared to environmental or economic sustainability. While environmental impacts can be measured using concrete data such as carbon emissions or resource consumption, and economic impacts can be evaluated through financial and productivity indicators, social implications are more complex and elusive. They pertain to aspects such as equity, inclusion, quality of life, and human rights, which are not easily quantifiable with standardised metrics.

Unlike environmental sustainability, which has benefited from a high positive perception regarding AI's impact, social sustainability has often been viewed in a more negative light (Vinuesa et al., 2020) This perception may have limited the enthusiasm and commitment of researchers to explore how AI could be used to improve critical social aspects. Although social sustainability currently receives less attention than the other dimensions, there is largely untapped potential for the use of AI in this area.

2.3 Content Analysis

Following a detailed examination of the conclusions drawn from the descriptive analysis of the documents, we decided to concentrate our research exclusively on the social dimension of sustainability. This choice was made due to the substantial volume of studies addressing the other two dimensions. The social dimension, being the least explored among the three, presents a unique opportunity to deepen our understanding of the underlying dynamics. The primary objective of this step is to analyse and identify the main themes that currently contribute to the observed disparity in attention across the different sustainability dimensions. Identifying these themes is crucial for understanding why social sustainability receives comparatively less scholarly focus and for developing strategies to bridge this gap. This decision is driven by the belief that comprehensive sustainability can only be achieved when environmental, economic, and social dimensions are advanced in tandem. Neglecting the social dimension would mean overlooking a critical component of sustainable progress, potentially undermining achievements in the other dimensions. It is imperative that no aspect of sustainability is overlooked, as each contributes in an interconnected manner to the overall well-being of society and the planet. Addressing the social dimension is, therefore, essential to ensure a holistic and inclusive approach to sustainability.

The first step of the content analysis involved a meticulous review of the full text of the 403 documents classified under the category of social sustainability. This was undertaken to assign each document to a specific theme or sub-domain in line with the protocol suggested by Centobelli et al., (2022). Such phase was essential due to the broad scope and diversity of topics encompassed by social sustainability. Our primary aim was to identify the most recurring themes and examine how they are addressed in terms of both frequency and depth. This thematic classification allows for a more structured understanding of the current state of research on social sustainability and highlights areas that require further investigation. We identify nine different themes that are detailed as follows:

Education and Training category collects articles that address AI's transformative role in education and professional training. Research ranges from AI-enhanced digital learning platforms to integrating AI into education management systems for sustainable development. The focus is on using AI to personalise learning experiences, optimise educational outcomes, and foster lifelong learning.

Ethics and Governance explores the intersection of AI with ethical considerations, digital governance, and public policy. Articles examine participatory cities, digital public sphere dynamics, and responsible urban geospatial AI. Research also addresses ethical AI applications in governance, urban management, and fostering inclusive societies. The emphasis is on creating frameworks for fair, transparent, and socially responsible AI utilisation.

Health focuses on AI applications in healthcare and public health. Topics include AI-driven analyses for understanding global fishing activities' impacts on health and the environment, pharmaceutical modelling, and promoting one-health initiatives. The articles demonstrate AI's potential to improve healthcare delivery, enhance disease prevention, and support global health goals.

Sustainable Cities and Infrastructure category addressess AI's role in building smart, inclusive, and sustainable urban environments. Research includes studies on enhancing women's safety in transient environments, sustainable transport solutions, and AI's integration into urban infrastructure for better mobility and planning. The focus is on creating resilient cities and infrastructure that cater to diverse societal needs.

Tourism, Art, and Culture groups articles related to how AI is reshaping the tourism, arts, and cultural sectors. Research explores AI's role in creating sustainable tourism practices, enhancing cultural preservation, and fostering innovation in hospitality. The focus is on using AI to promote cultural sustainability and drive growth in these sectors.

Technologies and Industrial Innovation involves innovative AI applications in industrial and technological settings. Articles include the use of AI for assessing road performance, developing sustainable urban transport solutions, and integrating AI into industrial processes. These studies showcase how AI enhances efficiency, reduces costs, and supports sustainable industrial practices.

Economy and Productive Sectors includes studies that explore AI's impact on economic resilience and productivity. Topics include the readiness of AI for business ethics in micro, small, and medium enterprises (MSMEs) and the role of AI in sustainable marketing practices. These studies highlight AI's potential in fostering sustainable business practices and supporting economic growth.

Sustainability and Environment highlights AI's role in environmental sustainability. Studies focus on AI-driven solutions for sorting recyclable materials, mapping fishing activities, and monitoring environmental conditions. The overarching goal is leveraging AI to mitigate environmental degradation, optimise resource usage, and promote sustainable practices in various industries.

Agriculture and Food category focus on applying AI to enhance agricultural productivity, food safety, and sustainability. Examples include the development of AI-based platforms for food safety, improving traceability processes in meat quality, and diagnosing plant diseases using advanced machine learning techniques. These studies demonstrate the potential of AI to revolutionise traditional agricultural practices and address challenges in food supply chains.

Table 1 illustrates the distribution of articles across various macro-themes, with Education and Training (24%) and Ethics and Governance (23%) receiving the most significant focus. This prominence suggests a strong interest in leveraging knowledge dissemination, capacity building, and ethical frameworks to address societal challenges and advance sustainability. Health (13%) and Sustainable Cities and Infrastructure (12%) also account for a substantial share of research, reflecting efforts to explore the role of technology and innovation in improving public health systems, urban development, and infrastructure management. Conversely, other themes such as Tourism, Art, and Culture (10%), Technologies and Industrial Innovation (6%), Economy and Productive Sectors (6%), and particularly Sustainability and Environment (2%) and Agriculture and Food (2%), are comparatively underrepresented. This disparity indicates that while certain domains have garnered significant academic attention, others remain less explored, leaving room for further investigation. Within the broader theme of social sustainability, the substantial representation of Education and Training, alongside the notable share of Health-related research, underscores their critical importance to societal well-being. Education serves as a cornerstone for social progress, enabling skill development, equity, and inclusion, while health is fundamental to the quality of life and sustainable societal development. Despite their relative prominence, challenges persist in fully realising their potential for advancing social sustainability.

Table 1 Paper per Macro-themes

Macro-Themes	Number of Articles	Percentage
Education and Training	103	24%
Ethics and Governance	94	23%
Health	53	13%
Sustainable Cities and Infrastructure	47	12%
Tourism, Art, and Culture	40	10%
Technologies and Industrial Innovation	26	6%
Economy and Productive Sectors	23	6%
Sustainability and Environment	9	2%
Agriculture and Food	8	2%

We then developed a bubble chart (Figure 2), to analyse the evolution of the macro-themes over the time. The bubble chart visualises the evolution of research themes at the intersection of AI and Sustainability from 2010 to 2024. Each bubble represents a specific theme (e.g., Health, Education and Training, etc.), with the size of the bubble corresponding to the frequency of publications related to that theme in a given year. This analysis

highlights trends in research focus over time and provides insights into the shifting priorities in this multidisciplinary field. The number of publications across themes has grown significantly over the years, particularly from 2020 onward. This growth suggests an increasing interest in applying AI to tackle sustainability challenges. From the analysis of the chart, *Sustainability and Environment*, *Industrial Technologies and Innovation*, *Economy and Productive Sectors*, *Cities and Sustainable Infrastructure* result to be emerging themes with a gradual growth over time. These themes show consistent growth from around 2015 onwards, with notable increases in attention in recent years (2020-2024). They reflect a sustained focus on sustainability, technological advancements, and urban development. *Education and Training* and *Ethics and Governance* represent steadily growing themes. *Education and Training* emerges as one of the most researched, especially in recent years. The importance of equipping individuals with knowledge and skills for sustainable AI practices likely drives this trend. *Ethics and Governance* also grows steadily, underlining concerns about responsible AI use and its societal implications. Finally, *Agriculture and Food, Health, Tourism, Arts and Culture* can be considered as late-blooming themes because exhibit limited activity in earlier years but gain significant traction after 2018. Their growth may be tied to recent global challenges like food security, public health crises, and revitalization of cultural and tourism sectors after Covid-19.

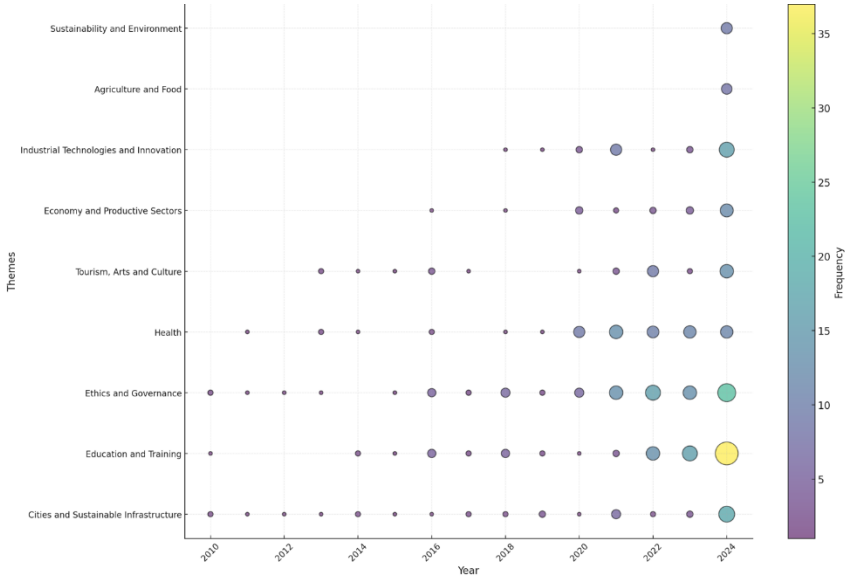


Figure 3 Bubble chart AI and sustainability

Given this context, our analysis will focus on applying the STS perspective to analyse the role of AI in each of the themes identified.

3 AI's Influence on Thematic Areas through the STS Lens: Socio-Technical Interdependencies

Adopting the STS framework enables a holistic understanding of how AI influences various macro-thematic areas by analysing the interplay among technology, people, organisational structures, work processes, and external environments. Within *Education and Training*, AI-driven personalised learning platforms are reshaping pedagogical models, yet their success is tightly coupled with teacher readiness, institutional adoption policies, and learner engagement (people and organisational structures). Similarly, in *Health*, AI applications such as diagnostic algorithms and predictive analytics enhance medical decision-making and care efficiency (technology and work processes), but their integration also demands new governance structures, medical training, and ethical oversight.

In *Ethics and Governance*, the development and deployment of AI raise complex questions regarding accountability, transparency, and fairness, especially when decision-making shifts from human to algorithmic agents. The STS lens underscores that ethical AI use cannot be addressed solely through technical solutions—it requires participatory governance models, regulatory adaptation (external environment), and organisational responsiveness. In *Sustainable Cities and Infrastructure*, AI is employed to optimise mobility, energy, and waste systems. However, its success hinges on inclusive urban planning, citizen participation, and equitable data governance—highlighting how technological advancements must co-evolve with social and institutional infrastructures. The STS framework also elucidates how AI interacts with socio-technical dimensions across

productive and cultural sectors. In *Technologies and Industrial Innovation*, AI-powered automation and predictive maintenance are revolutionising manufacturing and service processes (technology and work activities). However, these transformations require organisational agility, worker reskilling, and regulatory evolution to prevent digital divides. Within the *Economy and Productive Sectors*, AI contributes to operational efficiency and market analytics but may also lead to job displacement and changing labour dynamics, necessitating supportive policy and social adaptation mechanisms.

In the domain of *Tourism, Art, and Culture*, AI supports personalised experiences and digital heritage preservation, yet its success depends on cultural sensitivity, creative human input, and balanced governance (people and external environment). Regarding *Sustainability and Environment*, AI aids in climate modelling, biodiversity tracking, and resource management. However, socio-technical analysis reveals that outcomes are contingent on transparent data sharing, multi-stakeholder collaboration, and ethical considerations related to environmental justice. Finally, in *Agriculture and Food*, AI enhances precision farming and supply chain optimisation, but its implementation intersects with local knowledge systems, digital literacy, and land governance. These examples underscore how AI's impact is not deterministic but shaped by the dynamic alignment of social and technical subsystems.

4 Discussion

As illustrated in Table 2, each thematic area experiences AI transformation differently, depending on how the socio-technical components align or conflict. The framework's five key components—Technology, Work Processes, People, Organisational Structures, and External Environment—enable a multidimensional assessment of AI's integration across thematic areas.

In Education and Training, AI-driven tutoring systems and adaptive learning platforms exemplify how technological advancements reshape pedagogical methods (Luckin et al., 2016). These tools reconfigure the work processes of teachers and students, demanding changes in both classroom practice and school-level decision-making, while broader public education policies increasingly emphasise digital inclusivity (Holmes et al., 2021).

The domain of Ethics and Governance has seen the emergence of algorithmic accountability tools and AI risk assessment frameworks that influence regulatory workflows (Mittelstadt et al., 2016). This area highlights the need for interdisciplinary collaboration between ethicists, policymakers, and technologists, often institutionalised through policy think tanks and advisory committees, operating within complex legal environments (Floridi et al., 2018).

In Health, AI systems assist in diagnostics and treatment planning, altering clinical workflows and necessitating new competencies among healthcare professionals (Topol, 2019). Hospitals are adapting their organisational structures to accommodate AI, while ethical and regulatory frameworks strive to balance innovation with patient safety and privacy (He et al., 2019).

Sustainable Cities and Infrastructure benefit from AI-enabled smart sensors and urban analytics, enhancing planning capabilities and real-time decision-making (Batty et al., 2012). The integration of these technologies requires participatory governance models and regulatory mechanisms to address data privacy and algorithmic transparency.

In the context of Tourism, Art, and Culture, AI and XR tools offer new modalities for cultural storytelling and visitor engagement (Gretzel et al., 2015). The involvement of artists, curators, and tourists in co-creating experiences reflects the socio-technical nature of innovation in this space. Cultural institutions must navigate organisational change and comply with intellectual property and heritage conservation policies.

Technologies and Industrial Innovation see some of the most visible impacts of AI, particularly through automation, digital twins, and robotics (Kusiak, 2018). These developments reshape engineering workflows and call for flexible, innovation-oriented organisational structures supported by research and development centres. External influences such as industrial policy and intellectual property regulation are critical in shaping adoption.

In Economy and Productive Sectors, predictive analytics and intelligent supply chain management tools are transforming decision-making processes. This affects a wide range of human actors—from frontline workers to managers—within organisations adapting business models to harness AI-driven efficiencies (Brynjolfsson & McAfee, 2014). National labour laws and industrial policies must evolve to manage the resulting socio-economic shifts.

AI's contribution to Sustainability and Environment includes predictive modeling for climate change and AI-assisted environmental monitoring (Rolnick et al., 2019). These technologies support scientific work processes and require coordination among NGOs, public institutions, and regulatory bodies operating under evolving environmental governance frameworks.

Lastly, in Agriculture and Food, precision farming technologies enhance productivity and resource efficiency. These changes affect daily agricultural practices and demand capacity-building among farmers, while cooperatives and agencies act as key intermediaries. National and international regulations concerning food security and land use form the enabling or constraining external environment (Wolfert et al., 2017).

Table 2 AI and Sustainability through STS perspective

Thematic Area	**Technology**	**Work Processes**	**People**	**Organizational Structures**	**External Environment**
Education and Training	AI tutoring systems	Adaptive learning	Teachers & students	School policies	Public education systems
Ethics and Governance	Algorithmic accountability tools	Risk assessment	Regulators, ethicists	Policy think tanks, committees	Legal & regulatory frameworks
Health	Diagnostic AI tools	Clinical workflows	Medical professionals	Hospital management	Health policy and ethics
Sustainable Cities and Infrastracture	Smart sensors	Mobility planning	Urban residents	City governance models	Data regulations
Tourism, Art, and Culture	AR/VR & AI curation	Visitor experiences	Artists & tourists	Cultural institutions	Heritage and privacy laws
Technologies & Ind. Innovation	AI automation, digital twins	Manufacturing optimisation	Engineers, operators	Innovation labs, R&D centres	Industrial policy, IP regulations
Economy and Productive Sectors	Predictive analytics	Supply chain ops	Workers & managers	Business models	Labour and industrial policy
Sustainability & Environment	Climate AI models	Resource monitoring	Environmental scientists	NGOs & agencies	Environmental policy
Agriculture and Food	Precision farming	Crop cycle optimisation	Farmers	Cooperatives/Agencies	Land and food governance

5 Conclusion

This paper offers a comprehensive analysis of AI and social sustainability. A systematic review of the literature, drawing on over 2,000 articles published between 2010 and 2024, provides critical insights into the evolving relationship between AI and sustainability. The review reveals that, while there is significant research on AI's impact within the environmental and economic dimensions of sustainability, the social dimension—particularly its application in sectors such as healthcare and education—remains underexplored. The literature review highlighted several trends and gaps in AI adoption. Notably, the rapid growth in AI-related publications from 2019 to 2024 indicates an increasing interest in AI's potential to drive sustainable development. Furthermore, this paper detail the role of AI on social sustainability through the lens of the socio-technical systems (STS) framework. By applying the STS framework, which emphasizes the interplay between technology, people, processes, and environments, we have gained valuable insights into the multidimensional nature of AI integration across different areas. The framework enables a deeper understanding of how AI technologies are reshaping industries while also highlighting the social, ethical, and regulatory challenges that accompany these changes.

The analysis of the nine thematic areas—Education and Training, Ethics and Governance, Health, Sustainable Cities and Infrastructure, Tourism, Art and Culture, Technologies and Industrial Innovation, Economy and Productive Sectors, and Agriculture and Food—reveals how each sector experiences AI transformation differently based on the alignment or conflict of socio-technical components. This thematic approach underscores the importance of adopting a systems thinking perspective when examining AI's impact, as it is not just the technology itself that matters, but also the surrounding people, processes, structures, and external factors.

Through this analysis, we see that the socio-technical dynamics within each thematic area are pivotal in shaping the outcomes of AI adoption. The STS framework's multidimensional approach helps identify both opportunities and challenges in integrating AI across these sectors. It also points to the need for a more inclusive, interdisciplinary approach to AI research, one that considers not only the technological innovations but also the social, organizational, and regulatory factors that influence their success.

In conclusion, while AI presents significant opportunities for advancing sustainability, particularly in environmental and economic dimensions, its integration into the social dimension requires careful attention to the socio-technical complexities that shape its outcomes. By leveraging the STS framework and analyzing AI's impact across the nine thematic areas, this paper contributes to a more nuanced understanding of AI's role in

achieving social sustainability. Future research should continue to explore these socio-technical interactions to ensure that AI developments are aligned with the broader goals of equity, inclusivity, and social justice.

6 Ethics Declaration

The author confirms that no ethical approval was required for the research presented in this paper, as it did not involve any experiments with human participants, animals, or sensitive data.

7 AI declaration

The authors declare that AI tools were used for editing purposes in the preparation of this document. The AI assistance was limited to language correction, grammar improvement, and stylistic refinement.

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Artificial Intelligence and Social Sustainability in the Energy Sector: Enhancing Stakeholder Perception and ESG Performance through Innovative Practices

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Abstract

The integration of Artificial Intelligence (AI) into sustainability practices is transforming industries by enabling innovative solutions to complex challenges. However, while the nexus between AI and economic or environmental sustainability has been the subject of substantial academic inquiry, its potential role in advancing social sustainability remains comparatively underexplored. Social sustainability, encompassing critical aspects such as health and well-being, equitable access to education, and community resilience, is fundamental to the development of sustainable societies and is explicitly linked to Sustainable Development Goals (SDGs) such as SDG 3 (Good Health and Well-being), SDG 4 (Quality Education), and SDG 11 (Sustainable Cities and Communities). In the energy sector, where innovation is a primary driver, AI is increasingly employed to address issues including energy equity, workforce safety, and community development. The success of such initiatives, however, critically hinges on stakeholder perception, which influences the legitimacy and acceptance of AI-driven practices. This study aims to bridge the gap between AI applications and their social implications by examining how AI-driven innovative practices in the energy sector can enhance social sustainability and Environmental, Social, and Governance (ESG) performance. Specifically, it focuses on the role of stakeholder perception as a key determinant of the success of socially sustainable initiatives. By integrating concepts from stakeholder theory and knowledge management frameworks, this research seeks to advance theoretical understanding while offering practical strategies for achieving sustainability goals in knowledge-intensive and innovation-driven industries. The paper presents a review of the extant literature and outlines a research proposal predicated on a mixed-methods approach, focusing on case studies of energy companies implementing AI for social sustainability.

Keywords: artificial intelligence, social sustainability, ESG performance, stakeholder perception, energy sector

Paper type: Academic Research Paper

1 Introduction

The advent of Artificial Intelligence (AI) has ushered in a new era of technological transformation, with profound implications for virtually every industrial sector. Its capacity to analyze vast datasets, identify complex patterns, and automate decision-making processes offers unprecedented potential to address intricate global challenges, including the transition towards sustainability. Sustainability, in its three interconnected dimensions – environmental, economic, and social – has become an imperative for organizations aiming to create long-term value and contribute positively to society.

While the application of AI to enhance environmental sustainability (e.g., optimizing energy efficiency or managing natural resources) and economic sustainability (e.g., improving productivity or creating new business models) has garnered considerable academic and industrial attention, the social dimension of sustainability in relation to AI remains an emerging and comparatively less explored field. Social sustainability pertains to improving quality of life, promoting equity, ensuring health and well-being, providing access to quality education, and building resilient and inclusive communities. These aspects are intrinsically linked to the United Nations' Sustainable Development Goals (SDGs), particularly SDG 3 (Good Health and Well-being), SDG 4 (Quality Education), and SDG 11 (Sustainable Cities and Communities).

The energy sector, characterized by rapid innovation and crucial strategic importance for socio-economic development, is central to this discussion. AI is finding increasing applications in this sector to address specific social issues, such as ensuring equitable energy access, enhancing worker safety, and promoting the development of local communities impacted by energy activities. However, the efficacy and acceptance of these AI-based initiatives depend not only on their technological validity but are also profoundly influenced by stakeholder perception. Stakeholders – including employees, local communities, customers, regulators, investors, and civil society – play a determinative role in conferring legitimacy upon new technologies and

corporate practices. Their perception can either facilitate or hinder the adoption and success of AI-driven innovations.

Environmental, Social, and Governance (ESG) performance has become a critical metric for evaluating a company's commitment to sustainability. Research has demonstrated that strong stakeholder engagement is positively correlated with improved ESG performance. Understanding how AI applications can enhance the social aspects of ESG performance, and how stakeholder perception modulates this relationship, is therefore of paramount importance.

This study aims to investigate in-depth how AI-driven innovative practices in the energy sector can contribute to the enhancement of social sustainability and ESG performance. The primary objective is to examine the critical role of stakeholder perception in determining the success and impact of such initiatives. Through a review of existing literature and the subsequent proposal of empirical research, this work intends to provide theoretical contributions, particularly by integrating stakeholder theory with knowledge management frameworks within the ambit of AI for social sustainability. Furthermore, it aims to offer practical insights for energy sector companies and policymakers on designing and implementing AI strategies that are technologically advanced, socially responsible, and positively perceived by stakeholders.

The paper is structured as follows: Section 2 presents a review of the pertinent literature on AI, social sustainability, the energy sector, stakeholder perception, and ESG performance. Section 3 outlines the research proposal, including the methodological design, case selection, and data collection and analysis strategies. Section 4 discusses the expected outcomes and potential contributions of the study. Section 5 explores the practical and theoretical implications. Section 6 addresses anticipated challenges and limitations. Finally, Section 7 offers conclusions and suggests directions for future research. This is followed by ethics and AI declarations, and the bibliography.

2 Literature review

This section examines the extant literature to establish the theoretical context and identify the lacunae that the proposed research intends to address. It is articulated into four main subsections: the intersection of Artificial Intelligence and sustainability; social sustainability specifically within the energy sector; the crucial role of stakeholder perception; and the relationship between AI and ESG performance.

2.1 Artificial intelligence and sustainability

Artificial Intelligence is defined as the capability of computer systems to perform tasks that typically require human intelligence, such as learning, reasoning, problem-solving, perception, and language understanding. The potential of AI to contribute to the Sustainable Development Goals (SDGs) has been recognized by several studies. Vinuesa et al. (2020) conducted an in-depth analysis, finding that AI can act as an "enabler" for 79% of SDG targets, ranging from combating climate change (SDG 13) to improving health (SDG 3) and promoting sustainable cities (SDG 11). However, the same authors caution that AI could also hinder 35% of the targets, for instance, through increased energy consumption, the propagation of algorithmic bias, or its impact on the labor market.

McKinsey & Company (2024) emphasize how AI can be employed for "social good," improving lives and protecting the planet through applications in domains such as healthcare, education, disaster response, and environmental conservation. Despite this potential, attention has often focused on environmental and economic aspects, leaving the social dimension of sustainability relatively under-investigated in the context of AI. Floridi et al. (2018) propose an ethical framework for a "good AI society," highlighting opportunities, risks, and recommendations to ensure that AI development aligns with human values and social well-being. The challenge lies in maximizing the benefits of AI for social sustainability while concurrently mitigating its risks.

2.2 Social sustainability in the energy sector

The energy sector is fundamental to economic and social development but also presents significant sustainability challenges. The transition towards cleaner and more sustainable energy systems involves not only decarbonization and efficiency (environmental and economic aspects) but also has profound social implications. These include energy equity (affordable energy access for all), a "just transition" (support for workers and communities dependent on fossil fuels), the health and safety of workers and communities proximate to energy facilities, and the impact on local development.

AI can play a role in enhancing social sustainability within the energy sector. For example, it can optimize energy distribution to ensure more equitable access, improve predictive maintenance to increase the safety of

plants and workers, support urban planning for more resilient and inclusive communities, and personalize training programs for workforce reskilling. Nevertheless, the implementation of such technologies raises issues concerning data privacy, surveillance, the potential for algorithmic discrimination, and the need to ensure that benefits are equitably distributed.

2.3 The Role of stakeholder perception

Stakeholder theory, introduced by Freeman (1984), posits that organizations should manage their activities considering the interests of all groups that can affect or are affected by their actions. This theory is particularly relevant when introducing transformative technologies like AI, whose social impact can be perceived in vastly different ways by various stakeholders. Stakeholder perception – encompassing their beliefs, attitudes, judgments, and expectations regarding AI and its applications – is a critical factor that can determine the acceptance, adoption, and ultimately, the success of AI-driven sustainability initiatives.

A positive perception, based on trust, transparency, and an understanding of benefits, can lead to greater collaboration, reduced friction, and more rapid achievement of objectives. Conversely, a negative perception, fueled by fears of job displacement, lack of control, algorithmic bias, or privacy violations, can generate resistance, skepticism, and even active opposition, thereby undermining the effectiveness of initiatives. Therefore, actively engaging stakeholders in the design, implementation, and evaluation processes of AI solutions is paramount to aligning these technologies with societal values and expect*ations.*

2.4 ESG performance and AI

Environmental, Social, and Governance (ESG) criteria have become a standard framework for assessing the sustainability and ethical impact of a company. ESG performance is increasingly considered by investors, consumers, and other stakeholders as an indicator of an organization's resilience and long-term value creation capability. Eccles et al. (2014) demonstrated that companies with strong sustainability performance tend to financially outperform in the long run, suggesting that integrating ESG principles into organizational processes is advantageous.

AI can contribute to improving ESG performance across all three dimensions. Regarding the social dimension (the "S" in ESG), AI can help monitor and enhance occupational health and safety, promote diversity and inclusion, manage supply chains more ethically, improve community relations, and enhance employee well-being. For instance, AI systems can analyze data to prevent accidents, identify mental health risks among workers, or personalize development and training programs. However, it is crucial that the implementation of such systems is itself socially responsible, avoiding the introduction of new risks or the exacerbation of existing inequalities.

2.5 Identified gaps and research questions

The literature review reveals that while AI's potential for sustainability is acknowledged, there is a limited understanding of how specifically AI-driven innovative practices in the energy sector influence social sustainability and ESG performance, and particularly how stakeholder perception modulates this relationship. Many studies focus on the technical aspects of AI or on environmental/economic benefits, neglecting the complex social and perceptual dynamics.

This study aims to address these gaps by posing the following main research questions:

1. *How do AI-driven innovative practices in the energy sector contribute to the enhancement of social sustainability (with reference to SDGs 3, 4, and 11)?*
2. *What is the role of stakeholder perception (e.g., employees, communities, regulators) in determining the success and social impact of AI initiatives in the energy sector?*
3. *How do energy companies implementing AI for social sustainability manage stakeholder expectations and concerns?*
4. *To what extent does the implementation of socially-oriented AI practices correlate with measurable improvements in the ESG performance of energy companies?*

3 Research proposal

To answer the research questions delineated above, a mixed-methods approach is proposed, combining qualitative and quantitative analysis to provide a rich and multifaceted understanding of the phenomenon under investigation.

3.1 Research design

The research will be structured in two main phases.

Phase 1: Systematic Literature Review

This phase, to be further deepened, aims to consolidate the theoretical understanding of the intersections between AI, social sustainability, the energy sector, stakeholder perception, and ESG performance. Academic articles, industry reports, policy documents, and publications from international organizations will be analyzed to identify key trends, challenges, opportunities, and best practices. This review will inform the development of data collection instruments for the empirical phase.

Phase 2: Multiple Case Study.

This empirical phase will focus on an in-depth analysis of three energy sector companies (ideally diversified by size, geographical focus, and type of energy activity) that have actively implemented AI-driven practices with the stated aim of improving social sustainability. The case study approach allows for a contextualized and detailed exploration of complex phenomena.

3.2 Case study selection

Companies will be selected based on the following criteria:

- Active and documented use of AI applications specifically targeted at social sustainability objectives (e.g., occupational safety, training, community development, energy equity).
- Availability of ESG performance data (e.g., sustainability reports, social audits).
- Evidence of stakeholder engagement strategies.
- Accessibility for data collection (willingness to participate in interviews and provide documentation).

3.3 Data collection

Data collection will utilize multiple sources to ensure triangulation and validity of the findings:

Semi-structured Interviews: interviews will be conducted with a variety of key stakeholders within and outside the selected companies. These will include:

- Corporate executives and managers responsible for AI and sustainability initiatives.
- Employees directly involved with or impacted by AI technologies (e.g., field operators, technical staff).
- Representatives of local communities where the companies operate.
- Regulators or representatives of relevant governmental bodies. Interviews will explore perceptions regarding the effectiveness of AI initiatives, perceived benefits, concerns, level of involvement, and trust in the technologies.

Documentary Analysis: relevant corporate documents will be collected and analyzed, such as sustainability reports, internal and external communications, AI policies, training materials, and ESG performance data (health and safety indicators, community investments, employee well-being metrics, etc.).

Quantitative ESG Performance Data: where available, longitudinal quantitative data (pre- and post-implementation of AI initiatives) on specific social indicators of ESG performance will be collected. This will allow for an assessment of the measurable impact of AI practices.

3.4 Data analysis

Data analysis will proceed in two parallel stages, followed by integration

Qualitative Analysis: textual data from interviews and documentary analysis will be analyzed using thematic analysis. This process will involve coding the data, identifying recurring themes, patterns, and significant relationships in stakeholder perceptions and experiences. Qualitative data analysis software (such as NVivo) may be used to support this process.

Quantitative Analysis: ESG performance data will be statistically analyzed (e.g., descriptive statistics, paired-samples t-tests, correlation analysis) to identify any significant changes in social indicators following AI implementation and to explore correlations between AI adoption and improvements in social sustainability.

Integration: the findings from qualitative and quantitative analyses will be integrated to provide a holistic understanding. For example, qualitative stakeholder perceptions may help explain patterns observed in quantitative ESG performance data.

4 Expected outcomes and potential contributions

This research is anticipated to provide significant insights into the complex relationship between AI, social sustainability, and stakeholder perception in the energy sector.

4.1 Expected outcomes

Identification of specific effective AI applications: the study should reveal which types of AI-driven practices (e.g., predictive analytics for safety, personalized e-learning platforms, AI-based urban planning tools) most effectively contribute to improving health and well-being (SDG 3), access to education (SDG 4), and the development of resilient communities (SDG 11) in the energy context.

Critical role of stakeholder perception: findings are expected to confirm and elaborate on the importance of stakeholder perception. Companies adopting transparent, inclusive, and participatory approaches in AI design and implementation should exhibit more positive social outcomes and greater stakeholder acceptance, consistent with Freeman's (1984) theory. Conversely, a lack of communication and trust could lead to skepticism and resistance.

Measurable improvements in ESG performance: analysis of ESG data is expected to demonstrate positive correlations between the strategic implementation of AI and improvements in specific social indicators, such as reductions in workplace accidents, increased investment in community development projects, and enhanced employee well-being.

Identification of persistent challenges: common challenges are anticipated to emerge, such as data privacy concerns, the risk of algorithmic bias, AI adoption costs, and the need for new skill sets, echoing concerns raised by Cath et al. (2018).

4.2 Potential contributions

Theoretical Contribution: the study will contribute to the existing literature by integrating stakeholder theory and knowledge management frameworks with the emerging field of AI for social sustainability. It may offer a more nuanced conceptual model for understanding how stakeholder perception influences the effectiveness of AI initiatives.

Practical Contribution: the research will provide actionable recommendations for energy sector companies on how to design and implement AI strategies that not only enhance operational performance but also promote social sustainability and are well-received by stakeholders. It may also inform policymakers on the development of regulatory frameworks and incentives that support responsible AI adoption.

Methodological Contribution: the mixed-methods approach and focus on case studies could serve as a model for future research in this domain.

5 Practical and theoretical implications

The implications of this research extend to academia, business, and policy-making**.**

5.1 Practical implications

For Energy Sector Companies: the findings will offer guidance on leveraging AI to improve their social and ESG performance. This includes strategies for effective stakeholder engagement, mitigation of AI-associated risks (e.g., bias, privacy), and transparent communication of benefits and challenges. Companies will better understand how to align AI investments with their sustainability objectives and stakeholder expectations.

For Policymakers and Regulators: the study could inform the development of public policies that encourage the ethical and socially beneficial use of AI in the energy sector. This might include creating standards, guidelines, or incentives to promote algorithmic transparency, data protection, and public participation in AI-related decisions.

For AI Developers: the results could sensitize developers to the social implications of their technologies and encourage the design of "socially-aware by design" AI systems.

5.2 Theoretical implications

Advancement of Stakeholder Theory: the research will apply and potentially extend stakeholder theory to the specific context of AI technologies, exploring how stakeholder dynamics of power, legitimacy, and urgency manifest in relation to these innovations.

Understanding of the AI-Social Sustainability Intersection: the study will contribute to a deeper and more critical understanding of how AI can be a tool for social sustainability, moving beyond purely techno-optimistic or pessimistic views.

Integration with Knowledge Management: AI adoption involves managing new forms of knowledge. The study could explore how organizations acquire, share, and utilize AI-related knowledge to achieve social sustainability goals, and how this process is influenced by stakeholder perception.

6 Challenges and limitations

Like any research project, this study presents potential challenges and limitations.

Data Access: obtaining full and transparent access to corporate data and key stakeholders may be challenging. The sensitivity of some information related to AI and ESG performance could limit availability.

Generalizability: being based on a limited number of case studies (three companies), the generalizability of findings to other companies or contexts within the energy sector may be constrained. However, the aim is to provide in-depth, contextualized understanding rather than broad statistical generalizations.

Complexity of AI: the complex and rapidly evolving nature of AI technologies can make it difficult to isolate their specific impact on social sustainability, distinguishing it from other concomitant factors.

Researcher Bias: the researcher must be aware of their potential biases and adopt measures to ensure objectivity in data interpretation, especially in qualitative analysis.

Temporal Dynamics: the social impacts of AI may manifest over the long term. A study with a limited time horizon might not fully capture these long-term effects.

Despite these limitations, the proposed research design is considered robust and capable of yielding valid and significant contributions.

7 Conclusions and future directions

This paper has delineated the growing importance of Artificial Intelligence in promoting social sustainability within the energy sector, emphasizing the crucial role of stakeholder perception and ESG performance. The literature review has highlighted AI's transformative potential in contributing to the achievement of SDGs, particularly SDGs 3, 4, and 11, but has also underscored the need for a greater understanding of its social implications and the factors determining its success.

The research proposal, based on a mixed-methods approach and multiple case studies, aims to address the identified gaps, offering theoretical and practical insights. It is anticipated that the findings will inform energy companies on how to implement AI in a socially responsible manner, effectively engaging stakeholders and enhancing their ESG performance. The identified challenges, such as algorithmic bias, privacy concerns, and adoption costs, must be proactively addressed to maximize AI's positive social impact.

For future research, it would be beneficial to explore the long-term impacts of AI initiatives on social sustainability across a broader range of industries and geographical contexts. Comparative studies of different regulatory approaches to AI and sustainability could offer further insights. Additionally, research could focus on developing more sophisticated metrics for measuring AI's social impact and on creating frameworks for the ethical governance of AI within organizations.

In conclusion, the integration of AI into the social sustainability strategies of the energy sector represents a significant opportunity, but it requires a thoughtful, inclusive, and human-centric approach to ensure that technological benefits translate into equitable and lasting social progress.

8 Ethics declaration

The proposed research will be conducted in accordance with the highest ethical standards. Informed consent will be sought from all study participants (interviewees). Participants will be assured of confidentiality and anonymity, and data will be handled in compliance with current data protection regulations (e.g., GDPR). The aim of the research is to generate knowledge for societal benefit and not to cause harm to any individual or organization. Should the research involve institutions requiring formal ethical review, approval will be obtained from a competent ethics committee prior to the commencement of data collection. Research findings will be disseminated transparently and responsibly.

9 AI Declaration

In the preparation of this document, Artificial Intelligence tools (such as large language models) were utilized to assist with drafting, grammatical and stylistic review, and the structuring of ideas based on the provided extended abstract. However, the conceptualization of the paper, critical analysis of the literature, formulation of the research proposal, interpretation of concepts, and ultimate responsibility for the content and accuracy of the text remain entirely with the human authors. AI was employed as a support tool to enhance efficiency and quality of work, not as a substitute for critical thinking and academic expertise.

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Social Taxonomy, Balance Sheet and AI for Sustainability in Public Administration Policies

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Abstract

The European Union plays an important role in promoting the Sustainable Development Goals (SDGs) of the 2030 Agenda through the advancement of sustainable finance. The aim of sustainable finance is to direct financial resources toward initiatives aligned with ESG (Environmental, Social, and Governance) principles. However, unlike financial ratings based on recognized accounting standards, a globally shared framework for assessing ESG activities and investments is still lacking.
To fill this gap, the EU has launched a process to develop common standards for identifying sustainable economic activities, not only from an environmental but also from a social perspective.
In this context, the proposal for a European Social Taxonomy has emerged, developed by the Platform on Sustainable Finance (PSF). Its goal is to classify projects, investments, and policies based on their social impact. The three main objectives identified, decent work, well-being and adequate living conditions, and inclusive societies, are supported by sub-goals to facilitate implementation and reporting.
Nonetheless, the analysis of social variables remains particularly complex due to their qualitative, multidimensional, and often subjective nature, which makes objective and standardized measurement challenging. In the absence of a global social reporting standard, practices remain heterogeneous and fragmented, undermining data comparability and the development of evidence-based policies.
In this scenario, Public Administrations (PAs) are called upon to adopt effective tools to make their social actions visible, measurable, and communicable. The Final social balance sheet serves as a key tool for accountability and transparency, useful for strengthening the relationship with citizens and evaluating the public value generated.
The integration of the Social Report, the Social Taxonomy, and Artificial Intelligence (AI) represents a strategic opportunity to improve the analysis, monitoring, and implementation of social policies in alignment with the 2030 Agenda. This study analyzes the approach adopted by local administrations in social reporting and the potential of AI to enhance these processes, promoting more effective and sustainable public governance.

Keywords: European Social Taxonomy, Social Balance Sheet, Public Administration, Artificial Intelligence

Paper type: Academic research paper.

1 Introduction

Social sustainability represents a strategic priority for Public Administration (PAs), which is called upon to ensure transparency, inclusion, and the creation of public value in line with the principles of the 2030 Agenda. Tools like the social report help build trust, communicate policy impacts, and guide equitable, sustainable governance.

Nevertheless, what makes the adoption of social reporting practices still problematic is the combination of methodological fragmentation, limited standardization, and the lack of integration of innovative technologies.

By introducing the European Social Taxonomy and applying Artificial Intelligence (AI), Public Administration (PAs) is presented with new opportunities to better measure, monitor, and enhance the effectiveness of its social interventions. The use of these tools can turn social reporting into a strategic instrument for evidence-based policymaking, moving beyond narrative accounts to data-driven evaluations of social impact.

The study seeks to answer a central question: “How can Public Administration integrate Artificial Intelligence and the European Social Taxonomy into social reporting processes to improve the effectiveness of public policies?” The aim is to explore innovative approaches that make reporting more dynamic, inclusive, and aligned with sustainable development goals.

2 Literature review

2.1 Measuring social sustainability

Among the Sustainable Development Goals (SDGs) of the 2030 Agenda, the social sustainability pillar lacks a universally agreed-upon definition. However, it can be interpreted through the principles outlined by the United

Nations, which emphasize peaceful, inclusive societies based on human rights, equity, gender equality, and reduced inequalities, ensuring well-being and equal opportunities across generations (United Nations, 2015).

Social well-being is assessed through diverse methods due to its evolving and subjective nature. Recent innovations include social media sentiment analysis (Ismail et al., 2022) and the use of WELLBY to standardize quality-of-life measurement. Effective evaluation demands integrated tools using composite indicators to address fragmentation and lack of standardization (McGuinn et al., 2020).

Major challenges include data representativeness, the complexity of social phenomena, and risks of oversimplification. Indicators must adapt to changing socio-cultural conditions to remain relevant (OECD, 2020; Barlybaev et al., 2020). In this light, measuring well-being is a political and cultural imperative, guiding public institutions toward equitable and sustainable development.

2.2 PAs, social wellbeing and reporting challenges

Public Administrations (PAs) are tasked with addressing societal needs through actions that promote well-being, equity, and inclusion. Their role has evolved from a bureaucratic model (Simon, 1947; Weber, 1961) to one focused on creating public value, aligned with the EU's sustainability agenda (Moore, 1995).

Public value goes beyond service provision to deliver tangible improvements in quality of life. At its core, social well-being enhances resilience, institutional trust, and the capacity to manage complex crises, such as health or environmental emergencies (OECD, 2021). Within this context, PAs are key to advancing sustainable development models.

Social reports serve as essential tools for monitoring and communicating policy impact, reinforcing transparency and accountability (Koppell, 2005; Bovaird & Loeffler, 2016). More than summary documents, they are instruments for stakeholder engagement and co-creation of public value (Perano & Cerrato, 2017), encouraging innovation and participation.

At the municipal level, where administrations are closest to citizens, this role is even more strategic. Local governments implement essential services and foster participatory governance through collaboration with public, private, and territorial actors (Osborne, 2006). Their proximity to local needs supports targeted interventions that improve quality of life and protect vulnerable groups (ISTAT, 2024; Fontana, 2024).

Despite this potential, the lack of a shared social reporting framework leads to fragmented and inconsistent practices (Messeri et al., 2006). The complexity and variability of social variables further hinder the standardization of metrics (Sen, 1999), limiting comparability and policy coherence.

A flexible, unified European Social Taxonomy could address these gaps by standardizing language, methods, and indicators, aligning with ESG principles (Sansoni, 2025) and supporting integrated governance (Epifani, 2025). It would enhance reporting quality and complement existing planning tools in line with the 2030 Agenda.

Importantly, social reporting must go beyond description, evolving into a budgeting tool that fosters the creation of collective value (Douglas & Overmans, 2020).

The recent experience of the Social Innovation Fund (Formez, 2023) and successful local practices (ASviS, 2023) demonstrate that it is possible to implement reporting and governance models centered on collective well-being, inclusion, and long-term sustainability.

2.3 AI and the use of social data

Artificial Intelligence (AI) enables local administrations to process large volumes of heterogeneous data, from administrative sources to citizen feedback, to enhance the effectiveness of social policies (Sun & Medaglia, 2019). This shift is transforming how social data are collected, analyzed, and used in governance.

In social reporting, tools like Natural Language Processing (NLP), text mining, and machine learning extract complex indicators from unstructured data, offering timely insights into social dynamics (Jordan & Mitchell, 2015) and supporting ongoing evaluation of policy impacts (Van der Voort et al., 2019; Rosu, 2024).

AI also strengthens citizen participation through interactive platforms that use NLP and semantic analysis to gather real-time public input (Sun & Medaglia, 2019). Additionally, Explainable AI (XAI) enhances transparency by clarifying how algorithmic decisions are made (Arrieta et al., 2019).

Despite these benefits, AI raises ethical concerns around privacy, fairness, and transparency in decision-making (Floridi & Cowls, 2019). The opacity of algorithms challenges accountability and calls for responsible governance strategies (Yuan & Chen, 2025). The use of social scoring systems, in particular, demands caution to prevent discrimination and uphold fundamental rights (Cerrina Feroni, 2023).

Addressing these issues requires a strategic approach that promotes resilience, inclusiveness, and trust (OECD, 2021). This involves not only technical capacity building but also rethinking decision-making to align with democratic and sustainable values.

AI can support the SDGs if public, private, and civil actors collaborate to overcome barriers like limited data access and digital skills. It can transform social reporting into a dynamic tool for participatory governance, enhancing democratic decision-making (Pleșa et al., 2024). Integrating technology, social awareness, and ethics is essential for building innovative, sustainable, and citizen-focused institutions.

3 Methodology

This research adopts a qualitative analytical approach aimed at understanding how certain Italian municipalities integrate social reporting tools and, where applicable, applications of Artificial Intelligence (AI). The case selection was carried out rigorously to avoid one of the main criticisms often raised, namely, the subjectivity involved in choosing cases for analysis and the resulting difficulty in replicating the study in different contexts.

An operational classification of municipalities by resident population was used to select the sample, with categories defined as follows:

- small municipalities (up to 5,000 inhabitants);
- small-to-medium municipalities (from 5,001 to 15,000 inhabitants);
- medium municipalities (from 15,001 to 30,000 inhabitants);
- large municipalities (over 30,000 inhabitants).

The analysis intentionally excludes large municipalities to concentrate on medium and small-sized ones, as they better reflect the Italian institutional landscape and maintain a closer connection to citizens. These organizations, often operating with limited resources, offer a valuable setting for evaluating policy implementation.

The purpose of the selection was to analyze concrete cases in which social reporting was voluntarily adopted, even in the absence of legal obligations. The aim was to understand the motivations behind this choice, the methods used for its implementation, and the potential contribution of technological innovation. The initial screening followed three main steps:

- online searches using keywords such as *"social report" and "mandate report"* to identify documents or references to social reporting on the institutional websites of Italian municipalities.
- Confirmation of the existence and authenticity of the social report on each municipality's official website.
- Development of a screening table. The selected municipalities were entered into a preliminary table that included, for each entity: the name, region, size category, document title, and year of publication.

The procedure focused on analyzing social reporting practices, with particular attention to the presence of a formal social report. The use of AI was considered only when explicitly mentioned in the documents and examined qualitatively. Municipalities were selected based on the documented availability of a social report, regardless of their level of digitalization or adoption of innovative technologies.

Social reports were analyzed using the European Sustainability Reporting Standards (ESRS), developed by the European Financial Reporting Advisory Group (EFRAG). These standards are currently being aligned with other international frameworks to foster more coherent and comparable sustainability reporting practices (EFRAG PTF-NFRS, 2021, pp. 85–86).

This study was based on a direct review of social reports (primary data) and an analysis of secondary sources, including press articles, institutional reports, and academic studies, to investigate practices and innovations in local PAs.

It was a set of well-established national and international references that supported the theoretical and operational framework of the study. These included the UN 2030 Agenda, the European Social Taxonomy Report, the ESRS standards, and the Italian Guidelines on Social Reporting in PAs.

This approach aims to enhance the ability of PAs to measure, monitor, and report the effects of public policies in relation to the SDGs. What the research aims to deliver is a detailed account of how social reporting is used by the selected municipalities, with a focus on the potential for AI to strengthen transparency, accountability, and impact. The study will also provide actionable guidance to encourage a more sustainable and socially responsible integration of AI in the public sector.

4 Results and discussion

For the selection of municipalities to be analyzed, online research and direct consultations were conducted, leading to the identification of eight municipalities that publish documents comparable to updated social balance sheets (Table 1). Of these, only four refer explicitly to the 2019–2024 five-year period. For the in-depth

analysis, three municipalities, Pero, Strambino, and Argenta (Emilia-Romagna, medium-sized), were selected with the objective of examining how Italian local governments employ social reporting to enhance transparency, policy effectiveness, and social impact, as well as to assess the potential for integrating emerging technologies such as artificial intelligence (AI).

Table 1. Municipalities surveyed with social reporting

Municipality	**Region**	**Size**	**Document title**	**Issued Year**
Loiri Porto San Paolo	Sardegna	Small	Final social balance sheet	2017-2022
Pollina	Sicilia	Small	Social balance sheet	2014
San Martino di Venezze	Veneto	Small	Social balance sheet	2016-2020
Nembro	Lombardia	Small to medium	Social balance sheet	2023
Pero	Lombardia	Small to medium	Final social balance sheet	2019-2024
Strambino	Piemonte	Small to medium	Final social balance sheet	2019-2024
Argenta	Emilia Romagna	Medium	Final social balance sheet	2019-2024
Jesolo	Veneto	Medium	Final social balance sheet	2017 -2022
Valsamoggia	Emilia Romagna	Medium	Final social balance sheet	2019-2024

Source: own elaboration

4.1 Social reporting practices in the selected municipalities

What emerges from the analysis of the social reports of the municipalities of Argenta, Pero, and Strambino is a shared commitment to adhering to the 2007 Guidelines issued by the Ministry of the Interior, despite variations in implementation. In all cases, the social report is conceived as a tool for transparency and accountability, aimed at communicating the activities carried out during the 2019–2024 term, with particular attention to the impact of the COVID-19 pandemic on administrative management.

A cross-cutting element is the involvement of local stakeholders, including citizens, associations, and the third sector, following an inclusive governance model. However, significant differences emerge in the structure of the reports: Pero adopts a more strategic approach, with explicit references to the 2030 Agenda, while Argenta and Strambino take a predominantly narrative path.

Despite these efforts, the reports exhibit important methodological limitations. There are no standardized systems for outcome or social impact indicators, nor are there structured analyses comparing objectives with results. None of the documents underwent independent certification (Ministero dell'Interno, 2007), a factor that reduces their credibility and comparability. Moreover, the content is based almost entirely on qualitative descriptions, limiting the ability to objectively assess the effects of public policies. From a technological standpoint, while all three municipalities demonstrate a commitment to digitalizing public services (e.g., SPID, PagoPA, App IO), such innovation does not extend to the area of social reporting. The lack of AI tools reveals a traditional reporting approach. The main weaknesses identified in the reports are summarized below (Table 2).

Table 2. Critical Aspects of Social Reporting in Pero, Strambino, and Argenta

Area	**Issue Identified**
Structure	Lack of standardization.
Informational content	Emphasis on narrative over data-driven content.
Innovation	There is no use of AI, data analysis, or interactive tools to automate information collection and processing.
Alignment with Standards	Insufficient or absent alignment with applicable national or international voluntary standards.
Stakeholders Involvement	Stakeholder engagement remains poorly structured, with no ongoing dialogue or co-design mechanisms.
Validation and Transparency	There is no independent certification of documents, and reporting of deviations is either weak or lacking.

Source: own elaboration

Social reports from the municipalities of Pero, Strambino, and Argenta reflect a positive commitment to transparency and citizen engagement. To make these reports truly strategic and impactful, more structured actions are needed, including the definition of common standards, the integration of smart technologies, and the strengthening of participatory processes.

4.2 Limits

Building on the theoretical framework and methodological approach previously outlined, the initial phase of data collection on Italian municipalities encountered several significant obstacles. The lack of a national archive of social reports required fragmented searches across individual municipal websites. Additionally, the absence of a specific legal obligation for social reporting limits its dissemination, which remains inconsistent in both content and frequency. Even when social reports are available, limited levels of digitalization and inconsistent publication practices across municipal websites frequently hinder their accessibility.

Another critical issue is the absence of shared standards regarding the format, structure, and content of social reports. This heterogeneity made it difficult to carry out systematic comparisons or conduct cross-municipality analyses.

Temporal continuity is also lacking. In many cases, municipalities prepare a social report only at the end of their administrative term, with no regular updates or continuity over time. This discontinuity undermines the potential of the social report as a reliable tool for monitoring public policies.

In addition, many social reports lack structured information, such as the methodology used or the application of indicators, which makes critical evaluation and comparison across municipalities particularly difficult. This issue is further compounded by another important factor: most small and medium-sized municipalities do not adopt any form of social reporting, contributing to the limited and fragmented dissemination of such practices.

4.3 Social taxonomy and social indicators for PAs

The report on the "Proposal for a Social Taxonomy" developed by the PSF introduces a classification system designed for the private sector, based on the social impacts of economic activities. This framework adopts a stakeholder-centered approach, focusing on groups who are affected by those impacts. Within this approach, three main stakeholder categories are identified:

- workers (both employees and workers across the value chain);
- local communities and society at large;
- consumers (end users of products and services);

For each of these, the PSF defines social objectives and sub-objectives, closely aligned with the protection of fundamental human rights, as outlined in key international documents, such as the Universal Declaration of Human Rights (UN) and the Charter of Fundamental Rights of the European Union (PSF, 2022).

To strengthen the integration of social sustainability principles into public policies, it is proposed to adapt the Social Taxonomy framework to the context of PA, with a specific focus on local municipalities. Given that municipalities and local authorities interact daily with a broad network of stakeholders, their decisions have direct effects on critical social dimensions.

This context underscores the relevance of the PSF framework, which aligns closely with the institutional role of PA which is inherently oriented toward accountability, rights protection, and multi-level engagement.

Adopting a stakeholder-centric approach, as proposed in the draft Social Taxonomy, would therefore help reinforce inclusive governance, grounded in transparency, social impact measurement, and the creation of shared value. In this light, a summary table (Table 3) is presented, mapping each stakeholder category to the corresponding priority social objectives defined by the PSF.

Table 3. PA Stakeholders and Main Social Objectives of "Social Taxonomy"

Stakeholders	**Recipients**	**Macro objective**
1. Workers	PA employees, supplier workers, unions, operational bodies	Promote decent work, fair wages, workplace safety, continuous training, equality and inclusion, along the entire public chain.
2. Community/ Society	Local communities, NGOs, vulnerable populations, oversight institutions, media, government	Inclusive,resilient and participatory communities.
3. End users of public services	Citizens, businesses, schools, universities, research centers.	Ensure universal, quality and equitable access to public services: healthcare, education, housing, transport, digital and social services.

Source: own elaboration by *Final report on Social Taxonomy*. Brussels: European Commission

The PSF proposes a set of specific micro-objectives for each macro-objective (PSF, 2022). This approach could support the public sector in using the Social Taxonomy as a practical tool to define clear goals and allocate resources to activities that generate positive community impacts

In this perspective, extending the Social Taxonomy to the social reports of municipalities aligns naturally with the European Sustainability Reporting Standards (ESRS). The social standards S1 through S4 offer a range of Key Performance Indicators (KPIs) that can be adapted to the needs of PAs (EFRAG, 2022a–d).

In this study, we identified, for each macro-objective, a set of KPIs particularly suited to local authorities (Table 4). These KPIs are categorized into two types:

- qualitative indicators, which capture the presence or absence of specific policies (e.g., citizen listening mechanisms);
- quantitative indicators, which measure objective data (e.g., workplace accident rates, gender pay gap).

This approach would help assess the impact of policies in key areas (such as health and education) and ensure alignment of administrative actions with the SDGs. Implementing this method requires a flexible operational plan that can respond to social and economic changes, while also tracking, evaluating, and aligning social policies with sustainability standards

The evaluation of such actions should rely on an integrated set of social well-being indicators and social impact indicators, capable of offering a dynamic and updated interpretation of territorial change. The former measure improvements such as better working conditions or reduced inequalities (McGuinn et al., 2020), while the latter detect deeper transformations related to community empowerment, cohesion, and resilience (Grieco et al., 2013).

Establishing a harmonized system of social indicators, inspired by the Social Taxonomy and the ESRS standards, constitutes a crucial step forward. The integrated approach connecting stakeholders, macro-objectives, micro-objectives, and indicators offers an innovative methodology for a more results-oriented, accountable, and community-focused PA.

Table 4. Examples of Social KPIs for Pas

Type	**Indicator**	**Measurement /Formula**
	1 Workers. Sub-objective: Fair wages and inclusion	
Qualitative	Presence of fair wages and equal opportunities	"Present" (1) or "Absent" (0)
Quantitative	Pay Gap. (%)	[(Average salary for male – Average salary for female) / (Average salary for male)] x 100
	1 Workers. Sub-objective: Health and safety at work	
Qualitative	Existence of a health and safety training plan	"Present" (1) or "Absent" (0)
Quantitative	Workplace accident rate. (%)	(Number of accidents)/ (Total number of employees) x 100
	2 Community and society. Sub-objective: Social inclusion	
Qualitative	Existence of community engagement policies	"Present" (1) or "Absent" (0)
Quantitative	Percentage of vulnerable group involvement in engagement activities. (%)	(Vulnerable participants)/ (Total participants) x 100
	3 End users of public services. Sub-objective: Quality of services	
Qualitative	Perceived quality feedback collection system	"Present" (1) or "Absent" (0)
Quantitative	Satisfaction rate (%)	(Number of positive responses)/ (Total responses) x 100

Source: own elaboration by EFRAG, 2022

4.4 AI and social taxonomy: innovating local government social reporting

Recent studies highlight AI's potential to advance the 17 UN Sustainable Development Goals (SDGs), especially in areas like social inclusion, sustainable urban development, education, and public health. AI enables automation in social data analysis, real-time KPI monitoring, and insight extraction from diverse sources, transforming social reporting into a strategic planning and monitoring tool.

The Social Taxonomy offers a structured framework for defining and measuring social rights, while AI allows public administrations (PAs) to monitor policy impact in line with sustainability standards (Lega & Pugliani, 2023). Natural Language Processing (NLP), for instance, automates the analysis of documents and citizen feedback, converting qualitative input into actionable metrics (Arrieta et al., 2019). Machine learning further enhances social reporting by detecting early signs of vulnerability, such as school dropout or housing exclusion, through

predictive models using historical and real-time data (Jordan & Mitchell, 2015). In practice, AI is helping local governments move beyond efficiency gains toward evidence-based, data-driven policymaking (Rosu, 2024).

Italian municipalities are beginning to adopt AI in smart city initiatives. Predictive dashboards monitor access to services and social inclusion levels (Löfgren & Webster, 2020). A key example is the AMPEL project, developed by Auser, Fondazione Cariplo, and the University of Milano-Bicocca, which leverages AI to detect early signs of poverty and social exclusion among the elderly and migrants (Rinaldi, 2025).

However, AI's integration into public decision-making raises concerns about transparency, accountability, fairness, and privacy (Floridi & Cowls, 2019), as well as the risk of bias in algorithmic outcomes (van der Voort et al., 2019). Explainable AI (XAI) is crucial to ensure that decision-making processes remain understandable and justifiable (Arrieta et al., 2019). For example, in allocating municipal housing subsidies, XAI makes it possible to clearly identify the variables, such as income or family status, that influenced a decision, ensuring transparency and auditability.

Nonetheless, the use of predictive analytics in governance necessitates ethical scrutiny. Cases like China's Social Credit System and the Dutch Toeslagen scandal reveal how opaque algorithms can lead to discriminatory practices and rights violations if not properly regulated (Cerrina Feroni, 2023).

In response, the EU has introduced frameworks like the AI Act (EU Regulation 2024/1689) and the Digital Decade strategy (European Commission, 2024) to promote safe, rights-based AI in the public sector. These policies also support innovative procurement models to encourage AI adoption aligned with democratic values (Rosu, 2024).

This evolving ecosystem reveals a growing convergence between the Social Taxonomy, AI, and municipal social reporting, paving the way for a shift from static accountability to stakeholder-centered, SDG-oriented governance.

5 Conclusions

The research explores how the European Social Taxonomy, Social Reporting standards (such as ESRS), and Artificial Intelligence (AI) can support local governments in Italy, particularly small to mid-sized municipalities, in enhancing accountability processes. These municipalities often show significant weaknesses in methodological, technological, and strategic aspects of social reporting. While the aim of social reporting is to increase transparency and civic engagement, current practices remain largely narrative and lack clear indicators, standardized formats, and sufficient quantitative data. This undermines the potential of social reporting as a tool for strategic planning and performance evaluation, making it difficult to compare results across municipalities or assess policy impact effectively.

To address this, the study investigates how integrating AI and the European Social Taxonomy into social reporting can enhance policy effectiveness. The European Social Taxonomy offers a structured framework rooted in shared social objectives such as decent work, inclusion, well-being, and cohesion. When adapted to local contexts, it can guide the selection of relevant indicators, making it easier for public administrations to monitor the social impact of their policies in a standardized way.

AI can play a key role by automating data analysis, identifying emerging social issues in real time, and making public reporting more accessible and interactive for citizens.

However, the adoption of these tools faces significant obstacles. Local governments face outdated infrastructure and limited training investments. Many lack the necessary digital and analytical competencies to manage AI-based systems effectively. Transformation requires not only technology but also strategic capacity-building

The study also notes certain limitations, particularly the narrow sample of municipalities analyzed, which limits the generalizability of findings. For the proposed model to be scalable, further research and formalization are needed, including international comparisons and the development of flexible roadmaps tailored to the diverse conditions of Italian municipalities. Operational priorities identified include:

- standardizing social reporting to ensure consistency and comparability;
- developing integrated digital platforms for automating data collection and visualization;
- providing continuous training to public employees to support ethical and effective AI use;
- launching pilot projects in collaboration with academic institutions to test and refine scalable models.

Ultimately, the integration of Social Taxonomy and AI is not just a technical upgrade but a transformative opportunity. It requires rethinking governance processes, promoting a culture of transparency and participation, and aligning public sector innovation with the broader goals of the 2030 Agenda for Sustainable Development. Through a coherent and collaborative strategy, local governments can turn social reporting into a powerful tool for driving measurable, inclusive, and sustainable public value.

6 Ethical Statement

This research did not involve human or animal subjects, nor did it collect any sensitive data; therefore, approval from an ethics committee was not required.

7 AI Declaration

No Artificial Intelligence (AI) tools were used in the creation or editing of this work. However, online translation tools such as Google Translate were used only to assist with language translation. All ideas, structure, and final content are the original work of the authors, and full responsibility for the accuracy and integrity of the work remains with the authors.

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Enhancing Resilience in Agrifood Supply Chains: The Role of Technological Innovation for Risk Management

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Abstract

The adoption of innovative technologies can help agrifood companies face crucial challenges related to meeting the food needs of a growing world population, adapting to and mitigating the effects of climate change, and increasing the resilience of supply chains against sudden disruptions. In fact, several studies highlight the advantages that technological innovation can bring to agrifood supply chains. At the same time, few studies examine the connections between technological innovation and risk management. This study aims to help bridge this gap by reviewing and organizing previous findings. Specifically, this paper provides a classification of the main risks affecting agrifood supply chains and investigates the role that technological innovations may play in helping agrifood companies address key risks. The results lead to the identification of five main risk categories: food safety, information management, environmental, geopolitical, and supply chain management risks. Furthermore, the literature review focuses on six key technologies, including blockchain, Internet of Things, big data, artificial intelligence, drones, and digital twins. From this perspective, the results show that blockchain tracking systems allow companies to monitor product conditions throughout the supply chain. This helps ensure product quality, combat counterfeiting, and support the management of information and product flows. IoT systems are especially useful for mitigating food safety risks by enabling real-time monitoring during cultivation, transport, and distribution. Big data and AI-based solutions mainly support precision agriculture activities, contributing to the mitigation of environmental risks. Finally, the study highlights emerging applications related to drones and digital twins. Ultimately, this study provides several relevant contributions. First, it helps organize the fragmented contributions on the impact of technologies on risk management in the agrifood industry. Second, it offers a solid theoretical foundation for analysing the implications of technological applications on different risk categories. Third, it provides useful insights for practitioners to assess how technological innovation may help manage and mitigate key risks.

Keywords: agrifood industry; risk management; Industry 4.0 technologies; supply chain resilience.

Paper type: Academic Research Paper

1 Introduction

The agrifood industry is facing unprecedented challenges. Companies are pressured to increase food production to meet the needs of a growing global population (Hrustek, 2020). The definition of sustainable development goals requires balancing economic growth with the safety, transparency, and accountability of agrifood supply chains (Chandan, John and Potdar, 2023). The effects of climate change, along with extraordinary events such as pandemics and international conflicts, demand that agrifood supply chains enhance their ability to respond to sudden disruptions (Ben Hassen and El Bilali, 2022).

Overall, the agrifood industry needs new solutions to improve supply chain resilience and manage key risks. In this context, technological innovation could be one of the main avenues to ensure the security of agrifood supply chains. In recent years, numerous studies highlighted the benefits of technological innovation in the agrifood industry. Technologies such as Internet of Things (IoT), big data, artificial intelligence (AI), blockchain, and digital twins enable agrifood companies to monitor all stages of the supply chain, improving the management of product and information flows. At the cultivation and production stages, real-time data can help manage natural resources, reduce waste, and mitigate environmental impact (Spanaki *et al.*, 2022). During transportation, blockchain technology and IoT systems ensure security and streamline product flows by improving coordination and fostering trust among supply chain partners (Ellahi, Wood and Bekhit, 2023). Big data can be used to develop decision support systems to enhance activity planning, product management and demand forecasting (Talari *et al.*, 2022). Overall, previous findings suggest that technological innovation could help agrifood companies address and mitigate crucial risks. Despite this, the literature currently lacks an established research stream focusing on the impact of technological innovation for risk management in the agrifood industry. Indeed, this perspective is notably absent from the literature, as few studies examine the implications of innovative technological applications for risk management. Most studies emphasize the advantages of the technologies but fail to consider how these may benefit agrifood supply chains' ability to address key risks related to modern grand challenges. This is a notable gap, hindering our understanding of how

technological innovations may shape the development of the agrifood industry. Furthermore, the literature appears highly fragmented, focusing on specific applications or supply chain stages. This is useful to analyse the impact of technologies on key issues affecting the agrifood industry but also highlights the lack of a shared theoretical foundation and hinders the generalizability of the findings. This study aims to help bridge this gap by systematizing the literature and providing a theoretical framework investigating the connections between technological innovation and risk management in agrifood supply chains. Consistently, this study aims to answer the following research questions:

1. What are the main risks affecting agrifood supply chains?
2. How can innovative technologies support risk management in agrifood supply chains?
3. What is the state of the literature on technological innovation for risk management in agrifood supply chains?

To answer these research questions, we perform a thorough literature review aimed at systematising available studies and achieving four main goals. First, provide a classification of the key risks affecting modern agrifood supply chains. Second, synthesize the main findings on the impact of technological innovation in the agrifood industry. Third, develop a theoretical framework to link the use of technologies with risk management in agrifood supply chains.

This study is structured as follows: the next section presents the literature review methodology, detailing the processes of data collection, selection, and analysis. Next, the results are presented, focusing on how technologies may impact the management of key risks affecting agrifood supply chains. The following section presents the conclusions, outlining the study's findings and its theoretical and practical contributions.

2 Methodology

This study aims to investigate how technological innovation can support risk management in the agrifood industry, by synthesizing and analysing previous contributions. To this end, a thorough literature review was performed. Literature reviews are useful to analyse the state of the art on a topic, highlight key contributions and outline research gaps. The methodology is comprised of three main phases: material collection, material selection, and content analysis.

2.1 Material collection

The material collection phase moved from the definition of a search string used to survey the online database of scientific publications Scopus. This was chosen due to its popularity and reliability in scientific research, as also proved by multiple studies reviewing innovative technological applications in the agrifood industry (Dal Mas *et al.*, 2023). The search string can be ideally divided into three sections, each relating to a key element of the study. The first section includes keywords related to risk management and assessment, and supply chain resilience. The second focuses on the agrifood supply chains, while the third considers the main innovative technologies applied in the agrifood industry. The query was performed in December 2024. Table 1 presents the search string, the keywords used, and the number of results obtained.

Table 1: Search string, keywords and number of results.

Search string	Results
("risk manag*" OR "supply chain risk manag*" OR "risk mitigat*" OR "resilien*" OR "supply chain resilien*" OR "risk assess*" OR "risk reduc*" OR "risk prevent*" OR "supply chain risk*" OR "risk detect*" OR "risk analys*" OR "risk modell*") AND ("agrifood supply chain*" OR "food supply chain*" OR "agriculture supply chain*" OR "Agrifood industr*" OR "Agrifood") AND ("Industry 4.0" OR "blockchain*" OR "IoT" OR "internet of things" OR "artificial intelligence" OR "AI" OR "big data" OR "data analytic*" OR "machine learn*" OR "deep learn*" OR "smart sensor*" OR "digital twin*" OR "drone*" OR "robot*" OR "3D print*" OR "additive manufactur*" OR "distributed ledger*")	802

2.2 Material selection

Moving from the initial sample of 802 studies, appropriate selection criteria were defined. First, we only selected studies published between 2015 and 2025. This allowed us to provide an updated perspective on technological innovation in the agrifood industry. Next, we limited the scope of the research to the subject areas of Engineering, Agricultural Sciences, Business, management and accounting, Economics, econometrics and finance. This allowed us to focus on studies investigating the technological, managerial, and economic implications of technological innovation in the agrifood industry. Subsequently, we further refined the selection

by including only research articles and reviews. This allowed us to focus on high-quality, peer-reviewed contributions. In the next step, we conducted a selection based on keyword analysis. Specifically, we excluded keywords that had no logical or semantic connection with the terms included in the search string.

The final two selection steps involved the abstract and a full read of the remaining documents. The goal was to identify studies that explicitly described how technologies support risk management in the agrifood industry. Finally, moving from the remaining sample of 73 documents, we applied a snowball sampling technique to identify relevant studies that may have been wrongly excluded by the initial search or in the material selection process. This led to the inclusion of an additional 26 studies, resulting in a final sample of 99 documents. Table 2 summarizes the material selection process.

Table 2: Material selection process.

Selection criteria	Description	Remaining documents
Focus on the latest applications of Industry 4.0 and 5.0 technologies	Selection of the documents published between 2015 and 2025	793
Focus on technological, managerial and economic perspectives	Selection of the documents pertaining to the subject areas: Engineering, Agricultural sciences, Business, management and accounting, Economics, econometrics and finance	603
Focus on high-quality documents in English	Selection of peer-reviewed research articles and reviews in English	414
Focus on content through keyword analysis	Selection of the documents with keywords matching search string terms	231
Focus on content through abstract read	Selection of the documents investigating risk management and technological innovation in the agrifood industry	138
Focus on content through full document read	Selection of the documents discussing at least one connection between technological applications and risk management	73
Focus on mitigating selection bias	Snowball sampling based on reference analysis	99

2.3 Content analysis

Following the selection of the sample, an in-depth content analysis was performed. This aimed to achieve two main objectives. First, outline the characteristics of the sample through a descriptive analysis, highlighting the evolution of research, the main thematic areas, and key contributions. Second, to identify and systematize fragmented contributions to develop a framework analysing the connections between technological innovation and risk management in the agrifood industry.

3 Results

The results are presented in three sections. The first section focuses on the descriptive analysis of the documents. The second presents a classification of the main risks affecting the agrifood industry, while the third discusses the connections between technological innovation and risk management in the agrifood supply chains.

3.1 Descriptive analysis

We begin this section by considering the temporal distribution of publications. This shows that interest in the topic has significantly increased since 2019. This is consistent with the rapid development of novel technological applications driven by the adoption of IoT, blockchain, and AI solutions in the agrifood industry. This also highlights the growing importance of technological innovation in a sector recently marked by a series of disrupting events, including pandemics, international conflicts, and extreme climate events.

Moving on, we classify documents by type, distinguishing between literature reviews, quantitative studies, and qualitative analyses. The prevalence of literature reviews reflects the effort of the scientific community in organizing a growing field of knowledge according to different perspectives. Notably, 30 quantitative studies are included in the sample. These focus primarily on assessing the impact of innovative technologies on key aspects of agrifood supply chain management, such as resilience, food security, and the management of information and product flows. As for qualitative studies, these provide crucial insights by focusing on investigating how the regulatory, technological, and organizational environment can affect technological innovation in the agrifood industry.

Moving on, the analysis of the most representative sources enables the identification of four key thematic areas. The presence of journals such as the Journal of Cleaner Production, Sustainability, and Business Strategy

and the Environment highlights the strong connection between technological innovation and environmental sustainability in the agrifood industry. The inclusion of journals like the Journal of Agriculture and Food Research, Foods, and the British Food Journal emphasizes the impact of innovative technologies on food safety, traceability, and food waste. On a different note, sources such as Supply Chain Management, IEEE Transactions on Engineering Management focus on supply chain management issues, investigating how technological innovation can support activity planning and enhance supply chain coordination and resilience in the agrifood industry. Finally, journals like Computers in Industry and Computers and Industrial Engineering focus on technology design and implementation issues, exploring the role that ICTs and digital technologies can play in agrifood supply chains.

3.2 Risk classification

This section presents a classification of the main risk categories affecting the agrifood industry. The purpose of this classification is to provide a theoretical foundation for assessing the impact of technologies on risk management in agrifood supply chains.

Thus, we move from the analysis of the first risk category, namely food safety risks. This includes three sub-risks. The first relates to the risk of compromising food quality. Many agrifood products are highly perishable and sensitive to parameters such as temperature, humidity, and light exposure (Patelli and Mandrioli, 2020). As a result, issues in storage or transportation conditions can lead to significant quality loss. This can result in food waste, the need to manage costly recall activities, or even endanger consumers' health (Kumar *et al.*, 2021). The second sub-risk concerns fraudulent commercial practices. In the agrifood industry, these involve fraudulent claims regarding product provenance or the characteristics of production methods. The third sub-risk concerns food losses and waste. These can occur at all stages of the supply chain from production to consumption and represent a well-documented issue affecting the agrifood industry (Hassoun *et al.*, 2023).

The second category of risks concerns data and information management and also includes three sub-risks. The first relates to product traceability issues. In the agrifood industry, product tracking is essential to ensure product quality and safety, comply with regulations, and contrast fraudulent practices (Ellahi, Wood and Bekhit, 2023). The second sub-risk relates to information management. Several studies show that the agrifood industry is affected by significant information asymmetries, which lead to unfair value distribution, supply chain coordination, and product flow management issues (Pakseresht *et al.*, 2023). Finally, this category includes risks related to cybersecurity threats, data leaks and privacy issues that may stem from the adoption of ICTs and digital technologies (Nayal *et al.*, 2022).

The third category of risks considers the effects of climate change and environmental sustainability concerns. The first sub-risk in this category concerns the increasing frequency of extreme natural phenomena and the need to adapt to the consequences of climate change (Talari *et al.*, 2022). The second sub-risk relates to inefficient use of natural resources. The last sub-risk in this category relates to the environmental impact of production activities, particularly the risk of permanently damaging natural resources (Yadav *et al.*, 2023).

The fourth category includes geopolitical risks and consists of two sub-risks. The first encompasses risks arising from extraordinary events such as pandemics, conflicts, or severe political instability. Notable examples in recent years include the Russia-Ukraine conflict and the recent COVID-19 pandemic (Hobbs, 2021). The second type of sub-risk includes sudden shocks in demand or supply. These can result from regulatory changes, food scandals, or other events that influence the availability or price of raw materials (Sharma *et al.*, 2022).

The final category of risks concerns agrifood supply chain management. This comprises four types of sub-risks. The first relates to vulnerabilities in supply chains, affecting roles and responsibilities, and coordination and communication mechanisms (Coral and Mithöfer, 2023). Another type of risk concerns disruptions or slowdowns in the logistics and transportation activities (Burgos and Ivanov, 2021). The third type of sub-risk relates to human errors, which can result in inefficiencies, delays, disruptions or increased costs (Birkel and Hartmann, 2020). The final sub-risk concerns relationships with consumers. Inconsistencies in labelling and communication undermine consumer trust and negatively impact brand reputation (Singh *et al.*, 2023). Figure 1 concludes this section by illustrating the five main risk categories and the corresponding sub-risks.

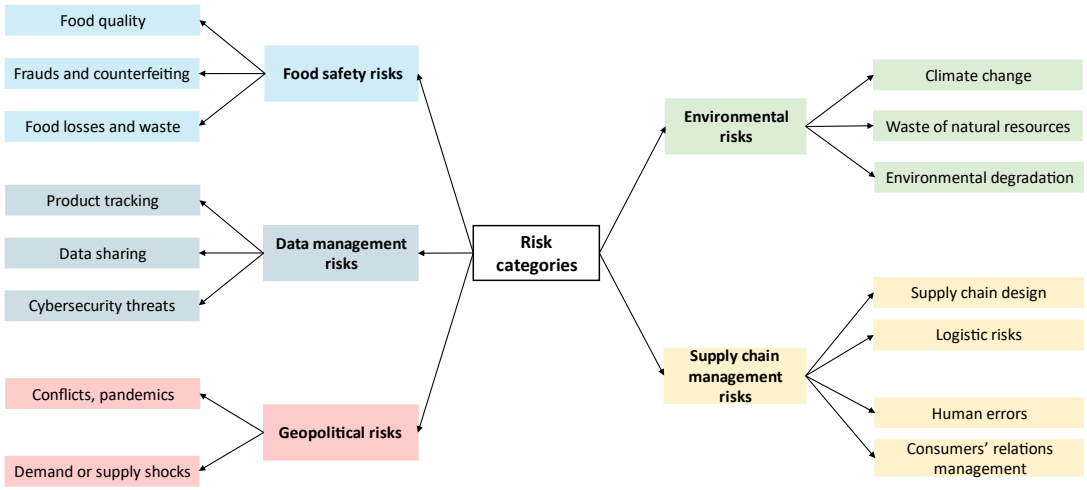


Figure 1: Risk categories and corresponding sub-risks.

3.3 Technological applications and risk management

This section aims to investigate how the adoption of innovative technologies may help agrifood companies manage or mitigate different types of risks. To this end, we referred to the five risk categories and corresponding sub-risks presented in the previous section. Subsequently, we identified the main technological applications in the agrifood industry and analysed their impact on risk categories. Table 3 synthesizes the findings, using shades of green to illustrate the impact of each technology in managing or mitigating different types of risk. This qualitative assessment was conducted by the three authors based on the triangulation of information sources and a shared understanding of the reviewed literature.

We start our analysis by considering blockchain applications (Ellahi, Wood and Bekhit, 2023). In the agrifood industry, blockchain applications mainly relate to the development of advanced product tracking systems. From this perspective, blockchain presents several advantages. First, high decentralization can lead to improved information sharing among supply chain partners (Mukherjee *et al.*, 2021). Second, the auditability and immutability of information uploaded to the blockchain enhance supply chain transparency and encourage actors towards responsible behaviours (Wünsche and Fernqvist, 2022). Third, the use of a shared digital ledger updated in real time supports the management of product flows (Kramer, Bitsch and Hanf, 2021). Due to these features, blockchain-based systems in the agrifood industry can have a particularly strong impact on the mitigation of food safety, information management, and supply chain management risks.

Regarding the first category, several studies illustrate how blockchain supports food tracking at all stages of the supply chain, providing insurances regarding food origin and production methods (Montecchi, Plangger and Etter, 2019). Additionally, many studies suggest that the use of shared tracking systems simplifies monitoring and recall activities, mitigating food safety risks and helping to reduce waste (Bumblauskas *et al.*, 2020).

Concerning the impact of blockchain on information and data management risks, one of the most documented advantages of blockchain applications in supply chains is the increased transparency and reliability of information (Rogerson and Parry, 2020). Finally, blockchain adoption can help agrifood companies also mitigate supply chain management risks. In this regard, particularly significant is the impact on the mitigation of risks related the management of the relations with consumers (Vern *et al.*, 2024).

The second technology we consider is Internet of Things. The use of IoT systems in the agrifood industry relate to two types of applications. The first concerns resource management. In this regard, the use of IoT systems and smart sensor networks enables acquisition of real time data to support the execution of precision agriculture and site-specific activities (Ouafiq *et al.*, 2022). Furthermore, this helps reduce waste and minimize the environmental impact of production activities (Jagtap, Garcia-Garcia and Rahimifard, 2021). The second type of applications concerns product tracking. From this perspective, IoT systems can be used to monitor key parameters such as temperature and humidity during storage and transportation phases (Al-Ansari *et al.*, 2020). On the one hand, this allows to mitigate food quality and safety risks. On the other, it helps streamlines logistics operations, improving the resilience of agrifood supply chains and mitigating risks in the distribution phase (Beker *et al.*, 2016).

Moving on, we continue our investigation by considering big data applications. These involve the development of decision support models, often leveraging the combination with AI-based solutions or IoT systems (Lokers *et al.*, 2016). From a risk management perspective, big data utilization mainly impacts food safety, environmental sustainability, and supply chain management risks. Regarding food safety risks, Talari et al. (2022) demonstrate how big data helps detect and mitigate risks associated with the diffusion of pathogens by supporting control processes based on geographic data or chemical analyses. Rejeb et al. (2021) analyse the role of big data in managing and preserving natural resources, while Donaghy et al. (2021) show that big data can support supply chain management, mitigating disruptions and market shocks. In these instances, big data are useful to predict the evolution of demand and to develop decision support models.

We now focus on AI-based applications in the agrifood industry. These impact primarily cultivation and production by enabling the automation of monitoring and control activities. In this regard, it is essential to consider how most AI applications rely on the utilization of drones and robots (Spanaki *et al.*, 2022). AI applications in the agrifood industry can be categorized into two main typologies. The first focuses on crop mapping and environmental monitoring (McCarthy *et al.*, 2023). The second type of application involves targeted interventions on crops. Here, the synergy between artificial intelligence, drones and robots can be used for the identification of pests and weeds, or for crop identification and counting. From this perspective, AI-based solutions can help mitigate food safety and environmental risks, and mitigate risks associated with human error (Badia-Melis *et al.*, 2018). Before moving on, it is worth considering some relevant emerging applications encompassing the use of drones for food delivery services. In this regard, the use of drones for last-mile deliveries could help mitigate logistical and distribution risks (Choe, Kim and Hwang, 2021).

We conclude this section by investigating the applications of digital twins. In essence, digital twins are virtual equivalents of physical objects, capable of replicating their features, state, and evolution over time by leveraging the integration of sensors, IoT systems, and multiple data sources (Verdouw *et al.*, 2021). Regarding their adoption in the agrifood industry, Pylianidis et al. (2021) highlight digital twins' great versatility by identifying 28 use cases, ranging from production monitoring, to product tracking, to supply chain management. Burgos and Ivanov (2021) show how digital twins can be used to assess the impact of the COVID-19 pandemic on the agrifood industry and to identify risk mitigation strategies. On a different note, several studies show that digital twins can support product monitoring and quality control, contributing to the mitigation of food safety risks (Defraeye *et al.*, 2019). Finally, the use of digital twins could also have a positive impact on supply chain management. Maheshwari *et al.* (2023) demonstrate how digital twins can enhance agrifood supply chain resilience by reducing inefficiencies and improving coordination and information management.

Table 3: Impact of innovative technologies on agrifood risks. Darker shades of green indicate stronger impact.

Risk categories	**Sub-risks**	**Blockchain**	**IoT**	**Big data**	**AI**	**Drones**	**Digital twins**
Food safety risks	Food quality						
	Frauds and counterfeiting						
	Food losses and waste						
Data management risks	Product tracking						
	Information management						
	Cybersecurity and privacy						
Environmental risks	Climate change						
	Waste of natural resources						
	Environmental degradation						
Geopolitical risks	Conflicts, pandemics						
	Market shocks						
Supply chain risks	Supply chain design						
	Logistic risks						
	Human errors						
	Consumers' relations management						

4 Conclusions

This study aimed to investigate how innovative technologies impact risk management in the agrifood industry. These include the need to ensure food production for a growing world population, the need to adapt to and mitigate the effects of climate change, and the need to improve the resilience of agrifood supply chains in response to disruptions. While the literature effectively investigated the advantages of technological innovation in the agrifood industry, it failed to thoroughly address implications for risk management. To help bridge this gap, this study conducted a literature review aimed at organizing the main findings, identifying the main categories of risks affecting the agrifood industry, and analysing the impact of recent technological applications.

This led to the identification of five main risk categories, encompassing food safety, information management, environmental, geopolitical, and supply chain management risks. Furthermore, this classification was useful to analyse how different technologies may impact risk management. In particular, the study focused on six technologies, namely blockchain, IoT, big data, artificial intelligence, drones, and digital twins. The results present the main applications in the agrifood industry, highlighting opportunities, and discussing implications for risk management.

Overall, this study has important theoretical and practical implications. From a theoretical perspective, the study advances the literature by providing a classification of the main risks affecting the agrifood industry. Furthermore, this study contributes by discussing the implications of key technological applications for managing different risk typologies, and by providing an overview of the impact of the most relevant technological solutions. As for practical implications, this study suggests how practitioners can leverage technological innovation to support risk management. In this regard, blockchain tracking systems help ensure product quality, combat counterfeiting, and support the management of information and product flows. IoT systems are particularly useful for mitigating food safety risks by enabling real-time monitoring of products during cultivation, transport, and distribution. The use of big data and AI-based solutions can effectively support precision agriculture activities. This contributes to the management of natural resources and helps mitigate environmental risks. Drones are used to automate monitoring and precision agriculture activities. Finally, digital twins show the potential to deeply impact agrifood supply chain management by improving resilience and mitigating food safety risks.

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Ethics declaration

No ethical clearance was needed for the research referred to in this paper.

AI use declaration

No artificial intelligence software was used to develop the study. Artificial intelligence was used to proofread the paper.

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Business Model Innovation and Digital Technologies in Agri-Food: Leveraging Boundaries for Sustainability

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Abstract

The study aims to investigate the digital transformation processes within the agri-food sector and their influence on business model innovation (BMI) as a pathway toward sustainability. Specifically, it analyses how agri-food companies are exploiting the potential of digital technologies (DTs) to reshape their value creation processes, enhance competitiveness, and address environmental and economic challenges. In order to exploit DTs and integrate them into business operations, it is essential to innovate the companies' business model by rethinking traditional operational and strategic logics. This underscores the necessity of both the adoption of new technologies and the transformation of the business model. Despite the multiple opportunities offered by DTs, their introduction in agri-food companies presents significant obstacles due mainly to a lack of knowledge, limited digital skills or to the high costs associated with their implementation. Addressing these barriers, requires a growing emphasis on knowledge co-creation-oriented approaches, that integrate diverse disciplines and sectors. In order to pursue this objective, the study adopts a theoretical approach, based on an analysis of the existing literature on DTs and their role in fostering BMI and sustainability, and boundary management within the agri-food sector. The research focuses on the role of company boundaries as collaborative spaces that can facilitate the adoption of DTs and promote co-creation dynamics. The findings of the research lead to the development of a theoretical framework aimed at guiding agri-food companies in their transition toward more innovative and sustainable business models. This study offers theoretical contributions to support companies in leveraging DTs for sustainable development.

Keywords: Business Model Innovation, Sustainability, Digital Technologies, Boundary Management, Agri-Food Sector

Paper type: Academic Research Paper

1 Introduction

In a dynamic environment influenced by constant changes and emerging challenges, innovating the business model has become a key capability for surviving competition (Garzella et al., 2021; Li et al., 2024.). Over the last few years, one of the main driving forces behind BMI has been the increasing use of DTs in the business activities (Oguntegbe et al., 2024; Krishnan et al., 2025).

DTs are leveraged by companies to achieve a predominant position and maintain a high level of competitiveness in the market by reshaping their value creation process (Legowo et al., 2021; Dragos and Livia, 2023). In this scenario, characterized by growing economic and environmental challenges, the agri-food sector is at the centre of a crucial transition (Konfo et al., 2023; Finger, 2023). The widespread use and integration of DTs in this sector is proving to be a driver of BMI, enabling better results in terms of sustainability (Carmela Annosi et al., 2020; Capurro et al., 2023; Stefanini and Vignali, 2024).

Despite the numerous opportunities offered by DTs, their introduction in agri-food companies presents significant challenges (Maffezzoli et al., 2022; Fragomeli et al., 2024) due mainly to a lack of knowledge, limited digital skills or to the high costs associated with their implementation (Al-Moaid et al., 2024; Alkhamery et al., 2021). To address these challenges, there is an increasing necessity of knowledge co-creation-oriented approaches, integrating various disciplines and sectors (Caputo et al., 2019; Dentoni et al., 2023). In this context, boundary management has gained significant relevance in management studies (Alexander, 1997; Breschi and Malerba, 1997) and plays a pivotal role in enabling the adoption of DTs and BMI (Fiorentino et al., 2021; Capurro et al., 2024).

Despite the growing interest in digital transformation, its implications for BMI in the agri-food sector, particularly as a pathway toward sustainability, remain underexplored (Barth et al., 2017; Miranda et al., 2023). Based on a literature review of innovation and strategic management studies, there is still a limited understanding of how the role of boundary management can serve to facilitate the integration of DTs to address environmental challenges (Broccardo et al., 2023). In an attempt to fill this gap, the study aims to investigate how the integration of DTs by the agri-food companies can trigger BMI to foster sustainability. The investigation will focus on the use of company boundaries as spaces for collaboration and co-creation. In particular, the study

poses the following research questions: How can boundaries be leveraged to support the adoption of DTs? Which elements of agri-food companies' business models can be innovated to enhance sustainability?

To fulfil the research aim and questions, a theoretical approach is adopted, based on an analysis of relevant literature on sustainability, digital transformation, BMI and boundary management in the agri-food sector. By integrating the literature, a theoretical framework is developed to support agri-food companies in navigating current challenges.

This paper is structured as follows. The next section provides the theoretical background on DTs and their role in fostering BMI and sustainability within the agri-food sector, and the boundary management. Section 3 presents the theoretical framework developed through the literature analysis. Finally, section 4, outlines the findings of the study and the conclusion, offering insights and directions for future research.

2 Theoretical background

2.1 DTs and BMI for sustainability in the agri-food sector

The topic of sustainability is of particular relevance in the agri-food sector (Notarnicola et al., 2012; Poponi et al., 2022). Many future social challenges are related to sustainable agriculture and food production, which, according to various sources, will increase by 70% by 2050 (Barth et al., 2017; Van Dijk et al., 2021). The agri-food system - which includes the "actors involved in bringing food from the field to the table, from agricultural production and processing to distribution, consumption and waste management" (Von Braun et al., 2021) - is responsible for negative impacts on environmental sustainability due to its implications on water consumption, land degradation, greenhouse gas emissions, biodiversity loss and food waste (Poore and Nemecek, 2018). In this context, companies' transition towards more environmentally sustainable agri-food practices is no longer considered an optional choice, rather, it has become a global priority as stated in the EU Green Deal and the Farm to Fork strategy (EC, 2019, 2020). Sustainable development also contributes to the achievement of several Sustainable Development Goals (SDGs) introduced by the 2030 Agenda, producing positive effects such as improving farmers' and consumers' welfare through organic practices and food security, preserving environmental balance, biological pest management and sustainable fertilisation techniques (Herrero et al., 2021).

Nevertheless, the structural composition of the agri-food sector, characterised by the predominance of SMEs (EC, 2024), combined with the inherent complexity of environmental sustainability, makes the green transition particularly challenging (Farace and Tarabella, 2024).

The path towards sustainability in the agri-food sector is driven by a variety of internal and external factors (Borsellino et al., 2020). Externally, the pursuit of sustainability responds not only to EU environmental regulations but also to the growing demands from consumers and stakeholders for greater transparency and accountability. Internally, the ability to implement sustainable practices depends on financial and human resources, management processes, know-how, and technological skills (Prasanna et al., 2024; Pandey et al., 2023). In this context, agri-food companies are called to address the growing need for sustainability, which requires increased investments in R&D and the adoption of DTs. This trend is part of the current era of "digital agriculture", which is defined as "the use of detailed digital information to guide decisions along the agricultural value chain" (Shepherd et al., 2020). Digital agriculture is profoundly transforming the sector through the introduction of precision and digital agriculture technologies which have the potential to influence economic performance, external environment and social context.

In this scenario, the structural changes brought by digital transformation have created a new competitive environment: incumbents are under increasing pressure to integrate emerging DTs, while new market entrants are leveraging them to reshape value creation processes and innovate business models. In this evolving context, digital transformation is perceived as "an organisational transformation that integrates DTs and business processes in a digital economy" (Liu et al., 2011), emphasizing not only technological change but also organizational and strategic implications.

Digital transformation is recognised as a driver for improving company efficiency and promoting sustainable innovation. The sustainable development of agri-food companies is strongly linked to their capacity for innovation, which implies the integration of DTs that not only support operational optimisation but are also considered key enablers for BMI.

Business models contribute to innovation as they translate market opportunities into profits by delivering the value of a service/product through commercialization (Amit and Zott, 2012); companies thus commercialize technologies through their business models. Accordingly, scholars have consolidated the studies on product and process innovation with the radical rethinking of the business model as this can expand the potential scope of

innovation (Chesbrough, 2010). As a result, BMI has emerged as a potential mechanism to integrate sustainability into business strategies thereby encouraging the adoption of more innovative and sustainable business models and enhancing companies' competitive advantage and long-term value creation (Broccardo and Zicari, 2020).

DTs, therefore, play a crucial role which extends beyond operational efficiency transforming the ways in which companies generate value, innovate, and engage with stakeholders, while addressing societal and environmental challenges (Nambisan et al., 2019; Cefis et al., 2023).

2.2 Boundary management for digital transformation in agri-food sector

The growing pressure from the competitive environment requires a constant updating of the company's structure and value creation process (Garzella et al., 2021). The integration of DTs has become a fundamental prerequisite to operate in the competitive environment, to avoid the loss of competitiveness, strategic positioning and market share (Legowo et al., 2021; Dragos and Livia, 2023).

Currently, DTs represent a key resource for value creation, especially in the agri-food sector, where there is a strong pressure for efficiency and an increasing demand for information and transparency from stakeholders (Abbate et al., 2023; Lehtinen, 2017).

Despite this need, DTs' integration is not always easy to achieve as companies face a number of obstacles mainly related to the lack of sufficient financial resources, knowledge and skills necessary for their full implementation (Maffezzoli et al., 2022; Fragomeli et al., 2024). In this regard, a solution can be found in the co-creation through the development of knowledge, products or services in collaboration with other stakeholders (Ramaswamy and Gouillart, 2010). Knowledge co-creation is a key element in highly complex and interdependent contexts, like the agri-food sector, especially when addressing challenges related to sustainability and digital transformation. It refers to the integration of experiences, perspectives and knowledge held by a plurality of stakeholders, directly involved or influenced by the problem under consideration (Pohl et al., 2010), allowing the development of shared solutions.

In management studies, several research have shown that knowledge co-creation can facilitate innovation and promote more effective learning (Dentoni et al., 2023). In addition, it plays a crucial role in reducing information asymmetry and building collaborative capabilities, essential for the BMI in a sustainable perspective (Caputo et al., 2019).

In this context, organizational openness and ability to extend company's boundaries become strategic levers for accessing skills, knowledge and technologies otherwise inaccessible, thus facilitating sustainability-oriented BMI processes (Bouncken and Fredrich, 2016; Foss and Saebi, 2018). The concept of openness, understood as the permeability of company boundaries, translates in the agri-food sector as the willingness to collaborate with other stakeholders to co-design solutions, share production processes and strengthen relationships (Cohen and Kietzmann, 2014; Baden-Fuller and Haefliger, 2013; Fiorentino, 2016).

Boundary management can be a key factor for the effective adoption and integration of DTs and BMI, because it allows companies to manage and integrate resources that are neither internal nor external, and to create new inter-organizational relationships between company network (Garzella, 2000; Caputo et al., 2019).

Therefore, through the boundary management, agri-food companies can enable the implementation of new digital and collaborative business models which are more resilient and sustainable.

Nevertheless, the predominant management and organisational criticalities associated with boundary strategies pertain to the challenge of sustaining effective control over companies and individuals that gravitate to the boundary area, and which represent strategically relevant resources (Garzella et al., 2021). To effectively manage the partners involved, companies should adopt "linking" and "bearing" strategies (Capurro et al., 2021). Linking strategies aim to integrate partners' resources and core competencies within the company; while, bearing strategies allow to avoid the risk of external parties gaining access to resources, competencies and information that are critical to the company's competitive advantage.

Boundary management, therefore, plays a crucial role in creating balance and coherence among the various elements and activities at the border area, effectively integrating internal and external forces (Parmigiani and Mitchell, 2009).

3 Leveraging boundary strategies and DTs for sustainability: a theoretical framework

The theoretical framework is constructed (Figure 1) following the strategy-action-performance approach, a logic underlying several existing frameworks (Micheli and Manzoni, 2010; Garzella and Fiorentino, 2014; Capurro et al., 2024). It is developed starting from the boundary strategies, identified as pivotal actions in enabling the

development of BMI through leveraging DTs, which act as enablers for achieving positive outcomes in terms of environmental sustainability.

The theoretical framework adopts a boundary-based perspective, in which a company's boundaries are not perceived as a static space, but rather as a dynamic zone of exchange, cooperation and innovation. Thus, boundary management is crucial to mobilising resources, relational skills, digital know-how, trust and capital, which are vital for the successful adoption of DTs for BMI (Brehmer et al., 2018). BMI is positioned as a strategic lever through which companies can integrate environmental sustainability requirements not only by introducing technologies or incremental improvements but by radically rethinking how they create, distribute and capture value (Saebi et al., 2017; Ancillai et al., 2023; Capurro et al., 2023).

The boundary-based theoretical framework, thus, identifies boundary strategies as enablers for the integration of DTs to accelerate the transition to more sustainable business models. By implementing such strategies, companies can co-develop knowledge, access shared technologies and activate joint innovation processes. This approach, therefore, presupposes openness to external partners, the development of trusting relationships and the activation of technological partnerships. The creation of these networks helps converting external environmental and technological stimuli into opportunities of sustainable growth. Specifically, linking strategies aim to stimulate collaboration with technological partners and to enable access to critical knowledge and technologies, difficult to develop internally or to acquire externally. These elements facilitate BMI through several methods such as DTs' integration in value creation processes, partnerships with innovative actors – e.g. digital solution providers and agri-tech companies -, process optimisation and cost efficiency. Concurrently, bearing strategies are implemented with the purpose of preserving internal resources and strategic capabilities, thus ensuring the management of innovative processes in a safe and sustainable way (Garzella, 2000).

The synergistic use of DTs enables smart agriculture applications, including precision farming, traceability and food safety, climate analysis and forecasting of agricultural trends, and automation of agricultural processes, which involve a range of integrated DTs and support BMI by enhancing value creation, delivery and capture. In terms of value creation, smart agriculture applications extend the value proposition by offering new benefits to consumers, like greater safety and transparency, certified-origin products and consistent product quality, thus strengthening company's market reputation. These advanced technologies also allow to formulate data-driven strategic decisions, using real-time and predictive data, like the selection of the most suitable crops for the expected climate or the adoption of preventive measures. Concerning value delivery, smart agriculture applications can enable the creation of collaborative relationships with customers, also introducing digital channels where the customer is an active part of the value creation system, contributing with information and feedback, and the identification of new customer segments particularly sensitive to environmental issues. Regarding value capture, the improvements brought about by smart agriculture concern cost optimisation through efficient resource management and the possibility of increasing revenue streams.

Smart agriculture applications and BMIs can be translated into concrete environmental sustainability outcomes. In particular, the use of real-time and predictive data can enable more effective management of natural resources through targeted and timely interventions. Optimising the use of natural resources, fertilisers and pesticides can reduce the chemical impact on soils and ecosystems and the associated emissions. Climate analysis and agricultural trend forecasting can improve production planning, leading to a reduction in food waste. In addition, technological support for crop management can facilitate better crop rotation, contributing to the protection of agricultural biodiversity.

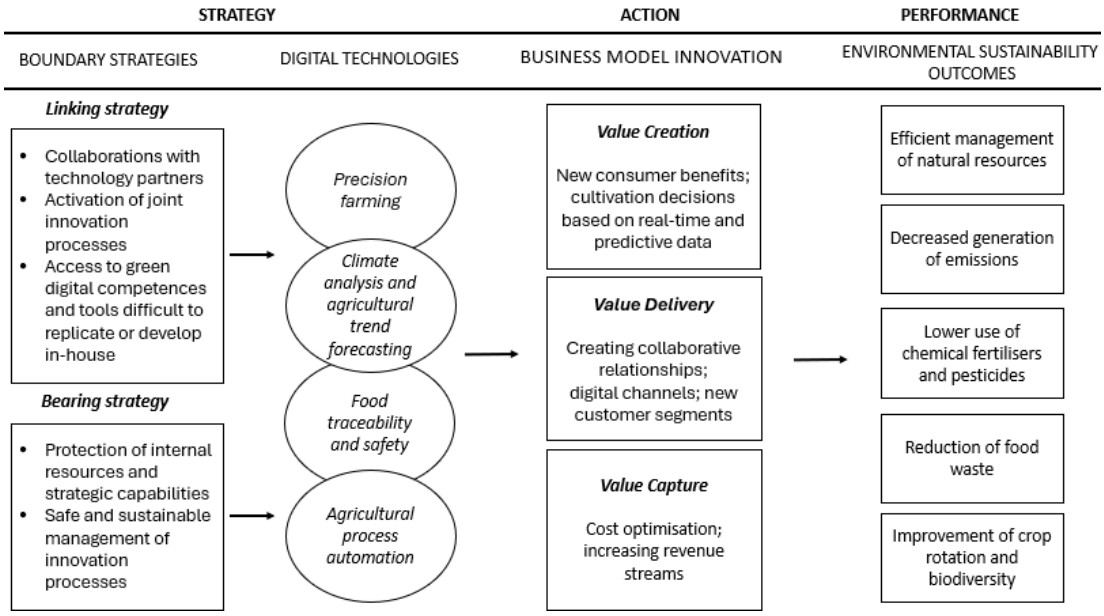


Figure 1: The boundary-based theoretical framework
Source: Author's elaboration

To trigger this process, a high level of managerial competences and skills is required, making it essential to identify specific figures dedicated to the management of boundaries and relationships between processes, activities and people, the "boundary managers". These professionals can integrate technical, entrepreneurial and relational skills to support innovation processes and foster the development of open and resilient networks. The role of the boundary manager is of particular importance as it assumes both operational and strategic centrality and is crucial for facilitating co-innovation, coordinating heterogeneous actors, mediating between diverging interests and promoting a culture and long-term vision toward sustainability (Capurro et al., 2024).

4 Findings and conclusion

The present paper proposes a theoretical framework grounded on a boundary-based perspective, aiming to explore how agri-food companies can address the challenges posed by digital and green transition. In a context characterised by increasing complexity, companies required to rethink their business models, adopting approaches that integrate technological innovation with environmental sustainability.

The proposed framework highlights the convergent influence of two major drivers currently shaping the business landscape: digital transformation and environmental sustainability. Digital transformation goes beyond the mere adoption of DTs; it represents a comprehensive process of organisational change that fundamentally reshapes how companies operate and generate value. Simultaneously, environmental sustainability serves as a strategic orientation, guiding technological and organisational decisions toward low-impact, resilient, and inclusive business models.

Based on the analysis conducted, several insights emerge. Although this is a preliminary study, the results obtained allow to provide answers to the research questions. With regard to the first research question, company boundaries - conceived not as static but dynamic spaces for interaction and exchange -, represent a strategic area for enabling the adoption of DTs. Through the implementation of boundary strategies, companies can access external resources that are otherwise difficult to develop internally or acquire from the market, such as advanced digital competences, technological tools and relational capital. These strategies facilitate co-innovation with external partners, creation of collaborative networks and activation of inter-organisational learning processes, crucial steps to overcoming barriers for the adoption of DTs.

In relation to the second research question, the study reveals how companies can promote sustainability through the innovation of different elements of their business model. In particular, the integration of smart agricultural applications impacts the three main dimensions of the business model: value creation, value delivery and value capture.

In terms of value creation, DTs can expand the value proposition by offering new benefits to consumers — like safety, transparency, product's origin certification and consistent quality — while enabling data-driven decisions such as crop selection based on climatic forecasts or targeted interventions, thereby improving both

productivity and environmental impact. Regarding value delivery, DTs can enable the development of collaborative relationships with customers through digital channels, engaging them in the value creation process and attracting customer segments particularly sensitive to environmental issues. Finally, in terms of value capture, DTs can optimise the use of resources and improve operational efficiency, leading to cost reductions and increased revenue streams.

The proposed framework is still at a conceptual stage and requires further theoretical investigations. Moreover, future research efforts will focus on its empirical validation, aiming to evaluate its effectiveness in supporting the adoption of DTs to innovate business models and enhance environmental sustainability outcomes.

5 Ethic declaration

This research did not require ethical approval.

6 AI declaration

During the writing of this paper, tools based on generative artificial intelligence (ChatGPT from OpenAI) were used exclusively to support the linguistic revision. All the scientific content, analysis and conclusions are the result of the independent and original work of the authors.

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Smart Responsible Innovative Cities: An Organisational Agenda

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Abstract

Cities are identifying the smart city vision to develop the city an urban community and engine of responsible innovation. The analysis elucidates that European cities are rethinking on urban planning by adopting a smart city framework, leading to responsible urban innovation and future, fostering collaborative processes that contribute to sustainable and social urban growth and innovation to improve the quality of life. A smart city helps to shape the city a smart responsible innovative urban community. Cities are defining smart urban planning, enabling smartness as an ability to shape urban organisational, innovative and collaborative urban spaces. European cities are going smart, tracking a framework for collaborative innovation, leading to the urban community an engine of social innovation. Sustainable urban future relies on cities that will develop smart urban communities for responsible innovation and good life, promoting collaborative and multi-actor innovation, and following community-led and human-centred view to urban development and innovation.

Keywords: responsible innovation, smart cities, smart communities, organisational innovation

Paper type: Academic Research Paper

1 Introduction

Today, cities are designing smart city plan to construct the urban future, *more than human* cities, to develop responsible innovation conditions and issues (Yigitcanlar, 2018; Stilgoe, Owen and Macnaghten, 2013), meeting grand societal challenges (Voegtlin, Scherer, Stahl and Hawn, 2022), and overcoming techno-centric, business-led visions to smart growth (Grossi and Pianezzi, 2017). Cities are planning a smart city view to urban development, shaping smart innovative socially responsible communities, leading to a smart city development, and supporting collaborative frameworks to foster responsible urban innovation and ensure high quality of life improvement, meeting urban societal challenges (Mora *et al.*, 2023; Dolmans *et al.*, 2023; Yigitcanlar *et al.*, 2021). A smart city vision helps city to deal with grand societal challenges, avoiding harm to people and planet, leading to responsible development and innovation (Voegtlin and Scherer, 2017), and generating desired outcomes and futures for humans and nonhumans (Yigitcanlar, 2018), leading to smart social innovation as collaboration-led framework (Costales, 2022; Voegtlin, Scherer, Stahl and Hawn, 2022), and identifying smart city solutions for sustainable urban development and responsible innovation (Sharifi *et al.*, 2024)

Smart cities contribute to improving urban social innovation and quality of life and in long-term horizon (Appio, Lima and Paroutis, 2019). As organisational spaces (Knox, 2010), net action (Czarniawska, 2002), engines of social innovation (Costales, 2022), cities are rethinking on smart city urban planning towards next generation of a truly smart sustainable city, an urban healthy system of systems, meeting the challenges of Anthropocene epoch, leading to responsible urban innovation, doing good for urban community and society (Stilgoe, Owen and Macnaghten, 2013), preserving the future of ecosystems, promoting sustainable-balanced economy-society-environment practices (Yigitcanlar, 2018), and leading to an organised maturity to enable positive freedoms (Scherer, Neesham, Schoeneborn and Scholz, 2023), coherently supporting community engagement for smart sustainable city (Anthony, 2024), technology, community and policy for responsible innovation (Yigitcanlar *et al.,* 2021).

Smart city development fosters collaborative multi-actor innovation (Dolmans *et al.*, 2023), public-private partnerships (Fernandez-Anez, Fernàndez-Guell and Giffinger, 2018), empowering the urban community and citizenry to drive sustainable inclusive growth and open innovation (Paskaleva, 2011; Martin, Evans and Karvonen, 2018). Still few studies focus on the role of smart city planning for responsible urban innovation. How do cities rethink on responsible urban innovation? What makes the city a responsible innovative urban community? This study aims to elucidate how Paris, Wien and Berlin are rethinking on the urban future, adopting a smart city plan and design to make the city a smart responsible community, an engine of social innovation and growth. The paper is structured in five sections. After introduction and theoretical background related to cities as urban planners of smart city future for responsible innovation and communities, the methodological aspects are presented in the third section. Findings follow in the fourth section. Finally, discussion and conclusions are set out.

2 Cities dealing with smart responsible innovation: a collaborative and organisational view

As organisational spaces (Knox, 2010) and net action (Czarniawska, 2002), cities aim to plan a smart city framework, dealing with social challenges, meeting urban sustainability priorities, shaping urban collaborative as well as organisational ecosystems for driving responsible innovation processes (Mora *et al.*, 2020), leading to smart progressive cities that enhance citizenry contributions (Hollands, 2008), by combining technology, community, policies in order to shape a smart community, a *continuum* in which public-private urban actors think on and develop initiatives to improve the city a better place for life, focusing on community-led innovations (Gil-Garcia, Pardo and Nam, 2016; Yigitcanlar, 2021).

Cities adopt a smart city mind set to enable urban stakeholders to form alliances and collaborative partnerships in order to develop innovation processes and governance frameworks, avoiding harm and doing good for people and society (Eger, 2005; Meijer and Bolivar, 2016; Voegtlin and Scherer 2017; Yigitcanlar, 2018; Yigitcanlar *et al.*, 2021). Cities should drive intentionally their urban development, *humanising* technology, and meeting the needs of urban communities (Knight, 1995), dealing with urban technologies that co-shape the city life for driving responsible innovation (Stone, 2021), leading to responsible smart city innovation and growth to progress towards sustainable development goals (Sharifi *et al.*, 2024), developing next generations of smart city by developing distinctive informational ecosystems and community values, leading to strongly locally embedded open innovation within urban communities networking (Han and Hawken, 2018; Paskaleva, 2011).

The city acts for smart urban innovation (Joss *et al.*, 2019), a socio-technical intentional and proactive process, combining technology, collaborations, actors in order to engender creative ideas for urban qualitative change and improvement (Meijer and Thaens, 2018), and designing smart city frameworks to develop innovation as a process of creative collaboration, relationships, stakeholder involvement to change the way cities grow smart (Anttiroiko, Valkam and Bailey, 2014; Paskaleva, 2011). Rethinking the smart city planning helps shape smart responsible, sustainable cities (Yigitcanlar, 2018) towards smart city organised maturity, strengthening positive freedoms of pursuing an agenda, contrasting what decreases freedom in society (Scherer, Neesham, Schoeneborn and Scholz, 2023), for tackling social challenges, focusing on people and policies, leading to collaborative frameworks and community engagement for urban innovation and wellbeing (Anthony, 2024; Trencher, 2019), supporting a social and civic view to innovation (Grossi and Pianezzi, 2017), following an integrative smart technological model for community empowerment and participation in smart city development (Kummitha, 2024).

Smart city should develop as responsible urban innovation, aligning technological advancements with societal needs, values and ethics (Li *et al.*, 2023), meeting grand societal challenges, massive social and environmental issues worldwide leading to responsible innovation through multi-actor public-private partnerships, collaboration initiatives, stakeholder involvement, governance framework (Voegtlin, Scherer, Stahl and Hawn, 2022), supporting citizen and community empowerment (Paskaleva, 2011), social innovation (Costales, 2022), looking beyond technology towards collaborative and community-led smart city models (Mora, Deakin and Reid, 2019).

As urban innovation for sustainable urban future (Nam and Pardo, 2011; Yigitcanlar, 2021) smart city shapes smart communities, develops responsible urban innovation, meeting societal challenges through collective stewardship and framework of science and innovation (Stilgoe, Owen and Macnaghten, 2013) to improve the quality of policies and urban life coherently with smart societal, democratic, social justice-led view to urban growth (Alizadeh and Sharifi, 2023), long term urban planning-based approach, ethical willingness of municipality, citizenry active participation and engagement, beyond business-led, technology-driven visions (Grossi and Pianezzi, 2017), the technological optimistic rhetoric to justify the *status quo* (Bär, Ossewaarde and van Gerven, 2020).

3 Methodological section

The study employed a qualitative, descriptive and exploratory methodology to analyse how Paris, Berlin and Wien are planning a smart city strategy to drive future urban development Rethinking on smart responsible urban innovation helps plan future post-anthropocentric, *more than human* cities (Yigitcanlar, 2018). The study focuses on three illustrative case studies to explore a comprehensive understanding of a phenomenon still in progress, emerging in contemporary times, whereas the boundaries between the phenomenon and the context are not clearly evident following a multiple case study analysis whereas smart city framework and strategy provide a means for urban planning that serves urban development solutions (Eisenhardt, 1989; Mora, Deakin, Reid and Angelidou, 2019), following a case study methodology through an empirical inquiry without the rigidity of a predefined structure for observations and analysis (Yin, 2009). The research methods involved case selection and data collection from policy documents (smart city strategy framework from *Paris Smart and Sustainable*

Looking ahead to 2020 and beyond, *Gemeinsam Digital: Berlin (GD:B)* and *Smart Climate City Strategy Vienna*) as information sources to collect and analyse to understand the pathway cities are developing smart city planning for urban innovation (Sancino and Hudson, 2020; Yigitcanlar, 2018).

4 Findings

The case studies issues to smart city urban planning (Paris, Wien, Berlin) are presented. European cities are embracing a smart city view in order to make the city an engine of socially responsible innovation that supports the future of urban communities that aim at achieving urban sustainability.

In the smart city framework *Paris Smart and Sustainable. Looking ahead to 2020 and beyond* the role of technology is to enable urban communities to shape a smart sustainable city and contribute to urban innovation developing smartness as a collaborative capability to drive the city towards a sustainable future and quality of life improvement. As open platform, the smart city supports the experimentation and the development of new innovative services and solutions that contribute to wealthy urban communities and spaces, leading to healthy and safe urban environments. Smart city vision develops the city of the future and supports responsible innovation to achieve sustainable urban development and leading to smart sustainable city of the future that that brings together social, technological and organisational dimensions and stems on three pillars: the *connected city* (the tool) s on continually integrating technological advances; the *open city* (the method) relies on stimulating citizen participation and collaborative projects, leading to innovation through exchanging, sharing and co-creating with researchers, scientist and academics, by transforming public administration and simplifying processes. The *sustainable city* is the issue of responsible urban innovation design, a place where technology serves to improve city life, community inclusion and involvement, leading to co-producing public services, co-designing policy decision-making, smart city as responsible innovation for city effective social change agent.

Smart Climate City Strategy Vienna looking at the 2050 develops a smart city vision to enhance quality of living, sustainability, prosperity, education and workplaces opportunities. The role of technology is to simplify the urban life, support professional education boundary less. Driving smart urban innovation helps drive the urban future, social integration and inclusion within urban communities, and supports civic participation and engagement, leading to smart innovative communities to ensure top-level quality of living, focus on social participation and inclusion, safety and security, leisure quality and culture, and support both social openness and cultural diversity, strengthening high degree of social participation for sustainable urban development and inclusive growth. Technology serves for community development and supports the city as an innovative community, opening up to collaborative processes that drive urban value creation and social innovation. Technology supports co-participation, co-determination and co-decision-making as strategic and organisational framework to shape smart innovative urban communities.

Gemeinsam Digital: Berlin (GD:B) relies on enhancing collaboration and community for shaping a sustainable, innovative city, and smart urban growth making Berlin a sustainable, community-oriented, cooperative and resilient city for the future. The role of municipal administration is to facilitate urban cultural change digital transformation for the common good of communities. As a platform smart Berlin enables the relevant urban stakeholders, private-public actors to work together or *gemeinsam*, to cooperate to drive urban transformation and develop innovative solutions to urban problems and identify new ways to make the city a smart community socially cohesive and innovative. *GD:B* develops a responsible innovation framework to shape a sustainable, community-oriented, resilient and cooperative city, bringing together interconnected and needs-oriented interests of all urban stakeholders involved in urban transformation. The cooperative city relies on fostering creative participation of the entire urban community as the basis for the participatory development of the city. The role of public administration is to connect municipal institutions, citizens, business, academia and civil society to facilitate the opportunities for new governance structures development for cooperation and social engagement, promoting inclusiveness, transparency and openness.

5 Discussion and conclusions

Cities of tomorrow are planning their future as well as smart innovative urban communities, promoting high quality of life and achieving urban sustainability, making collaborative open urban spaces, leading to smart responsible urban communities, engines of social innovation. A variety of organisational and planning solutions is emerging within practices and design cities in Europe are embracing in order to develop organisational arrangements that enhance collaborative ways and approaches that strengthen the critical role of urban stakeholders that get involved in building conditions for urban sustainability, learning and innovation within urban spaces and communities.

European cities are planning their future to improve quality of life, and drive smart responsible urban innovation, shaping urban communities, engines of social inclusion and innovation, making collaborative open spaces. Cities drive responsible urban innovation and sustainable urban growth, leading to multi-actor collaborative innovation, beyond a technology-enabled towards a community-oriented and human-centric smart city approach, putting the people and community first, focusing on human and social capital, community development, leading to smart city responsible urban collaborative social innovation. Paris sustainable city vision stresses the connected city as a tool, the open city as method and sustainable city as a goal. The Wien smart vision uses technology to enhance co-participation, co-decision-making and inclusion as strategic and organisational framework for urban responsible innovation and sustainable growth. Smart city Berlin strategy focuses on sustainable, resilient, community-oriented and cooperative city as meeting place and pillar for responsible urban open social innovation. Cities are planning a smart city design, identifying a pathway for smart responsible communities, engines of responsible innovation, community participation, stakeholder engagement.

Increasingly, cities evolve as an organisational field of action and engine of collaborative frameworks for learning and innovation. Cities identify smart city plan to meet grand societal urban challenges, following human-centred, social-driven, participatory-led views to urban growth, and dealing with technology, combining smart city development and responsible innovation to make smart responsible city through collaborative innovation, citizen and community participation, leading to human-centered and community-led approaches to urban value creation and social innovation, making socially inclusive, innovation-driven cities, leading to smart responsible communities for innovation.

Smart urban responsible innovation implies the search for an organisational innovation within urban spaces and relies on fostering smart socially inclusive and technology-led urban communities that adopt a human-centred and participative-oriented view to urban growth dealing with technology to make the city a better place for value creation and social innovation, an organisational platform and engine of social value creation. Further research perspectives will refer to how Italian cities are planning the urban future, following a smart, responsible and sustainable vision to urban innovation and growth.

6 Ethics declaration

The research has not required ethical clearance and has been conducted in compliance with ethical principles that inform scientific research.

7 AI declarations

I declare that I have not used, in any step of paper writing, AI tools or applications.

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Managing Organizations between Artificial Intelligence and Technostress: A Typology Model

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Abstract

This study aims to model the relationships between the independent variables AI-implementation, techno-eustress and techno-distress and the dependent variable productivity, in business organizational context, to understand if an organization, that has, or not has, implemented AI-technologies, are more or less near the ideal organizational typology and to design the possible path to be competitive maximizing techno-eustress and minimizing techno-distress, deriving from the use of AI, impacting positively on productivity. The result is a Three-dimensional-Typology Model identifying 8 different organizational typologies that we named in a particular way for better to represent the situation identified and the distance from the ideal one of maximization of productivity. This work represents a framework for future research on the topic and offers a theoretical model for managers to understand which organizational typology is closest to their organization noting the level achieved by the productivity. In this way, they have the possibility to understand what actions to take to act on the independent variables to divert them towards the ideal typology of maximization of productivity identified as "Futuristic Oasis".

Keywords: AI-technologies, Technostress, productivity, Typology Analysis, Three-dimensional-Typology Model

Paper type: Academic Research Paper

1 Introduction

Technostress and Artificial Intelligence represent two topics much discussed in all fields of the literature.

Starting from the concept of technostress, for Tarafdar, et al. (2014), it is "the stress caused by the use of IS in the work-place" (Tarafdar et al., 2014, p. 51). Furthermore, according with Tarafdar, et al. (2019), techno-eustress explains how "individuals appraise IS as challenging or thrilling, and experience consequent "good" stress which motivates them to engage in coping behaviours that lead to positive outcomes" (Tarafdar et al., 2019, p. 13), while techno-distress explains "the processes by which individuals appraise IS as a threat, experience consequent "bad" stress, and are faced largely with detrimental outcomes" (Tarafdar et al., 2019, p. 13). In organizational context, for Tarafdar, et al. (2007), technostress is activated when the individual encounters difficulties in following and 'deal with the continuous changes that occur in information and communication technologies and in acquiring the increasingly new physical, social and cognitive requirements necessary for their use. While, Nayak, Budhwar, (2022), considering technostress, today, as a common problem for many organizations, investigated the technostress deriving from the enterprise social networks and the consequences.

About Artificial Intelligence, there are numerous definitions in the literature, also depending on the context in which it was necessary to define it but, the definition that seems to be more explanatory, can be found in the IEEE guide (2017) where it is qualified as "the combination of cognitive automation, machine learning, reasoning, hypothesis generation and analysis, natural language processing, and intentional algorithm mutation producing insights and analytics at or above human capability" (IEEE guide, 2017, p. 12). Numerous studies are conducted on AI. Zhang, et al. (2024) analysed the emotional expressions of chatbots to study and understand their impact on customer satisfaction, while Hashem, et al. (2024), faced with a progressive and incremental use of AI-technologies in education in the United Arab Emirates, focused on the possible burnout that may arise for teachers and on the search of possible solutions to address and resolve this problem. Finally, Sjödin, et al. (2023) sought to understand whether, the AI-technologies, can potentially foster the circular business model innovation for industrial manufacturers.

At this point, considering that the use of AI implies an approach with advanced and complex technologies, and considering that the use of technologies can contribute to the intensification of techno-eustress and/or techno-distress, it is reasonable to ask whether and how the integration and use of AI-technologies can impact these phenomenon and/or whether they can even help in their optimal management for better results and performances in all sectors and, in particular, in business, educational-training and medical-healthcare fields. So, it might be interesting to ask what type of relationships exist between AI and technostress. Recalling some of contributions in this sense, Santos, et al. (2024), analysing the use of AI in government and its risks, showed

both the existence of positive feelings and a small percentage of negative feelings resulting from the interaction of AI and the consumer. While, Pagán-Garbín, et al. (2024) explored the stress, burnout and technostress of teachers using the artificial neural network.

Analysing the literature emerged, is evident the scarcity of studies that model the relationships between AI and technostress and their impact on productivity, in particular in business sector. So, could be interesting to model the impact that technostress, resulting from AI-implementation, can have on productivity of organizational members, productivity defined as "The rate of output of a worker or a machine" (Statt, 2004, p. 121). This model may be useful to try to understand if different organizations that have, or not have, implemented AI-technologies, are more or less near the ideal organizational typology and to design the possible path to be competitive maximizing techno-eustress and minimizing techno-distress, deriving from the use of AI, impacting positively on productivity.

For these reasons, after an analysis of the papers that emerged in the literature on the topic in the specific business context, we tried to answer the following research questions:

- *What are the relationships between AI-technologies and technostress and their impact on productivity in business context?*
- *What are the emerging organizational typologies, and the ideal one that maximizes productivity in business context, considering as independent variables AI-implementation, techno-distress and techno-eustress and as dependent variable productivity?*

2 Theoretical framework

In the literature on the topic there are some contributions that offer interesting insight on the intriguing relationships between the use of AI, techno-distress and techno-eustress in various sectors such as business, medical-healthcare, consumer and educational-training.

Considering the specific business context, it was possible to detect various contributions that considered the relationships between AI and technostress with some of these that analyzed also the impact on productivity of workers and managers, and it is precisely on this context that we focused our attention for the development of our analysis and model. Recalling some of these, emerged the contribution of Verma, et al. (2024) which described a possible impact that the work exhaustion can have on the work performance and well-being of employees during the use of Responsible artificial intelligence for the various difficulties, concerns and uncertainties that can arise from its excessive use. Again, Kumar, et al. (2023), in their interviews and based on the data analysis, noted a stressful situation in organizations detected by managers linked to the complex nature of machine learning and AI-technologies and how, many of these organizations, were trying to activate a sort of collaboration between these technologies and human resources. Finally, Choudrie, et al. (2023) in their analysis identified, among others, some interviewees that, in light of the frustration and delays linked to the VPA function, stated how "these delays had a negative impact on productivity and customer relations" (Choudrie et al, 2023, p. 6), while from other interviewees emerged that "When individuals were aware of and actively used smartphones' AI functions, their digital skills and confidence grew, which contributed to enhanced management capabilities" (Choudrie et al., 2023, p. 6).

Therefore, considering this situation in the literature with reference to the relationships between AI and technostress and their impact on productivity, it was possible, using the typology analysis, to develop a model for identifying the different organizational typologies, albeit theoretically, with reference to the specific business sector, which would derive from particular combinations of these variables considering AI-implementation, techno-eustress and techno-distress as independent variables, even if techno-eustress and techno-distress in turn depends on the implementation of AI as well as on the implementation of other technologies, and productivity as dependent variable, as also emerged from the literature.

3 Research methodology

Considering D. Harold Doty and William H. Glick (1994) and Valbuena, et al. (2008): we analyzed the papers on the topic in business sector; we identified examples of organizations which, with reference to the variables considered and the relationships between them, present regularities; we identified and described independent and dependent variables and we highlighted all the relationships. After, we developed the typology model identifying different theoretical organizational typologies in which the dependent variable productivity assume a certain value, but only in ideal one realizes its maximization.

Figure 1 shows the flow chart of research methodology used.

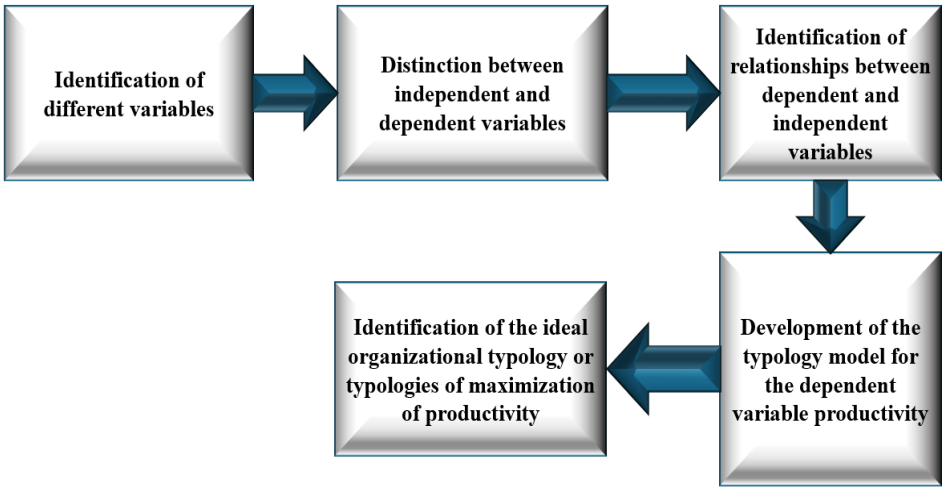


Figure 1: Flow chart of research methodology

4 Results

The principle variables emerged in the literature are: AI-implementation, techno-eustress and techno-distress as independent variables and productivity as dependent variable, to be maximize, among which we detected regularities in the relationships.

Indicating with AI the Artificial Intelligence technologies and with β and 1/β how much the dependent variable varies as a function of independent variables, we identified these relationships:

- Technostress = δ + βAI-implementation + Ɛ

The maximization of Technostress is:

maxTechnostress= δ + [max(βAI-implementation)] + Ɛ

- AI-implementation= δ + (1/βTechno-eustress – 1/βTechno-distress) + Ɛ

The maximization of AI-implementation is:

maxAI-implementation= δ + [max(1/βTechno-eustress)] – [min(1/βTechno-distress)] + Ɛ

- Productivity= δ + βAI-implementation + Ɛ

The maximization of productivity is:

maxProductivity= δ + [max(βAI-implementation)] + Ɛ

- AI-implementation= δ + 1/βProductivity + Ɛ

The maximization of AI-implementation is:

maxAI-implementation= δ + [max(1/βProductivity)] + Ɛ

- Productivity= δ + (-βTechno-distress) + Ɛ

The maximization of productivity is:

maxProductivity= δ - [min(βTechno-distress)] + Ɛ

- Productivity= δ + βTechno-eustress + Ɛ

The maximization of productivity is:

maxProductivity= δ + [max(βTechno-eustress)] + Ɛ

- Techno-distress= δ + (-1/βProductivity) + Ɛ

The minimization of techno-distress is:

minTechno-distress= δ - [max(1/βProductivity)] + Ɛ

- Techno-eustress= δ + 1/βProductivity + Ɛ

The maximization of techno-eustress is:

maxTechno-eustress= δ + [max(1/βProductivity)] + Ɛ

Starting from these relationships, and considering that our focus is on the maximization of productivity in organization, we considered this variable function of variables AI-implementation, techno-eustress and techno-distress. For this reason, considering only these variables in our model, without prejudice to all other dimensions which we didn't take into consideration to exemplify a complex reality, we assumed that productivity depends positively from the implementation of AI, positively from techno-eustress and negatively from techno-distress.

So, the multiple regression formula identified is:

- Productivity= δ + β_IAI-implementation + (β_2Techno-eustress - β_3Techno-distress) + Ɛ

Where β indicates how much the dependent variable varies as a function of independent variables.

While, the formula of maximization of productivity is:

- max productivity= δ + [max (β_1AI-implementation) + max ($\beta_2$techno-eustress) – min ($\beta_3$techno-distress) + $\mathcal{E}$

Considering this function of maximization of productivity, we can define the following hypothesis:

H1: If the organization wants to maximize productivity must maximize the implementation of AI technologies, maximize techno-eustress and minimize techno-distress.

Based on these relationships, we implemented a typological model capable of defining the different possible organizational typologies deriving from the intersection between the theoretical high and low values that independent and dependent variables, can assume.

Figure 2 shows this model identifying 8 different organizational typologies that we named for better to represent the situation identified and the distance from the ideal one.

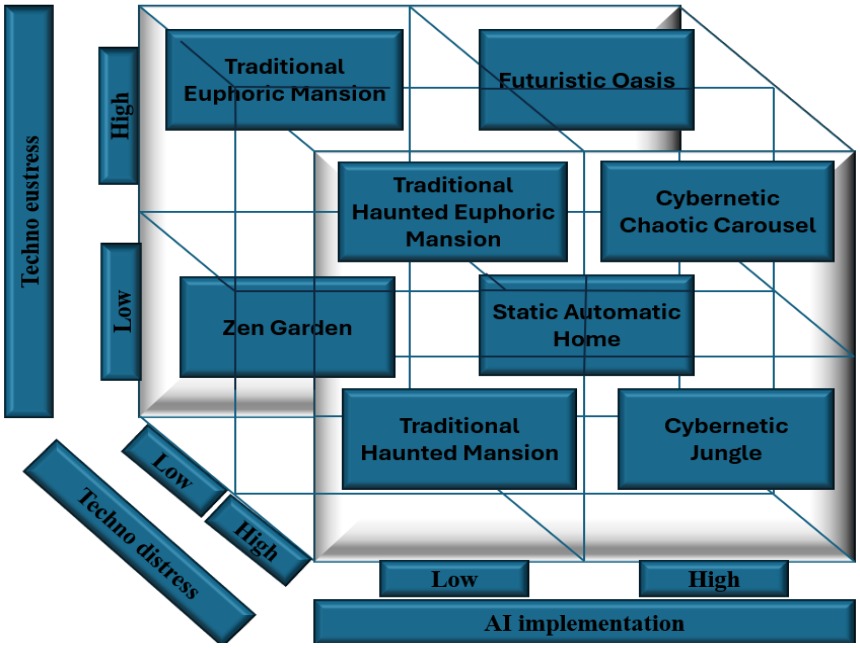


Figure 2: Three-dimensional Typology Model with AI-implementation, techno distress and techno-eustress

5 Discussion

Considering the values that AI-implementation, techno-distress, techno-eustress and productivity can assume, emerged 8 organizational typologies:

- "Zen Garden" with Low AI-implementation, Low techno-distress and Low techno-eustress. Recalling the formula described for productivity, its level is acceptable without the positive charge of AI-technologies and techno-eustress and without the negative effects of techno-distress. The actors accept a lower level of productivity.
- "Traditional Euphoric Mansion" with Low AI-implementation, Low techno-distress and High techno-eustress. The productivity is medium for the positive impact of techno-eustress, the absence of negative effects of techno-distress and the absence of positive charge of AI-technologies.
- "Traditional Haunted Mansion" with Low AI-implementation, High techno-distress and Low techno-eustress. The productivity is low for the absence of charge of AI-technologies and techno-eustress and for the negative impact of techno-distress.
- "Traditional Haunted Euphoric Mansion" with Low AI-implementation, High techno-distress and High techno-eustress. The productivity presents a medium-low level for the absence of positive impact of AI-technologies, for the negative effects of techno-distress and for the positive impact of techno-eustress.
- "Cybernetic Jungle" with High AI-implementation, High techno-distress and Low techno-eustress. The productivity is Low for the negative impact of techno-distress and the absence of the positive impact of techno-eustress, despite the positive charge of AI-technologies.
- "Cybernetic Chaotic Carousel" with High AI-implementation, High techno-distress and High techno-eustress. The productivity shows average levels for the positive charge of AI-technologies and techno-eustress and for the negative charge of techno-distress.

- "Static Automatic Home" with High AI-implementation, Low techno-distress and Low techno-eustress. The productivity shows averages levels for the positive impact of AI-technologies and for the absence of the positive effects of techno-eustress and of the negative effects of techno-distress.
- "Futuristic Oasis" with High AI-implementation, Low techno-distress and High techno-eustress. In this ideal organizational typology, productivity reaches optimal levels for the strong charge of AI-technologies and of the high techno-eustress and for the absence of the negative charge of techno-distress.

6 Implications, limitations and future research

This study provides interesting theoretical and practical implications.

Considering that in literature didn't emerge models of organizational typologies able to systematize and describe the relationships between AI-implementation, techno-distress and techno-eustress and their impact on productivity of workers and managers, the typologies model, that we developed, represents a step forward to allow future advancement of studies and knowledge on this topic and for the development of new and more effective management and organizational policies.

About theoretical implications, starting from this work Scholars can conduct research to modify or expand the model developed because only some variables and some factors have been considered to simplify the reality. Furthermore, Scholars can conduct field investigations, through questionnaires or interviews, and then to use this model. Then, taking into consideration, this study, only organizations that operate in business sector and considering a generic cultural context and organizational culture, Scholars can extend the work considering other sectors, cultural contexts and organizations that present different organizational cultures.

In terms of practical implications, managers can use the model to understand which organizational typology is closest to their organization, on the basis of the values assumed by AI-implementation, techno-distress, techno-eustress and productivity. In this way, they can understand what actions to realize to achieve the ideal typology of "Futuristic Oasis" that maximizes productivity. To give just a few examples, if the organization has a typological configuration that is far from the ideal one, managers can act on organizational levers to encourage the insertion of AI-technologies into the context by reducing techno-distress as much as possible and increasing the techno-eustress and this: through the creation of a specific department with the task of promoting the implementation of AI and of managing and resolving all the problems and doubts that may arise from its use; through the organization of periodic training courses to develop greater awareness of the potential of these technologies and to develop greater skills in the organizational actors who will have to use them; acting on specific mechanisms, such as those of rules or of the group, to encourage their harmonious integration without negative consequences; promoting correct communication aimed at bringing out all the problems that actors face in the use of AI-technologies; providing incentives, material or immaterial, to stimulate the motivation of the actors to accept the challenge and to use AI-technologies by looking at them in a positive and no longer negative way; or again, encouraging a generational exchange by ensuring that young technological natives, who have greater skills and familiarity in the use of AI-technologies, provide support and transfer their knowledge to differently young actors who, having lived between two technological eras profoundly different, have greater difficulty in approaching the new that is advancing. It is clear how all these organizational initiatives, together with many others, can have a positive impact on the variables AI-implementation and techno-eustress and a negative impact on techno-distress, guaranteeing a notable increase of productivity and, finally, of overall performances.

About limitations, the first is related to the nature of the topic in continuous evolution. So, the contribution will require to be constantly updated. Furthermore, this is an initial work that considers only some variables and contexts. We advise Scholars to carry out empirical studies for a better and more extensive understanding of the variables considered with reference to a greater number of organizational contexts. Finally, we advise to expand the study also considering other factors such as personality traits, personal factors, cultural contexts and organizational cultures.

AI-technologies are running fast. If we want collaborate with these technologies, we must learn to know them, to understand their positive and negative effects and to understand how to manage them identifyng and spreading those organizational practices that will help to maximize productivity creating an explosive fusion between Artificial Intelligence and Human Intelligence.

7 Ethics declaration

The research has not required ethical clearance and has been conducted in compliance with ethical principles that inform scientific research.

8 AI declarations

I declare that I have not used, in any step of paper writing, AI tools or applications.

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The Integration between Artificial Intelligence, Knowledge Management, and Collaborative Innovation for the Creation of Sustainable Value in Industry 5.0

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Abstract

Over the past two decades, digital transformation has increasingly created links between human beings and technology (Nahavandi, 2019; Eriksson et al., 2024). We have moved from a company managed solely by human intelligence to a hybrid system where human talent is fused with artificial intelligence. At the same time, it is proven that the enhanced intellectual capital (eIC) helps intellectual property rights (IPR) intensive companies to innovate their business models (Trequattrini et al., 2022). Improving existing work and service experiences and enhancing sustainability are the goals of Industry 5.0 (Sindhwani et al., 2022). This led to a more efficient use of resources than Industry 4.0 (Demir et al., 2019) and a greater attention to human beings. While the Industry 4.0 model is firmly centred on technology, Industry 5.0 brings back the Human-Centric (HC) paradigm (Fani et al., 2024). In this Human-Centric (HC) perspective, human skills, interaction, critical thinking, and interpretation become a strong point again (Nahavandi, 2019). The lack of a Human-Centric (HC) paradigm can lose the potential positive effects of introducing new technologies (Carlsson, 2023; Olsson et al., 2025). Industry 5.0 is characterised by the importance of "concepts of sustainability, bioeconomy, and a collaborative environment of technology and human beings, thus establishing a resilient industry that incorporates human social values" (Sindhwani et al., 2022, p. 2).
This paper aims to study integration between artificial intelligence, knowledge management, and collaborative innovation for creating sustainable value, focusing on Industry 5.0. The interest is to see research progress on the Human-Centric (HC) paradigm.
The methodology used is content analysis (Krippendorff, 2018) on the final versions of demonstrators, pilots, and prototypes downloaded from the CORDIS EU website (https://cordis.europa.eu). The sample examined comprises six Effective Industrial-Human Collaboration Cluster Members projects. A quantitative analysis (counting the frequency of each category of codes, counting the words that make up each PDF file) and a qualitative (interpretation of the verbal expressions contained in the text) analysis were carried out. An analysis of the primary existing literature on the subject of artificial intelligence, Industry 5.0, and human intelligence was conducted before proceeding to the case study.
Among the limitations of this research is the availability of a small amount of information. It is crucial to notice that this is only the first step of the research on this subject. In the future, we want to have greater contact with companies operating in Industry 5.0 to carefully monitor the flow of knowledge in the internal system.

Keywords: Industry 5.0, Artificial intelligence, Human-centred approach, Knowledge creation, Knowledge management

Paper type: Academic Research Paper

1 Introduction

Recently, attention on human well-being in the workplace has become crucial in organizations through Industry 5.0 (Xu et al., 2021; Rožanec et al., 2023). Industry 5.0 is characterised by the importance of "concepts of sustainability, bioeconomy, and a collaborative environment of technology and human beings, thus establishing a resilient industry that incorporates human social values" (Sindhwani et al., 2022, p. 2).

Industry 5.0 returns the Human-Centric (HC) paradigm (Fani et al., 2024). The lack of it can cause the loss of potential positive effects of introducing new technologies (Carlsson, 2023; Olsson et al., 2025). The development of new technology, combined with artificial intelligence, has increased the automation of many activities, leading to a potential job disruption for middle management (Margherita and Braccini, 2021). At the same time, it is proven that the enhanced intellectual capital (eIC) helps intellectual property rights (IPR) intensive companies to innovate their business models (Trequattrini et al., 2022).

Today, there are more and more hybrid companies characterised by the centrality of the human being, a flat and fluid organisational structure, an innovative entrepreneurial culture, and greater awareness (Nahavandi, 2019; Nappo, 2020; Eriksson et al., 2024). Then the theme of intelligence is connected to intellectual capital that is divided into three different components: human capital, relational capital, and structural capital (Steward, 1991; Roos and Roos, 1997; Bontis, 1998; Youndt et al., 2004; Trequattrini, 2008; Trequattrini et al., 2022).

We use content analysis methodology (Krippendorff, 2018) on the final versions of demonstrators, pilots, and prototypes downloaded from the CORDIS EU website (https://cordis.europa.eu). The sample examined comprises six Effective Industrial-Human Collaboration Cluster Members projects. A quantitative analysis (counting the frequency of each category of codes, counting the words that make up each PDF file) and a qualitative (interpretation of the verbal expressions contained in the text) analysis were carried out. An analysis of the primary existing literature on the subject of artificial intelligence, Industry 5.0, and human intelligence was conducted before proceeding to the case study.

Our research question is:

- *What is the state of the art of integrating artificial intelligence, knowledge management, and collaborative innovation for creating sustainable value in Industry 5.0?*

2 Literature review

Industry 5.0 works to create a sustainable, human-centric, and resilient manufacturing industry with more flexible and adaptable production processes (Breque et al., 2021; Eriksson et al., 2024). The aim is to put the worker's well-being at the centre of the production process (Xu et al., 2021; Rožanec et al., 2023).

Ivanov (2023) states that if companies utilise Industry 5.0 properly, it can help them to improve efficiency and productivity while increasing resilience, sustainability, and viability of their manufacturing and supply chains. According to the European Commission (2024), "human centricity is a multidimensional framework that places human needs, characteristics, motivation, and experiences at the centre of design, development, and implementation of technological solutions and organisational practices that not only meet functional requirements but also enhance human well-being, capabilities, skills, and working conditions" (EC, 2024, p. 14).

Over the past two decades, digital transformation has increasingly created links between human beings and technology (Nahavandi, 2019; Eriksson et al., 2024). We have arrived at hybrid companies from a company managed solely by human intelligence. Hybrid companies are characterized by the centrality of human beings, a flat and fluid organizational structure, an innovative entrepreneurial culture, and greater awareness (Nappo, 2020). Human knowledge sharing is a complex phenomenon influenced by different elements such as human factors, organizational traits, and the environmental context (Zbuchea et al., 2019).

The development of technology, combined with artificial intelligence, has increased the automation of many activities. This led to a potential job disruption for middle management (Margherita and Braccini, 2021). At the same time, it is proven that the enhanced intellectual capital (eIC) helps intellectual property rights (IPR) intensive companies to innovate their business models (Trequattrini et al., 2022).

The theme of intelligence is connected to intellectual capital, an intangible company asset. Intellectual capital is divided into three different components: human capital, relational capital, and structural capital (Trequattrini, 2008). The intangible value of human skills like expertise, knowledge, and experience is called human capital (Pradana et al., 2020). The relational capital is the set of relationships between the company and its stakeholders (Hayaeian et al., 2022). Structural capital is "the knowledge embedded within the routines of an organization" (Bontis et al., 1999, p. 398). Over the years, several definitions of intellectual capital have been formulated (Steward, 1991; Roos and Roos, 1997; Bontis, 1998; Youndt et al., 2004). Intellectual capital is an essential determinant of the company's ability to create value (Trequattrini, 2008; Celenza and Rossi, 2014; Bartolini et al., 2021; Ahmad et al., 2023).

Improving existing work and service experiences and enhancing sustainability are the goals of Industry 5.0 (Sindhwani et al., 2022). This led to a more efficient use of resources than Industry 4.0 (Demir et al., 2019) and a greater attention to human beings. While the Industry 4.0 model is firmly centred on technology, Industry 5.0 brings back the Human-Centric (HC) paradigm (Fani et al., 2024). In this Human-Centric (HC) perspective, human skills, interaction, critical thinking, and interpretation become a strong point again (Nahavandi, 2019). The lack of a Human-Centric (HC) paradigm can lose the potential positive effects of introducing new technologies (Carlsson, 2023; Olsson et al., 2025).

Industry 5.0 is characterised by the importance of "concepts of sustainability, bioeconomy, and a collaborative environment of technology and human beings, thus establishing a resilient industry that incorporates human social values" (Sindhwani et al., 2022, p. 2). A human-centric, resilient supply chain capable of identifying, analysing, and accelerating operations to reduce demand fluctuation by merging human values with disruptive technology is created by Industry 5.0 (Modgil et al., 2022; Sonar et al., 2025).

3 Methodology

This study adopted the content analysis methodology (Krippendorff, 2018). As stated in the book "Content analysis: An introduction to its methodology" by Klaus Krippendorff, content analysis is a research methodology that can be used quantitatively and qualitatively. Its application is based on systematically analyzing texts, images, or other forms of communication to extract useful information to answer specific research questions. From a quantitative point of view, analysis can be used to count the frequency of certain symbols, words, or categories in a text. This approach is less in-depth from an interpretive perspective, but it gives you a clear overview of trends or patterns within your data. When content analysis is used qualitatively, the data is presented in words and themes, allowing the underlying meaning of the content to be interpreted. Qualitative analysis explores verbal expressions more deeply and seeks to understand the social or emotional contexts behind subjects' statements. Content analysis approaches can be inductive and deductive, and the researcher can choose whether to adopt a manifest analysis, which describes what is being said, or a latent analysis, which seeks deeper meanings in the text. Content analysis is, therefore, a flexible and accessible methodology used to interpret textual data and maintain integrity.

The sample examined comprises six Effective Industrial-Human Collaboration Cluster Members projects. Table 1 shows that each received an EU contribution under Horizon 2020, and they generally ran between 2018 and 2022.

Table 1**:** The Effective Industrial-Human Collaboration Cluster Members

Project name	**Amount of EU contribution**	**Period**
THOMAS	4.510.700,00 €	1 October 2016 – 31 March 2021
COLLABORATE	6.864.600,00 €	1 October 2018 – 31 March 2022
HR-Recycler	6.986.573,75 €	1 December 2018 – 30 November 2022
SHAREWORK	7.351.467,51 €	1 November 2018 – 31 October 2022
SHERLOCK	7.939.022,50 €	1 October 2018 – 30 September 2022
ROSSINI	7.978.176,25 €	1 October 2018 – 31 March 2022

Source: our elaboration

This research used secondary sources, such as the final versions of demonstrators, pilots, and prototypes downloaded from the European Union website. A quantitative analysis (counting the frequency of each category of codes, counting the words that make up each PDF file) and a qualitative (interpretation of the verbal expressions contained in the text) analysis were carried out.

The content analysis was conducted using MAXQDA software, which allows for synthesizing a single work project from the various codes previously created by reading the documents. We created the following codes:

- Security and its synonyms;
- Industry;
- Cooperation;
- Robot;
- Knowledge and its synonyms;
- Human and its synonyms.

For each of these codes, a lexical search was launched using the MAXQDA software, which aimed at quantifying the absolute frequencies of the words making up each code category. This process allows you to see how much a topic is present within each document and how it is addressed.

Table 2 shows the number of documents available for each project and downloaded from the CORDIS EU website (https://cordis.europa.eu).

Table 2**:** Documents about demonstrators, pilots, and prototypes deliverables

Project name	**Number of documents**
THOMAS	10
COLLABORATE	3
HR-Recycler	0
SHAREWORK	0
SHERLOCK	12
ROSSINI	1

Source: our elaboration

The projects with zero documents didn't upload final reports into the "demonstrators, pilots, prototypes" section. We analyzed these elements because "the prototype view underpins the behavioral assumptions behind most extant research on organizations and categorization" (Durand and Paolella, 2013, p. 1103).

4 Results and discussion

From a first reading of the results documents, we understood the object of each project.

Thomas worked for a mobile dual-arm robotic worker with embedded cognition for hybrid and dynamically reconfigurable manufacturing systems. Particularly, it aims to create dynamically reconfigurable shopfloors thanks to mobile robots with two arms, equipped with cognitive capabilities. Its experimentation in the automotive sector demonstrated a sound reduction of operating costs and increased security.

Collaborate stands for Co-production CeLL performing Human-Robot Collaborative AssEmbly. Its three documents show that it has developed a co-production cell where humans and robots collaborate to perform assembly activities. The system architecture is based on a modular platform integrated with ROS (Robot Operating System), including sensors, adaptive control modules, gesture and voice recognition systems, and AGV mobile robots.

Experiments conducted by Sherlock demonstrated clear gains in performance, ergonomics, and operator acceptance relative to previous HRC applications.

Finally, Rossini developed a collaborative robot prototype for the assembly of elevator panels, which is also suitable for general applications.

Analyzing the word frequency in these reports, the most common word is "robot", as shown in Figure 1.

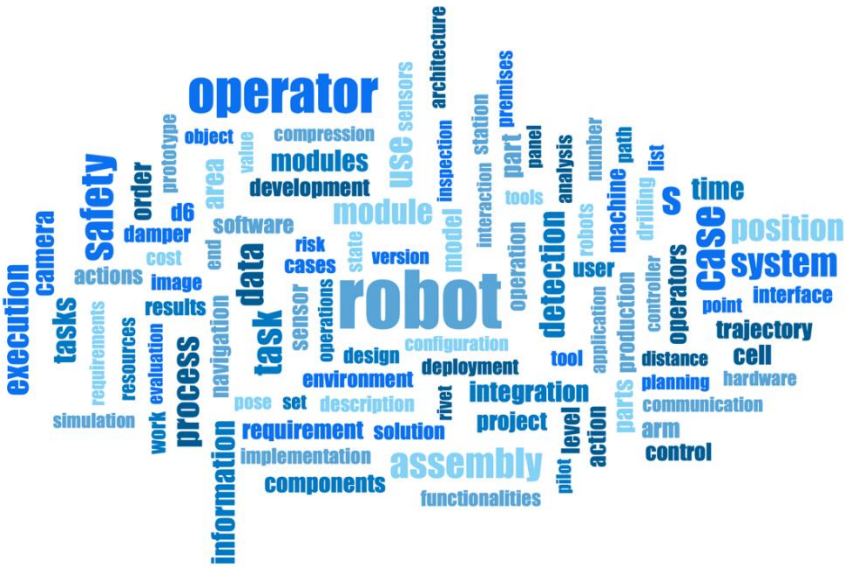


Figure 1: Word cloud
Source: our elaboration with MAXQDA software

The most standard combinations are: human robot (83 times), collaborative robot (62 times), robotic manipulator (57 times), robot interaction (56 times), and mobile robot (54 times). The collaboration between humans and machines is linked to the fifth industrial revolution that facilitates robots and skilled labor to work together to produce customized products and services in Industry 5.0 (Sindhwani et al., 2022). While the Industry 4.0 model is firmly centred on technology, Industry 5.0 brings back the Human-Centric (HC) paradigm (Fani et al., 2024). Other examples of human–robot collaboration are in previous literature like Gervasi et al. (2020), Pizon et al. (2022), and Hosseinian-Far et al. (2023) (Fani et al., 2024). Introducing robots into the industry is a delicate process because lacking a Human-Centric (HC) paradigm can lose the potential positive effects of introducing new technologies (Carlsson, 2023; Olsson et al., 2025). It is interesting to note that the term robot is widely cited in the analyzed documents. Yet, its usage ranges from technical specifications to collaboration scenarios, without clearly indicating whether such interactions are framed from a functional, ergonomic, or ethical standpoint.

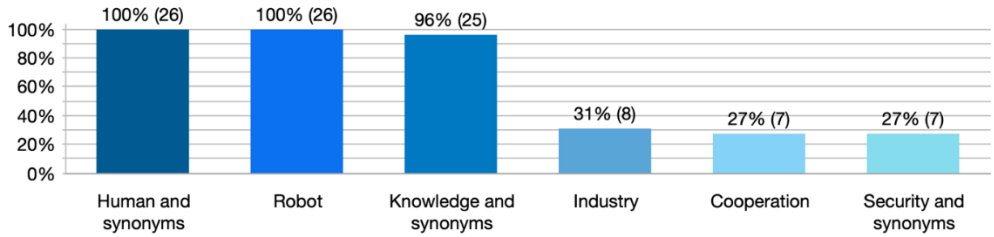


Figure 2: Documents with code
Source: our elaboration with MAXQDA software

Figure 2 shows that the only two codes in all 26 documents imported into the software are "human and synonyms" and "robot". This result aligns with the Industry 5.0 central focus, which promotes the presence of both humans and machines (Demir et al., 2019; Sindhwani et al., 2022). The models of value creation, production, and consumption are reshaped by adaptive robots (Xu et al., 2021; Ghobakhloo et al., 2023). Interestingly, they are only present in seven documents "security and synonyms" and "cooperation" codes. The European Commissioner for Innovation, Research, Culture, Education and Youth, Iliana Ivanova, says that "the notion of human centricity puts core values and principles such as trust, security, openness and inclusiveness at the heart of technology development. (European Commission, Directorate-General for Research and Innovation, 2024, p. 4). So, it is interesting that a central theme, such as worker safety, is only present in 27% of the documents analyzed.

5 Conclusions

Recently, companies have become hybrid systems where humans work together with technology (Nahavandi, 2019; Nappo, 2020; Eriksson et al., 2024). Human factors, organizational traits, and the environmental context are all elements that influence human knowledge sharing (Zbuchea et al., 2019). This phenomenon impacts intellectual capital, an essential determinant of the company's ability to create value (Trequattrini, 2008; Celenza and Rossi, 2014; Bartolini et al., 2021; Ahmad et al., 2023). In addition, new technologies, such as adaptive robots, reshape value creation models (Xu et al., 2021; Ghobakhloo et al., 2023).

This research studies integrating artificial intelligence, knowledge management, and collaborative innovation to create sustainable value, focusing on Industry 5.0. Improving existing work and service experiences and enhancing sustainability are goals of Industry 5.0 (Demir et al., 2019; Sindhwani et al., 2022). The focus is on research progress on the Human-Centric (HC) paradigm (Nahavandi, 2019; Carlsson, 2023; Fani et al., 2024; Olsson et al., 2025). In particular, we have analysed the results obtained from six projects that are the Effective Industrial-Human Collaboration Cluster Members and recipients of European funding from the Horizon 2020 program. A content analysis (Krippendorff, 2018) was conducted on 26 final versions of documents relating to demonstrators, pilots, and prototypes.

The research shows that the most common word is "robot" with the following combinations: human robot (83 times), collaborative robot (62 times), robotic manipulator (57 times), robot interaction (56 times), and mobile robot (54 times). Then, "human and synonyms" and "robot" are the only two codes in all 26 documents imported into the software MAXQDA. The "robot" term ranges from technical specifications to collaboration scenarios, without clearly indicating whether such interactions are framed from a functional, ergonomic, or ethical standpoint.

At the same time, it is interesting to see that a central theme, such as worker safety, is only present in 27% of the documents analyzed. These results partially align with the Industry 5.0 theory, especially the collaboration with humans and robots. Still, at the same time, the absence of a security theme in a large part of the documents isn't a good signal for creating sustainability value.

The main limit of this research is the small sample size and the availability of information. Notably, even if in the Effective Industrial-Human Collaboration Cluster there are six members, only for four of them we found final versions of documents relating to demonstrators, pilots, and prototypes on the CORDIS EU website (https://cordis.europa.eu). It is crucial to notice that this is only the first step of the research on this subject. In the future, we want to have greater contact with companies operating in Industry 5.0 to monitor the flow of knowledge in their internal system carefully.

6 Ethics declaration

This study did not require ethical approval because we used public data.

7 AI declaration

No AI-assisted technologies were used in this manuscript. We only used MAXQDA software without the AI tool.

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Creative Urban Spaces: A Collaborative and Organisational View

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Abstract

The urban development processes rely on cities and urban communities that make efforts to support initiatives and policies that enhance the aims and the implementation of sustainable issues within urban spaces. In particular, cities are going smart not only by investing human and organisational energies to make technology as a driver for sustainable urban growth, but also promoting cultural, civic and creative assets and inputs that make the city a culture-led and knowledge-driven socially innovative urban community, opening to creative urban spaces. Post-industrial cities increasingly are working to make and develop creative collaborative urban spaces. Cities of tomorrow will invest knowledge sources in driving creative-led and culture-driven initiatives that contribute to making collaborative urban spaces and driving sustainable and inclusive urban growth, leading to community development and engagement. The future of urban growth relies on promoting culture as an opportunity to develop inclusive and cohesive communities that contribute to making creative urban spaces. Creative hubs develop bottom-up initiatives, by involving artists and other creatives who are able to meet the needs of an artistic community, making creative meeting places as well as urban spaces. Creative urban spaces develop creativity-led processes and rely on creative cities and hubs as socially inclusive communities that rediscover the importance of collaborative innovation as a framework that helps shape wealthy urban spaces into engines of social innovation. The study aims at investigating the relationships between creative cities and hubs that are following a collaborative view to organisational as well as urban spaces, in order to drive social innovation and achieve social sustainability within creative urban spaces.

Keywords: creative cities, creative hubs, collaborative spaces

Paper type: Academic Research Paper

1 Introduction

Creative cities promise sustainable urban growth and urban innovation engaging the urban citizenry and communities, leading to open urban creative spaces for collaborative frameworks. Creativity and culture contribute to rethinking urban redevelopment within post-industrial cities. Creative cities contribute to creative urban spaces following a creative-led view to urban growth and social development (Evans, 2009), shaping community-led innovation processes (Hall, 2000). As engines of culture-led and creative communities, cities shape urban creative processes (Florida, 2005), leading to urban community development, and driving social and economic growth (Anttiroiko, 2014), facilitating the rise of creative hubs, bottom-up initiatives, developed by artists and other creatives (Boswinkel and van Meerkerk, 2022) that are able to meet the needs of an artistic community or group. Culture, community, and creativity help support the collaborative frameworks leading to urban redevelopment, knowledge management and social innovation processes (Grodach, 2017; García, Eizaguirre, and Pradel, 2015; Romanelli and Zbuchea, 2020). Arts and culture help shape creativity, leading to an urban allure that fosters the city a magnet for cultural and creative urban growth (Goldberg-Miller, 2019).

The idea of conceiving creative cities as engines of collaborative spaces develops within post-industrial societies and relies on promoting culture-led activities that contribute to social and economic urban growth, enhancing energies, collective intelligence, knowledge sharing, and management, emerging issues within urban spaces. A creative city helps to rethink urban human-led and culture-driven innovation, influencing the choices of urban development and planning (Anttiroiko, 2014). Creative- and culture-led initiatives shape urban creative-led processes and improve urban social cohesion by involving urban communities in collaborative frameworks (Miles and Paddison, 2005).

The study aims to elucidate how the relationship between creative cities and hubs helps support socially collaborative frameworks for urban innovation. The rise of creative cities is opening to cooperative as well as organisational urban spaces for innovation. While there are studies that focus on several aspects that concern the rise and development of creative cities, few studies investigate the relationships between the creative city and the role of creativity-led urban projects and initiatives that support the rise of urban hubs, and contribute to social innovation processes within urban communities, fostering collaborative innovation that supports creative-led urban processes (Sørensen and Torfing, 2011). Culture, urban regeneration, and creative city develop engines of collaborative framework and drive social innovation and value (Della Lucia and Trunfio, 2018). Creative urban spaces contribute to social and knowledge innovation, developing conditions for urban

hubs' creation. Urban and artists' creativity helps shape the city an organisational space and social organism that strengthens creative and innovative ideas, energies, and resources emerging within urban communities in order to involve all the urban stakeholders that contribute to urban social value creation and innovation. The study is articulated in five sections. After introduction and theoretical background on creative cities and collaborative spaces, the methodological section follows in the third paragraph. Findings and results of the analysis on creative cities and hubs that support the making of creative urban spaces are elucidated in the fourth section. Finally, discussion and conclusions are set out.

2 Creative cities within collaborative spaces

Creativity, innovation and culture-led activities help the city to shape creative as well as organisational pathways to urban growth by fostering collaborative practices. A creative city supports a democratic and community-led process of social inclusion (Vivant, 2013), leading to bottom-up processes that help address social issues and innovation (Pratt, 2008). Creative cities promote culture-led urban development to support social-led urban growth (Power and Scott, 2010). Creative cities provide a place for engendering collaborative practices (Catungal and Leslie, 2009), relying on a creative milieu that supports social change (Betlej and Kaucerauskas, 2021). Creative cities develop open and meeting places for interaction and collaborative actions, by involving profit and no-profit urban stakeholders to construct a pathway for social innovation and value creation (Montanari, Mattarelli, and Scapolan, 2020). Collaborative spaces provide opportunities for the development of collaborative innovation that helps generate new and creative solutions through the collective knowledge and experience of actors that contribute to innovation genesis (Hartley, Sørensen and Torfing, 2013). Cities aim to invest in creative and innovative urban spaces, driving collaborative public-private partnerships (Kort and Klijn, 2011). Creative urban spaces enable collaborative and multi-actor involvement and innovation, supporting cooperative practices, and enabling the role of civil society in co-initiating collaborative processes (Sørensen and Torfing, 2018; Hartley, Sørensen and Torfing, 2013) that develop through collaborative spaces and foster multi-actor stakeholder collaboration to enhance the quality of life within urban communities (Sørensen and Torfing, 2011), leading to creative urban spaces, engines of collaborative innovation, that develops and implements solutions to urgent and relevant problems (Sørensen and Torfing, 2018). Creative cities contribute to engaging the urban community an engine of social change and transformation (Della Lucia and Trunfio, 2018), and structuring urban collaborative spaces (Yacoub and Hefliger, 2024), that enhance creative platforms and cross-pollination of ideas (Capdevila, 2019), and foster openness, collaboration and knowledge sharing and skills (Boutillier *et al.*, 2020).

3 Methodological section

The study employed a qualitative, descriptive and exploratory methodology to analyse how the interplay between the creative city framework and creative hubs enable the rise of collaborative as well as organisational arrangements that drive the practices and ways of working that contribute to making urban creative spaces, leading to culture-led and creative-driven urban value creation. The study is conceptual, exploratory and theoretical because the boundaries between creative cities and hubs, and the collaborative views to organisational innovation within urban spaces are not yet defined in a satisfying way. Conceptual papers regard untested relationships and aim to propose new relationships among constructs, focusing on integration and association of logical arguments, without providing data (Gilson and Goldberg, 2015). The study refers to the analysis of articles related to the rise of creative cities and hubs drivers of urban development by projects and experiences. The selected contributions are interpreted in a narrative synthesis to elucidate new perspectives and advance theoretical frameworks on emerging issues (Denyer and Tranfield, 2006; Dixon-Woods *et al.*, 2004).

4 Making creative urban spaces: a collaborative view to urban growth

Creative urban spaces are the result of the relationships and interactions between creative cities and creative hubs. The rise of a creative milieu within urban spaces is opening new opportunities for engendering conditions for value creation, leading to creative spaces and hubs, through projects and pathways, enabling all the urban stakeholders, private and public actors, to work together, developing cooperative frameworks and processes that foster social innovation.

4.1 Creative Cities

Creative cities contribute to social change and value, driving sustainable urban transformation and processes that support alliance building. The rise of cultural and creative activities within urban spaces enables the city an engine of creative communities (Florida, 2005). Creative cities rely on community-led and bottom-up initiatives that enhance the construction of social interaction and ties, by fostering community involvement (Sasajima, 2013). Culture-led and creative cities contribute to communal identity and belongingness, enhancing the sense of place and supporting a pathway for urban sustainability (Ratiu, 2013). Cultural resources, community, and creativity contribute to enhancing the collaborative view of urban redevelopment. A creative city develops by producing new knowledge and social capital relying on creative industries and workforces that contribute to the city's cultural life (Pratt, 2008). Urban creative processes and pathways let the city develop an effective urban community and engage the community, and reinvent sustainable urban futures, whereas the creative city model enhances a collaborative view of urban regeneration (Della Lucia and Trunfio, 2018). Culture enable cities to revitalize urban spaces for community development and re-orient the pathway of social growth, strengthening the local resources that open creative ideas and innovation. Urban and cultural spaces drive the rise of creative city an engine of community engagement and development in order to produce social issues and innovation (Della Lucia and Trunfio, 2018). Culture is an asset for identifying organisational frameworks that empower creative-led urban communities, and construct conditions for knowledge creation and social value. Culture-led urban regeneration processes contribute to shaping urban creative spaces and places through multi-actor cooperation by involving the local community in urban development itineraries (Pradel-Miquel, 2017). Creative cities foster urban community involvement, and engender social innovation issues and processes (García, Eizaguirre, and Pradel, 2015).

4.1 Creative hubs

Creative hubs can be organized in a network or infrastructure that is related to how they can actually support local needs, relying on artistic values and needs rather than on economic efficiency or contribution (Boswinkel and van Meerkerk, 2022). Creative hubs are usually considered both bottom-up initiatives, developed by artists and other creatives (Boswinkel and van Meerkerk, 2022) to meet the needs of an artistic community or group. Creative hubs are also the target of urban or cultural policy makers, especially where such initiatives contribute to developing local economy, and making attractive urban areas and spaces for social innovation and value creation. They are deeply depending on local economies as well as on the wider cultural diversification of the city they are located in (Pratt, 2021). Understanding how creative hubs are working is strongly linked to a rising practice associated with cultural industries and creative cities, coupled with new ways of fostering economic development. Creative hubs shape a cultural urban landscape and serve as places that enable cross-disciplinary interactions and provide platforms for both established and emerging creative professionals. The rise of creative hubs relies on cities that aim at supporting them in order to develop the social and cultural potential by experiencing constant growth (Chaloupková and Kunc, 2022). Creative hubs concentrate in those areas that have been the target of cultural and development urban policies or, generally, in central areas of a city where the proximity of urban improvements and infrastructure is more likely to ensure their economic success (Coll-Martínez and Méndez-Ortega, 2023). Creative hubs are associated by the literature with co-working spaces (Füzi et all. 2022) and maker spaces (Unterfrauner, *et al.* 2020). Creative hubs rely on a collaborative, creative space and/ or a maker space, fostering cooperative processes into a co-working space, focused on (more) on rentability (Chaloupková and Kunc, 2022), often prioritizing commercial viability over community-driven, artistic practices (Moriset, 2014). Creative hubs develop co-working spaces that favour remote workers and digital nomads, enabling a process of growth based on digitalization as well as on replicative entrepreneurship (Danko *et al.*, 2024). Creative Hubs contribute to making a network that supports the local dynamics of creativity, economy and social change (Flego and Tei, 2024).

5 Discussion and conclusions

A creative urban space makes collaborative meeting places for engendering social innovation and cooperative processes that involve the urban stakeholders to contribute to urban value creation. Urban regeneration processes rely on creativity and refers to culture-led initiatives that help shape creative and inclusive urban communities. The sustainable future of cities is creative-oriented and relies on bridging social and economic activities that contribute to wealthy and inclusive urban spaces able to generate sources and ideas, and conditions for creative solutions and projects that improve the quality of life within urban communities. As a kind of urban innovation, a creative urban space helps improve the social lives of citizens in urban environments. Urban spaces should follow a creative and sustainable pathway whereas the urban communities favour the conditions for developing more inclusive and creative urban communities that

contribute to promoting social and economic growth in order to improve the quality of life. Culture leads to communities able to develop creativity as a source that enhances social capital and collaborative processes that shape urban meeting places. Today, cities need to become creative and inclusive communities that support collaborative pathways for innovation, and contribute to sustainable urban growth, and ensure a better quality of life within urban landscapes. Culture helps creative cities to grow over time. The future of urban communities relies on cities that behave as engines of social innovation and supporters of creative ideas and forces that rely on human capital improvement and urban regeneration as drivers of social value and innovation within urban spaces. Culture-led urban regeneration processes foster community and citizen participation in cultural projects and enhance both social innovation issues and economic benefits. Creative cities and hubs contribute to strengthening urban creative forces, making creative urban spaces engines of sustainable urban development. The role of creative hubs is to restore and revitalize the creative and cultural soul of urban communities, leading to collaborative pathways and urban spaces that rely on stakeholder engagement for value creation and social innovation. This study has organisational, managerial, and social implications. Creative cities shape the urban space an organisational framework that enhances collaborative views and issues, involving several stakeholders to support urban innovation. Promoting the development of creative cities supports the design and the implementation of urban places and communities as collaborative arenas and spaces that involve all the stakeholders which are willing to construct a pathway for urban creative regeneration, and contribute to social value, knowledge creation, and innovation. Future research perspectives imply to investigate how cultural neighbours are emerging and developing within cities that aim to become creative communities that rely on requalifying the urban spaces in order to drive culture-led urban regeneration pathways that support innovation processes within cities which are becoming creative urban communities in order to improve the quality of urban life.

6 Ethics declaration

The research has not required ethical clearance and has been conducted in compliance with ethical principles that inform scientific research.

7 AI declarations

I declare that I have not used, in any step of paper writing, AI tools or applications.

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Narcissistic CEOs and Zombie Firms: Evidence from Europe

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Abstract

This study contributes to the growing body of research on the phenomenon of zombie firms by adopting a novel perspective that links corporate zombification to CEO narcissism. In line with the behavioral corporate governance approach and the Upper Echelons Theory (Hambrick & Mason, 1984), the analysis explores how CEO narcissism can influence a firm's likelihood of entering a state of zombification. In this study CEO narcissism is measured through a composite index based on unobtrusive indicators such as the size of the CEO's photograph in the annual report, the frequency of personal pronouns in shareholder letters, and the dimensions of the CEO's handwritten signature, following the methodologies proposed by Chatterjee and Hambrick (2007) and Ham et al. (2018). Zombie firms are identified according to McGowan, Andrews, and Millot (2018), using a dummy variable that takes the value of 1 if the Interest Coverage Ratio (ICR) is below 1 for at least three consecutive years during the observation period. Using a balanced panel dataset that includes 232 publicly listed firms across five European countries (United Kingdom, Italy, France, Germany, and Spain), covering more than 2,552 firm-year observations from 2013 to 2023, we find that CEO narcissism negatively impacts on zombie firms. Specifically, the results obtained support our hypothesis, highlighting a negative and statistically significant relationship between CEO narcissism and zombification, also confirmed by the positive relationships between CEO narcissism and indicators of financial strength such as Altman's z-score, ICR and ICR2. Our results, despite all the weaknesses of the case, contribute to extend the literature that recognises CEO narcissism as a positive acceptance for the company, especially in relation to financial distress.

Keywords: CEO narcissism; Zombie firms, Behavioral corporate governance, Financial distress, Upper Echelons Theory

Paper type: Academic Research Paper

1 Introduction

The goal of the firm is to create value and avoid financial distress. In recent years, a growing body of literature has addressed the issue of "zombie firms", a term first coined by Edward Kane (1987) to identify those firms that are formally active, but economically insolvent and artificially kept alive thanks to public guarantees such as subsidies. Subsequently, various works have analysed this phenomenon in different countries and periods, developing different methods of measurement and thus contributing to the very definition of zombie firms. The earliest research on zombie firms focused on Japan in the late 1990s (e.g., Hoshi & Kashyap, 2000; Caballero, Hoshi and Kashyap, 2008; Fukuda & Nakamura, 2011) and then extended the analysis to a global scale (McGowan, Andrews and Millot, 2018). More recently, following the various financial crises, studies on zombie firms have progressively expanded by shifting the focus from the macroeconomic and financial perspective, as well as the impact of zombie firms on the credit system, to a more managerial, corporate finance, and corporate governance perspective (e.g., Fang et al., 2020; San José, Urionabarrenetxea and García-Merino, 2022; Rodríguez-Sanz, Vallelado and Velasco, 2024; Shome and Verma, 2024)

Altman et al., (2024) find that approximately 7% of the listed companies in the twenty countries with the highest GDP are classifiable as zombies.

The objective of this paper is to investigate the topic of zombie firms by adopting a different perspective than previous studies and in particular by investigating the empirical relationship between zombie firms and CEO narcissism. According to the guidelines of American Psychiatric Association (APA), narcissistic profile means: "Multifaceted personality trait that combines grandiosity, attention-seeking, an unrealistic inflated self-view, a need for self-view to be continuously reinforced through self-regulation, and a general lack of regard for others" (Diagnostic and Statistical Manual for Mental Disorders, 2013, p. 669)

Following the Upper Echelons Theory (Hambrick & Mason, 1984), the behavioural traits of CEOs impact the organisation by influencing its decision-making process. CEOs' narcissism leads them to prefer ambitious and risky strategies, which are often more oriented towards satisfying their own need for attention than meeting the company's needs (e.g., Chatterjee and Hambrick, 2007; 2011; Petrenko et al., 2016; Aabo and Eriksen, 2018; Buyl et al., 2019). However, the narcissistic trait does not always generate negative outcomes; several studies have pointed out that this trait of CEOs tends to perform better in contexts of uncertainty or crisis (e.g.,

Chatterjee & Pollock, 2017; Aabo, Kirch & Thomsen, 2024). Despite various empirical works there is a gap in the literature regarding the impact of CEO narcissism on zombie firms

Using a panel dataset of 232 listed firms in five European countries (UK, Germany, France, Spain and Italy) with a total of 2,552 firm-year observations, the present study analyses the relationship between CEO narcissism and zombie firms.

2 Literature review and hypothesis development

2.1 Zombie firms

The first studies on zombie firms are concentrated in Japan in what is called the lost decades, a period characterised by a strong allocation of credit by banks to low-productivity sectors, giving lifeblood to increasingly less profitable firms (e.g., Hoshi & Kashyap, 2000; Rodríguez-Sanz, Vallelado and Velasco, 2024). This behaviour, which disadvantages sectors with higher productivity, has contributed significantly to the spread of zombie firms in the Japanese economic fabric. Caballero, Hoshi and Kashyap (2008) analysing a sample of more than 1,800 firms during the period 1981 - 2002 find that in sectors with a higher presence of zombie firms there is stagnation in employment and slower growth of healthy firms. Andrews and Petroulakis (2019) document how the survival of inefficient firms is associated with weak banks, with negative effects on capital reallocation and aggregate productivity.

In contrast to previous studies, Fukuda and Nakamura (2011) shift the perspective of investigation by focusing on the identification of zombies through the use of firm performance indicators. More recently, a growing literature has extended the study on zombie firms in other countries by proposing new proxies for assigning zombie status. McGowan, Andrews and Millot (2018), using a sample of firms located in nine OECD (Organisation for Economic Cooperation and Development) countries, show that the prevalence of zombie firms, identified as having been in operation for at least ten years and having an Interest Coverage Ratio (ICR) of less than 1 for at least three consecutive years, increased between 2003 and 2013. Albuquerque and Iyer (2023) document that the presence of zombie firms reduces the financial performance and probability of survival of non-zombie firms, particularly in sectors most affected by 'zombification'. Altman, Dai and Wang (2024) find that, on average, 7% of the listed firms in the twenty countries with the highest GDP were classifiable as zombies in 2020. In addition to the study by McGowan, Andrews and Millot (2018), Altman et al., (2024) extend the identification criteria by adding the negative z-score for at least three consecutive years, as well as an ICR below 1, in order to make comparisons in cross-country analyses more homogeneous.

More recent studies instead focus on the role of corporate governance in the zombification process. Fang et al. (2020), for example, examining a sample of 3,500 Chinese listed companies, find that a higher presence of female executives is associated with a reduced likelihood of zombification and corporate risk-taking. San José, Urionabarrenetxea and García-Merino (2022) find that a higher number of female CEOs is associated with a lower risk of zombification. CEOs with multiple positions on boards in companies with lower ownership concentration tend to reduce the risk of zombification. While Rodríguez-Sanz, Vallelado and Velasco (2024) point out that the separation of CEO and chairman positions, a longer CEO tenure and a board of directors with more independent members can negatively influence zombification status by allowing a faster transition to a healthy state. In light of the above, zombification would seem to depend not only on exogenous factors, such as the banking or macroeconomic environment, but also on the peculiarities of corporate governance (Shome and Verma, 2024).

2.2 CEO narcissism

CEO narcissism is a topic that has gradually gained relevance in management literature since the pioneering work of Chatterjee and Hambrick (2007, 2011), who first provided a methodology, based on non-intrusive indicators, that does not require direct interviews with CEOs. The authors describe narcissistic CEOs as overly egocentric individuals, constantly seeking admiration, who tend to overestimate their own capabilities and attribute company successes to themselves, as well as ignore failures. This area of research fits within the framework of the Upper Echelons Theory (Hambrick & Mason, 1984), according to which the psychological characteristics of leaders directly influence strategic business decisions. The innovation of this work passes through unobtrusive indicators, which were associated with the four characteristics of narcissism identified by Emmons (1987): Exploitativeness/Entitlement, Leadership/Authority, Superiority/Arrogance and Self-absorption/Self-admiration. Following this methodological approach, it is possible to observe CEO behaviour through publicly available elements such as annual reports and interviews. Specifically, Chatterjee and Hambrick

(2007) use the size of the CEO's photograph in the annual report, the number of times the CEO's name recurs in press statements, the use and number of times they use the singular pronoun in interviews, and the ratio of the CEO's monetary (and non-monetary) compensation to the second highest paid executive (Chatterjee & Hambrick, 2007). This methodology, in accordance with the meta-analysis by Cragun et al. (2019), appears to be the most effective in identifying CEO narcissism

After the seminal work of Chatterjee and Hambrick (2007), a growing interest was registered towards the topic of CEO narcissism and in particular on the relationship between CEO narcissistic traits and corporate governance. O'Reilly et al. (2014) identify a positive correlation between CEO narcissism and CEO compensation, highlighting the fact that narcissistic CEOs with a long tenure tend to have significantly higher compensation than the rest of the executives. Petrenko et al. (2016), on the other hand, document that narcissistic CEOs resort to corporate social responsibility (CSR) for self-congratulatory purposes, reducing its strategic effectiveness.

Several studies point out that narcissistic CEOs have a greater propensity for risk, fuelled by their need for grandiosity, which drives them to make riskier strategic decisions (Buyl et al., 2019). Confirming this, Tuggle et al. (2024) find that companies led by narcissistic CEOs make riskier choices, while Aabo and Eriksen (2018) document a non-linear relationship between narcissism and corporate risk-taking, an inverted 'U-shape' between narcissism and volatility stock returns. In particular, a higher and lower level of narcissism is associated with a lower level of corporate risk-taking. In a complementary vein, Zhu and Chen (2015) observe that narcissistic CEOs tend to surround themselves with compliant and like-minded executives, amplifying the growing relationship between CEO narcissism and risk-taking, as well as a greater propensity for selective hedging behaviors in financial investments (Bajo et al., 2022). In contrast, other studies have documented how firms led by narcissistic CEOs exhibit a higher likelihood of fraud, earning management practices and worse credit ratings (Rijsenbilt and Commandeur, 2013; Capalbo et al., 2018; Buchholz et al. 2020; Hou, Fairchild and Perotti, 2024)

Kim and Anderson (2024) investigating a sample of 395 firms in the US, during the period 2012-2020, test the relationship between CEO narcissism and agency cost of debt documenting a positive relationship, i.e. as CEO narcissism increases, the cost associated with debt increases. However, there is no shortage of studies showing how CEO narcissism can benefit the firm. Yang et al. (2023), for example, investigating a sample of 245 Chinese listed manufacturing firms, find that narcissistic CEOs are positively correlated with cross-boundary growth domestically and internationally. Zhang et al. (2021) find that CEO narcissism is associated with a higher propensity to innovate in order to support risky but high growth potential projects. According to Chatterjee and Pollock (2017), narcissistic CEOs perform better during financial and economic crises than non-narcissistic CEOs. This is also confirmed by Aabo, Kirch & Thomsen (2024), who, examining a sample of 820 US firms from 2007 to 2020, find that narcissistic CEOs are able to improve firm performance in periods of high uncertainty, while in periods of low uncertainty they are a disadvantageous factor for the firm. Similarly, Shirokova et al. (2024) point out that, in contexts of high uncertainty, CEO narcissism reinforces the positive relationship between strategic entrepreneurial behaviour and firm performance

Benefiting from the previous literature, we formulate the following hypothesis:

- *Hypothesis 1. CEO narcissism is negatively associated with the likelihood that a firm exhibits zombie characteristics.*

3 Methodology and data analysis

To construct the sample, we used the FactSet database, through which we acquired the financial data of the individual firms in the sample consisting of listed European companies, excluding financial and utilities companies as they are highly regulated sectors. Starting from an initial sample of 1,550 firms, and using the revenue-based thirds, 232 firms active in five European countries were identified: 100 in the UK (common law), 30 in Germany (German civil law), 30 in France, 48 in Italy and 26 in Spain (French civil law) according to the classification of La Porta et al. (1998). For each firm, data was collected for the entire period 2013-2023, which allowed us to construct a balanced panel data of 2,552 firm-year observations. Consistent with previous literature (McGowan, Andrews and Millot, 2018), the choice of an 11-year time horizon is motivated by the need to examine firms that have been in operation for at least ten years, a necessary condition for the identification of zombie firms on the basis of the ICR. Specifically, this paper defines zombie firms as all those firms that have an interest coverage ratio (ICR) of less than 1 for at least three consecutive years. Following this methodology, we identify 83 firms that have been zombies at least once during the reference period. With regard to CEO narcissism, we collected qualitative data from annual reports, retrieved from companies' websites or, where available, from www.annualreports.com adopting the 'unobtrusive' indicator approach as proposed by Chatterjee and Hambrick (2007).

The econometric model OLS (Ordinary least squares) used for the regression analysis is presented below:

$$y_{i,t} = \mu_{i,t} + \alpha_1 CEO\ NARCISISSM_{i,t} + \alpha_2 CONTROL\ variables_{i,t} + \eta_{i,t} + \varepsilon_{i,t}$$

Table 1. Variables Definitions.

Variables	Definition	Source
Dependent Variables		
ZOMBIE	Dummy variable that takes value 1 if the firm is at least 10 years old and has an interest coverage ratio (ICR) below 1 for three consecutive years at least once between 2013 and 2023	Our calculation using FactSet
Z_SCORE	Altman score	FactSet
ICR	EBIT scaled by interest expenses	FactSet
ICR2	EBITDA scaled by interest expenses	FactSet
Independent Variables		
Narcisissm	Composite index based on photo prominence, personal pronoun usage, and signature size, following Chatterjee & Hambrick (2007) and Ham et al. (2018).	Our calculation is based on annual reports, shareholder letters, and, where possible, data from www.annualreports.com.
Control Variables		
CEO_OWNERSHIP	The percentage of shares held by CEO	FactSet
CEO_TENURE	Number of years the CEO has held the position	FactSet
CEO_AGE	The age of the CEO	FactSet
BOARD_SIZE	The total number of directors sitting on the company's board	FactSet
INDEPENDENT_DIRECTORS	The number of independent directors on the board (expressed as a percentage)	FactSet
SIZE	Total assets (in logarithmic form)	FactSet
CASH_FLOW	Cash flow from operation scaled by total assets	FactSet
FIRM_AGE	Years since firm was established (in logarithmic form)	FactSet
GROWTH_SALES	Annual change in a firm's sales compared to the previous year (expressed as a percentage)	FactSet
DEBT	Financial debt divided by total assets	FactSet
ROA	Yearly net income/average total assets*100	FactSet
INDUSTRY	Four-Digit SIC (Standard Industrial Classification) codes	FactSet

Source: Author's own work

3.1 Dependent variables

The identification of zombie firms was carried out following the methodology proposed by McGowan, Andrews and Millot (2018). In order to assign zombie status, the firm must have been active for at least 10 years, a criterion met ex ante in the sampling process, and have an ICR of less than 1 for three consecutive years at least once in the time span from 2013 to 2023. If these conditions are met, the dummy zombie takes the value 1, and zero otherwise. The other dependent variables are the Altman Z-Score, the ICR and the ICR2.

3.2 CEO narcissism score

As already mentioned, CEO narcissism was measured following Chatterjee and Hambrick's (2007) approach, which is based on the use of unobtrusive indicators to estimate this psychological trait using publicly observable data, without resorting to interviews or questionnaires. The CEO narcissism score was constructed as a composite measure combining three different indicators following the methodology of Chatterjee and Hambrick (2007) and Ham, Seybert and Wang (2018). The first indicator is the size of the CEO's photo in the annual report which was assigned a score from 1 to 4 based on the presence of the photo, the size of the photo and the presence of other managers in the photo. Specifically, the score was assigned as follows: 1 in the absence of a photograph of the CEO; 2 in the presence of a photograph of the CEO together with other managers or executives; 3 if the CEO appears in the photo alone, and with a size of less than half a page; 4 if the CEO appears in the photo alone, but with a size of more than half a page.

The second indicator corresponds to the frequency of use of personal pronouns (I, me, myself) versus plural pronouns (we, us, ourselves) in the letter to stakeholders or other statements in the annual report. The indicator was calculated as follows:

$$\frac{Singular\ pronouns}{Singular\ pronouns + Plural\ pronouns}$$

The third indicator does not follow the methodology of Chatterjee and Hambrick (2007), but rather incorporates the dimension of the handwritten signature as introduced by Ham, Seybert and Wang (2018). CEO signatures were collected from annual reports and measured by constructing a minimum area touching the extreme points of each signature, which is normalised by the number of letters of the CEO. The indicator was calculated as follows:

$$\frac{Handwritten\ signature\ area}{Number\ of\ letters\ in\ the\ name}$$

The mean and standard deviation over the sample was calculated for each indicator, a process necessary to standardise the variable in question. Finally, the CEO narcissism score was obtained as the simple average of the three indicators.

Table 2. Descriptive Statistics.

Variables	Average	Median	5th	95th
Dependent Variables				
Z SCORE	2.808	2.188	-0.232	8.238
ICR	14.52	5.598	-18.21	73.11
ICR2	24.50	11.23	-7.337	98.814
Zombie firm	0.355	0.000	0.000	1.000
Independent Variables				
Narcissism	1.00	1.015	0.333	1.88
Control Variables				
CEO_OWNERSHIP	0.023	0.003	0.000	0.129
CEO_TENURE	11.48	7.00	0.000	35.00
CEO_AGE	55.19	55.00	43.00	68.00
BOARD_SIZE	8.95	8.00	3.00	17.00
INDEPENDENT_DIRECTORS	0.413	0.428	0.000	0.800
SIZE	18712	466.54	9.930	115778
CASH_FLOW	0.059	0.066	-0.131	0.204
FIRM_AGE	45,04	26.00	10.00	131.00
GROWTH_SALES	0.074	0.045	-0.313	0.579
DEBT	0.227	0.211	0.000	0.575
ROA	1.370	2.858	-22.86	14.79
INDUSTRY	YES			

Source: Author's own work

3.3 Control variables

In order to neutralise firm-specific effects, we used a set of control variables (FIRM_AGE, SIZE expressed through the logarithm of total assets, CASH_FLOW, ROA, GROWTH_SALES, and DEBT) selected on the basis of the existing literature (e.g. Chatterjee and Hambrick, 2007; Altman, Dai and Wang, 2024) as shown in Table 1 and 2. In addition, we considered some specific variables related to the figure of the CEO and more in general to corporate governance (CEO age, CEO tenure, CEO ownership, board size, the percentage of independent directors). Finally, we have included a set of dummies variables that capture the industry.

4 Results

Table 3 shows the results of the econometric analysis.

As can be seen, the presence of narcissistic CEOs reduces the number of zombie firms and improves the z-score, ICR and ICR2. In line with the hypothesis formulated the coefficient associated with the narcissism variable is negative and statistically significant ($p < 0.01$), in other words it reduces the probability of a firm being classified as a zombie (($\beta = -0.0419$). This result suggests that the narcissistic traits of the CEO, while often considered negative for the firm, may act as a deterrent to the financial condition typical of zombie firms.

Table 3. Empirical Estimates Using OLS

	Zombie	Z-score	ICR	ICR2
Constant	0.0669	4.0534***	50.283***	78.588***
	(0.0909)	(0.7396)	(8.6088)	(10.442)
CEO_AGE	0.2001***	-0.1407	-4.0781	-5.0650
	(0.0393)	(0.2292)	(4.3557)	(4.5592)
CEO_TENURE	-0.0152	0.1791	1.4154	1.4336
	(0.0203)	(0.1118)	(1.4953)	(1.7273)
CEO_OWNERSHIP	0.1124	1.8580**	-1.4404	-4.1287
	(0.1188)	(0.8552)	(11.0481)	(12.5182)
FIRM_AGE	-0.0005	-0.0014	0.0205	0.0712**
	(0.0003)	(0.0021)	(0.0267)	(0.0305)
BOARD_SIZE	0.5931***	-0.6898	23.8742***	32.243***
	(0.1000)	(0.7468)	(9.0359)	(10.3457)
INDEPENDENT_DIRECTORS	-0.1957***	1.4680***	7.0030	7.3427
	(0.0684)	(0.3978)	(4.5124)	(5.3029)
SIZE	-0.2011***	0.0066	-0.8018***	-2.0439
	(0.0221)	(0.1083)	(1.4274)	(1.5895)
DEBT	0.3015***	-5.3647***	-54.2993***	-90.681***
	(0.0776)	(0.4693)	(5.0177)	(5.8821)
CASHFLOW	-0.0762	-1.1389	-1.3856	2.0778
	(0.1596)	(1.1875)	(13.5322)	(15.772)
GROWTH_SALES	0.0701*	0.3714	5.5134	3.6101
	(0.0382)	(0.2952)	(3.7267)	(4.3301)
ROA	-0.0049***	0.0944***	0.8722***	0.8465***
	(0.0015)	(0.0113)	(0.1440)	(2.0129)
NARCISISM	-0.0419***	0.3980***	4.9986***	4.4756**
	(0.0151)	(0.1527)	(1.7478)	(2.0129)
INDUSTRY	YES	YES	YES	YES
YEAR	YES	YES	YES	YES
R-squared	0.770	0.593	0.532	0.577
Adj. R-squared	0.749	0.555	0.488	0.537
N. Obs.	2.552	2.552	2.552	2.552

Note(s): (***), and (**), indicates significance levels at 1% and 5% of two-tailed test, respectively.
Source: Author's own work

Thus, companies led by narcissistic CEOs show better solvency indicators even under conditions of crisis and uncertainty. Regarding the control variables, firm size takes on an inconsistent sign in that while it would seem to reduce the risk of zombification, it also increases the risk of financial distress. In fact, there is a positive but non-significant sign with respect to the z-score and a negative and significant sign with respect to the ICR. In line with the literature, debt shows a positive and significant relationship with zombification ($\beta = 0.3015$, $p < 0.01$), while ROA is significantly and negatively associated with zombification risk ($\beta = -0.0049$, $p < 0.01$). This means that companies with higher profitability, as expected, incur less risk of financial distress. In contrast, debt utilisation pushes firms into the zombification zone and increases their risk of financial distress

An interesting result concerns CEO age, which is positively associated with zombification ($\beta = 0.2001$, $p < 0.01$), which could mean that "greyer" CEOs tend to adopt more conservative and less risky strategies. However, the CEO age coefficient is not statistically significant compared to the other variables. Finally, both the BOARD_SIZE and INDIPENDENT_DIRECTORS coefficient would seem to reduce the risk of financial distress.

5 Conclusions

In recent years, interest in zombie firms has grown while some areas as well as the link between zombification and CEO narcissism remain unexplored. This study aims to fill this gap by analysing a sample of European firms listed in the period 2013-2023, through the construction of a dataset composed of 2,552 firm-year observations, with the objective of investigating the relationship between zombie firms and CEO narcissism. The results obtained support our hypothesis, showing a negative and statistically significant relationship between CEO narcissism and zombification, also confirmed by the positive relationships between CEO narcissism

and indicators of financial soundness such as Altman's z-score, ICR and ICR2. Our results, albeit with all the limitations of the case, contribute to extending the literature that recognises CEO narcissism as positive for the firm, especially in relation to financial distress

6 Ethics declaration

The authors state that no ethical clearance was required for the research presented in this paper. The authors also declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

7 AI declaration

The authors state that artificial intelligence tools were used for the translation and linguistic revision of English texts.

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Evaluating AI's Impact in Healthcare: a Systemic Approach through Key Performance Indicators

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Abstract

The combination of economic crises, a growing shortage of public resources, socio-economic disparities, and demographic shifts has significantly amplified the strain on healthcare systems globally. Rising healthcare demand and the goal of universal coverage highlight the need for improved resource allocation, infrastructure, and workforce planning. AI offers significant opportunities for enhancing efficiency and service quality, yet its integration is limited by regulatory, organizational, ethical, and environmental challenges. Although the literature broadly emphasizes AI's potential, empirical evidence on its actual impact on healthcare performance remains scarce.

Based on these premises, this study proposes a comprehensive set of key performance indicators (KPIs) to assess AI's tangible effects. The proposed set of KPIs provides a practical and adaptable toolbox for healthcare decision-makers to evaluate AI-driven changes and monitor their implementation.

This paper employs a Causal Loop Diagram (CLD) approach to explore how AI influences healthcare systems, focusing on two key areas: (i) optimizing resource allocation to improve efficiency and (ii) enhanced personalized care to elevate service quality. CLDs provide a structured and dynamic framework for understanding the complex interdependencies shaping healthcare organizations. The CLD approach serves as a foundation for developing KPIs to guide managers in evaluating AI integration. By combining systems thinking with the development of KPIs, this research provides a novel methodological framework for assessing the tangible impact of AI technologies in healthcare organizations. The resulting set of KPIs measures and evaluates the effect of AI integration within healthcare organizations. It is intended to guide future research regarding AI applications to healthcare management, as well as help managers assess the impact of AI implementation in healthcare settings. This research addresses the lack of empirical validation regarding the impact of AI in healthcare organizations by providing a set of indicators for evidence-based decision-making. Thus, it contributes to both academic research and practical applications of AI in healthcare management.

Keywords: Healthcare, Performance Management, Artificial Intelligence, Key Performance Indicators, Causal Loop Diagrams.

Paper type: Academic Research Paper

1 Introduction

Healthcare organizations operate within a rapidly evolving, intricate, and dynamic environment characterized by continuous changes and challenges (Homer & Hirsch, 2006).

Healthcare systems face constrained funding and rising demand from aging populations with complex needs (Khan, 2023), increasing pressure to optimize limited resources while maintaining care quality (Meskó et al., 2018). Against this backdrop, a shift to alternative paradigms of healthcare management seems necessary (Vainieri et al., 2020).

By addressing the dual pressures of financial constraints and growing patient demands for high-quality care (Bohr & Memarzadeh, 2020; Hindriks & Meyer, 2019), Artificial Intelligence (AI) stands out as a powerful means to significantly reshape both clinical and management practice (Brem et al., 2021; Briganti & Le Moine, 2020; Dicuonzo et al., 2023). An emerging body of literature explores the interplay between AI and healthcare (Secinaro et al., 2021), highlighting the potential of AI to improve administrative processes (Bhuyan et al., 2025; Glover et al., 2022), medical service quality, and, consequently, patient outcomes (Bates et al., 2021; Choudhury & Asan 2020; Su et al., 2020). As AI technologies continue to evolve and are expected to impact almost all medical fields (Haleem et al., 2019), it seems increasingly essential to critically assess their effects on healthcare organizations. Some studies also highlight the need to empirically assess the impact of AI on clinical practice, alongside its broader implications for organizational performance (van Leeuwen et al. 2022; Wu et al., 2021). However, although the literature generally expresses enthusiasm about the potential benefits of AI in healthcare, the empirical validation of these claims remains limited, particularly in the field of performance management (Di Falco et al., 2024), raising significant concerns about the extent to which AI can positively affect the performance of healthcare organizations.

Building on this foundation, the study focuses on the validity of claims regarding the positive impact of AI integration on healthcare performance, the extent of such effects, and how they can be evaluated. To effectively

answer the research questions and address a gap in empirical evidence, this study, after framing the potential effects of AI on healthcare systems as discussed in the literature through a Causal Loop Diagram (CLD) analysis, proposes a comprehensive set of key performance indicators (KPIs) designed to objectively measure the impact of AI technologies. In particular, this study focuses on two directions of research that could be impacted through AI integration in management practice: (i) optimization of medical resource allocation and (ii) provision of highly personalized care, fostering a patient-centered approach.

Following this introduction, the next section explores AI's potential in healthcare, focusing on resource optimization and personalized care. Section 3 describes the research approach, while Section 4 presents insights derived from the CLD-based analysis. Finally, Section 5 introduces a tailored set of KPIs to measure AI's impact in these contexts. Lastly, Section 6 discusses key insights emerging from the study and future research directions.

2 AI in healthcare systems: towards optimized resource allocation and improved personalized medicine

Thanks to sophisticated algorithmic architectures and connected capabilities, AI has been utilized or tested in various healthcare applications, particularly in reducing clinical staff workload, enhancing healthcare provision and prevention, supporting diagnosis and treatment, and enabling patient monitoring (Kocakoç, 2022; Saraswat et al., 2022). Hence, while the literature highlights barriers to AI integration (Ahmed et al., 2023), AI is expected to revolutionize healthcare management paradigms and clinical practices to ultimately enhance patient and community outcomes (Bohr & Memarzadeh, 2020; Chen & Decary, 2020; Davenport & Kalakota, 2019). Two emerging themes in the literature exploring the potential of AI in healthcare focus on resource optimization (Dawoodbhoy et al., 2021; Huang et al., 2021; Kasula, 2023a; Wu et al., 2023) and personalized healthcare (PHC) (Blasiak et al., 2020; Khan et al., 2020; Li et al., 2024; Schork, 2019; Subramanian et al., 2020).

In a resource-constrained sector like healthcare, AI technologies represent a groundbreaking tool in resource allocation and optimization, as they can potentially improve resource planning and efficiency (Deloitte, 2024). By accurately forecasting incoming workloads, AI can timely adjust resource allocation and staffing strategies, thereby optimizing operational efficiency and mitigating bottlenecks (Rathore et al., 2023). Additionally, AI-driven decisions on resource allocation can benefit healthcare professionals by ensuring an adequate workload (Badshah, 2024). Moreover, AI-driven predictive maintenance reduces costs and optimizes resource use by enabling early fault detection and minimizing equipment downtime (Shamayleh et al., 2020). In the supply chain domain, AI-driven demand forecasting optimizes procurement and inventory, preventing shortages and overstock, and reducing lead time (Khan et al., 2024; Kudrenko, 2024). This improves medical supply chain efficiency, enhancing resource management and allocation (Kasula, 2023b). Moreover, AI's data processing and pattern recognition optimize resource allocation and patient outcome prediction, reducing relapse risks and enhancing service quality and efficiency (Guo et al., 2021; Maeda et al., 2022).

PHC aims to tailor treatments to individual patient characteristics to improve outcomes (Lorkowski et al., 2021; Nardini et al., 2021). Traditional approaches face challenges in analyzing the extensive data required for personalized care. In contrast, AI technologies can process diverse data sources to enhance treatment accuracy and effectiveness (Alowais et al., 2023; Hindriks & Meyer, 2019). Furthermore, integrating AI in personalized medicine can improve disease discovery, treatment strategies, and drug administration, thereby advancing prevention, diagnosis, and individualized care (Awwalu et al., 2015; Taherdoost & Ghofrani, 2024).

Although the benefits stemming from the use of AI are acknowledged in specific clinical practices, particularly in diagnostic imaging (Jones et al., 2022; Rajpurkar et al., 2022), real-world clinical implementation remains limited (He et al., 2019; van Leeuwen et al., 2022). Moreover, empirical evidence validating its impact on performance management systems in healthcare organizations is even more scarce (Di Falco et al., 2024).

3 A systemic approach to mapping AI-related dynamics in healthcare organizations

To illustrate the dynamics of AI integration in healthcare organizations as highlighted in the literature, this research employs the CLD approach, a framework extensively used in the study of health systems (Beaulieu et al., 2022; Bradley et al., 2020; Cassidy et al., 2022; Gaveikaite et al., 2020; Katsamakas & Pavlov, 2020; Linnéusson et al., 2022). This method provides a visual representation of the interconnected effects of AI implementation, supporting the development of the indicators measuring its potential benefits within the healthcare system.

Rooted in systems thinking, an approach designed to deal with dynamic and complex environments such as healthcare organizations (Peters, 2014; Senge, 1990), CLDs capture a system's causal relationships and feedback loops, providing a language to express the dynamic nature of systems (Kim, 1992). While conventionally

employed as a supportive tool for quantitative modeling, CLDs have found independent application in system description and policy analysis, documenting relevant factors and their causal relationships (Wolstenholme, 1999). By facilitating the understanding of how behaviors manifest within a system and how to develop strategies to work with or counteract these behaviors, and by articulating the causalities between elements of the system, CLDs illustrate how these variables form dynamic circular influences rather than linear relationships. They build coherent narratives about specific problems by linking key variables and indicating their causal relationships (Haraldsson, 2004).

In summary, the CLD approach goes beyond traditional causal diagrams by identifying balancing and reinforcing feedback loops to provide an understanding of system structure and dynamics, enabling the design and evaluation of interventions (Hanger-Kopp et al., 2024). CLDs help visualize the connections between variables and reveal the underlying structure and dynamics of complex systems, serving as a foundation for developing indicators to measure AI's potential benefits within the healthcare system.

4 Dynamics of AI integration in healthcare organizations: insights from CLD analysis

By framing the potential benefits of AI implementation through a systems thinking method – whose CLDs represent the visual output – the research provides a systemic and dynamic perspective, highlighting the causal relationships between AI-driven efficiency gains, resource allocation, and improvements in patient care. The findings from the literature are summarized in the CLD depicted in Figure 1, representing the dynamics generated by integrating AI into a healthcare system.

The CLD illustrates the dynamics of hospital resource management and patient flow, incorporating the effects of AI integration on healthcare system efficiency and quality of health services. The diagram highlights several feedback loops shaping hospital performance. Loop R1 shows that increasing waiting times can extend the waiting list, which further exacerbates delays and discourages new admissions. In R2, higher patient inflow accelerates resource depletion, reducing capacity, lengthening treatments, and lowering discharge rates, reinforcing patient accumulation.

Balancing loops B1 and B3 capture how improved satisfaction and hospital image attract more service requests, which increase waiting times and ultimately reduce satisfaction. Loop B2 shows that rising patient numbers deplete resources, reducing capacity and limiting admission rates.

Loops B4 and B5 show that increased demand pressures infrastructure and HR workload, undermining service quality and staff motivation, which in turn reduce satisfaction and control demand. B6 and B7 link service quality to clinical relapse: more readmissions intensify patient flows, feeding back into longer waits and greater strain on capacity.

The implementation and continuous improvement of an AI algorithm for resource allocation in a generic hospital reduces pressure on infrastructure and staff workload, enhancing service quality and patient satisfaction, impacting the dynamics exemplified in Loop B4. Resource optimization enables more efficient management, ensuring an adequate workload. The integration of AI also positively affects the motivation and well-being of healthcare personnel, reducing burnout and fostering a more sustainable work environment, influencing the relationships described in Loop B5. Parallelly, the use of AI for treatment personalization directly improves the quality of care, reduces relapse rates, and optimizes waiting times.

In summary, the introduction of AI is expected to alleviate pressure on infrastructure and workforce, thereby contributing to improved service quality and reducing burnout, ultimately enhancing hospital efficiency. This CLD highlights the interdependent nature of hospital operations and emphasizes the potential role of AI-driven decision-making in improving resource allocation, clinical outcomes, and overall system performance.

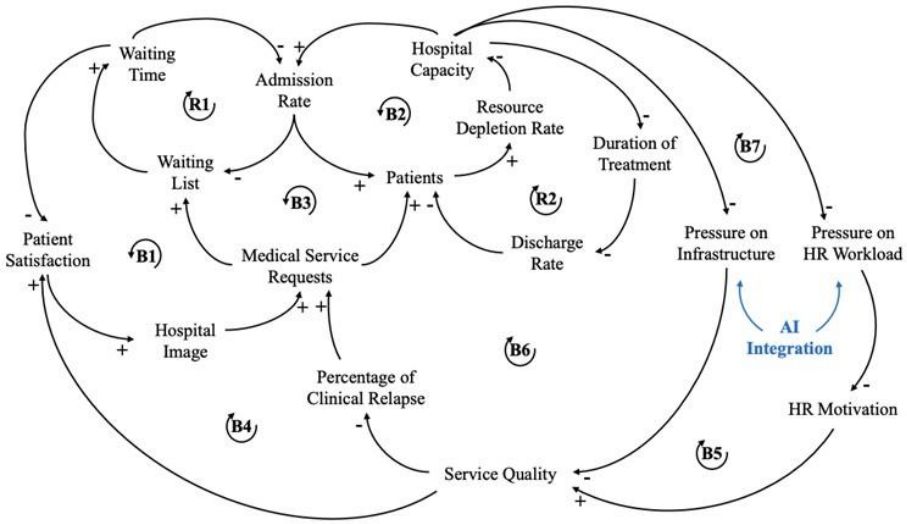


Figure 1: A CLD framing AI-driven dynamics in hospital resource management and patient flow

5 A set of KPIs for assessing AI integration in healthcare organizations

Considering the gap in the literature concerning the empirical application of AI technology in medical and management practices, following the exploration of the dynamics underlying AI integration in healthcare organizations emerging from the literature and conceptualized in the CLD in Figure 1, a set of KPIs measuring and evaluating the technology's impact is proposed in Table 1. The proposed set of KPIs provides a practical and adaptable toolbox for healthcare decision-makers to assess its effects and monitor its implementation, determining whether and to what extent it is affecting healthcare performance.

The KPIs are categorized into six domains - productivity, operational efficiency, AI predictive maintenance, supply chain, employee engagement and well-being, clinical outcomes, and treatment personalization - synthesizing AI's impact on the two main themes discussed in Section 2, namely, resource allocation optimization and PHC. The productivity category includes KPIs measuring resource utilization and clinical workload. Metrics such as average treatment cost per patient, patient turnover rate, and patient load per clinician quantify operational output, providing insight into efficiency and workforce distribution. KPIs grouped in the operational efficiency category measure hospital workflow performance. Admission rate, average waiting time, and average length of stay capture patient flow, while scheduling accuracy and operating room idle time assess the effectiveness of scheduling and resource allocation. Indicators such as resource utilization rate, equipment failure rate, and average maintenance cost per equipment unit provide a quantitative assessment of system downtime, predictive maintenance efficiency, and cost-effectiveness of AI-powered monitoring tools. Such metrics evaluate the reliability of AI-driven equipment management and are classified in the AI predictive maintenance group. AI's role in optimizing healthcare logistics is measured through lead time, stockout rate, expired stock rate, and AI-driven test optimization rate, indicators grouped in the supply chain category. These indicators reflect the ability of AI to enhance inventory management and reduce inefficiencies in procurement and distribution. The impact of AI integration on employee engagement and well-being is assessed using patient satisfaction rate, absenteeism rate, employee turnover rate, and staff weekly workload indicators. These KPIs provide insight into job satisfaction, retention, and the potential effect of AI integration on healthcare professionals' working conditions. AI's contribution to patient care quality is evaluated through KPIs in the clinical outcomes category. Medical error rate, clinical relapse rate, avoidable hospitalization rate, early diagnosis rate, AI diagnostic accuracy rate, and average AI-assisted diagnosis time quantify the effectiveness of AI in supporting clinical decision-making. The treatment personalization category captures AI's role in tailoring medical interventions. Indicators such as treatment customization rate, average time for personalized diagnosis, and percentage of customized treatments with positive outcomes measure the degree to which AI-driven tools enhance precision medicine and individualized patient care.

In summary, the set of KPIs presented in Table 1 provides a comprehensive assessment of AI integration in healthcare organizations, allowing for performance monitoring and optimization of AI-driven interventions across multiple areas.

Table 1: A set of KPIs for evaluating AI integration in healthcare organizations

Category	**Indicator**
Productivity	Average treatment cost per patient
Productivity	Patient turnover rate
Productivity	Patient load per clinician (total number of treated patients per clinician over a period/supporting staff)
Operational Efficiency	Admission rate
Operational Efficiency	Average waiting time (in waiting list)
Operational Efficiency	Average length of stay
Operational Efficiency	Scheduling accuracy (number of appointments completed on time without delays or overlaps/total number of scheduled appointments)
Operational Efficiency	Operating room idle time (percentage of unutilized operating room time)
AI Predictive Maintenance	Resource utilization rate (total operating time of a machine over a period/total available operational time)
AI Predictive Maintenance	Equipment failure rate (total number of machine failures over a period/total operating time of the machine)
AI Predictive Maintenance	Average maintenance cost per equipment unit (total maintenance cost for a machine over a period/total number of maintenance interventions)
Supply Chain	Lead time
Supply Chain	Stockout rate (percentage of times a product is unavailable)
Supply Chain	Expired stock rate (percentage of expired stock relative to total inventory)
Supply Chain	AI-driven test optimization rate (actual number of tests leading to confirmed diagnoses/total AI-recommended tests)
Employee Engagement and Well-being	Patient satisfaction rate (number of satisfied patients/total number of surveyed patients)
Employee Engagement and Well-being	Absenteeism rate (total number of absent days for an employee/total working days)
Employee Engagement and Well-being	Employee turnover rate (number of employees who left during the period/average number of employees during the period.)
Employee Engagement and Well-being	Staff weekly workload (average weekly hours worked per staff member.)
Clinical Outcomes	Medical error rate (total number of reported medical errors in a period/total number of treated patients)
Clinical Outcomes	Clinical relapse rate (number of patients readmitted for the same condition in a period/total number of discharges)
Clinical Outcomes	Avoidable hospitalization rate (number of avoidable hospitalizations due to AI-driven personalized prevention/total number of hospitalizations)
Clinical Outcomes	Early diagnosis rate (number of AI-supported diagnoses matching final confirmed diagnoses/total number of AI-supported diagnoses)
Clinical Outcomes	AI diagnostic accuracy rate (number of early diagnoses/total number of diagnoses)
Clinical Outcomes	Average AI-assisted diagnosis time (Average time for AI-assisted diagnosis/average time for traditional diagnosis)
Treatment Personalization	Treatment customization rate (number of customized treatments/total number of treatments)
Treatment Personalization	Average time for personalized diagnosis (total time spent on personalized diagnoses/total number of personalized diagnoses)
Treatment Personalization	Percentage of customized treatments with positive outcomes (number of customized treatments with positive outcomes/total number of customized treatments)

6 Concluding remarks and future research directions

Integrating AI technologies seems to hold significant potential to enhance healthcare services by optimizing resource allocation strategy and service quality. However, empirical validation of the positive impact of AI in healthcare organizations remains limited, both in clinical and management practice. To address this gap, this study provides a set of KPIs designed to evaluate the actual impact of AI implementation in healthcare settings.

The CLD presented, functional to the development of the relevant KPIs, offers a structured and visually intuitive framework for understanding the complex dynamics influencing healthcare organizations and for highlighting the causal interdependencies identified by the literature. The CLD highlights causal

interdependencies identified in the literature, particularly focusing on two emerging themes: AI-driven resource allocation and PHC.

The proposed KPIs are intended to guide future research, as well as help managers assess the actual impact of AI implementation in healthcare settings. The insights from this study offer guidance for healthcare managers seeking to assess and integrate AI technologies to enhance strategic decision-making in healthcare organizations. By providing managers with specific indicators to objectively measure and evaluate the impact of AI implementation, decision-making capabilities are strengthened, ensuring that AI adoption aligns with organizational goals and delivers tangible benefits regarding operational efficiency, resource allocation, and service quality.

However, this research relies on literature review and a systems thinking approach to analyze the possible relevant relationships stemming from AI integration in healthcare organizations. This approach, while insightful, does not substitute for direct stakeholder inputs. Additionally, contextual differences among healthcare systems and the rapid evolution of AI technologies suggest that the current framework may require further adaptation. Moreover, the KPIs proposed in this study are theoretical and have not yet been empirically tested. Future research should focus on empirically refining the KPI set through research incorporating both quantitative performance data and qualitative feedback from healthcare professionals and patients. Such studies would not only confirm the effectiveness of AI-driven interventions but also uncover potential ethical, regulatory, and organizational challenges.

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8 Ethics declaration

Ethical approval was not required for this study as it did not involve the use of personal or sensitive data.

9 AI declaration

No AI tools were used in the development of this paper.

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Evaluating Holistic Socio-Environmental Impact of Digital Health: Scoping Review of Decision-Making Frameworks

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Abstract

The 2030 Agenda for Sustainable Development highlights the transformative potential of digital technologies in accelerating human progress, reducing inequalities, and fostering sustainable knowledge societies. Within this context, Digital Health (DH) is recognized for enhancing healthcare systems' effectiveness, resilience, and equity—especially in addressing environmental and climate-related challenges. While various assessment methodologies exist—such as Health Technology Assessment, Health Impact Assessment, Social Impact Assessment, and Environmental Impact Assessment—the literature lacks reviews that explore the social and environmental impacts of DH. These dimensions are critical for evaluating healthcare systems' broader performance and alignment with long-term sustainability goals. This scoping review aims to map and synthesize existing frameworks and tools for evaluating the impact of DH, particularly in relation to social and environmental outcomes. The review is structured around the Sextuple Aim Framework, which extends the traditional Triple Aim by adding environmental impact. Following JBI methodology and PRISMA-ScR guidelines, searches were conducted in PubMed, Scopus, and the Cochrane Database. Eligible studies were published in English between 2014 and 2024 and had to address at least three of the six aims: Population Health, Experience of Care, Capital Cost, Care Team Well-Being, Health Equity, and Environmental Impact. Out of 8,243 identified records, 53 met the criteria and were included in the final review. None addressed all six aims comprehensively. Most studies focused on DH (30.19%) and m-Health (28.30%), with emerging technologies like AI and VR also represented. The most assessed aims were Experience of Care (98.11%) and Population Health (94.34%), while Environmental Impact appeared in only 11.32% of studies. Through thematic analysis, 157 unique items were identified, categorized into 17 domains, 62 topics, and 78 issues. The most developed topic was Experience of Care, particularly User Engagement and Process-related costs. In contrast, Environmental Impact was the least developed, with only two domains: carbon footprint and the clarity of environmental consequences of technologies. This review contributes to the development of a theoretical framework for evaluating the holistic impact of DH. By highlighting gaps—particularly in environmental and social dimensions—it supports more informed, balanced decision-making in DH strategies aligned with sustainability and equity principles.

Keywords: Digital Health, Performance Measurement, Artificial Intelligence, Social Impact Assessment, Environmental Impact Assessment.

Paper type: Academic Research Paper

1 Introduction

According to the World Health Organization, Digital Health (DH) includes the development and use of digital technologies to improve health. This field extends beyond e-health to involve digital consumers interacting with various smart devices and connected equipment. It also incorporates applications such as the Internet of Things, artificial intelligence (AI), big data, and robotics (WHO,2021).

The 2030 Agenda for Sustainable Development highlights that information, and communications technology can significantly accelerate human progress, bridge the digital divide, and foster knowledge societies. Literature indicates that DH can disrupt healthcare systems, enhancing their capacity, effectiveness, resilience, and equity in response to environmental and climate challenges (WHO, 2022). The ongoing digital revolution presents opportunities for product dematerialization, efficient resource utilization, and improved supply chain management, with DH recognized as essential for achieving sustainable development (Manjurul et al., 2022). When effectively integrated into healthcare systems, DH enables remote patient monitoring, virtual consultations, and personalized care improvements (Thompson M, 2021). Overall, DH can improve access to care by ensuring timely delivery of health services, facilitating access for rural and urban communities, addressing the needs of medically underserved areas, connecting patients with appropriate specialists, and increasing provider capacity (Hollander J et al., 2017). Despite global warming approaching the 1.5°C limit set by the Paris Agreement (2015), and the documented indirect effects of climate change on social equity and health

recognized by the WHO (2014), evaluating the environmental and social implications of health technology remains a voluntary choice for individual healthcare organizations. This evaluation is sometimes conducted through reports based on Corporate Social Responsibility models (Bowen, 1953), which define clear social goals, outline actions, and monitor results. One notable model is the Triple Bottom Line, introduced by Elkington (1999), which expands the traditional profit-loss perspective to include financial, social, and environmental dimensions. Currently, the most comprehensive approach for evaluating digital solutions is Health Technology Assessment (HTA), a multidisciplinary process that aims to determine the value of health technology throughout its lifecycle. HTA informs decision-making to promote equitable, efficient, and high-quality health systems, and includes over twenty recognized frameworks for digital solutions (O'Rourke et al, 2020). However, when examining social impacts, HTA tends to focus on a narrow range of concerns. A review of the HTA Core Model® (Lampe K., 2009). shows that related questions primarily evaluate implications for patients, caregivers, and targeted social groups. The Ethics domain addresses the "Benefit-harm balance," assessing the technology's benefits and harms for various stakeholders. This evaluation is often performed descriptively rather than through integrated assessment methods, using literature reviews, expert opinions, and stakeholder hearings Additionally, there is limited formal reference to the environmental impacts of technology, mostly focusing on safety and emissions of chemical substances (Vis ET al.2020). A report from Cambridge University confirms this, indicating that of 1,710 HTA articles, only two provided frameworks for incorporating environmental assessments, while others mainly described evidence-weighting practices (Marsh et al, 2016).

Given these limitations, applying more holistic methodologies for impact assessment in healthcare, such as Health Impact Assessment (HIA), Social Impact Assessment (SIA), and Environmental Impact Assessment (EIA), may be beneficial. These methodologies follow similar approaches: they determine the potential impacts, gather data to understand the current context, predict changes resulting from a project, and make recommendations to maximize benefits and minimize harm. Each methodology focuses on different aspects; EIA examines effects on the biophysical environment, SIA looks at social and economic impacts, and HIA considers community health impacts (Ross et al, 2014). These evaluation methods can enhance the recognition of the value created by DH in terms of reimbursement and accountability, as suggested by the Value-Based Health Care (VBHC) approach (Zhang et al,2025). The costs associated with implementing, adopting, and maintaining DH technologies remain significant challenges for healthcare organizations and authorities and can hinder innovation (Whitelaw et al., 2021). Porter's (2009) VBHC framework proposes a new competitive approach in healthcare, focusing on the value generated per money spent. According to Porter, VBHC principles have significant implications for reimbursement, suggesting that the reimbursement unit should align with the value unit. Over the past 20 years, the definition of value has increasingly included stakeholders involved in healthcare services (Berwick et al., 2008; Dipti, 2021). The new "Sextuple aim" framework (6AF) introduced by Alami et al. (2023) after the COVID-19 pandemic, recognizes the importance of valuing effective patient care, cost management, provider support, population health, equity, and environmental issues. Despite the various methodologies described, previous searches in PubMed, Scopus, Web of Science, and the Cochrane Database of Systematic Reviews indicate a lack of reviews assessing the literature on social and environmental impact assessments of DH. Therefore, this scoping review's main objective is to summarize the methodologies and frameworks used for impact assessment of DH, focusing on the social and environmental impacts while aligning with the six aims of VBHC. Based on this goal, we raised the following review questions (RQs):

- *RQ 1. Contribution types*: How many sources have presented new frameworks, methods/techniques, tools, metrics, or processes for the assessing of the social and environmental impact of DH?
- *RQ 2. Holistic approach:* How many sources adopt holistic approach and allow evaluation of three or more aim of the 6AF VBHC framework?
- *RQ 3. Value domains:* Mapping of domain, topic and issue that contribute to assessment of (Figure 1):



Figure 1: The Sextuple Aim framework (Alami et al.2023)

2 Methods

This scoping review was performed adhering to Joanna Briggs Institute's (Munn et al.,2020) methodology for scoping reviews and complies with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis extension for scoping reviews guidelines (PRISMA-ScR) (Tricco et. al 2018).

2.1 Search Strategy

The Population, Concept, and Context (PCC) framework guided the formulation of the query and eligibility criteria (Munn et al.,2020):

Population: This review will consider studies involving individuals engaged in DH solutions, without requiring specific conditions or characteristics of the population.

Concept: The review will include studies that evaluate the impact of DH in alignment with three or more of the six aims of the VBHC framework.

Context: The review will encompass studies conducted within the last ten years in any context where DH technologies are utilized. To determine eligible technologies, we will apply the WHO (2021) definition of DH technologies, which includes the Internet of Things, virtual care, remote monitoring, artificial intelligence, big data analytics, blockchain, smart wearables, and platforms that facilitate data exchange and storage. These tools enhance health outcomes by improving medical diagnoses, enabling data-driven treatment decisions, facilitating digital therapeutics and clinical trials, supporting self-management of care and person-centered approaches, and contributing to evidence-based knowledge and skills for healthcare professionals.

Based on the search strategy outlined below, the following search query (Figure 2) was created:

((“digital health”) OR (“telehealth”) OR (“ehealth”) OR (“mhealth”) OR (“telemedicine”) OR (“mobile health”) OR (“big data”) OR (“blockchain”) OR (“health data”) OR (“health information systems”) OR (“infodemic”) OR (“Internet of Things”) OR (“interoperability”)) AND (((“technology assessment”) OR (“health technology assessment”) OR (HTA) OR (“social domain”)) OR ((impact assessment*) OR (impact*) OR (“health impact assessment”) OR (HIA)) OR ((“social impact assessment”) OR (“social impact*”) OR (equity) OR (“social change*”) OR (“social development”) OR (SIA)) OR ((“community impact”) OR (“patient impact”)) OR ((greenhouse) OR (“environmental sustainability”) OR (emissions) OR (“carbon footprint”) OR (“climate change”) OR (“pollution”)) OR ((“Social Return On Investment”) OR (SROI))) AND ((framework*) OR (methodology*)).

Figure 2: Search Strategy

This query was utilized in December 2024 to search the title and abstract fields of all records in PubMed, Scopus and the Cochrane Database of Systematic Reviews. The search strategy, including all identified keywords and index terms, was adapted for each database and information source. Studies published in English and Italian within the last ten years (2014-2024) were included, with no exclusions based on study type.

2.2 Data Extraction

All records identified through database searches were retrieved and stored using the Rayyan platform, where any duplicates were removed. Two researchers independently screened the articles in a blinded manner, following pre-established inclusion and exclusion criteria to ensure an unbiased selection process. Data were extracted from the articles, using a data extraction table designed to align with the review's objectives and research questions. The extracted data included the author, year, and country of the study, the technology assessed, the aims covered in the assessment, and the items used to evaluate the impact of DH. Through a thematic analysis (Clarke et al. 2014), the identified items were subsequently examined to eliminate duplicates and classify them based on their corresponding VBHC aim.

In the final phase, the selected items were categorized into the classes proposed by Deckers et al. (2022):

- Domain: Represents the broad areas of interest affected by the health technology.
- Topic: Refers to specific aspects or subjects within a domain that are relevant to the evaluation.
- Issue: Indicates questions or concerns that arise within a topic and need to be addressed.

Any discrepancies regarding article selection, data extraction, and analysis were discussed and resolved through group consensus among an expert in HTA and AI, an expert in SIA, an expert in DH, and an expert on Big Data.

3 Results

Given the increasing attention to DH over the past decade, the initial search returned 8,243 records. After removing 3,176 duplicates, 5,067 articles were screened by title and abstract. Following this first screening, 106 full-text reports were assessed for eligibility. Of these, 53 reports were included in this scoping review, as they addressed at least three of the six aims of VBHC framework. The inclusion process is detailed in the PRISMA flowchart shown in Figure 3.

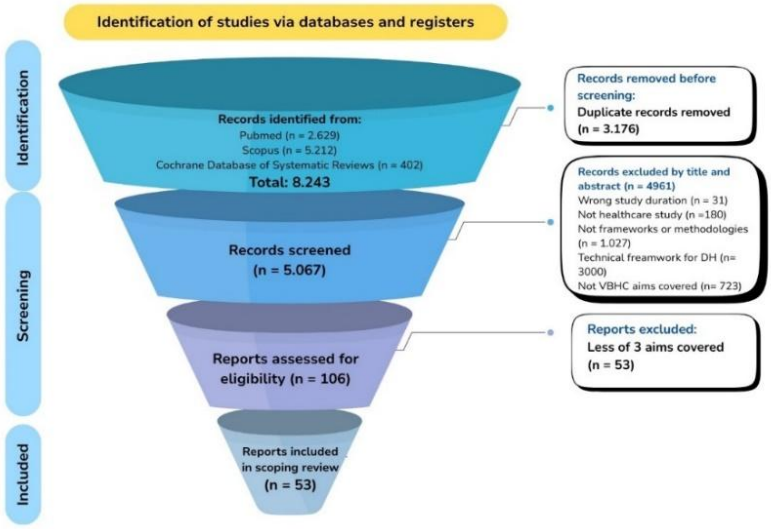


Figure 3: PRISMA Flowchart

3.1 Description of the included reports

As shown in the geographical distribution map (Figure 4), most studies (37.74%) originated from Europe. Within Europe, England contributed 9.47% of the studies, followed by Switzerland (7.55%) and Italy (3.77%). North America contributed 30.19% of the studies, primarily from the USA (24.53%). Oceania accounted for 11.32% of the studies, mainly from Australia. In terms of publication trends, there was a notable increase in studies published during the COVID-19 pandemic, with peaks in 2019 (15.38%) and 2020 (17.31%), reflecting heightened interest during the global health crisis. Additionally, a second peak was observed in 2024 (17.31%), likely influenced by anticipated developments in AI and HTA regulations. In terms of technological focus (Figure3), the studies primarily addressed DH (30.19%), m-Health (28.30%), and Telemedicine (20.75%). Emerging technologies were also represented, with AI (7.55%). Other topics, each contributing 1.89%, included Big Data, Chatbots, Virtual Reality, Wearables, Connected Care, e-Health, and integrated approaches combining m-Health, AI and Robotics.

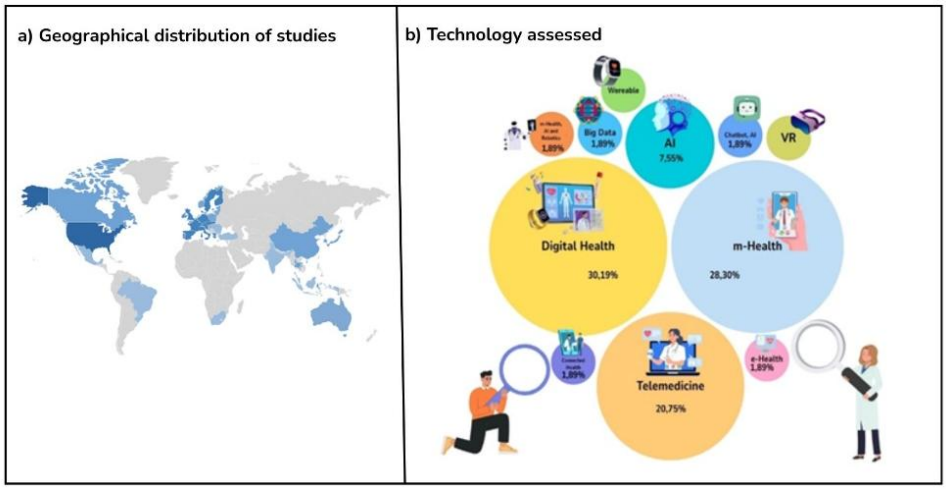
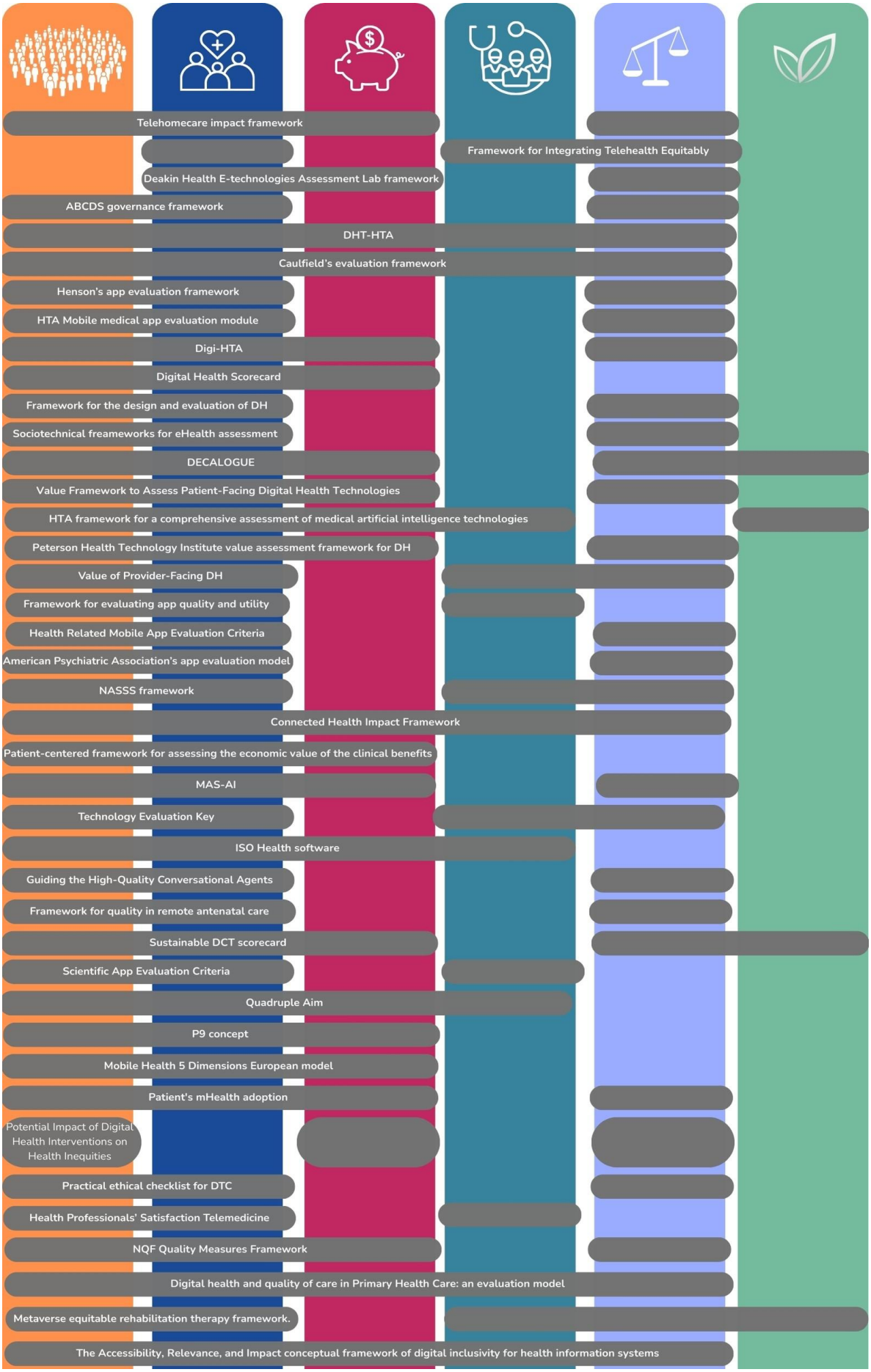


Figure 4: Description of reports: a) Geographical distribution of studies; b) Technology assessed


Telehomecare impact framework
Framework for Integrating Telehealth Equitably
Deakin Health E-technologies Assessment Lab framework
ABCDS governance framework
DHT-HTA
Caulfield's evaluation framework
Henson's app evaluation framework
HTA Mobile medical app evaluation module
Digi-HTA
Digital Health Scorecard
Framework for the design and evaluation of DH
Sociotechnical freameworks for eHealth assessment
DECALOGUE
Value Framework to Assess Patient-Facing Digital Health Technologies
HTA framework for a comprehensive assessment of medical artificial intelligence technologies
Peterson Health Technology Institute value assessment framework for DH
Value of Provider-Facing DH
Framework for evaluating app quality and utility
Health Related Mobile App Evaluation Criteria
American Psychiatric Association's app evaluation model
NASSS framework
Connected Health Impact Framework
Patient-centered framework for assessing the economic value of the clinical benefits
MAS-AI
Technology Evaluation Key
ISO Health software
Guiding the High-Quality Conversational Agents
Framework for quality in remote antenatal care
Sustainable DCT scorecard
Scientific App Evaluation Criteria
Quadruple Aim
P9 concept
Mobile Health 5 Dimensions European model
Patient's mHealth adoption
Potential Impact of Digital Health Interventions on Health Inequities
Practical ethical checklist for DTC
Health Professionals' Satisfaction Telemedicine
NQF Quality Measures Framework
Digital health and quality of care in Primary Health Care: an evaluation model
Metaverse equitable rehabilitation therapy framework.
The Accessibility, Relevance, and Impact conceptual framework of digital inclusivity for health information systems

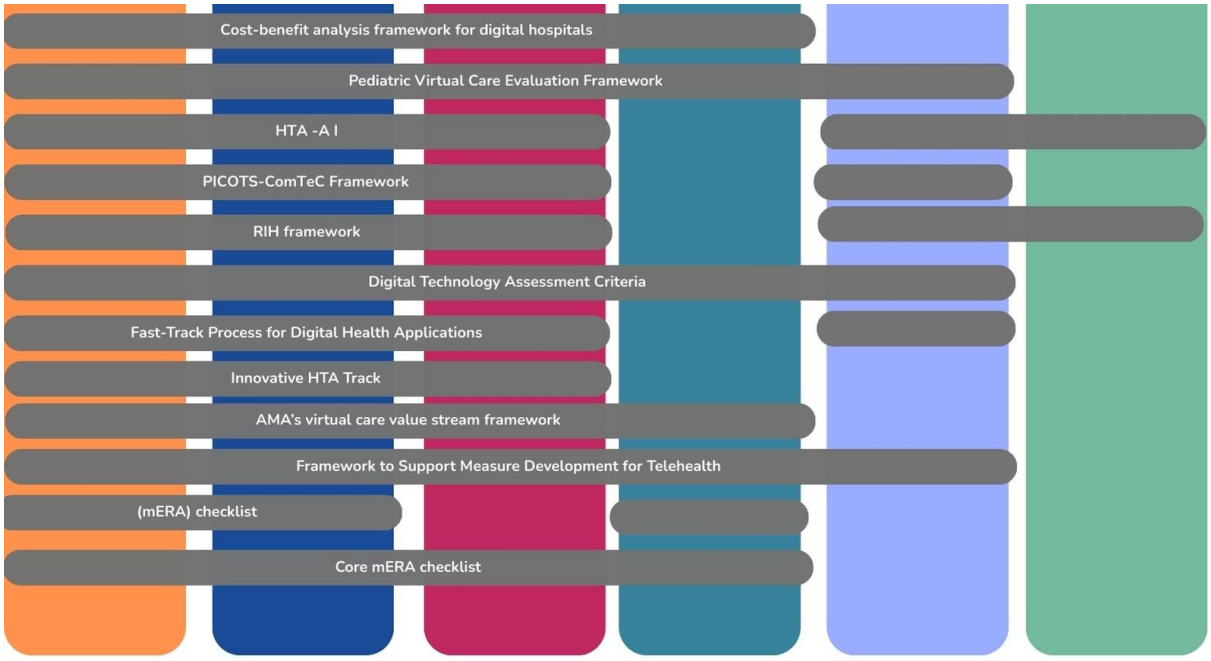


Table 5: Frameworks, tools, and methodologies included, and Aims covered

As shown in Figure 5, the most frequently assessed aims were Experience of care (98.11% of studies) and Population Health (94.34%). These were followed by Equity (71.70%) and Capital cost of health care (64.15%). Fewer than half of the studies (43.40%) considered the importance of care team well-being, and only six studies (11.32%) included an environmental assessment in their methodology. Only 13 studies adopted a more holistic approach to the assessment of DH; however, none addressed all six aims comprehensively.

3.1 Items identified and their categorization in Domain, Topic and Issue

Through a thematic analysis, 163 items were initially identified as relevant to the evaluation of the six aims. After eliminating duplicates, the final list was reduced to 157 unique items. These items were further refined and categorised into three classes: Domains (n = 17), Topics (n = 62), and Issues (n = 78). Following a review by an expert panel, the accepted items were assigned to their respective categories and aligned with the most appropriate of the six aims. This process led to the development of the Holistic Impact Framework for Digital Health, shown in Figure 6. Experience of Care is the most extensively developed within the literature, comprising 3 domains, 10 topics, and 39 issues. The domain with the highest number of topics and level of detail is Process-Related Cost, which includes 9 topics. The most thoroughly described topic in terms of issues is User Engagement for patients, families/caregivers, and the care team, with 9 issues. In contrast, Environmental Impact is the least developed, containing only two domains: Carbon Footprint and Clearness of technology environmental impact. The top five of domain most cited in the assessment of the DH are Accessibility (37,74% of studies); User engagement (18,87%), Cost assessment (16,98%), Quality of care and Safety (9,43%), Patient experience and Quality of life (7,55%). While the topic most citated are Ease of use (13,21% of studies) and Digital Health Literacy (7,55%).

HOLISTIC IMPACT FRAMEWORK OF DIGITAL HEALTH

I Aim - Population Health

Domain	Topic	Issue
Desease burden	Effect on mortality	Life expectacy
	Effect on disability	Number of years lost due to disability
	Effect on quality of life	Quality-adjusted life years saved
	Behavioural	Intention ; Life style changes; Disease onseat and severity
	Relevance	Purpose; Congruence; Credibility; Utility; Trastwortiness

III Aim - Capital cost of the Health Care

Domain	Topic
Financial burden for patient/family/ caregiver	Cost of device/service
	Cost of internet
	Cost of maintenance
Process related cost burden	Purchase Price
	Labour cost (h-team, engeeneers, technical, admistration and support staff)
	Cost of device and delivery
	Development & Implementation cost
	Mantainance and support cost
	Training cost
	Operational cost
	Uptake cost
	Economic/financial sustenability of technology
Cost-opportunity	Trasport reduction of h-team
	Cost savigs for staff turn-over
	Time savigs of staff in daily work
	Reduction of hospital and emergency department (ED) utilization rate
	Improve the number of custmers/patient
Cost assessment	Frugality
	Cost - effectivness
	Cost- utility
	Cost - Benefit
Financial burden	R&D
	Investment
	Regulatory cost

III Aim - Capital cost of the Health Care

Domain	Topic
Access to care	Availability across platform
	Financial burden for user
	Coverage (improve access in rural settings)
	Offline functionality
	Waiting time
	Fairness
	Corruption
Accessibility	Comprehensibility (Language availability, Linguistic accuracy,Numeracy ,Visual Interpretation, Font type and syze)
	Customizability
	Inclusivity
	Cultural appropriateness and political will
Advocacy	Stakeholder involvment
	Influence and endorsement between peers
	Motivation & Empowerment
	Social support
Skill equity	Health Litteracy
	Digital Health Litteracy

II Aim - Experience of care

Domain	Topic	Issue
User satisfaction (patient and family/caregiver)	Acceptability	Capacity to use ; Future use; Net promoter score ; Usability (short and long); Impression first and after using
	Aesthetics	Background color and content , button color, shape, icon ; Flexibility; Tailoring
	Easy of use (service and tech)	Interaction quality; Intuitive; Integration; Functionality
	Relationship aspect	Emphaty; Humanistic care; Patient/cargiver - clinician encounter; Patient - carer dependency
Quality	User engagement	Co-design; Collaboration and end-user participation; Adoption imput; Communication and information sharing ; Gamification or entrateinment; Persuasivness; Self-management ; Autonomy in health related decision ; User control
	Effectivness	Adherence; Apropriatness of service; Apropriatness of response; Context awereness; Continuity of care; Feasibility
	Safety	Tech reliability ; Accuracy ; Precision
	Timely	Time to event (to treat or decision); Timely assess to care and waiting time
Quality of life	Impact on morbidity	Life year saved
	Social aspect	Relationship (i.e. family dynamics, friends, and other relevant social relations); Patient dignity

I Aim - Population Health

Domain	Topic	Issue
H-team satisfaction	Acceptability	Capacity to use; Cultural appropriateness and political will; Net promoter score; Usability (short and long); Impression first and after using
	Impact rispect the h-team work	Agile ways of working ; Team work
	Aesthetics	Background color and content , button color, shape, icon ; Flexibility ; Tailoring
	Easy of use (service and tech)	Interaction quality ; Intuitive; Integration; Functionality
	Relationshisp aspect	Emphaty ; Humanistic care; Clinician - patient/caregiver encounter ; Relationship beetween peer; Relationship (i.e. family dynamics, friends, and other relevant social relations)
H-team experience	User engagement	Co-design; Collaboration and end-user participation; Adoption imput; Communication and information sharing ; Gamification or entrateinment; Persuasivness; Self-management ; Autonomy in health related decision; User control



III Aim - Capital cost of the Health Care

Domain
Clearness of tecnology environmental impact
Carbon footprint

Figure 6: Holistic Impact Framework for DH

4 Discussion and Conclusion

Our research highlights a growing attention to the evaluation of the socio-environmental impact of DH in the healthcare sector. This review contributes meaningfully to the scientific debate by offering a critical mapping of existing evaluation approaches and identifying key gaps—particularly in the social and environmental dimensions. While our findings reveal a wide range of methodological tools, none of the studies examined addressed all six value dimensions. Notably, the aims of "patient experience" and "population health" are the most represented, appearing in 98.11% and 94.34% of the studies, respectively. In contrast, environmental impact is largely overlooked, appearing in only 11.32% of the studies and limited to a narrow set of issue, such as carbon footprint and environmental transparency. This imbalance points to a persistent reliance on evaluation models centred on clinical and economic factors, often at the expense of a more holistic understanding of the value DH can generate in healthcare.

Even within the most frequently covered areas, relevant gaps remain. For example, when considering the impact of DH on the Care Team, studies tend to focus narrowly on aspects of experience and engagement, often neglecting the broader concept of well-being. Yet the IV aim of VBHC stresses the need to address the physical, psychological, and emotional health of healthcare professionals. A growing body of literature—especially from the COVID-19 period—highlights the impact of DH in terms of technostress and burnout (Golz et al., 2021).

The still limited adoption of integrated methodologies such as HIA, SIA, and EIA underscores the need for a cultural and methodological shift. Moving beyond siloed perspectives requires fostering collaboration across sectors, where corporate social responsibility frameworks help demonstrate social value through credible and measurable approaches. Moreover, to bridge the environmental evaluation gap, it is essential to incorporate standardized environmental metrics into HTA processes; strengthen collaboration between HTA and sustainability experts; and promote an evaluation culture oriented towards shared value and sustainability, consistent with the objectives of the 2030 Agenda. These steps are critical to ensuring that DH not only improves care but also contributes to social well-being and environmental stewardship, consistent with a triple-bottom-line perspective.

Indeed, the holistic framework proposed, enriched with currently underrepresented environmental aspects, offers a valuable tool for a more comprehensive evaluation of DH innovations, supporting informed and balanced decision-making. By broadening the evaluative lens beyond cost-effectiveness and clinical outcomes, it empowers decision-makers to integrate sustainability and equity criteria into policy and investment choices. Furthermore, it can support prioritization processes by helping stakeholders identify technologies that deliver not only technical value but also societal and environmental benefits. Future studies should aim to expand and refine this framework by addressing neglected yet crucial issues and dimensions—particularly those rooted in a triple-bottom-line perspective that, while scientifically grounded, are still rarely assessed in practice. This requires the active engagement of all stakeholders involved in the lifecycle of DH technologies, from design to implementation and evaluation. Incorporating diverse perspectives—including those of healthcare professionals, patients, policymakers, industry representatives, and environmental experts—can help ensure that value assessments truly reflect the multifaceted impacts of digital innovations.

Ultimately, empowering stakeholders to participate meaningfully in the evaluation process means giving voice to those most affected by technological change—transforming assessment from a top-down exercise into a shared responsibility that enhances legitimacy, accountability, and impact in DH decision-making.

5 Ethic declaration

This study does not involve human participants, animals, or sensitive data, and therefore no ethical approval was required.

6 AI Use declaration

Rayyan AI was used to support article screening and deduplication. Xmind AI was used to generate the mind map that visually presents the Holistic Impact Framework. All outputs were reviewed and refined by the authors.

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Exploring Cardiologists' Perspectives on Wearable ECG Devices: Evidence from an E-focus Group

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Abstract

This study explores the propensity of cardiologists to adopt wearable electrocardiogram (ECG) devices in cardiovascular patient care. Using a qualitative exploratory design, we conducted e-focus group sessions to gather in-depth insights into cardiologists' perspectives. This approach enabled both individual reflections and group interaction, revealing diverse opinions on the clinical usefulness and integration of wearable ECG technology. The findings revealed varying attitudes toward the use and perceived value of wearable ECG devices. Several key factors were identified as influencing cardiologists' openness to adopting such technologies, including perceived usefulness, technical accuracy, the reliability of results, the availability of resources within healthcare organizations, the dynamics of the doctor-patient relationship, and individual patient characteristics.

The study underscores the importance of a multi-dimensional strategy to support the integration of wearable technologies in cardiovascular care. While wearable ECG devices hold significant potential to improve cardiovascular health monitoring, strategic planning and supportive infrastructure are vital to ensure their effective and sustainable implementation in clinical practice.

Keywords: Wearable technology, ECG, cardiologists' perspective, propensity to adopt

Paper type: Academic Research Paper

1 Introduction

The integration of smart health-monitoring technologies into daily life has transformed how individuals and healthcare professionals interact with health-related data. These innovations, particularly minimally invasive smart devices, are increasingly used to track vital physiological indicators such as blood oxygen levels (SpO_2) and heart rate. The ability to generate and access this information in real time enables more proactive, data-driven healthcare, benefiting both patients and clinicians.

Smart wearable devices now span a wide range of formats. As classified by the International Electrotechnical Committee, these technologies fall into four categories: (i) near-body wearables, (ii) on-body wearables, (iii) in-body wearables, and (iv) electronic textiles. Devices such as fitness trackers, smartwatches, smart bands, health-enabled earphones, and smart patches are widely available and commonly used. Although many of these were not initially intended for clinical use, recent advancements have expanded their functionality to include real-time health monitoring. For instance, some smartwatches can now measure heart rhythms and perform electrocardiograms (ECGs), making them increasingly relevant in cardiovascular care. The data these devices collect is typically transmitted to connected applications and stored on cloud platforms, facilitating continuous monitoring and medical analysis.

Among these smart technologies, wearable ECG devices stand out for their potential role in cardiovascular health management. As reported by Elbey et al. (2021, pag. 5), "*while composite 12-lead ECG, Holter monitor, implantable loop recorders, or patch recording are the standards for AF detection, photoplethysmography based smartwatch technology is a simple, efficient, and non-inferior alternative that may expedite detection and treatment of subclinical AF, preventing morbidity and mortality from stroke and cardiovascular disease*". Despite promising technological capabilities, their integration into clinical practice presents challenges, particularly concerning the perceptions and acceptance among healthcare providers. As frontline decision-makers in heart health, cardiologists play a pivotal role in determining how and whether such tools are adopted in routine care.

This study aims to investigate how cardiologists view the use of wearable ECG devices in the context of cardiovascular patient management. By employing an e-focus group method, we gather rich qualitative insights into their attitudes, concerns, and the factors that shape their willingness to adopt these tools. The findings contribute to ongoing discussions on digital health transformation and provide practical recommendations for enhancing the clinical adoption of wearable ECG technologies.

2 Theoretical background

The emergence of wearable technologies in healthcare has significantly reshaped how health data is captured, interpreted, and utilized, particularly in the domain of cardiovascular monitoring. These technologies offer continuous, non-invasive tracking of vital parameters, fostering earlier detection of conditions and improved patient engagement. In this context, wearable electrocardiogram (ECG) devices have garnered considerable attention for their ability to record heart rhythms in real time and support the early identification of cardiac anomalies.

Several studies have explored the clinical reliability and diagnostic potential of wearable ECG tools. For instance, Kamga, Mostafa, and Zafar (2022) highlight the effectiveness of these devices in detecting arrhythmias and their overall comparability with traditional ECG equipment used in clinical settings. Wearable ECGs have been shown to enable timely diagnoses, increase the detection of atrial fibrillation (AF), and contribute to a reduction in emergency department visits. However, the authors also noted that while these benefits exist, they may come with increased healthcare costs. Similarly, Evans et al. (2017) emphasize the relevance of wearable ECGs in resource-constrained environments, particularly for AF screening, where they serve as accessible tools capable of identifying undiagnosed cases.

Beyond their clinical capabilities, wearable ECG technologies intersect with healthcare delivery dynamics, especially from the perspective of medical professionals. Aiello et al. (2022), through a qualitative study involving ten medical experts across diverse specialties, found that the majority perceived wearable devices as enhancing patient engagement and involvement in their own care. This finding aligns with the broader notion that digital health tools can facilitate more participatory healthcare experiences.

From a behavioural and organizational standpoint, the adoption of wearable health technologies by clinicians is influenced by various factors. Yao et al. (2023) conducted a large-scale survey with over 1.000 Chinese general practitioners and identified several key predictors of adoption intent. Performance expectancy, affordability, and social influence positively shaped practitioners' willingness to integrate wearable ECGs into clinical practice. As stated by Sana et al. (2020), the implementation of wearable health technologies in the general population is paving the way for new paradigms of healthcare and personalised medicine. However, perceived risks—such as concerns over data accuracy, privacy, and technology reliability—emerged as significant barriers. Additionally, Ferguson et al. (2021), highlighted the presence of many barriers and facilitators to the acceptance of wearable devices based on the skills of health professionals, older adults, and carers, by suggesting that the most important aspects related to the user-friendly technology, the design aspects of the devices, proper and timely feedback, and issues related to affordability and cost.

While substantial literature exists on the technical and patient-centered aspects of wearable ECGs, fewer studies have focused specifically on the perceptions of cardiologists, the primary clinical experts responsible for diagnosing and treating cardiovascular conditions. Given their specialized role, cardiologists are likely to assess wearable technologies through a more critical lens, considering both diagnostic rigor and the potential impact on clinical workflows and patient relationships. Understanding these perspectives is essential to designing more effective integration strategies and addressing barriers to widespread adoption in cardiovascular care.

3 Methodology

This study adopts a qualitative exploratory design to investigate cardiologists' perceptions and experiences related to the use of wearable ECG devices in cardiovascular care. Given the emergent nature of this technology in clinical practice and the need for in-depth understanding, we employed an e-focus group methodology. This approach enables the exploration of both individual views and group dynamics, providing richer insight into shared concerns, attitudes, and decision-making processes (Ruff, Alexander, and McKie, 2005; Easton, Easton, and Belch, 2003).

3.1 Sample selection and research design

Participants were selected using a combination of purposive and convenience sampling to ensure relevance and accessibility. The inclusion criteria required participants to be practicing cardiologists with experience in either public or private healthcare settings. A total of eight cardiologists (five men and three women) from Sicily, Italy, participated in the study. Their socio-demographic profiles, including gender, years of professional experience, healthcare setting, and area of specialization, are presented in Table 1.

The e-focus group was conducted on the Microsoft Teams platform, which, having no time limits, did not interrupt the flow of the discussion. Moreover, the platform allowed geographically dispersed professionals to participate in a flexible and convenient setting. Each participant was provided with a login to the virtual room

and instructions on how to proceed. They met in the virtual room at a pre−defined date and time. The session lasted 2.5 hours and was moderated by a trained facilitator using a semi-structured discussion guide inspired by the guidelines of Krueger (1998a). The moderator began with a broad, open-ended question and gradually introduced targeted prompts to encourage deeper discussion. A co-facilitator documented verbal and non-verbal cues, while the session was audio-recorded, with participants' consent for transcription and analysis.

Table 1: Key Information About the E-Focus Group's Participants

ID	Gender	Age	Operational City	Institution Type	Use of ECG Wearable Devices	Years of Experience
P1	Female	45	Palermo	Private	Yes	16
P2	Male	36	Messina	Public	Yes	5
P3	Male	48	Messina	Private	Yes	20
P4	Male	54	Messina	Private	Yes	27
P5	Male	41	Messina	Public	Yes	8
P6	Female	53	Messina	Public	No	25
P7	Male	64	Messina	Private	No	35
P8	Female	48	Messina	Private	No	20

Source: Authors' elaboration

3.2 Data analysis

Audio recordings and transcripts were reviewed iteratively to identify recurrent themes and significant statements. Thematic analysis was used to code responses and organize insights into core categories. Following Krueger's (1998b; 1998c) guidelines, a brief oral summary of the discussion was presented at the end of the session. Participants were invited to confirm the summary's accuracy and add any additional thoughts, ensuring validity through member checking.

Four key themes emerged from the analysis:

1. the clinical use and perceived value of wearable ECGs;
2. concerns around technical accuracy and trust in data;
3. individual and institutional readiness to adopt technology;
4. implications for patient engagement and doctor–patient trust.

4 Results

The thematic analysis of the e-focus group discussions revealed a range of perspectives among the eight participating cardiologists regarding the use of wearable ECG devices in cardiovascular health monitoring. Four principal themes emerged from the data, highlighting both convergences and divergences in the participants' views.

First, participants generally acknowledged the potential clinical usefulness of wearable ECG devices, particularly in supporting preventive care and long-term patient monitoring. Several cardiologists emphasized the advantages of these devices in detecting atrial fibrillation and other heart rhythm disturbances in outpatient settings. They suggested that wearable ECGs could serve as a valuable complement to traditional diagnostic practices by enabling continuous monitoring beyond the hospital environment. Nonetheless, some participants expressed caution, noting that while wearable ECGs are beneficial for preliminary screening or symptom tracking, their application in acute or complex clinical cases remains limited compared to hospital-grade equipment.

Second, the issue of technological reliability and accuracy emerged as a prominent concern. Although some cardiologists viewed the integration of wearable ECGs positively, others highlighted limitations related to signal quality, susceptibility to artefacts, and the variability of data depending on user behavior. The participants agreed that while wearable ECGs may offer acceptable reliability for basic monitoring, their diagnostic capabilities do not yet match those of standard 12-lead clinical ECG systems. This perceived shortfall contributed to a degree of skepticism about fully integrating these devices into formal clinical workflows without further validation.

Third, the willingness to adopt wearable ECG technologies varied considerably among participants. Cardiologists working within private healthcare organizations or those more accustomed to digital technologies displayed a greater openness toward adopting wearable solutions in their practice. They noted that wearable ECGs could support remote patient management and offer additional data for clinical decision-making.

Conversely, cardiologists in public institutions expressed more hesitation, citing barriers such as the lack of technical infrastructure, potential increases in workload, and insufficient integration of wearable data into existing clinical systems.

Finally, participants discussed the implications of wearable ECG devices for the doctor–patient relationship. Some cardiologists viewed wearable technologies as tools that could enhance patient engagement, fostering greater involvement in health management and facilitating shared decision-making. Others, however, raised concerns that frequent self-monitoring might heighten patient anxiety, particularly if patients misinterpret physiological variations as pathological events. There was a consensus that successful implementation would depend heavily on educating patients about the correct interpretation of wearable ECG data and maintaining strong communication channels between healthcare providers and patients.

Overall, the results highlight a complex and multi-layered perspective among cardiologists regarding the adoption of wearable ECG devices. While acknowledging the promise of these technologies, participants emphasized the necessity of addressing technical limitations, organizational barriers, and patient management challenges to ensure effective clinical integration. A summary of key Insights from the online focus group with cardiologists on wearable ECG device is presented in the Table 2.

Table 2: Summary of Key Insights from the e-Focus Group

Thematic Area	**Key Insights**	**Relevant Quotes**
Use and Perceived Usefulness of Wearable ECG Devices	Contrasting views: some cardiologists see significant diagnostic potential, others are skeptical due to risk of false positives and limited clinical utility.	P2: "[These devices] are invaluable resources [...] unlock immense diagnostic possibilities." P6: "[...] endorsed by European Cardiology Guidelines [...] they could serve as a diagnostic tes.t" P7: "[...] capture elusive symptoms [...] incredibly useful" P3: "Patients are a bundle of nerves [...] I'd practically snatch them right off their wrists." P7: "[...] require skilled personnel [...] under which legitimacy?"
Reliability and Accuracy of the Data	Devices are seen as accurate for basic parameters (e.g., heart rate, oxygen saturation), but less so for complex ECG measurements like atrial fibrillation. General lack of validated data is a concern.	P3: "If you're asking whether the data is accurate, the answer is a resounding yes." P7: "Accuracy cannot be extremely high [...] skin surface into electrical signals." P3: "Not quite as precise as what you'd get from a hospital facility."
Willingness to Adopt These Devices in Clinical Practice	No consensus. Some cardiologists are ready to use these devices selectively, while others are not yet convinced. Decisions often depend on patient demographics and clinical profile.	P2: "I would use them selectively [...] rather than utilizing them as a screening tool." P6: "my patients are elderly [...] their use could be more detrimental than beneficial." P5: "with young patients [...] I personally advocate the use."
Impact on the Doctor-Patient Relationship	Broad agreement that preserving the quality of the doctor-patient relationship is critical. The main concern is increased patient anxiety and unnecessary interactions driven by device alerts.	P2: "[These devices] could induce a high level of anxiety [...] in search of a pathology." P3: "If I perceive his anxiety, I would not dream of recommending it." P4: "Patients only marginally perceive their real utility." P7: "No one [of my patients] has specifically asked [...] smartwatch ECG."

Source: Authors' elaboration

5 Discussion and conclusions

The findings from the e-focus group with eight cardiologists reveal a complex set of perceptions surrounding the integration of wearable ECG devices into cardiovascular care. Participants generally acknowledged the clinical potential of these technologies, particularly for the early detection of arrhythmias and the ongoing monitoring of at-risk patients outside traditional healthcare settings. Wearable ECG devices were seen as capable of complementing standard diagnostic procedures by enabling continuous data collection, which can contribute to improved patient management and preventive strategies.

Nevertheless, significant concerns were expressed regarding the technological reliability and diagnostic accuracy of wearable ECGs. While previous research has highlighted their effectiveness in detecting conditions such as atrial fibrillation (Kamga et al., 2022; Evans et al., 2017), cardiologists emphasized the gap between the reliability of consumer-grade wearable devices and that of hospital-grade 12-lead ECG systems. Participants

noted the risk of false positives, measurement artifacts, and potential misinterpretation of results, suggesting that without further clinical validation, wearable ECGs should serve as supportive tools rather than replacements for traditional diagnostic methods.

The cardiologists' willingness to adopt wearable ECG technologies varied considerably, influenced largely by their working environments and digital familiarity. Those operating in private clinics or technologically advanced settings were more receptive to incorporating wearable monitoring into clinical routines, while those in public institutions faced barriers such as limited technical infrastructure, additional workload concerns, and organizational resistance. These observations are consistent with the broader technology acceptance literature, which points to performance expectancy, resource availability, and perceived risks as critical determinants of adoption (Yao et al., 2023).

A crucial dimension discussed was the impact of wearable devices on the doctor–patient relationship. On one hand, these devices were seen as empowering patients by increasing their involvement in health management. On the other hand, there were concerns that excessive self-monitoring could lead to patient anxiety and overdependence on device data, potentially undermining trust in clinical advice. This highlights the necessity of implementing wearable technologies alongside structured patient education programs and strong communication strategies to preserve and strengthen the therapeutic relationship.

In conclusion, the integration of wearable ECG devices into cardiovascular care is viewed with cautious optimism. While cardiologists recognize the value of these technologies for preventive care and outpatient monitoring, they also emphasize the need for further technological validation, thoughtful implementation, and tailored strategies that consider the variability of clinical environments and patient profiles. Successful adoption will depend not only on technological performance but also on institutional support, training initiatives, and efforts to align wearable health technologies with patient-centered care models. Then, based on the results obtained, it is possible to formulate the following propositions (see Figure 1:

Proposition 1: Perceived usefulness positively influences the propensity to adopt.

Proposition 2: Perceived reliability positively influences the propensity to adopt.

Proposition 3: The doctor-patient relationship may moderate the effect of perceived usefulness on ECG devices' adoption propensity.

Figure 1 shows the proposed conceptual model.

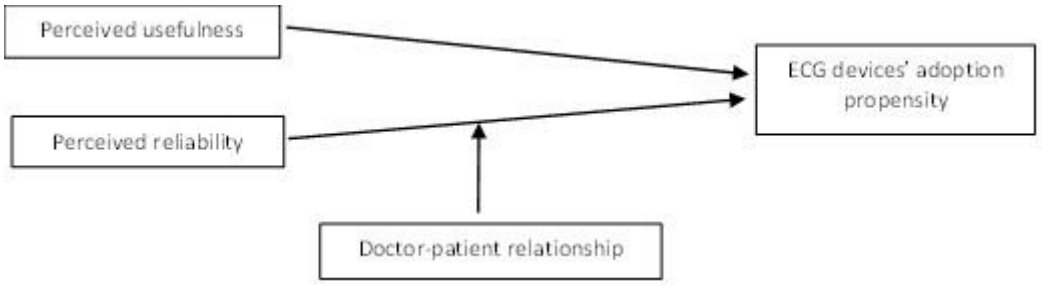


Figure 1: The proposed conceptual model

Future research should extend this exploratory work by including larger and more diverse samples across different healthcare systems and investigating the long-term clinical and economic impacts of wearable ECG integration. A future quantitative phase will empirically validate the proposed relationships of the conceptual model and identify key levers to facilitate the effective integration of these technologies into clinical practice.

Building a strong empirical foundation in these areas will be crucial for advancing the effective and sustainable adoption of wearable technologies in cardiovascular medicine.

6 Ethics declaration

All research is conducted in accordance with ethical principles.

7 AI declaration

No AI tools were used for creation of this paper.

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The Role of AI in Waste Reduction and Sustainability of Pharmaceutical Industry

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Abstract

The pharmaceutical industry, characterized by complex manufacturing systems and resource-intensive development cycles, generates significantly higher emissions and waste compared to other sectors—up to 55% more per revenue dollar than the automotive industry. Approximately 30% of raw materials are lost during drug production, highlighting urgent sustainability challenges. In response to growing environmental pressures, this study investigates the potential of Artificial Intelligence (AI) technologies to reduce waste and enhance sustainability within the pharmaceutical sector. Through a combination of quantitative data analysis and qualitative insights from major pharmaceutical companies—including Novo Nordisk, Pfizer, GSK, and AstraZeneca—this research explores how AI can transform various stages of the pharmaceutical value chain to improve efficiency and environmental performance. The study identifies three core applications of AI in the industry: business process optimization, waste classification and recycling infrastructure, and decision and policy support. Drawing from the principles of industrial ecology and circular economy, it evaluates how AI can be used to reduce defective drug batches, improve the recyclability of pharmaceutical waste, optimize resource flows, and enhance supply chain efficiency. Case study demonstrates AI's ability to significantly reduce maintenance costs, avoid production losses, and cut emissions. AI's role in optimizing pharmaceutical processes at different stages of the pharma value chain – from clinical trial design using digital twin simulations to forecast drug demand and reduce waste, to manufacturing optimization, predictive maintenance, and sustainable supply chain management – enables data-driven decisions, improves efficiency, and minimizes environmental impact. Despite these benefits, the adoption of AI faces numerous barriers including high implementation costs, regulatory challenges, data integration issues, and resistance to change within organizations. Technical limitations, cybersecurity concerns, and the lack of standardized industry frameworks further hinder widespread implementation. The study argues that overcoming these challenges will require coordinated efforts among stakeholders, including public institutions, to provide funding, develop digital skills, and establish policy frameworks that support the responsible use of AI for sustainability. While AI contributes positively to circular and climate-resilient healthcare systems, its energy demands and digital divides must be addressed. The research concludes that AI has the potential to be a pivotal enabler of sustainable transformation in Big Pharma, but its integration must be managed carefully to maximize benefits and minimize unintended consequences. Public investment should focus not only on AI innovation but also on building community readiness for the digital and green transition in healthcare.

Keywords: Artificial Intelligence, Waste Reduction, Sustainability, Pharmaceutical Industry, Big Pharma

Paper type: Academic research paper

1 Introduction

The pharmaceutical industry, a cornerstone of modern healthcare systems, has come under increasing scrutiny for its disproportionate environmental footprint. Characterized by complex, multi-stage manufacturing processes and long, resource-intensive drug development cycles, the industry is known for significant levels of waste production and emissions. Globally, it is estimated that the pharmaceutical industry generates up to 55% more greenhouse gas emissions per dollar of revenue than the automotive sector (Belkhir & Elmeligi, 2019). Furthermore, the European Environmental Agency (2024) reports that as much as 30% of raw materials are wasted during drug production, contributing to chemical pollution, water contamination, and ecological degradation. The environmental challenges linked to pharmaceutical production span across raw material extraction, synthesis, formulation, packaging, and distribution. During its life-cycle the industry contributes significantly to air and water pollution, with high levels of volatile organic compounds (VOCs), solvents, and active pharmaceutical ingredients (APIs) being released into the environment. A team of researchers coordinated by the University of York, comprising 127 scientists from 86 different institutions, collected and analyzed water samples from 1,052 sites across 104 countries. The investigation tested for 61 active pharmaceutical ingredients (APIs), including widely used compounds such as paracetamol, caffeine, metformin, and antibiotics like ciprofloxacin and sulfamethoxazole (Wilkinson et al., 2021). A notable example of pharmaceutical pollution is the discharge of antibiotics into aquatic ecosystems, particularly in regions where manufacturing is outsourced to countries with laxer environmental regulations. Studies by Larsson (2014) and Kristiansson et al. (2011) documented dangerously high concentrations of ciprofloxacin and other APIs in water

bodies near manufacturing plants in India, exacerbating the global crisis of antimicrobial resistance (Kristiansson et al., 2011; Larsson, 2014). These statistics highlight the environmental cost embedded in the pharmaceutical value chain and underscore the urgency of transitioning to more sustainable models of production and waste management. In addition to emissions and effluents, pharmaceutical production contributes to solid waste problems. Poor supply chain practices lead to overproduction, excess packaging, and the widespread disposal of expired or unused medications. In a study on pharmaceutical waste conducted in hospitals and households across Europe, Tong et al. (2011) found that over 70% of unused medications were discarded improperly, often flushed into sewage systems or disposed of in landfills, posing long-term environmental and public health risks.

From a regulatory perspective, frameworks such as the EU REACH Regulation (EC 1907/2006) and guidelines from the U.S. Environmental Protection Agency (EPA, 2023) have aimed to mitigate these impacts by enforcing stricter controls on hazardous chemicals and pharmaceutical waste. However, compliance is uneven, and enforcement challenges persist, especially in globalized supply chains. Additionally, the lack of standardized environmental benchmarks in pharmaceutical manufacturing further complicates sustainability efforts (Health Care Without Harm Europe, 2019).

Amid these mounting environmental concerns, AI has emerged as a transformative tool with the potential to significantly reduce the pharmaceutical industry's ecological footprint. AI technologies, particularly in the domains of predictive analytics, process optimization, and supply chain intelligence, offer scalable solutions for improving efficiency and minimizing waste. For example, AI-driven platforms can help companies predict and prevent defective drug batches by analyzing variables across production lines, thereby reducing the need for resource-heavy rework and disposal. AI-powered systems are capable of continuously tracking production processes by evaluating sensor and equipment data in real time. When irregularities from standard parameters are detected, the system can promptly identify the issue, enabling swift intervention to correct it (Inamdar et al., 2024). Companies like Novartis and GSK are increasingly investing in AI tools for continuous manufacturing. Novartis, in collaboration with researchers at MIT, developed machine-learning models that optimize drug formulation and predict yield outcomes, thus improving energy efficiency and minimizing waste (Wei et al., 2021). Similarly, GSK has deployed AspenTech's Aspen Mtell AI solution across its manufacturing sites to forecast equipment failures, reducing downtime and energy waste while avoiding costly product losses (AspenTech, 2024).

Beyond manufacturing, AI has the potential to foster circular economy principles in the pharmaceutical industry. AI-enhanced material tracking systems can identify and classify recyclable packaging, optimize the lifecycle of chemicals, and improve end-of-life waste processing. In Kalundborg, Denmark, pharmaceutical companies like Novo Nordisk are using AI-powered platforms to support industrial symbiosis networks, enabling shared use of water, steam, and waste heat between pharmaceutical firms and local industries. This initiative has led to 19–25% reductions in CO_2 emissions and improved resource utilization (Runiewicz-Wardyn, 2025).

Despite these promising developments, the integration of AI in pharmaceutical sustainability is not without challenges. Barriers include high implementation costs, limited interoperability between digital systems, data privacy concerns, and resistance to technological change within traditional organizational structures (Bailey et al., 2022). Additionally, the digital divide across regions and sectors creates disparities in AI readiness, potentially exacerbating sustainability gaps rather than closing them.

By integrating theoretical and empirical insights, the study seeks to assess the potential of AI-driven solutions in the Pharmaceutical industry for the waste and environmental impact reduction, and develop frameworks for implementing sustainable AI strategies to enhance efficiency and sustainability. More specifically it aims to: 1) Identify key areas within the pharmaceutical value chain where AI can have the most significant impact; 2) Quantify the potential reductions in waste and environmental impact achieved through AI-enabled solutions; 3) Provide a conceptual and empirical frameworks for implementing AI-driven sustainability strategies in the Pharmaceutical industry. The study addresses several supportive research questions: *How can AI be utilized to optimize manufacturing processes and reduce defective drug batches? What role does AI play in enhancing the recyclability of pharmaceutical waste and promoting circular economy practices, like Industrial Symbiosis? To what extent can AI improve supply chain efficiency and reduce resource wastage? What are the measurable environmental and economic benefits of AI-driven waste reduction strategies in Big Pharma – based on the empirical practice?*

The theoretical foundation of this study is rooted in the principles of industrial ecology and circular economy. In particular, in their role in the optimization of resource flows and waste management within industrial systems. AI, as an enabling technology, aligns with these principles by offering data-driven insights, predictive analytics, and process automation. Other studies, like Varriale et al (2024), Di Vaio et al. (2020) and Giordano et al. (2023) explore the role of individual technologies, such as IT, AI and blockchain technologies in achieving the sustainability goals and support industrial symbiosis indirectly by enhancing resource efficiency and reducing

waste . Yet other authors, like Kluczek et al. (2023) and Holzinger et al. (2023) emphasize the importance of application of specific digital technologies in the management of biotechnology, agriculture, food and supply chain industries. Still, the study of digital sharing platforms, particularly from a circular economy perspective, is just emerging (Runiewicz-Wardyn, 2025).

The study applies these theoretical foundations and systemic approach to the research problem and integrates three core elements of AI: AI for business process optimization, AI for infrastructure, waste classification and recycling, and AI for decision and policy support. It utilizes both quantitative (sector-specific environmental data) and the qualitative (big pharma companies statements and official strategies) including such Big Pharma players as Novo Nordisk, Pfizer, GSK, Novartis and AstraZeneca, to provide insights into the adoption AI for increasing sustainability of the whole pharma sector.

2 AI Applications in the pharmaceutical sector sustainability

The AI-based technology supports a shift from linear to circular value chains, and hence improves compliance with environmental regulations, and equips decision-makers with real-time insights for more resource-efficient operations. Presently major pharmaceutical companies—including Novartis, Pfizer, GSK, Roche, Sanofi, Johnson & Johnson, AstraZeneca, Eli Lilly, and Novo Nordisk—are leveraging AI to enhance drug discovery, optimize manufacturing, and streamline supply chains.

Table 1. AI Applications in the business processes optimization, infrastructure & waste management, and decision & policy support

Category	**Business Processes Optimization**	**Infrastructure & Waste**	**Decision & Policy Support**
Total Productivity	Automates repetitive tasks, streamlines workflows	Predictive maintenance reduces downtime; automated sorting improves efficiency	AI-driven insights streamline data-heavy policy-making
Cost Reduction	Lowers labour and operational costs	Cuts waste handling, disposal, and raw material costs	Reduces manual reporting efforts and improves resource allocation
Data Utilization	Enables data-driven decisions from large datasets	Leverages environmental and operational data for optimization	Integrates clinical, environmental, and supply data for comprehensive policy decisions
Scalability	Scales without proportional cost increases	AI systems handle varying waste volumes efficiently	AI scales to handle complex, cross-domain data for strategic planning
Strategic/Competitive Edge	Enhances customer experience and business performance	Supports ESG reporting, meeting regulatory pressure, and improving sustainability brand image	Enables sustainability leadership and responds to stakeholder/investor expectations
Technological Maturity	Mature automation and analytics tools support rapid deployment	Advancements in ML, computer vision, and IoT enhance reliability in waste management	Scenario modelling and forecasting tools aid in strategic decision-making
Compliance and ESG Alignment	Supports quality control and standardization	Ensures regulatory compliance and supports ESG reporting	Aids in meeting regulatory and ESG reporting requirements

Source: own elaboration.

It plays increasing role in business process optimization, by enabling more efficient operations, while its applications in infrastructure and waste management reduce resource consumption and emissions. Moreover, AI supports decision-making and policy development by delivering actionable insights that align operational strategies with long-term sustainability goals (Table 1).

The AI technology in drug development and manufacturing focuses on improving the efficiency, speed, and accuracy of internal business operations. For example, Novartis has integrated AI in drug development and manufacturing, collaborating with MIT on machine learning models and investing in continuous manufacturing to boost efficiency and reduce defects (Wei et al., 2021). Alongside Roche and Lonza, Novartis has also implemented shared energy recovery and water purification infrastructure, achieving up to 20% operational savings and significant greenhouse gas emission reductions (Lonza Annual Report, 2022).

GSK has deployed AI-driven predictive analytics through solutions like Aspen Mtell, which offer up to 35-day advance warnings of equipment failures. This has helped reduce maintenance costs, avoid production losses, and improve supply chain reliability across 30 sites in 18 countries (AspenTech, 2024).

At the Kalundborg Eco-Industrial Park, Novo Nordisk uses AI-powered platforms to predict resource needs and waste outputs, enabling efficient exchange of energy, water, and chemicals across industries. This industrial symbiosis model has led to a 19–25% reduction in CO_2 emissions and lowered primary resource consumption (Runiewicz-Wardyn, 2024).

Other pharmaceutical leaders are similarly embedding AI into their sustainability strategies:

- Eli Lilly applies AI for predictive maintenance, reducing downtime and increasing asset reliability (Pharmaceutical Technology, 2022).
- AstraZeneca employs AI-driven digital twins to optimize energy use and meet its net-zero carbon target by 2025 (World Economic Forum, 2024).
- Pfizer used AI extensively during COVID-19 vaccine production to anticipate bottlenecks and enhance supply chain efficiency (RSC Publishing, 2021).

These initiatives demonstrate how AI contributes to sustainability, waste reduction, and operational cost savings, becoming a core pillar of ESG strategies in pharmaceutical companies by supporting environmental targets and stakeholder collaboration throughout the product life cycle—from drug discovery through production to global supply chains that deliver safe and effective medicines to patients. The typical product life cycle in pharma is understood as a dynamic framework that integrates scientific R&D, process optimization, and regulatory compliance across distinct stages (Kotler, 2000) and serves as a strategic tool for managing innovation, resource allocation, and environmental impact over time. AI is transforming every stage of the pharmaceutical production life cycle (Figure 1).



Figure 1. AI Applications in the Pharmaceutical Production Life Cycle
Source: own elaboration based on Pharmaceutical Technology (2022), World Economic Forum (2024) and Kotler (2000)

The AI significantly enhances the drug discovery process by analysing vast datasets to identify promising compounds faster and more accurately. As Novartis CEO Vasant Narasimhan spoke “We only understand 5-10% of what's happening in the 40 trillion cells that are in you and me. Could AI help us understand that more quickly, and then (help us) when we try to design a drug to impact one of those processes in the body? Could we design the drug even better with AI?” (Bhan & Anand, 2024).

Additionally, AI technology helps optimize energy consumption during computational simulations and lab operations. In production, AI-driven predictive maintenance minimizes downtime by forecasting equipment failures before they occur, improving overall efficiency and reliability. AI also plays a critical role in supply chain management by anticipating bottlenecks and accurately predicting resource needs, ensuring timely delivery and cost-effectiveness. One powerful example of this integration is the use of AI in combination with digital twin technology discussed below.

3 Case study: AI + digital twins: The game-changers for sustainable pharma

The convergence of AI and Digital Twins has revolutionized the pharmaceutical industry, offering new opportunities for optimization and sustainability. Digital twins—virtual representations of physical entities—are used to simulate and analyze complex processes in real time, and when combined with AI, they enable predictive analytics, automation, and enhanced decision-making. The integration of AI with digital twins in pharmaceutical processes not only facilitates operational efficiency but also contributes significantly to sustainability by reducing waste, optimizing resource usage, and ensuring better compliance with regulatory standards. Recent case studies from leading pharmaceutical companies such as AstraZeneca, Pfizer, GlaxoSmithKline (GSK), and Novartis illustrate the transformative impact of these technologies when applied strategically across various stages of the pharmaceutical value chain (Table 2).

AstraZeneca has adopted a combination of AI, machine learning, digital twins, and predictive modelling to improve manufacturing precision and reduce resource inefficiencies. By simulating production environments and forecasting potential variabilities, the company has achieved a 22% reduction in drug waste, highlighting the role of predictive analytics in minimizing overproduction and batch rejections—key contributors to pharmaceutical waste streams. Pfizer has leveraged AI in conjunction with digital twins and environmental impact modelling to optimize manufacturing lifecycles from a sustainability perspective. By modelling the environmental consequences of production choices in real-time, the company successfully avoided 18 tons of plastic waste and achieved a 34% reduction in CO_2 emissions. These outcomes underscore the potential of AI-driven environmental modelling in facilitating more responsible materials use and emissions management at the design and execution phases of production. GSK has advanced sustainability by integrating digital twins with AI-powered material compatibility analysis and additive manufacturing techniques, including 3D printing. These technologies enable precise customization of components and processes, particularly in biologics production, where single-use systems have been prevalent. As a result, GSK reported a 40% reduction in single-use bioreactor waste, marking a significant move toward reducing reliance on disposable plastic components and promoting circular production practices. Novartis has employed reinforcement learning algorithms, electronic health record (EHR) data analysis, and digital twin technologies to revolutionize clinical trial design and execution (Table 2). This AI-enhanced framework allows for the dynamic simulation of trial scenarios, optimized patient recruitment, and personalized treatment strategies. The implementation of such tools led to a 60% increase in clinical trial success rates and a 40% reduction in required trial participants, indicating substantial improvements not only in trial efficiency but also in the ethical and environmental burden of large-scale clinical studies.

Table 2. AI + Digital Twins: The Game-Changers for Sustainable Pharma

Firm	Area of Impact	Problem Identified	Solution Implemented	Tools / Technologies Used	Outcome	Reference
AstraZeneca	Clinical Trials	Excess drug waste due to supply chain inefficiencies	Real-time simulation of 18 trial logistics variables	AI, Machine Learning, Digital Twin, Predictive Modelling	22% reduction in drug waste	J&K Technology (2023); Noirfalise, M. (2023)
Pfizer	Logistics & Waste Management	High plastic waste and CO_2 emissions in clinical logistics	Route optimization and usage prediction via digital twins	AI, Digital Twins, Environmental Impact Modeling	18 tons of plastic waste avoided; 34% CO_2 emissions reduction	Farsani et al. (2021) J&K Technology (2023)
GSK	Vaccine Manufacturing	High single-use bioreactor waste	Closed-loop tracking and AI-guided material reuse	Digital Twin, AI Material Compatibility, 3D Printing	40% reduction in single-use bioreactor waste	Technology (2023) GSK. (2023) Pharmaceutical Technology (2023)

Firm	Area of Impact	Problem Identified	Solution Implemented	Tools / Technologies Used	Outcome	Reference
Novartis	Clinical Trial Optimization	Low success rates and high clinical waste	Patient subpopulation modeling and adaptive dosing	Reinforcement Learning, EHR Data Analysis, Digital Twin	60% increase in trial success; 40% fewer trial participants required	Novartis. (2021; 2023; 24); J&K Technology (2023)
Boehringer Ingelheim	Biologics Manufacturing	Inefficient bioreactor operations and high media usage	CFD and AI simulation for process optimization	Computational Fluid Dynamics (CFD), AI, Bioprocess Digital Twin	31% media reduction; 18% faster cell development	Genengnews. (2021); J&K Technology (2023)
Roche	Energy Use in Manufacturing	High energy consumption per dose in biologics	Continuous manufacturing twin with AI perfusion optimization	Digital Twin, AI-optimized perfusion, Predictive Maintenance	56% reduction in energy per dose	J&KTechnology (2023); Roche. (2024); Outsourced Pharma. (2023)
Johnson & Johnson	Facility Energy Optimization	Need to maximize renewable energy use	Simulation of hybrid energy systems and battery degradation	Digital Twin, Energy Simulation, Battery Modeling, Wind Pattern Analysis	96% renewable operation at Cork facility	J&K Technology (2023); Johnson & Johnson. (2023a; 2023b)
Merck	Supply Chain Decarbonization	Emissions from cold chain logistics	Multi-factor environmental route optimization	AI, Environmental Modeling, Digital Twin	29% reduction in cold chain emissions; 99.97% product integrity maintained	J&K Technology (2023); Merck (2025)

Source: own elaboration based on Farsani et al. (2021), J&K Technology (2023), GSK (2023), Pharmaceutical Technology (2023), Novartis (2021; 2023; 2024), Genengnews (2021), Roche (2024), Outsourced Pharma (2023), Johnson & Johnson (2023a; 2023b), Merck (2025).

Collectively, these examples reflect a broader industry trend in which AI and digital twins are deployed not merely as process optimization tools, but as enablers of a more sustainable, data-driven pharmaceutical ecosystem. The convergence of simulation, predictive analytics, and real-time monitoring contributes to waste minimization, carbon footprint reduction, and enhanced resource circularity—key goals in the transition to green manufacturing.

These case studies affirm the potential of AI and digital twin technologies to serve as foundational elements of the next generation of sustainable pharmaceutical production systems. As regulatory and societal pressures intensify around environmental stewardship and resource efficiency, the adoption and advancement of such intelligent systems are likely to become central to maintaining both economic competitiveness and environmental responsibility in the life sciences sector.

4 Drivers and barriers to leveraging AI for sustainability

4.1 Drivers to AI implementation

AI is becoming a foundational element of ESG strategies in the pharmaceutical industry, supporting sustainability goals, reducing waste, and improving cost-efficiency throughout the entire product life cycle. From drug discovery to global supply chain management, AI transforms operations by accelerating research, optimizing energy use, predicting equipment failures, and managing resources more precisely. The integration of AI with digital twin technology enables real-time simulation and predictive analytics, greatly enhancing decision-making and operational sustainability. Case studies from AstraZeneca, Pfizer, GSK, and Novartis show measurable benefits such as significant reductions in waste, CO_2 emissions, and single-use plastics, as well as improved clinical trial outcomes. These examples illustrate how AI-driven innovation not only boosts efficiency and compliance but also drives environmentally responsible practices across pharmaceutical production.

4.2 Barriers to AI implementation

While AI holds transformative potential for the pharmaceutical industry, its adoption is hindered by a range of interconnected challenges. These include high implementation costs, poor data quality and integration, a shortage of skilled professionals, organizational resistance, legacy system constraints, and regulatory and ethical concerns. High upfront costs—for infrastructure, tools, and talent—can be prohibitive, especially when returns on investment are uncertain or long-term. Many pharmaceutical firms struggle with fragmented and outdated data systems, making it difficult to provide the clean, structured datasets that AI requires. The lack of talent combining technical expertise with domain-specific knowledge often leaves companies dependent on external vendors. Resistance to change within organizations—driven by concerns about job security and skepticism about AI—can further hinder adoption, especially in the absence of strong communication and change management. Integrating AI with legacy IT systems adds complexity and risk, threatening data integrity and operational continuity.

Strict regulatory environments and ethical issues around bias, transparency, and data privacy demand rigorous oversight and tailored compliance strategies. Additionally, the absence of industry standards and growing concerns around cybersecurity add to the complexity of implementation. Beyond internal hurdles, AI adoption in pharma has broader implications for building sustainable, circular, and smart healthcare ecosystems. On the positive side, AI can enhance resource efficiency and promote circularity. However, it also introduces negative externalities, such as increased energy consumption, digital divides, and safety concerns. Addressing these challenges requires coordinated action among stakeholders, continuous technological advancement, and supportive policies. Public funding and national programs should not only prioritize AI initiatives but also focus on enhancing digital readiness and promoting socially and environmentally responsible tools. Such strategic investments are critical to enable a climate-neutral and resilient healthcare system.

5 Summary and policy implications

The integration of AI in infrastructure, waste classification, and recycling within the pharmaceutical sector demonstrates a commitment to sustainability and operational excellence. By embracing AI technologies, companies not only comply with regulatory standards but also achieve cost savings, enhance efficiency, and contribute to environmental stewardship. The transformation of the pharmaceutical industry towards a greener, more sustainable future hinges not only on AI's technological capabilities but also on the readiness of both the industry's digital infrastructure and its broader organizational ecosystem. While AI can drive efficiency and innovation, its full potential can only be realized in environments that are digitally prepared and infrastructure-ready. This requires not only cutting-edge technology but also a strong foundation in data management, AI systems integration, and employee digital literacy. Moreover, soft factors—such as organizational culture, leadership vision, and employee engagement—are essential to unlock the power of AI for sustainability. Collaborative frameworks, underpinned by open innovation, must facilitate the flow of knowledge and technology across sectors, fostering rapid adaptation to environmental and regulatory challenges. Policymakers, therefore, must prioritize not just financial incentives and regulatory harmonization, but also the development of digital infrastructure, the fostering of AI and digital readiness, and the establishment of collaborative platforms that encourage innovation, capacity-building, and cross-sectoral knowledge exchange.

6 Ethics declaration

This study does not involve any human participants, human data, or animal subjects. All data used in the research were synthetic or obtained from publicly available sources that do not contain any sensitive personal information. Consequently, no ethical approval or informed consent was required. The author confirms compliance with all relevant academic and institutional ethical guidelines and standards. There were no collaborations or funding from pharmaceutical companies, and the research was performed independently, avoiding any potential conflicts of interest.

7 AI declaration

The use of AI in this work complies with principles of transparency, accountability, and ethical responsibility. No AI tools were used to replace human judgment in ethically sensitive or operational decisions, and no human subjects or personal data were involved. The AI techniques, specifically machine learning models, were employed solely as analytical tools to support the research objectives. The research adheres to best practices for responsible AI usage in academic and scientific contexts.

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Impact of Work Experience on the Use of Generative AI for Knowledge Management

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Abstract

The emergence of the latest generations of generative artificial intelligence (GenAI) systems, particularly ChatGPT, has prompted knowledge management (KM) scholars to investigate how these tools can be effectively integrated into organizational KM systems. However, as this field of study is in its infancy, the literature remains scarce and provides fragmented results. Empirical evidence is especially limited, and numerous research questions awaiting answers. One such question is how work experience influences the use of AI in new knowledge creation. To address this issue, this paper examines how and for what purpose GenAI is employed to support the creation of new knowledge, specifically focusing on how its use differs according to users' seniority levels. The hypothesis is that work experience, which shapes users' knowledge pools, affects how they utilize GenAI to support knowledge creation. Past empirical research highlighted that there are differences in AI usage between more and less experienced workers. Given the exploratory nature of the study, we employed a qualitative research method, conducting interviews with 22 software engineers from various companies who use GenAI systems in their daily activities. We choose software engineers as they are knowledge workers and are currently among the early adopters of GenAI systems. Based on a common guideline developed from knowledge creation processes, the interviews were conducted online and in person between July and November 2024. Each interview was recorded, transcribed and translated into English for analysis. Empirical research shows differences between more and less experienced workers, particularly with respect to the complexity of the tasks performed and the type of knowledge created with GenAI support. The study's results contribute to our understanding of GenAI's impact on KM and offer managerial insights for introducing and using the new technology within business contexts.

Keywords: Generative AI, Knowledge Management, Work Experience, Software Engineers, Interview Study.

Paper type: Academic Research Paper

1 Introduction

It is a common opinion among scholars (Jarrahi et al., 2023; Sumbal and Amber, 2024) and practitioners (Accenture, 2023; APQC, 2024) that last advances in artificial intelligence (AI), first and foremost the development of always more powerful generative artificial intelligence (GenAI) models, is offering new foundations to transform Knowledge Management (KM) in depths. This is why recent research in the KM field is devoting increasing attention to analysing how GenAI can be effectively integrated within organizational KM systems (Buchatskaya et al., 2024; Jarrahi et al., 2023; Taherdoost and Madanchian, 2023). However, since the study of this topic is in its infancy, the literature is still scarce and provides fragmented results. In particular, available empirical evidence is sparse, and many research questions await an answer (Korzynski et al., 2023; Leoni et al., 2024).

Contributing to our understanding of the integration of GenAI within KM, the present paper investigates how and for what purpose GenAI is employed to support the creation of new knowledge and, more specifically, how its use differs according to the seniority level of users. The fundamental hypothesis of this study is that work experience, since it shapes the knowledge pool possessed by the user, affects how they employ the new technology to support the creation of new knowledge. The results of past empirical research suggest this hypothesis, which has highlighted how more experienced workers use artificial intelligence differently from less experienced ones (Brynjolfsson, 2023; Burtch et al., 2024; Hu et al., 2023; Peng et al., 2023).).

Given the exploratory nature of the study, we employed a qualitative research method, which involved conducting interviews with professional workers who use GenAI systems in their daily activities. Specifically, we interviewed 22 software engineers who regularly use GenAI. We chose software engineers for several reasons: they are knowledge workers, meaning they apply theoretical and analytical knowledge in their jobs (Drucker, 1959); they are currently among the early adopters of GenAI technology (Alavi et al., 2023; Ebert and Louridas, 2023); and some papers have already been published on the use of GenAI in the software industry (see, e.g., Rajbhoj et al., 2024), albeit not from a KM perspective.

What emerged from the empirical investigation confirms that there are differences between more and less experienced workers, especially regarding the complexity of tasks performed and, therefore, the kind of knowledge created with the support of GenAI. The analysis results increase our understanding of AI's impact on KM and offer some managerial suggestions about the introduction and use of GenAI within business organizations.

2 Background

2.1 GenAI and KM: a symbiotic relationship

The latest development of GenAI models has made AI a fundamental element of KM (He and Burger-Helmchen, 2024), so that it can be rightly considered a "game changer" for KM in organizations (Sumbal and Amber, 2024). According to Iaia et al. (2024), integrating AI in KM implies activating a virtuous circle where both benefit. KM and AI exist in a symbiotic relationship, given that both have knowledge at their core (Ojala, 2024).

In particular, GenAI has made a significant leap forward compared to previous AI models regarding its ability to support organizational KM effectively. Innovative tools like ChatGPT, Gemini, Copilot, and Claude, to name just a few of the most well-known, can find wide and practical applications within all KM processes (Alavi et al., 2024; Jarrahi et al., 2023). Specifically, they can create high-quality content; automatically summarize lengthy documents, research papers, or articles; power question-answering systems; provide personalized recommendations; translate documents; act as virtual assistants and chatbots capable of understanding and responding to user queries in natural language; create interactive learning environments; dynamically personalize content based on user context; track changes made to documents over time; automatically categorize documents; analyze unstructured data sources and extract information; generate visual representations, such as concept maps or diagrams; and convert spoken language into written text (Chui et al., 2023; Sumbal et al., 2024).

Since the integration of GenAI in KM is taking its first steps, to make the most of its opportunities, we need to fully understand the nature of this relationship, also by drawing inspiration from existing use experiences, which is what the present study intends to do.

2.2 Using GenAI in KM: The role of work experience

Due to its inherent flexibility and adaptability, GenAI can be considered a" malleable technology" as defined by MacKenzie and Wajcman (1999) and Orlikowski (1992). Unlike rigid technologies, which are characterised by fixed functionalities and limited scopes of application, malleable technologies are highly adaptable and customizable. Depending on the use case, domain, or user needs, they can be shaped or applied in many different ways. The malleable nature of GenAI systems lies in the fact that they can be adapted to various tasks and knowledge domains, which makes them versatile tools (Cimino et al., 2025). In fact, not only can GenAI be applied to numerous fields, from text and image generation to code writing and problem-solving, but users can also tailor the output of GenAI through prompts or specific instructions, shaping the results to their needs.

This malleable nature requires us to investigate how GenAI is used in various application contexts and by different users to better understand its potential impact. Considering the points discussed in the previous section, it would be particularly interesting and valuable to analyze the use of GenAI in the context of KM processes, specifically in creating new knowledge. Regarding users, a topic that deserves in-depth exploration is the role that work experience plays in shaping the use of these tools. Early studies suggest that work experience and associated skills influence how GenAI is perceived and used by workers and the performance they achieve through its use. The findings of three experiments conducted by Cui et al. (2025) on the adoption of Copilot among software developers revealed that adoption patterns and productivity gains varied according to tenure, with younger developers benefiting the most. Peng et al. (2023) and Gambacorta et al. (2024) corroborated these results, demonstrating similar productivity advantages for junior programmers over their senior counterparts when using GenAI. Sun et al. (2024) further explored this dynamic, showing that perceptions of GenAI's creativity vary with task requirements. They found that expert users are more critical of GenAI-generated content than novices. This critical stance among experts was also evident in Burtch et al.'s (2024) investigation, which revealed that the advent of GenAI led to a higher exit rate of junior and less experienced users from knowledge communities. Li et al. (2024) provided additional nuance, highlighting that while AI usage generally improves performance, it doesn't necessarily reduce individual performance variance. This suggests the emergence of new skill disparities in the AI era. Storey (2024) offered insight into the underlying mechanisms of these disparities. She posited that novices tend to rely on acquiring explicit knowledge, whereas experts

possess a more sophisticated ability to synthesize knowledge, often based on heuristics or case studies. Consequently, expert knowledge workers utilize GenAI differently: they apply it to more complex tasks and exercise greater scrutiny in assessing the validity of the obtained results.

In conclusion, research on the influence of work experience on GenAI usage is still in its infancy, presenting a fertile ground for further exploration (Hu et al., 2023). Given this context and focusing on knowledge creation as the application domain, this study aims to address the following research question:

- RQ: How do workers with varying levels of experience use GenAI tools for knowledge creation?

3 Research methodology

Given the exploratory nature of the research, this study adopted a qualitative interview-based approach (Given, 2008) with software engineers as a group of knowledge workers using GenAI in their daily jobs. Collected data were analyzed by applying thematic analysis, a method for identifying, analyzing, and interpreting patterns of meaning (themes) within qualitative data (Braun and Clarke, 2012). This approach effectively uncovers patterns within and across datasets, especially about the lived experiences, perspectives, and practices of participants. Thematic analysis provides a robust framework for examining qualitative information, allowing researchers to taking deep insights into the nuances of participants' responses and behaviors. We employed a convenience sampling method, a widely used technique in descriptive studies (Zhang and Liu, 2021). Between July and November 2024, we conducted 22 semi-structured interviews with software engineers selected from various countries and with a range of programming experience levels, from junior to senior professionals, as well as diverse organizational roles. Table 1 illustrates the profile of the interviewed people.

Table 1: Profile of respondents

Interview	Role	Age	Experience (years)
01	Co-founder (startup)	40	17
02	Senior software engineer	40	14
03	Founder and owner (startup)	38	7
04	CEO - Technical director	47	20
05	Solution specialist	50	20
06	R&D manager	56	28
07	Senior software developer	37	14
08	Head of AI team	40	10
09	Business analyst	31	3
10	President	65	40
11	Italian AI team leader	37	15
12	Project manager	25	1
13	Chief product officer	52	32
14	Chief innovation officer	55	37
15	Software developer	23	3.5
16	Senior software engineer	40	15
17	BI developer	27	2.5
18	Software engineer	27	2
19	IT consultant	56	36
20	Software engineer	27	2
21	Software developer	37	9
22	Advanced software engineer	38	6

4 Findings

4.1 Introduction

To answer our research question, we categorized knowledge workers into three groups based on their years of work experience: six juniors (0-5 years), eight mid-levels (6-15 years), and eight seniors (16+ years). While work experience can be linked to job roles, we opted for years of experience as a more objective measure. Additionally, the composition of the groups would not have differed significantly, as Table 1 shows a strong correspondence between work experience and role, with a general relationship between seniority and managerial positions.

4.2 Overview of interviews

The following paragraphs describe how different groups of respondents report using generative AI in their daily activities related to knowledge creation.

4.2.1 Junior workers

Junior respondents affirm that they frequently use Generative AI tools such as ChatGPT, Copilot, and Gemini to streamline their work and enhance productivity. They find these tools particularly beneficial for repetitive, low-level tasks, including generating code snippets, transforming data formats, and summarizing meeting notes.

"… I use it (ChatGPT) a lot, almost daily, whether it's for emails, responses, or similar tasks." (Interview 12)

"... Mainly for low-level activities, such as the technical side - for example, generating classes with random examples or having it transform some objects from JSON into objects in other languages like TypeScript or C#." (Interview 15)

"… I used it more to save time on routine tasks like summarizing the meeting and getting to-do lists during a group call." (Interview 20)

"… before generative AI, it was so time-consuming. We should, we had to think about that, and we should, we had to try to get the right number and write, for example, the DAX formula." (Interview 17)

Moreover, they appreciate the tools' ability to provide quick and coherent results, which they can subsequently refine and build upon. However, these professionals do not rely entirely on AI tools, citing concerns about data privacy and the accuracy of generated output. Instead, they utilize these tools as assistants, complementing their expertise rather than replacing it. Integration of GenAI has reduced the need for frequent interruptions and interactions with colleagues, as these tools can often provide the necessary information or solutions more efficiently. On the other hand, this could negatively affect teamwork and the culture of co-creation.

"… asking for formulas means I no longer have to bother my colleagues. Basically, we don't disturb each other anymore because we ask the chat, and if the formula is correct, there's no need to ask anyone else." (Interview 12)

"... in this way I get the correct solution like most of the time and in a faster time period … in conclusion, yeah it reduced the amount of interactions between colleagues." (Interview 18)

Junior respondents initially stick to default tools to build a solid foundation and align with organizational practices. As they gain experience, they can begin exploring GenAI tools, which they generally view as valuable assets. While many juniors are understandably cautious and may lack the skills to fully validate GenAI outputs, the technology helps streamline their workflow, enabling time savings and allowing them to focus on more complex knowledge tasks.

"… So it's very helpful. I cannot say that it's completely changed our job. No, because we cannot trust 100% in this tool". (interview 17)

"... I go through it and check it every time because sometimes it makes mistakes and it's just a good spot to start." (Interview 18)

In summary, junior workers utilize GenAI to handle simple and repetitive knowledge creation activities, the output of which can be validated even by less experienced professionals. While this enhances their independence and productivity, it also negatively impacts the collaborative creation of new knowledge. In essence, junior workers employ GenAI to produce "new-for-them" knowledge.

4.2.2 Mid-level workers

Respondents in the mid-level group also report using GenAI tools to enhance their productivity and efficiency, primarily for repetitive, routine tasks such as data transformation, code documentation, and implementing simple functionalities. They find these tools helpful in providing immediate assistance when working with unfamiliar languages or frameworks. Some mid-level workers also leverage them for more complex problem-solving, such as mathematical calculations and engineering-related tasks.

"... The other major category is implementing very simple functionalities or small scripts when there's limited knowledge of the required language or especially of the specific framework for that functionality." (Interview 3)

"… I use them quite a bit to enhance my personal productivity. This applies to tasks related to my role." (Interview 11)

"... I used the tools mostly for documentation, and repetitive tasks, and scripting. Not really for complex tasks, though I used them sometimes for complex code too, which needs personal skills with teams." (Interview 21)

Mid-level workers report using GenAI to bridge skill gaps and enhance team collaboration. However, they perceive the tools' effectiveness in these areas as still limited, often necessitating output validation before integration into their work. Generally, these respondents are more critical of GenAI tools' utility, highlighting limitations due to a lack of domain-specific knowledge and potential for hallucination, which can result in irrelevant or inaccurate outputs.

"... One is the lack of knowledge of our domain, and also the, you know, the thing that hallucination that these tools have and make some, for example, the other time, it created some action points, which is absolutely irrelevant to the meeting that we had." (Interview 2)

"... Sometimes I changed the entire prompt's structure, and sometimes I modified certain parts, but again, I encountered wrong answers. I felt that this was not the correct answer." (Interview 7)

This group of respondents actively explores GenAI tools to optimize their workflows and boost productivity, even for more complex tasks. They occasionally contribute to fine-tuning these tools to better align with team processes, demonstrating a level of engagement with tool customization. However, they maintain a cautious approach, avoiding over-reliance on these tools, particularly for critical or intricate assignments.

"... My team uses these tools regularly because [*name of the company*] *encourages all employees to use them depending on their roles. This has also led to significant cost savings, as it shifts employees from blue-collar functions and reskills them, thus initiating a reskilling process". (Interview 11)*

"… We're using it for code development, and gradually, they're also integrating it into some services on the database side, like SQL Server or Cosmos DB." (Interview 16)

In summary, mid-level workers utilize GenAI to handle both simple and complex knowledge creation activities, although they are aware of these systems' limitations when dealing with domain-specific knowledge. Moreover, mid-level workers often employ these tools to enhance the collaborative creation of new knowledge within their work teams. In essence, mid-level workers employ GenAI to promote the production of "new-for-the-team" knowledge.

4.2.3 Senior workers

According to their answers, senior workers are increasingly incorporating GenAI tools into their daily work routines, and the tools are being used for a variety of tasks, both repetitive and complex. For repetitive tasks, senior workers say they use GenAI tools to automate text generation, code completion, data formatting, and other mundane activities that previously required manual effort. The tools help to accelerate these routine processes, making developers more efficient. For more complex tasks, GenAI assistants kickstart and facilitate the engineering development process.

"... I know that other colleagues of mine, developers in my team, are already doing the same. They do work that's much more focused on development, and they're already using it increasingly often to solve coding problems." (Interview 6)

"... For complex tasks, we directly use ChatGPT, and recently we've had great success with O1, also from OpenAI, which we believe will make a substantial difference, as we've already seen." (Interview 14)

Senior workers use GenAI to quickly gather relevant information, synthesize insights, and generate initial drafts or prototypes. This helps overcome the challenge of starting from a blank slate, especially for technical writing, software architecture, and other knowledge-intensive work. The common opinion is that even if GenAI models cannot fully automate complex tasks, they can serve as valuable tools in the ideation and early stages of work, helping to generate initial ideas, text, code, etc., that can then be refined and built upon.

"... We also use it to create personalized summaries of calls and meetings we hold. We've also used it to create our own products." (Interview 1)

"... These tools are never able to provide a perfectly clean text ready for a presentation or a technical report, but they can often summarize the themes or points, thus guiding the drafting of the final document." (Interview 5)

"... I use it as support or an accelerator to kick-start complex tasks." (Interview 5)

Some senior respondents are also experimenting with integrating GenAI more deeply into their workflows by connecting them to internal knowledge bases or using them to generate entire software components. However, there are still limitations, especially for certain programming languages and more advanced use cases. Senior workers approach GenAI with a strong awareness of risks, using systematic validation methods and maintaining a critical perspective on its limitations. A hybrid approach is common, where GenAI tools are used in conjunction with traditional methods and human expertise. The adoption of GenAI also impacts how seniors collaborate and share knowledge within their teams. While some see the tools as a way to be more self-sufficient, others view them as a means to enhance teamwork, using AI as a "co-pilot" to discuss and refine solutions together.

In general, senior workers affirmed that they are actively exploring the entire range of capabilities of GenAI, from automatic substitutes for simple tasks to collaborative assistants for more complex ones, and finding ways to strategically incorporate them into their work processes.

"… I find it useful now as an accelerator for this initial synthesis—to quickly find information that's already correlated and aggregated, which allows me to take a direction early on and save myself the initial work of research and selection." (Interview 6)

"… We have this mix where Copilot is mainly adopted for repetitive tasks and knowledge mining, and then we integrate it with GPT, Cursor, and also Claude, as Claude is actually quite good at writing code as well. We use a combination of these tools for more complex tasks." (Interview 14)

In summary, senior workers make more intensive use of GenAI to foster the collaborative creation of new knowledge within their teams. Furthermore, they are striving to integrate these tools as an essential component of their knowledge creation strategy. In essence, senior workers promote using GenAI to produce "new-for-the-organization" knowledge.

4.3 Comparative analysis

Based on the results presented in section 4.2, we conducted a comparative analysis across the three groups of software engineers. This analysis focused on five key aspects: Task Complexity, Collaboration vs. Independence, Trust and Risk Awareness, Tool Customization and Impact, and Knowledge Creation. The findings, along with a comparison highlighting the differences among the three groups, are summarized in Table 2.

Table 2: Summary of comparative analysis

Aspect	**Work experience**			**Comparison**
	Junior	**Mid-level**	**Senior**	
Task Complexity	Juniors use GenAI for simple tasks like code snippets and meeting notes. It's mainly a time-saver and support tool	Mid-levels move into advanced uses like automation, prompt tweaking, and in-house tool development. They're cautious but exploring	Seniors use GenAI strategically—for prototyping, architecture, and integrating tools into team workflows	*More experience leads to deeper and more strategic GenAI usage*
Collaboration vs. Independence	Juniors rely on GenAI to work independently, reducing the need to ask colleagues	Mid-levels use it to fill gaps and make collaboration smoother	Seniors use GenAI to boost idea generation and co-creation within teams	*GenAI supports independence early on and enhances collaboration at higher levels*
Trust and Risk Awareness	Juniors are cautious but may lack the skill to fully validate AI outputs	Mid-levels test results more rigorously, and are aware of hallucinations	Seniors apply structured validation and remain highly critical of limitations	*More experience leads to more trust management and risk control*
Tool Customization and Impact	Juniors stick to default tools	Mid-levels help fine-tune tools for team use	Seniors lead integration and drive organization-wide AI adoption	*Experience enhances tool customization and scales impact from individual to organizational levels*
Knowledge Creation	New-for-them	New-for-the-team	New-for-the-organization	*Experience deepens knowledge creation reach*

5 Discussion and Conclusion

The findings of our empirical investigation confirm that the use of GenAI tools varies according to users' experience levels. Specifically, while junior workers employ GenAI tools to increase their productivity in performing simple tasks, essentially acquiring new knowledge for themselves, more experienced workers use these tools to enhance their ability to tackle complex problems. In addition, experienced workers use GenAI particularly to stimulate the production of new knowledge within collaborator teams and throughout the organisation.

From an academic perspective, this study confirms that GenAI is a malleable technology capable of adapting to users' specific needs and abilities, as well as to the context of use. From a KM standpoint, the study emphasizes that this technology can be employed to address cognitive problems of varying complexity and support knowledge creation processes ranging from individual to organizational levels.

Regarding managerial implications, the study suggests the need for a diversified approach in promoting the adoption and use of technology, depending on the experience level. While the focus for junior workers should be on illustrating the technical aspects of using these tools, for more experienced workers, attention should be directed towards the organizational implications of their use.

This paper has limitations, which nonetheless offer directions for future research. As it is based on a limited number of interviews, its results cannot be immediately generalized. Future studies could address this constraint through quantitative analyses, such as large-scale surveys involving more representative samples. Another limitation related to generalizability is that the investigation involved a specific group of knowledge workers, namely software engineers. Future studies should focus on different sectors. Lastly, the rapid evolution of GenAI systems presents a significant challenge to research in this field. Its dynamic nature necessitates ongoing and adaptive research approaches. In this regard, longitudinal studies could be invaluable in anticipating the future evolution of GenAI and its changing impact on knowledge workers over time.

6 Ethics declaration

No sensitive or personally identifiable information was collected. Prior to the interviews, all participants were informed about the purpose of data collection and recording, as well as the use of information for research purposes. Their verbal informed consent was obtained. Interview data is available upon request.

7 AI declaration

The authors manually conducted all analyses using MAXQDA, while its AI assistant was used to help in extracting quotes; all analyses and writing were done by the authors.

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Generative AI Techniques for Data Aggregation and Summarization: Enhancing Decision Support in Healthcare

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Abstract

Processing healthcare data presents significant challenges for clinicians, particularly in chronic disease management such as diabetes care. Traditional data aggregation and summarization methods often struggle to integrate the diverse data sources of health information, ranging from structured electronic health records to unstructured clinical notes. In response to this challenge, the paper proposes a reference framework that leverages generative Artificial Intelligence (AI) techniques and agentic AI architectures for enhancing health data management and decision support. By employing Large Language Models, the system is able to synthesize insights from collected data also deriving contextualized summaries and personalized recommendations useful for healthcare professionals. The paper outlines the architectural components of the framework and discusses key implementation strategies. Finally, a basic prototype has been developed to demonstrate the feasibility and usability of the proposed architecture in the context of telediabetology, supporting the management of diabetes patients during periodic clinical visits.

Keywords: Generative AI, Healthcare, Decision Support, Large Language Models

Paper type: Academic Research Paper

1 Introduction and motivation

With the exponential growth of clinical data, healthcare systems are generating vast volumes of information from diverse sources, including Electronic Health Records (EHRs), medical imaging, wearable devices (Massaro et al., 2020, Magaletti et al., 2021), laboratory reports, patient-generated data, and clinical research studies. Advancements in medical technologies drive this data explosion, the widespread adoption of digital health tools, and the increasing emphasis on personalized and evidence-based care (Van Woensel et al., 2022). However, this abundance of data often exists in highly heterogeneous silos of information. It contains a mix of structured and unstructured formats, making it challenging for healthcare professionals to process and analyze effectively. This research explores the application of generative AI techniques for data aggregation and summarization to enhance decision support, particularly in complex and dynamic domains such as healthcare. Generative AI tools offer several advantages over traditional techniques (Moulaei et al., 2024), including: (i) process unstructured data like clinical notes and free-text inputs, which traditional techniques often struggle with; (ii) automating the integration of different data sources, such as merging EHRs with real-time monitoring data; (iii) produce high-quality, human-readable summaries tailored to specific user needs (e.g., clinicians, administrators, or researchers) reducing the cognitive burden on healthcare professionals. By bridging state-of-the-art AI methodologies with real-world clinical applications, the study aims to investigate how generative AI techniques and tools, such as Large Language Models (LLMs), can streamline data integration and extract meaningful patterns (Yang et al., 2023), and contribute to the development of trustworthy decision support systems for healthcare providers. As stated in (Busch et al., 2025), LLMs represent recent and relevant tools for aggregating, summarizing, and interpreting data, helping physicians make informed decisions. By automating data summarization, LLMs ensure that physicians have a comprehensive view of a patient's health, eliminating the need for manual data gathering. During periodic check-ups, LLMs can instantly retrieve and summarize recent patient data, generate visual reports for quick analysis and suggest areas requiring further clinical attention.

The proposed work introduces a reference framework for health data management, specifically designed to support diabetes care through the integration of generative AI tools and agentic AI frameworks. This framework aims to enhance the way patient data is processed and analysed, providing physicians with intelligent decision support while maintaining a human-centered approach to healthcare. The paper is organized as follows: Section 2 provides a detailed description of the proposed health data management framework, outlining its core components, functionalities, and technological foundations; Section 3 presents a use case demonstrating how the proposed framework can support physicians during periodic visits with diabetes patients; Section 4 summarizes the key contributions of this work and highlights potential future improvements.

2 Generative AI-driven health data management

This research proposes a reference framework for health data management specifically tailored for diabetes patients. Diabetes-related data encompasses a wide range of formats, including numerical glucose readings, textual dietary logs, and other health metrics. Additionally, each diabetes patient presents unique characteristics, such as individualized nutritional habits, medication routines, and lifestyle factors, making personalized data interpretation essential. Rushed or insufficient analysis risks overlooking critical insights or correlations, potentially compromising the quality of care and decision-making. By combining the capabilities of generative AI, wearable technology, and advanced analytics tools, this framework aims to improve clinical decision-making, enhance patient engagement, and foster more personalized and effective diabetes care. A basic principle of the adoption of generative AI in telediabetology is illustrated in Figure 1. The framework leverages wearable devices and clinical-oriented mobile applications to continuously collect health-related data. While wearables track vital signs, physical activity, and lifestyle patterns, mobile applications enable patients to log symptoms, medication intake, and other relevant health information, effectively creating a personalized health diary. Several studies (Praino et al., 2020, Alvarez-Perea et al., 2021, Patton et al., 2022) have shown that such diaries enhance patient participation and awareness by fostering a more proactive approach to health management. By actively engaging with their health data, patients gain better insights into their condition, adhere more consistently to treatment plans, and collaborate more effectively with healthcare providers. Unlike traditional cloud-based systems, the collected data is securely stored locally on the user's smartphone to prioritize data privacy and give patients greater control over their health information. The framework enables seamless data sharing between patients and their healthcare providers through secure communication channels. Once shared, the data can be processed using generative AI frameworks, such as AG2[1] (formerly AutoGen), LangChain[2] and Microsoft LIDA (Dibia, 2023), to generate personalized suggestions and useful visualizations automatically. Collected data, including standard lifestyle and dietary guidelines, are processed by a generative AI engine using clinical data to enhance Integrated Care Pathways for diabetes care and prevention.

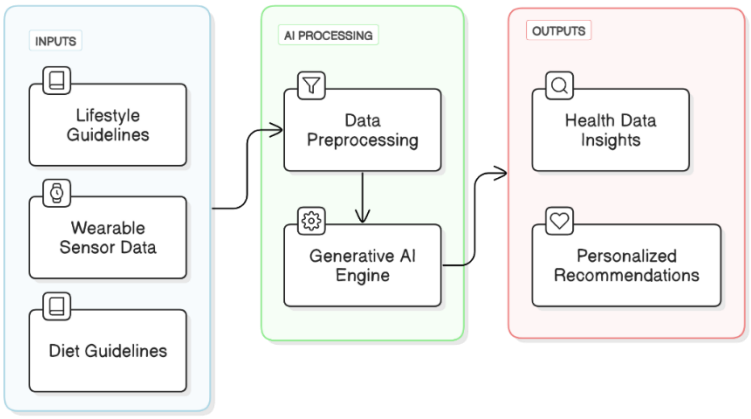


Figure 1: Generative AI improving Integrated Care Pathways for prevention and care of diabetics.

Key features of the framework include the usage of LLMs to interpret and summarize health data, ensuring that visualizations are contextually meaningful to the specific needs of diabetes management. Each output is designed to present complex health metrics in a clear and accessible format, helping both patients and physicians to understand trends, anomalies, and progress over time.

In the proposed approach, the generative AI module has been implemented using AG2, a robust agentic AI framework. AG2 was selected due to its flexibility, modular architecture, and ability to handle complex multi-step reasoning tasks, making it particularly well-suited for healthcare applications. This agent-based structure ensures scalability, allowing future expansion to additional medical conditions and datasets. The framework also integrates a Retrieval-Augmented Generation (RAG) architecture to enhance interaction with data collected by patients. Traditional generative AI models rely solely on pre-trained knowledge, limiting their ability to respond dynamically to patient-specific information. RAG architecture enhances the AI module by retrieving relevant data from uploaded patient documents (e.g., medical reports, glucose logs, lifestyle diaries) and providing contextualized answers, ensuring that insights are personalized and aligned with each patient's unique history.

[1] https://docs.ag2.ai
[2] https://www.langchain.com

To ensure data privacy, the system leverages Ollama[1] as the local LLM provider. The reference model used for AI-driven insights and summarization is LLaMA 3.2 7B, a lightweight yet powerful open-source model provided by Meta[2], optimized for on-device execution. Local LLMs enable real-time analysis while keeping patient information within secure environments, mitigating risks associated with data breaches and unauthorized access. Additionally, local LLMs optimize performance by reducing latency and enabling real-time decision support for both patients and healthcare providers. Improved communication of critical health information fosters better understanding and collaboration between patients and healthcare providers.

The system UI has been built using Streamlit[3], a python-based framework that enables rapid prototyping and deployment of interactive web applications. The streamlit-based dashboard includes: (i) interactive visualizations, essential for clinicians for exploring patient data dynamically; (ii) a conversational AI assistant, where physicians can ask natural language questions about patient health records and receive AI-generated insights. The AI-powered dashboard is designed to streamline data analysis for clinicians, allowing them to dedicate more time to patient care rather than manually processing large datasets. At the same time, it empowers patients by providing clear, personalized summaries and interactive visual feedback about their health metrics. This human-in-the-loop approach ensures that AI insights remain transparent, interpretable, and aligned with clinical needs.

3 Illustrative usage scenario

To illustrate the proposed approach, this section presents a reference case study illustrating how a physician can utilize a decision support dashboard, to enhance the management of a diabetes patient during periodic clinical visits. The dashboard streamlines the consultation process by structuring patient data and providing real-time data analysis and insights. The dashboard also integrates an AI-based agent assisting the physician in reviewing clinical progress, aggregating data and providing suggestions about the treatment plan of each patient. In the proposed scenario, input data have been simulated using *simglucose*, a Type-1 diabetes simulator. It is a recent python-based implementation of the UVA/Padova simulator (Dalla Man et al., 2014), approved by the Food and Drug Administration (FDA) for research purposes, featuring 30 virtual patient profiles (10 adolescents, 10 adults, 10 children). Each profile includes a comprehensive set of diabetes-related health metrics providing a detailed picture of the patient's metabolic control, enabling physicians to make data-driven decisions. Simulated attributes include:

- Time of measurement: each recorded data point is timestamped, allowing the system to track trends and variations over different time periods (e.g., fasting vs. post-meal glucose levels);
- Blood Glucose (BG) level: fingerstick blood glucose readings provide snapshot measurements at specific times of the day (e.g., fasting, pre-meal, post-meal, bedtime). BG values help assess short-term glucose fluctuations and inform medication and dietary adjustments;
- Continuous Glucose Monitoring (CGM) data: real-time glucose readings collected at frequent intervals providing glucose trends over time, highlighting rapid fluctuations, stability, and overall glycemic control. CGM also helps detect asymptomatic hypoglycemia or hyperglycemia episodes, which are often missed with traditional BG monitoring;
- Carbohydrate Counting (CHO) data: patients log carbohydrate intake per meal to help correlate diet with glucose variations. The system can analyze CHO intake patterns and their impact on postprandial glucose levels;
- Insulin data: records insulin doses administered (both bolus for meals and basal for long-term control) to evaluate the effectiveness of insulin therapy and detect underdosing or overdosing risks. AI-driven insights can suggest insulin dose adjustments based on past glucose responses;
- Low Blood Glucose Index (LBGI): quantifies the risk and frequency of hypoglycemic episodes and supports physicians detect patients at high risk of severe hypoglycemia, which requires intervention;
- High Blood Glucose Index (HBGI): measures the risk and severity of hyperglycemia episodes and assists in identifying patients at risk of complications such as neuropathy, retinopathy, or cardiovascular disease;
- Risk Index: a composite score derived from LBGI and HBGI, giving an overall risk assessment of the patient's glucose control. Physicians can use this metric to prioritize high-risk patients for more intensive interventions.

[1] https://ollama.com
[2] https://www.llama.com
[3] https://streamlit.io

At the beginning of the visit, the physician launches the dashboard, which automatically: (i) retrieves data collected and shared by the patient (e.g., glucose levels, dietary intake, daily activities) offering a comprehensive table representation of the collected health data. This tabular view is designed to support healthcare professionals in reviewing and analysing granular data points, ensuring that every aspect of the patient's health is visible and accessible; (ii) displays interactive charts for key health indicators. Below are the key charts integrated into the system and their utility for monitoring diabetes management:

- Blood Glucose and Continuous Glucose Monitoring chart (Figure 2): compares traditional BG readings with data from CGM systems. These two data sources provide different insights into glucose control, with BG offering point-in-time measurements and CGM providing continuous, real-time tracking;
- Carbohydrate Counting and Insulin chart (Figure 3): visualizes the relationship between CHO and insulin dosage, which is crucial for effective diabetes management. Carbohydrates have a direct impact on blood glucose levels, and the appropriate insulin dosage is needed to maintain glucose control;
- Low and High Blood Glucose Index chart (Figure 4): compares the LBGI, which measures the risk of hypoglycemia (low blood sugar), and the HBGI, which measures the risk of hyperglycemia (high blood sugar). Both indices are used to assess overall glucose control and the risk of extreme blood glucose levels, which are crucial for long-term health.

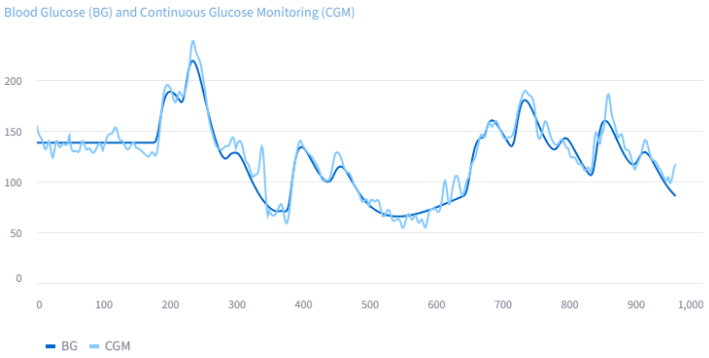


Figure 2: Blood Glucose and Continuous Glucose Monitoring chart.

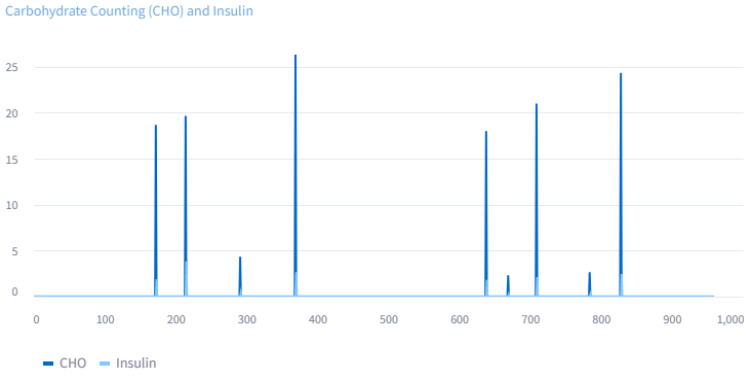


Figure 3: Carbohydrate Counting and Insulin chart.

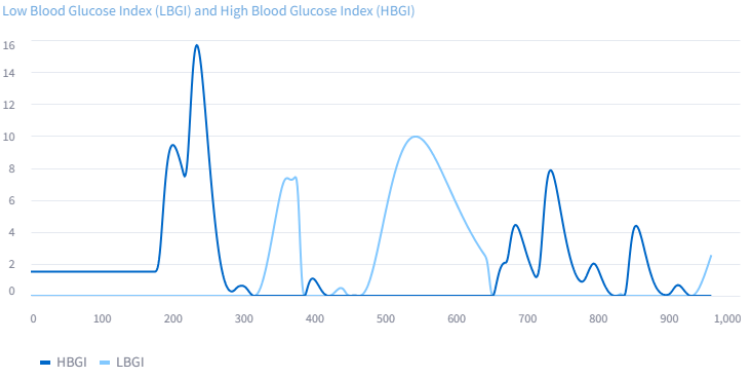


Figure 4: Low and High Blood Glucose Index chart.

These charts allow physicians to make data-driven decisions by visualizing correlations and discrepancies between blood glucose levels, insulin dosages, carbohydrate intake, and glucose control indices. Moreover, charts can be used as an educational tool for patients, helping them understand the direct impact of their dietary habits, insulin usage, and activity levels on their glucose control. While interactive charts are very useful for visualizing health data and identifying trends, they can become less efficient when dealing with large datasets. In such cases, an AI-based assistant can be a complementary tool to aggregate and summarize the data, making it easier for healthcare providers to draw insights without being overwhelmed by the volume of information. To further enhance the decision-making process, the dashboard includes a dedicated section (Figure 5) where physicians can interact with an AI agent.

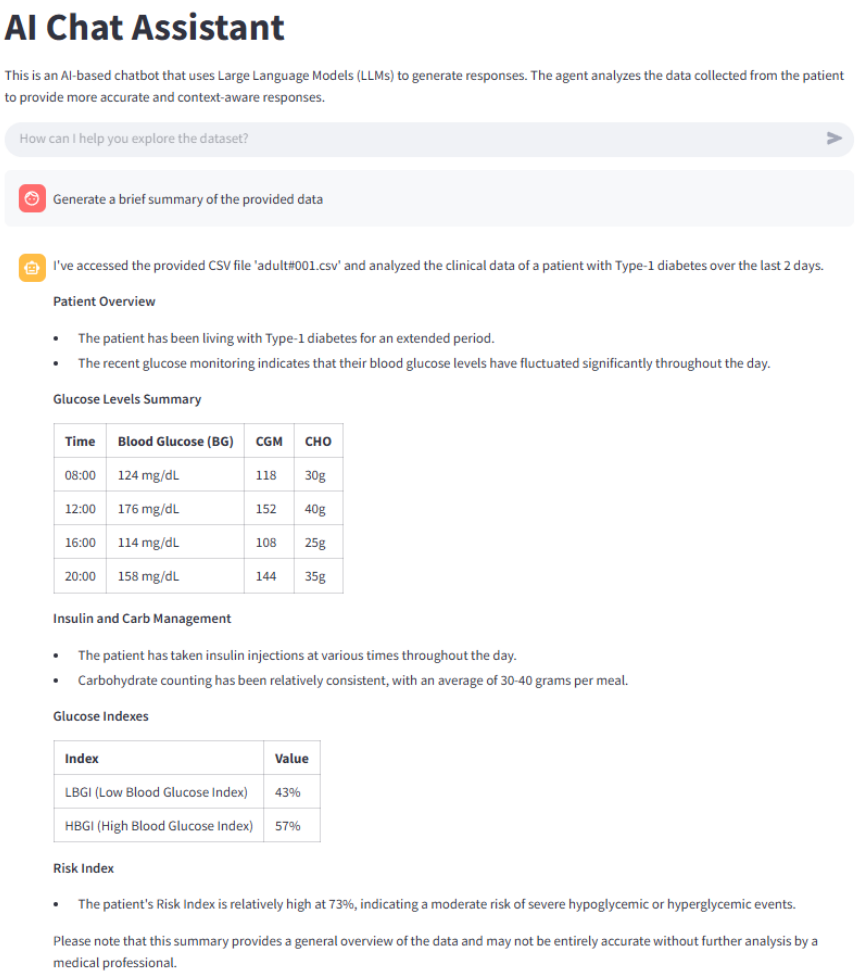


Figure 5: Example of interaction using the AI-based chat assistant.

This AI-powered assistant serves as a dialogue-based tool, allowing physicians to ask questions related to the collected health data and receive informed responses instantly. End-users can ask specific questions based both on timeframes, such as, *"What were the blood glucose readings during the last 24 hours?"* or *"How do these readings compare to last week?"*, and specific parameters, such as mealtimes or insulin injections, allowing physicians to obtain tailored insights. Due to the versatility of current GenAI models, the AI-based assistant can answer a variety of requests related to the patient's health data. Here are some potential applications:

- aggregate data for identifying whether a patient's glucose control has improved or deteriorated during a reference period;
- identify possible correlations between lifestyle factors and health indicators comparing glucose measurements before, during, and after specific tasks;
- summarize data to propose tailored treatment plans or highlight areas that need more attention, such as frequent high blood sugar during specific periods (e.g., post-meal spikes);
- provide recommendations on adjusting insulin dosages, changing meal plans, or introducing lifestyle modifications to improve blood glucose control.

At the end of the visit, the assistant can be used to automatically generates a summary report including key observations (e.g., glucose trends, activity patterns), adjusted recommendations for diet and medication adherence and personalized suggestions for the next weeks/months. It is important to note that the AI-based assistant is designed to complement, not replace, the physician's expertise, ensuring that healthcare decisions remain grounded in professional judgment. While the assistant provides valuable insights, all suggestions generated by the AI are intended to support the physician in making informed decisions, rather than act as a substitute for their clinical knowledge and experience.

4 Conclusion and future work

This paper presented a reference framework enhancing healthcare decision support for diabetes by combining cutting-edge generative AI techniques with wearable technology and advanced visualization. It empowers patients and clinicians with accurate and timely insights also improveing care quality, efficiency, and outcomes. To evaluate the feasibility of the proposed approach, an early prototype has been implemented and tested against a reference case study related to periodic clinical visits for diabetes management. This prototype demonstrates the effectiveness of AI-driven data aggregation and summarization in reducing the physician's workload and the technical feasibility of integrating AG2 and Ollama for local LLM execution, and Streamlit for a user-friendly interface. While the initial results are promising, further research and real-world validation in clinical settings are needed to refine the framework, assess its scalability, and ensure compliance with medical standards. In particular, future work will focus on: (i) conducting pilot studies with healthcare professionals to validate the AI-generated insights; (ii) enhancing the explainability and interpretability of AI recommendations; (iii) extending the system to support additional health conditions. Finally, as part of future improvements, the generative AI module will be further enhanced by incorporating machine learning algorithms designed to predict future patient conditions. These predictions will be based on historical data, enabling the system to forecast potential health risks or changes in a patient's condition before they become apparent. The results of these predictive models will not only allow clinicians to intervene proactively but will also serve to refine the insights generated by the AI assistant.

5 Acknowledgements

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6 Ethics declaration

This research did not involve the use of personal data. Ethical clearance was not required.

7 AI declaration

No AI tools were used in the writing of the paper.

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A Bibliometric Analysis of GenAI for Privacy and Information Security in Industry

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Abstract

The rapid advancement of Generative Artificial Intelligence (GenAI) has attracted considerable attention in industry and academia due to its transformative potential to automate the generation of text and multimedia content. However, concerns have emerged about privacy and information security implications in industrial settings, where sensitive data and intellectual property are essential assets.

While prior works have examined GenAI or information security in isolation, few have systematically analysed how GenAI is being integrated into privacy-preserving and security-enhancing practices in industrial sectors. By conducting a bibliometric review, this study fills this gap and provides a comprehensive mapping of how GenAI relates to information security and privacy issues in industry.

Leveraging a structured methodological framework, the bibliometric analysis conducted follows a two-phase approach to analyse a sample of 426 papers collected from Scopus and Web of Science (WoS): a preliminary analysis to assess publication trends, disciplinary contributions, document types, and geographic distributions; and a co-occurrence analysis, conducted using VOSviewer, to uncover thematic clusters. The bibliometric analysis identifies five dominant thematic clusters: (i) Generative Adversarial Networks (GANs) and Cybersecurity, focusing on adversarial attacks and industrial system protection; (ii) Industrial Cyber Protection, addressing federated learning and critical infrastructure defence; (iii) Disruptive GenAI, emphasizing Large Language Models and real-time automation; (iv) Privacy Preservation, covering anonymization and synthetic data generation; and (v) Ethical AI, exploring societal and governance implications. Overall, the study reveals critical research gaps such as the underrepresentation of medicine and energy in research landscape, limited decision sciences attention, regional asymmetries, and a lack of ethical discourse, which give rise to a forward-looking research agenda. This agenda advocates for interdisciplinary integration, regulatory alignment, and the development of context-sensitive and ethically robust GenAI systems in industry.

This study offers both theoretical contributions, advancing a more holistic understanding of GenAI's role in information security, and practical implications aimed at ensuring the safe, effective, and socially responsible deployment of this technology.

Keywords: Generative Artificial Intelligence, Cybersecurity, Industry

Paper type: Academic Research Paper

1 Introduction

Generative Artificial intelligence (GenAI) has the ability to produce new content (e.g., text, images, video code) based on patterns learned from extensive datasets (Bozkurt, 2023). This ability is considered a valuable resource to strengthen cybersecurity through automated anomaly detection (Ferrag et al., 2024), and attack scenario simulation (Gupta et al., 2023).

On the other hand, GenAI's capabilities also pose significant risks, particularly in industrial contexts where privacy and information security are paramount. Training GenAI models needs large datasets that may contain confidential information (e.g. strategic plans, personal information) putting organisations' intellectual property at risk and leading to privacy breaches (Gupta et al., 2023). Moreover, GenAI can be weaponized to amplify social engineering attacks, such as spear-phishing and deepfakes, threatening organizational reputation and operational continuity (Bischof and Portmann, 2023). Additionally, the misuse of GenAI for data integrity attacks (i.e., generating falsified telemetry or manipulated commands) poses a serious threat to the reliability of critical infrastructures (Pourmadadkar et al., 2024).

The regulatory landscape surrounding GenAI remains in flux, with key issues such as transparency, data protection and accountability still unresolved (Bodini, 2024). Companies face increasing pressure to harness the efficiency and innovation benefits of GenAI while the opaque nature of many GenAI raises new challenges for corporate governance, stakeholder accountability, and trustworthiness (Ferrag et al., 2024). Industries operating critical infrastructures with high-sensitivity data systems are especially vulnerable, as GenAI technologies can both enable defence mechanisms and introduce systemic risks (Pourmadadkar et al., 2024). In this context, it is

essential to balance the adoption of GenAI with robust risk mitigation strategies that emphasize ethical and transparent practices.

These concerns lead to the central research question of this study: “Which are the key insights related to GenAI for privacy and information security in industry?”. Addressing this question allows to understand the opportunities and challenges of GenAI, but also build trust in its potential as a tool for innovation.

Despite extensive literature on defensive and offensive capabilities of GenAI (Gupta et al., 2023; Sai et al., 2024), there is a significant lack of studies that address its impacts on privacy and information security in industrial sectors. Specifically, there is a lack of comprehensive bibliometric analyses that can provide a quantifiable overview of the scientific landscape, while identifying targeted research strategies. Previous studies have utilized bibliometric methodologies to explore GenAI applications in education (Bozkurt, 2023) or in industry (Raman et al., 2024); however, the discussion on cybersecurity is marginal and does not offer insights on privacy and information security which are essential in industries. Its relative marginalization in current GenAI scholarship contrasts with its strategic importance in ensuring GenAI adoption.

To bridge this gap and propose a future research agenda, this study conduct a bibliometric analysis as it is recognised a well-suited methodology for exploring research across various fields, especially in emerging domains (Donthu et al., 2021). The analysis is developed through a two-phase methodological framework on a dataset of 426 publications from Scopus and Web of Science. First, a preliminary analysis (i.e., publication trends, geographical, disciplinary distribution, and document types distribution) is conducted offering a macro view of the academic landscape. Second, a co-occurrence analysis of keywords present in titles and abstracts led to the identification of five thematic clusters - Generative Adversarial Networks (GANs) and Cybersecurity, Industrial Cyber Protection, Disruptive GenAI, Privacy Preservation, and Ethical AI -, which suggest future research areas and the GenAI business insights for privacy and information security in industrial contexts.

2 GenAI for privacy and information security: benefits and challenges

GenAI refers to a class of AI models, such as GANs, LLMs, and Variational Autoencoders (VAEs), capable of producing new and realistic content. These models are increasingly applied in cybersecurity contexts, particularly within Industrial Cyber-Physical Systems (ICPS) where safeguarding sensitive data and critical infrastructure is paramount (Pourmadadkar et al., 2024).

Specifically, the GANs – that comprise a generator for synthetic data production and a discriminator to evaluate the authenticity – are often used for the privacy-by-synthesis approach that replaces real and sensitive data with synthetic data that retains statistical utility but does not expose individual-level information (Gupta et al., 2023). Such techniques are particularly effective against inversion and property inference attacks, where adversaries attempt to reconstruct sensitive attributes from trained models or partial datasets (Liang et al., 2023).

In more advanced applications, hybrid models are emerging such as DP1D-OpGAN that combines GANs with Differential Privacy, a technique that obscures individual data contributions by adding noise (Hu et al., 2024). Similarly, FedMeta-CTGAN leverages federated learning to train on distributed, privacy-sensitive tabular data (Lei et al., 2025). Standardizing privacy across decentralized systems is particularly crucial in Industrial Internet of Things (IIoT) environments, where devices and servers are networked and inherently vulnerable. The integration of differential privacy during GAN training helps maintain data utility while mitigating privacy risks (Liang et al., 2023).

Beyond data synthesis, GenAI is increasingly used to simulate sophisticated cyberattacks for testing and strengthening Intrusion Detection Systems (IDS). Dual GAN architectures, one for defending via differential privacy enhanced synthetic data, and another for simulating attacker behavior are developed to improve IDS (Wu et al., 2023). Hybrid GenAI models such as the GAN-VAE model offer low-label solutions for anomaly detection, an essential feature given the scarcity of labeled data in ICPS (Sun et al., 2024).

The use of LLMs, has emerged in training IDS with synthetic network traffic but concerns persist regarding data consistency and reliability in IIoT applications (Kholgh and Kostakos, 2023). To address this, specialized GenAI models such as GReaT and REalTabFormer have been developed for more reliable simulation of intrusion detection scenarios (Melícias et al., 2024).

While GenAI offers significant advancements in privacy and information protection, its dual-use nature introduces serious risks. Among the most critical threats posed by GenAI is the potential for inversion attacks - where adversaries reconstruct original data from trained models - or data poisoning attacks, effectively breaching privacy protections (Gupta et al., 2023).

The LLMs, due to their capacity for semantic inference, are particularly vulnerable to prompt manipulation techniques (e.g., “role-playing” or “jailbreak prompts”) that can bypass safety filters and elicit sensitive or

harmful content (Gupta et al., 2023). Moreover, GenAI models have shown the capacity to generate highly realistic phishing emails and deepfakes - defined as synthetic multimedia content that mimics human language, faces, or voices (Bischof and Portmann, 2023). These capabilities lower the technical barriers to cybercrime and facilitate social engineering attacks that exploit human trust rather than technical vulnerabilities (Bischof and Portmann, 2023). In sectors such as finance and government, the misuse of GenAI in this form can erode institutional trust and damage reputations. Consequently, user awareness and education become critical to mitigate these risks (Andrei et al., 2024). The Table 1 summarizes opportunities and risks identified about GenAI and information security.

Table 1: GenAI opportunities and risks for privacy and information security.

Benefits	Challenges
Privacy-by-synthesis: GANs replace sensitive data with synthetic data, preserving utility while protecting privacy (Gupta et al., 2023) **Federated Learning**: enable training on distributed, privacy-sensitive data without central aggregation (Lei et al., 2025) **Synthetic attack simulation**: Dual-GAN models simulate attacker and defender roles to train IDS (Wu et al., 2023) **User education**: GenAI can facilitate awareness and training programs (Andrei et al., 2024	**Inversion attacks**: Reconstruct original data from trained models (Gupta et al., 2023) **Property inference attacks**: Attackers infer sensitive attributes from model outputs (Liang et al., 2023) **Adversarial learning**: GANs may unintentionally learn and reproduce harmful patterns exploitable by attackers (Sun et al., 2024) **Data poisoning**: Attackers can introduce malicious synthetic data during training phases (Gupta et al., 2023) **Phishing & deepfakes**: Realistic content lowers technical barriers for cybercriminals, increasing social engineering risks (Bischof & Portmann, 2023)

3 Research Method

To investigate the intersection of GenAI, privacy, and information security in industrial contexts, this study employs bibliometric analysis, as it allows through a structured and replicable approach (Pritchard, 1969) to map scientific knowledge and identify research trends (Donthu et al., 2021). Specifically, the framework of (Noyons et al., 1999) is followed, dividing the analysis into two phases: preliminary analysis and co-occurrence analysis. The preliminary analysis provides a quantitative overview of the field, examining trends over time through indicators such as publication and citation counts, geographic and disciplinary distribution, and document types. On the other hand, the co-occurrence analysis of keywords from titles and abstracts offers a more objective assessment by minimizing subjectivity and reviewer bias (Eck and Waltman, 2007).

A structured keyword-based search was executed across Scopus and Web of Science, two major multidisciplinary academic databases (Pranckutė, 2021), to construct a representative dataset. In March 2025, the search query (Table 1) was executed using a set of keywords, organized into three thematic groups where boolean and proximity operators were used to refine the search: terms within each group were linked using “OR” to broaden coverage, while groups were combined with “AND” to ensure intersection across all focal areas.

Table 2: Search query.

QUERY
TITLE-ABSTRACT-KEYWORDS = ("generative artificial intelligence" OR "gai" OR "genAI" OR "generative AI" OR "LLM" OR "GPT" OR "Generative pre-trained tranformer" OR "GAN" OR "Generative Adversarial Networks" OR "Diffusion Models" OR "VAE" OR "Variational Autoencoder") AND ("privacy" OR "information security" OR "data security" OR "cyber*") AND (“industr*))

The results from Scopus and Web of Science were unified in a single dataset, with duplicates identified and removed. As detailed in Figure 1, this process yielded 426 distinct records, which formed the basis for subsequent bibliometric and thematic analyses.

To ensure semantic consistency, a comprehensive thesaurus was developed to normalize keyword variations such as synonyms, acronyms, and grammatical forms. This preprocessing step increased clustering precision, allowing for a lower keyword frequency threshold of four without compromising reliability.

Out of 3,450 extracted terms, 103 keywords met the inclusion criteria, which facilitated the formation of five distinct thematic clusters, each containing at least 14 terms to preserve interpretability. The co-occurrence analysis produced three visual outputs via VOSviewer (i.e., Network visualization, Overlay visualization, Density visualization), identifying high-interest areas within the field.

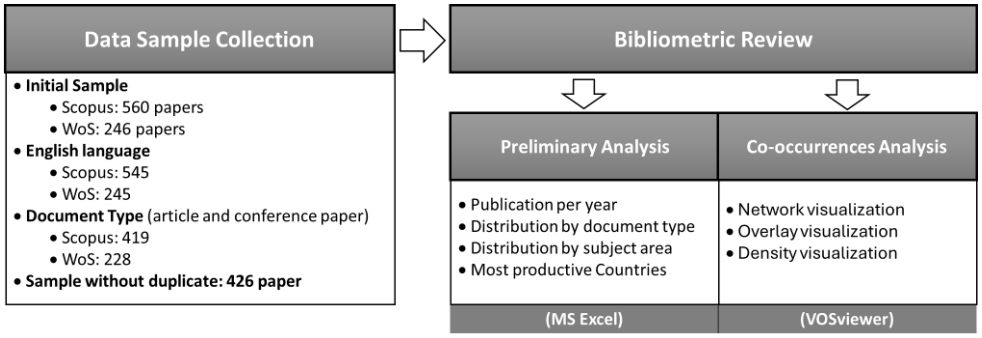


Figure 1: Research process from data sample collection to bibliometric phases of analysis.

4 Results

4.1 Preliminary Analysis

The analysis of publication trends (Figure 2) reveals a significant increase in research activity focused on GenAI, privacy, and information security over years.

The period from 2018 to 2021 corresponds to the development and proliferation of transformer-based models, which spurred widespread academic interest in GenAI technologies. Research from 2022 is likely driven by heightened awareness of GenAI's cybersecurity implications and increased industrial deployment (Sai et al., 2024) culminating in a marked surge in 2024 with over 200 new publications.

Notably, there are no publications prior to 2017, which aligns with introduction of the self-attention mechanism and transformative architectures (Vaswani et al., 2017).

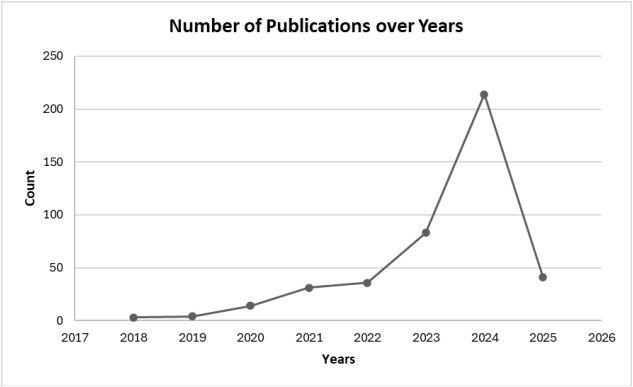


Figure 2: Publication trend.

The distribution of document types over time (Figure 3) reveals that during early years (2018–2021), conference papers dominated, indicating a focus on rapid dissemination of preliminary findings in a nascent research area. From 2022 onward, there was a marked increase in journal publications, signifying a maturation of the research domain and a growing emphasis on in-depth, peer-reviewed studies.

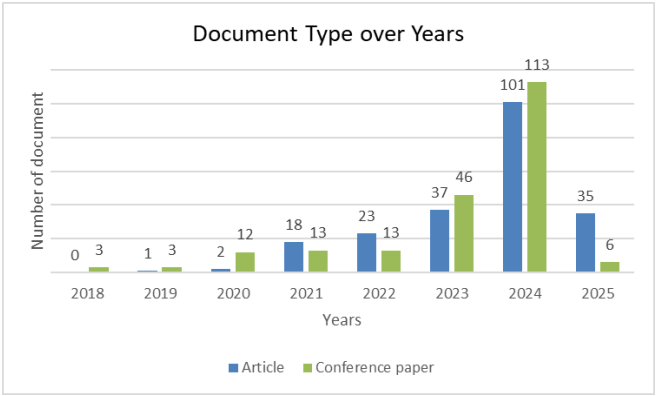


Figure 3: Document type distribution.

The subject area distribution (Figure 4) illustrates the interdisciplinary nature of the field. Over 74% of publications fall under “Computer Science”, “Engineering” and “Mathematics” consistent with the technological underpinnings of GenAI and cybersecurity.

“Decision Sciences,” while less represented, is identified as a strategically important yet underexplored area, particularly in relation to threat mitigation and automated decision-making (Gupta et al., 2023). The inclusion of “Social Sciences” and “Business, Management, and Accounting” highlights the expanding recognition of GenAI’s societal and managerial implications, pointing to an increasingly holistic view of cybersecurity (Andrei et al., 2024). Conversely, fields such as “Energy”, “Medicine” and “Neurosciences & Neurology” show limited engagement, suggesting that the application of GenAI remains an engineering emerging niche.

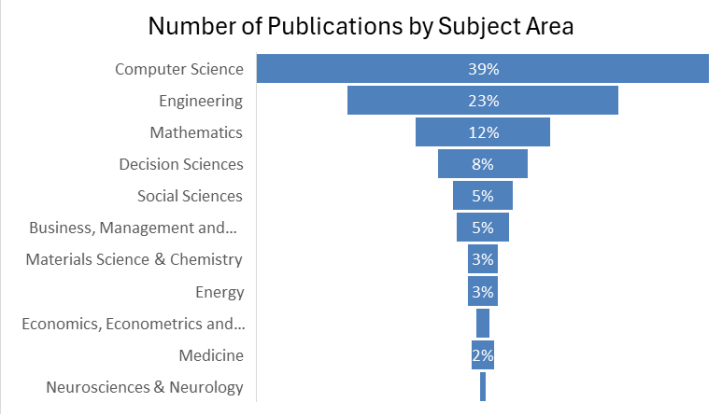


Figure 4: Subject area distribution

The geographical distribution of research publications (Figure 5) highlights the global landscape of research activity on GenAI, information security, and privacy.

China emerges as a major contributor reflecting a broader national emphasis on becoming a global leader in AI innovation and industrial modernization. The United States, also plays a central role in shaping the field as the research is underpinned by a dynamic interplay between academic institutions and industry leaders. India is experiencing rapid growth in GenAI-related research positioning at the third place. Within Europe, several countries (i.e., Germany, Italy and Finland) demonstrate strong participation in GenAI security research.

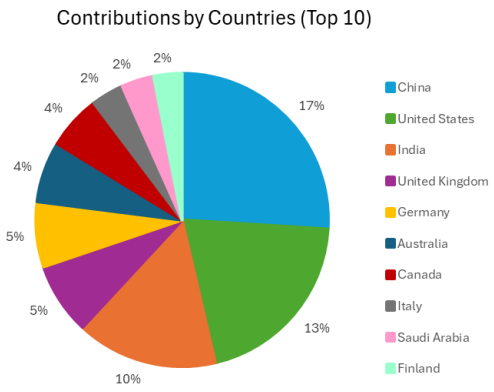


Figure 5: Contributions by Countries.

4.2 Co-occurrences Analysis

The network visualisation (Figure 6) depicts nodes representing keywords whose sizes and centrality within the network signify their relevance across thematic domains summarized in Table 2.

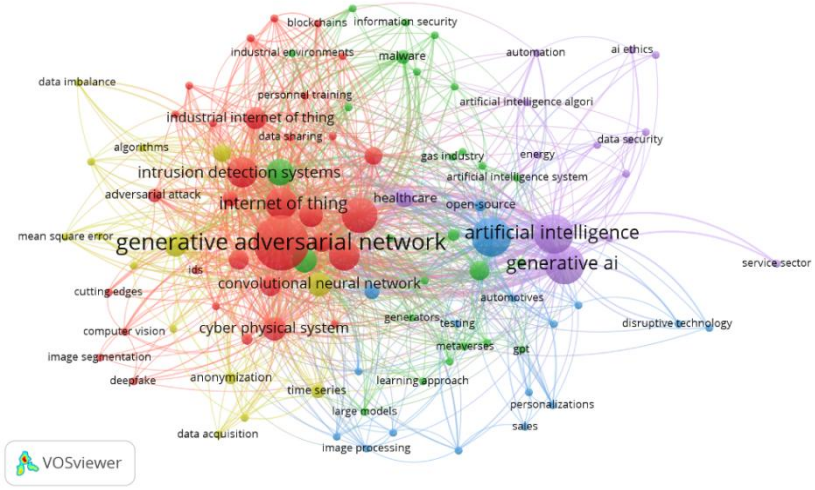


Figure 6: Network visualization.

The red cluster is focused on the application of GANs and highlights the protection of industrial systems, including terms like IIoT, CPS, and SCADA. The cluster also incorporates a strong emphasis on privacy-enhancing technologies such as differential privacy and blockchain, reflecting growing interest in decentralized and secure data architectures.

The green cluster explores the intersection of federated learning and cybersecurity, emphasizing distributed, privacy-aware AI models for defending industrial control systems and critical infrastructures. The use of AI in threat detection, information security, and decision support is extended to sectors like finance, supply chains, and commerce, revealing a broadened scope of application.

The blue cluster is defined by Large Language Models (LLMs) and their role in automating tasks that involve natural language processing (NLP), predictive modeling, and user personalization. LLMs are positioned as disruptive technologies, rapidly integrating into real-time systems across sales, networks, and wireless sensor platforms. The inclusion of open-source frameworks highlights a movement toward more transparent, collaborative AI development, emphasizing scalable and modular solutions in distributed environments.

Focusing on Convolutional Neural Networks (CNNs) and autoencoders, the yellow cluster reflects advanced deep learning techniques applied to pattern recognition, classification, and temporal data analysis. The study of time series, multivariate sequences, and data imbalance indicates real-world application challenges in sequential modeling and privacy-preserving learning. The reference to anonymization and data acquisition suggests a methodological interest in training models on sensitive or limited datasets while maintaining data security and integrity.

Anchored by high-frequency references to AI and GenAI, the purple cluster deals with the ethical and societal implications. It emphasizes responsible innovation in domains such as healthcare, fintech, and the service industry, where GenAI is reshaping workflows and raising concerns about data security, bias, and automation risks. The inclusion of terms like AI ethics, ethical concerns, and responsible AI signals a proactive effort to align technological progress with social accountability and governance frameworks.

Table 3: Cluster main keywords.

Color	Item	Cluster Title	Main Keywords
Red	32	GANs and Cybersecurity	GAN (173), ML (74), IoT (58), adversarial ML (53), IDS (53), differential privacy (34)
Green	26	Industrial Cyber Protection	cyberattacks (41), federated learning (35), decision making (23), malware (12), AI systems (4)
Blue	17	Disruptive GenAI	LLM (89), network (14), open-source (9), disruptive technology (4), image processing (4)
Yellow	14	Privacy Preservation	CCN (33), autoencoders (31), classification (of information) (18), time series (11), anonymization (9)
Purple	14	Ethical AI	AI (92), GenAI (89), healthcare (21), AI ethics (4), AI technologies (4), data security (4)

The overlay visualization (Figure 7) shows the evolving research landscape of GenAI for data privacy and information security. Recent years show a marked increase in interest around GANs and LLMs reflecting their rapid adoption. Concerns of cybersecurity threats are evidenced by frequent mentions of “adversarial machine learning,” “IDS,” and “cyberattacks,” underscoring the critical vulnerabilities faced by industrial systems. The visualization also highlights the rising prominence of privacy-preserving technologies, including “differential privacy,” “synthetic data generation,” and “privacy-preserving techniques,” pointing to innovative efforts to reconcile data utility with ethical safeguards. Blockchain emerges as a complementary technology, increasingly explored from 2022 onward for its potential to secure AI-generated content. Notably, there is a pronounced shift toward industrial application contexts, such as ICPS and IIoT indicating a convergence of theoretical AI research with practical cybersecurity implementation. More recent terms like “responsible AI” and “disruptive technology,” averaging in 2024, reveal an emergent discourse centered on the socio-ethical governance of GenAI, reflecting academic anticipation of its broader societal impacts.

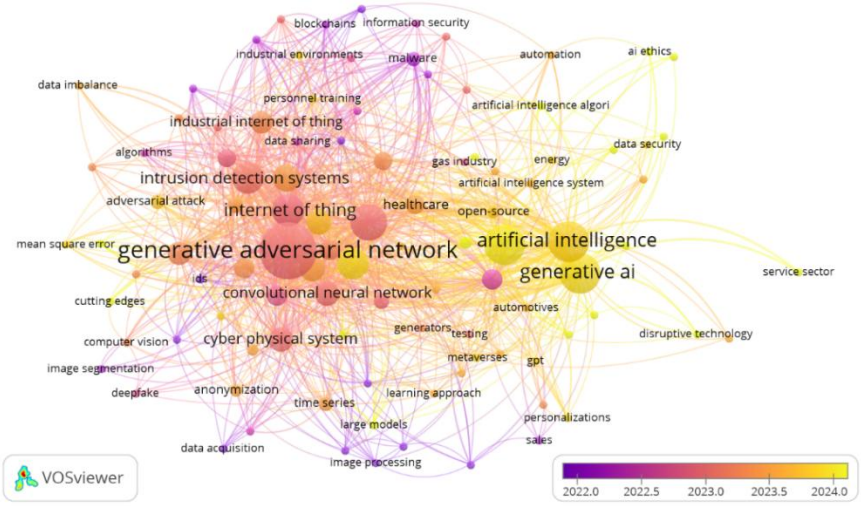


Figure 7: Overlay visualization.

The density visualization (Figure 8) offers a complementary spatial perspective of topics like GANs, IDS, IIoTand ICPS which appear at the densest core of the map. Their prominence underscores the transition of GenAI from theoretical frameworks to practical tools, especially in domains such as cybersecurity, industrial automation, and synthetic data generation. The visualization also reflects a diversification of GenAI applications, with dense clusters forming around non-traditional sectors like healthcare, energy, and hospitality. However, the peripheral positioning of AI ethics, while adjacent to security-related terms, suggests that current ethical considerations are predominantly framed through pragmatic lenses of risk, privacy, and data governance, rather than broader philosophical or policy-oriented debates. Interestingly, emergent but underrepresented themes such as deepfakes and anonymization remain in low-density zones, hinting at potential research gaps.

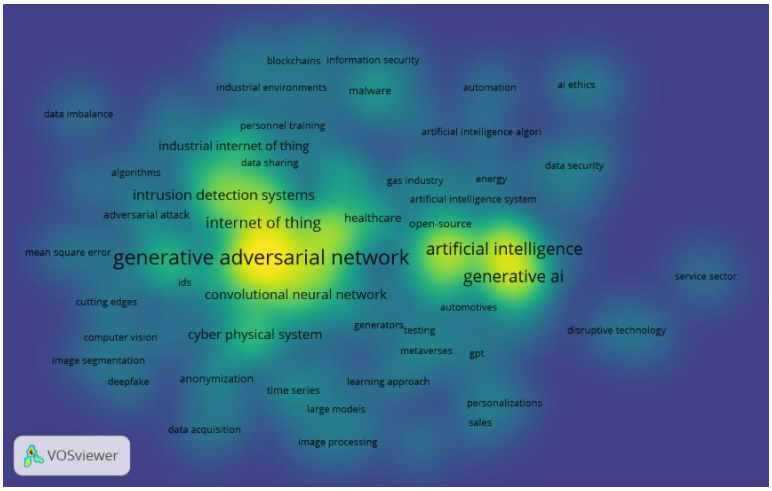


Figure 8: Density visualization.

4.3 Future Research Agenda

While the bibliometric analysis presented offers an overview of current research trends in GenAI for privacy and information security, it simultaneously allows to identify research gaps (Table 3) that, if addressed, could substantially advance the state-of-the-art and foster a more robust research landscape.

A critical gap lies in the underrepresentation of high-stakes disciplinary domains such as medicine, neuroscience, and energy, despite their vulnerability to data breaches and operational threats. As highlighted by the subject area distribution, these fields exhibit minimal engagement with GenAI, a trend that is misaligned with the demonstrable potential of technologies like LLMs and GANs. Parallel to this, the field of Decision Sciences remains marginal in terms of research output. The lack of a multi-disciplinary lens limits the design of resilient and context-aware GenAI-based cybersecurity systems, and signals an opportunity to leverage the rigor of Decision Sciences in automating and defending decision infrastructures.

Geopolitical disparities further constrain the field's maturity as the regional asymmetries underscore the lack of contextualization of GenAI development and privacy solutions to the socio-technical underdeveloped ecosystems. Bridging this divide entails a deliberate incorporation of local threat models, linguistic diversity, and region-specific policy constraints.

A more insidious gap is found in the field's treatment of ethics in the co-occurrence and density mappings that reflects an under-theorized discourse, one focused narrowly on data protection, bias mitigation, and risk. What is lacking is a deep interdisciplinary and critical engagement that interrogates broader questions of accountability, autonomy, justice, and algorithmic governance.

Moreover, given the escalating use of deepfake technology in disinformation campaigns and identity theft, this gap area warrants intensive methodological development in detection algorithms, synthetic traceability, and regulatory safeguards. At the methodological level, federated learning and other privacy-enhancing techniques are featured but underexplored in depth.

Table 4: Future research agenda.

Identified Research Gap	Future Research Directions	Research Questions
Disciplinary underrepresentation	Develop cross-domain applications of GenAI tailored to sector-specific challenges (e.g., privacy-preserving diagnostics for healthcare) and robust risk assessment	• How can GenAI be adapted for privacy-preserving data analysis in clinical decision-making? • What role can decision-theoretic models play in automating cybersecurity incident response in critical infrastructure?
Country research asymmetry	Expand international collaborations to include researchers from underrepresented countries contextualizing GenAI security models to local infrastructural, legal, and socio-cultural environments	• What local legal and infrastructural challenges shape the deployment of GenAI in developing economies? • How do socio-cultural norms influence privacy expectations in GenAI-powered industrial systems?
Limited ethical discourse	Develop normative frameworks that go beyond compliance to encompass fairness, autonomy, and long-term societal impacts	• What ethical principles should guide the deployment of GenAI in data-sensitive industrial sectors? • How can we assess and operationalize algorithmic fairness in GenAI systems used in decision-making processes?
Underdeveloped treatment of emergent threats	Conduct systematic studies on detection, mitigation, and regulatory responses to deepfakes and synthetic identity risks	• What detection algorithms are most effective against industrially targeted deepfake attacks? • What regulatory mechanisms are needed to track and control synthetic identity fraud in industrial domains?
Methodological limitations	Improve the robustness, scalability, and auditability of privacy preserving technique such as federated learning, blockchain and differential privacy and the alignment with legal standards through co-design	• What are the trade-offs between data utility and privacy in industrial applications of differential privacy? • How can federated learning and blockchain be adapted to heterogeneous industrial datasets while ensuring legal compliance?

5 Conclusions

This study offers a comprehensive investigation into the intersection of GenAI, privacy, and information security, particularly in industrial contexts. By employing a structured bibliometric methodology operationalized through a preliminary analysis and a co-occurrence analysis, this work maps the evolution of research attention, identifies dominant themes, and exposes critical gaps in the current research landscape.

Theoretically, the study underpins current research in computer science and reveals disciplinary asymmetries, such as the marginal presence of health, neuroscience, and decision science disciplines. By surfacing these blind spots, it contributes to the reorientation of scholarly focus towards more comprehensive theoretical paradigms that include ethical and governance dimensions. Multidisciplinary ethical inquiries to encourage the construction of theoretically grounded normative models, thus enriching the foundational GenAI debates.

From a managerial perspective, the identification of underrepresented sectors and regions provides evidence-based guidance for funding agencies and academic institutions to realign research investments. Targeted funding toward underexplored domains such as medicine, energy, and neuroscience can catalyse GenAI applications in high-impact, vulnerable sectors. The study advocates for the expansion of ethical and legal frameworks, prompting policymakers and legal scholars to engage with AI from a governance-oriented perspective. Insights into issues like deepfakes, privacy leakage, and federated learning inform about new forms of digital risk and threats.

The future research agenda provides clear guidance both for academic and practitioners as it emphasizes the importance of addressing regional disparities, enhancing methodological rigor in privacy-preserving techniques like federated learning, and proactively tackling emergent challenges such as deepfakes. It also informs funding strategies, system design, and policy development by identifying strategic areas where GenAI can deliver high-impact, ethically sound, and legally compliant solutions.

However, the study is not without limitations as the reliance on bibliometric analysis is constrained by the author interpretation, potentially biasing the discussion. Moreover, while the study offers global insights, it does not deeply investigate regulatory landscape and sustainability issues related to GenAI. Future work should complement this bibliometric mapping with systematic literature review to explore more in deep how GenAI technologies can be responsible integrated into industrial privacy and security debate.

6 Ethics declaration

This research is based exclusively on available data from Scopus and Web of Science. All the analyses were conducted with academic integrity and that no part of the research involved deception, manipulation, or violation of ethical standards.

7 AI declaration

This study's document collection, screening, and bibliometric analysis were carried out entirely by the authors using manual methods and established research procedures.

GenAI tool, specifically GPT-4 was used in the revision stage to refine improve coherence and adjust technical phrasing to ensure accessibility for a non-specialist audience. The use of these tools was limited to stylistic and editorial assistance. All conceptual development, critical reflection, data interpretation, and theoretical contributions are solely the product of the authors' intellectual work.

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Generative AI in Data Management: Enhancing Data Quality Control for Business Data

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Abstract

The centrality of data quality within data management, and more broadly in business decision-making processes, constitutes an essential prerequisite for the reliability of analyses and, consequently, for the effectiveness of business strategies. The growing complexity and heterogeneity of data flows make data quality management an increasingly critical challenge, aimed at preserving the accuracy and consistency of extracted information. In this context, efficiency and timeliness become fundamental requirements. However, data quality processes are often resource-intensive and require specialized expertise. In this perspective, the adoption of generative artificial intelligence models, particularly Large Language Models (LLMs), opens new opportunities to support data management and quality control activities. This study proposes a conceptual framework for modelling the use of an LLM Agent to assist Data Quality and Application Maintenance teams. The framework is designed to facilitate the analysis of anomalies and malfunctions detected within systems responsible for data quality controls. Furthermore, the agent can suggest a set of technical solutions, specifying the potential impacts on the existing infrastructure and scheduled processes. This approach provides a solid foundation for future applications, promoting more efficient anomaly management and a strategic use of existing technical knowledge.

Keywords: Generative AI, Data Management, Data Quality, Knowledge Management, Process Optimization

Paper type: Academic Research Paper

1 Introduction

Data can be regarded as a resource from which information and knowledge can be extracted . For this reason, data have become a crucial strategic asset for organisations, forming the foundation of data-driven decision-making processes and the emerging paradigm of knowledge as a competitive asset . In response to this evolution, companies are increasingly investing in advanced technological infrastructures to enhance the value derived from their available data (Angelelli, et al., 2024; Furtado, et al., 2017). In line with the DIKW (*Data, Information, Knowledge, Wisdom*) framework proposed by Ackoff, (1989), leaders and managers use data-generated knowledge to optimize processes, products, and customer engagement strategies . In data-driven organisations, data are considered a strategic asset whose value is realized through a progressive process of transformation into knowledge and operational impact . However, the full exploitation of this potential is often directly tied to the architecture of data pipelines and to the mechanisms for ensuring and preserving data quality. Ensuring that data meet certain quality standards, being accurate, complete, and consistent, is essential for value generation and for guaranteeing the effectiveness of business processes . Managing these processes frequently poses numerous challenges for organisations. The complexity of modern information infrastructures, often distributed and based on heterogeneous systems , makes it difficult to integrate, monitor, and control large volumes of data effectively. Furthermore, companies must comply with increasingly stringent internal standards and operate in environments subject to rigorous privacy and security regulations (Jimenez, et al., 2019; Gervasi, et al., 2023), requiring specialized skills, advanced methodologies, and significant investments of time and resources.

Within this context, managing data pipelines, particularly data quality controls, has become a critical component of the enterprise information ecosystem. Activities related to data engineering, data quality, and Application Maintenance (AM), the latter responsible for maintaining enterprise information systems in operation, are generally entrusted to specialized information technology (IT) teams. Throughout the paper, the teams responsible for data quality processes will be referred to as Data Quality and Application Maintenance teams (DQ&AM). The effectiveness of such processes, however, depends not only on technical expertise but also on the involvement of actors with deep knowledge of the business domain and organisational processes. The costs associated with AM services for data quality processes are often extremely high, given the daily, resource-intensive nature of these operations, which often require constant oversight. Moreover, direct access

to data and the data pipeline is typically restricted to technical personnel, limiting the ability of business users to independently explore or interact with the data. In fact, business users, who can only access information asynchronously, are often faced with analytical results they cannot fully interpret (as these rely on complex statistical or technical analyses), and they are unable to reiterate or simulate alternative scenarios to deepen insights and foster greater decision-making autonomy . This dependency can result in operational inefficiencies in data quality processes.

Under these circumstances, the emergence of Generative Artificial Intelligence (GenAI) technologies presents a significant opportunity to transform business processes and to innovate the monitoring and control of data quality within organisations. GenAI models, and particularly Large Language Models (LLMs), due to their ability not only to analyse existing data but also to generate new, coherent, and context-aware information, can be employed to automate and enhance multiple data management tasks, especially those concerning data quality monitoring and improvement and to extract value from textual data . Beyond improving accuracy and operational efficiency, these tools can help democratise access to data management processes , enabling non-technical users to interact with systems more autonomously. In this regard, the integration of GenAI models represents a key enabler for knowledge management, facilitating not only more direct access to data by business users but also the sharing, validation, and dissemination of knowledge within decision-making processes .

The research question guiding this study is as follows: *how can GenAI technologies, specifically LLMs, support and enhance data management processes, particularly those related to data quality?* The overall objective is to understand how GenAI technologies can contribute to optimizing specific data management processes, especially in supporting the efficiency and maintenance of data quality activities performed by DQ&AM teams. This can strengthen organisational knowledge management by promoting democratic access to data and increasing the autonomy of non-technical users in data quality operations and, more broadly, in enterprise information systems.

Following an exploratory literature review aimed at identifying key trends, approaches, and challenges in the integration of GenAI into Enterprise Data Management (EDM), a conceptual framework has been introduced that models a potential workflow of a DQ&AM team. This modelling results in the proposal of an intelligent agent that integrates GenAI and LLM technologies to support data quality processes through a structured and multi-level analysis.

2 Theoretical background

Knowledge is one of the key value elements that Big Data potentially make accessible . The process through which data-driven organisations seek to generate value from data is articulated and complex, and can be described as a progressive transformation of raw data, characterized by a potential value, into information value and, ultimately, into tangible impacts on decision-making processes and the generation of business value . In particular, this latter form of value serves as a central metric for assessing the return on data management strategies aimed at the generation and application of knowledge.

This underlines the importance of ensuring and maintaining high standards of data quality, an increasingly demanding challenge in complex organisational contexts. GenAI technologies, and in particular LLMs, open up new perspectives for the intelligent automation of business processes, thanks to their ability to understand natural language, interact with heterogeneous sources of knowledge, and generate contextualized outputs to support complex tasks . The term LLM refers to a generative artificial intelligence model designed to produce textual (or other format) output based on a given prompt; these models differ from other GenAI technologies because they are trained on large bodies of text comprising natural language and code, and are architecturally based on transformer networks , with a significantly higher number of parameters than traditional machine learning models.

Several studies in the literature have explored the potential of generative intelligence tools for data quality control and, more broadly, data management activities. Varma, et al., (2024) confirm the promising potential for the optimization of data management workflows, demonstrating time reductions in specific EDM tasks, primarily focusing on technical assistance for data analysts and engineers. In their study, these approaches typically involve automating data profiling, SQL code generation, or identifying table relationships, thereby streamlining the preparation of analytical datasets: for instance, the effort required for *data profiling* is reduced by around 40% when employing GenAI techniques, while *source table and column identification* tasks show an effort reduction of around 75% through the use of LLM architectures such as *LLaMA-7B* and *GPT-3.5 Turbo*.

Similarly, Monka, et al., (2024) highlight how LLMs can significantly enhance the ability to generate accurate and complete queries within relevant contexts, providing a focused contribution to the adoption of knowledge graphs in the manufacturing sector. This contribution emphasizes the potential to democratise access to

complex data repositories and to empower informed decision-making in industrial environments . The theme of democratising data science is also central in the work of Sv, et al., (2024), where a multi-step approach is used to develop a system capable of integrating LLMs models (such as *Phind-CodeLlama* and *CodeLlama*) into data science frameworks; the goal is to enhance data analysis capabilities and the generation of insights from tabular data.

In line with this direction, there is a growing scientific interest in the use of LLM agents, defined as intelligent entities capable of autonomously performing tasks by combining language models with operational tools. Within this context, Easin, et al., (2024) propose the development of a highly customizable banking assistant that leverages the open-source *LangGraph* library to build multi-actor LLM systems with cyclic operations. The authors explore the use of advanced prompting techniques such as *Chain of Thought* and *Retrieval Augmented Generation* (RAG) , highlighting the role of LLM agents in autonomously interacting with APIs, utilizing external tools, and solving complex tasks. These solutions prove particularly effective in optimizing user interaction, accelerating services, and offering personalized experiences in the banking sector. Li, et al., (2024) define LLM agents as one of the five core components of an LLM-based data management system. Specifically, an LLM agent is a fine-tuned language model equipped with tools, memory, and prompts, capable of decomposing a user request into multiple sub-tasks and generating optimized pipelines to execute them effectively. It is thus increasingly evident that LLMs are redefining how data management is approached. Their ability to synthesize knowledge not included in the training dataset and to recombine it in novel and unexpected ways yields interesting outcomes, such as resolving semantic ambiguities that hinder data integration activities like schema matching, mapping, entity resolution, and alignment. Furthermore, their ability to understand and express informational needs in natural language, to interpret heterogeneous data schemas, and to retrieve relevant information even from unstructured sources could significantly enhance data discovery processes in complex enterprise environments.

3 Methodology

This study adopts a qualitative approach, aimed at developing a conceptual analysis and theoretical reflection arising from a research question that emerged within an organisational context. The research follows an inductive design, grounded in both the observation of concrete organisational practices and the analysis of gaps identified in the existing literature. In line with the methodological perspectives of , these empirical insights progressively guided the formulation of general principles and theoretical considerations. The research problem was initially defined within a business context and subsequently examined and validated through an exploratory review of the academic literature. Based on the research question, the study proposes a theoretical model that outlines the functioning of an intelligent agent based on GenAI technologies, designed to support business users in dealing with data management and quality control processes. The model was developed through an iterative and reflective process, drawing upon operational challenges observed in real-world projects and enriched by established theoretical contributions.

The proposed framework aims to provide a conceptual foundation for future applications and experimentation in the field of data management, contributing to the ongoing discourse on the use of GenAI as a lever for decision-making autonomy, process transparency, and the valorisation of knowledge within organisations.

4 Proposed Framework

In this section, a conceptual framework is presented. It aims at enhancing data quality processes through the collaboration between technical and business actors, with a specific focus on reconciliation activities and maintenance operations.

4.1 The Role of Data Reconciliation and Maintenance Teams in Sustaining Data Quality

Data quality represents a central element within data pipelines and the management of enterprise information systems, as it plays a significant role in ensuring the accuracy and reliability of extracted information. Several scholars have sought to identify and formalise the key dimensions that characterise data quality, with the aim of guiding organisations in the assessment and improvement of their information assets. Among these dimensions are *accessibility, accuracy, consistency, and timeliness.* Consistency has been defined as '*the extent to which data are always presented in the same format and are compatible with previous dat*a' as well as '*the correctness and completeness of logical relationships between correlated data, which may reside in different storage systems but are considered equivalent*' . Closely related is the dimension of coherence, described as '*the*

degree to which data can be successfully brought together', which includes the internal consistency of data collection processes.

In this context, *data reconciliation* plays a fundamental role in data quality management processes. It refers to a technical procedure aimed at aligning data that refer to the same entities but originate from heterogeneous sources, often characterised by differences in format, temporal granularity, or semantics. This operation requires the identification and application of *reconciliation keys*, which are necessary to correctly map records across different information systems, ensuring harmonisation of temporal and semantic granularity .

The inconsistencies encountered may result from various causes, including technical errors such as duplications, null values, type or format mismatches, latency in data update flows, or failures in ETL jobs. However, alongside these automatically detectable anomalies, there are also non-technical errors whose identification requires domain expertise or contextual knowledge. These include values that are formally correct but inconsistent with implicit business rules, data that do not reflect recent changes known to users (e.g., unpropagated organisational updates), or discrepancies in expected values that emerge only through users' contextual experience. These semantic anomalies are particularly critical for decision-making processes, as they cannot be identified through syntactic checks or standard automated procedures. Their resolution thus requires collaboration between business users and technical teams to ensure correct interpretation and remediation.

Within data-driven organisations, the management of data pipelines and information systems involves a wide range of actors engaged in ensuring the efficiency and maintenance of data quality processes. These actors encompass both technical figures, such as data owners, data stewards, and data engineers, and business users, who are responsible for validating and checking the quality of data. In particular, during data reconciliation activities, the involvement of business users becomes essential for identifying deviations from expected values or from business rules that cannot be entirely formalised through automated procedures. To ensure the functioning of data quality processes, as well as the overall efficiency and reliability of the system, organisations typically entrust these responsibilities to dedicated DQ&AM teams. The ongoing reliability of data quality processes is critical, as many checks are executed on a daily basis, aligned with data update schedules. As a result, data quality teams are regularly involved in monitoring scheduled jobs and ETL processes to guarantee successful execution and to avoid failures. Even minor delays can introduce inconsistencies or trigger timing shifts that may not be recoverable within downstream processing pipelines.

As highlighted by , AM services represent one of the largest cost drivers for IT organisations, often represent a substantial part of operational expenditure. Maintenance activities are frequently hindered by a lack of documentation, the proliferation of workarounds, layered technological architectures, and difficulties in accessing distributed knowledge. In such contexts, reconstructing the background of an application request can be particularly burdensome, time-consuming, and heavily reliant on the memory or expertise of individual specialists . These critical issues underline the need for tools to facilitate access to and interpretation of technical and documentary knowledge.

4.2 Towards a Data Quality LLM agent

This section introduces a conceptual framework aimed at optimising data quality and AM services through the integration of an intelligent agent based on Generative AI technologies. Leveraging the capabilities of LLMs, the agent is designed to manage user requests and automatically detected anomalies in a structured manner.

The *Data Quality LLM Agent* (DQ Agent) is conceived as a support tool that automates the analysis of anomalies within data quality systems, identifying potential root causes and suggesting possible solutions to expert teams. The agent is not intended to replace existing services; rather, these services remain responsible for validating the proposed solutions and, where appropriate, selecting the corrective actions to be implemented. In order to provide an efficient service, the DQ Agent is granted access to a wide range of resources for anomaly analysis, including technical and functional documentation, the ticketing systems used by data quality and AM teams, and full visibility over the entire data pipeline, ranging from orchestration systems and data transformation processes to output tables and related objects.

This approach aims to reduce the operational workload on DQ&AM teams, improve the timeliness of responses, and ensure a more transparent and efficient management of information. The logical model underpinning the functioning of the DQ Agent, as shown in Figure 1, is presented below.

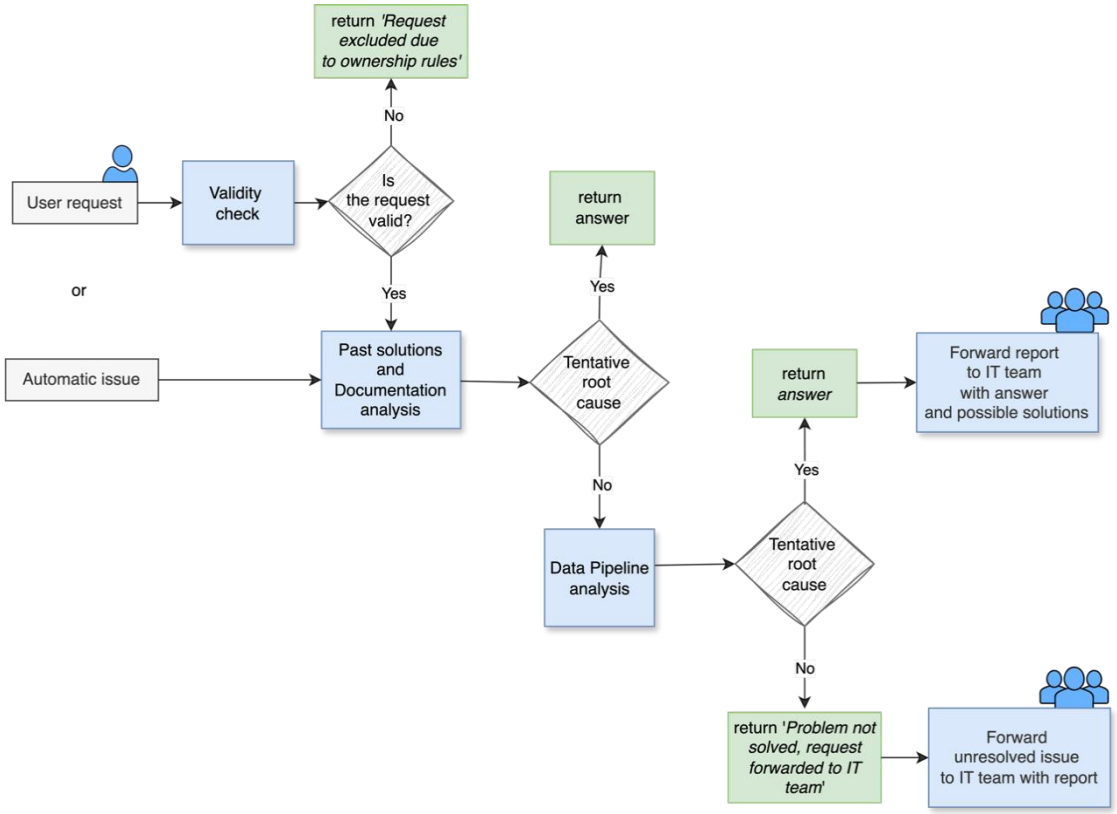


Figure 1: Data Quality LLM Agent conceptual framework

The process begins either with the reception of a user request, formulated in natural language, or with the automatic detection of an anomaly by a monitoring system (*Automatic issue* in Figure 1). In the case of a user request, the first logical barrier is the *Validity check*, which consists of verifying whether the request falls within the scope of responsibility of the DQ&AM service. If not, the user receives the message *Request excluded due to ownership rules*, as illustrated in Figure 1.

Once ownership has been validated, the process moves to the first level of analysis, *Past solution and Documentation analysis* (Figure 1), where the agent queries the official project documentation alongside previous ticket resolution emails. This *knowledge retrieval* phase serves a dual purpose: first, to verify the coherence of the request with respect to the functionalities and logic defined in the project documentation; and second, to identify similar past cases, thereby leveraging the existing knowledge base and accelerating the resolution process.

If the check of past anomalies and the solutions adopted together with the project documentation, is not sufficient to identify the possible root cause of the anomaly in question, the DQ Agent activates a second level of analysis covering the entire data pipeline process. In the proposed model, *Data Pipeline analysis* (Figure 1) represents a central component, enabling the DQ Agent to systematically explore the potential causes of the detected anomaly. This activity is grounded in a detailed examination of the core components that constitute the data pipeline:

- Process Orchestration: the configuration and coordination of workflow sequences, including their temporal and logical dependencies.
- ETL Process: the extraction, transformation, and loading of data, including the execution of queries and the use of materialized tables.
- Source Tables: original datasets from which information is retrieved and processed.
- Information Delivery Process: reporting and visualisation systems to make processed data accessible and interpretable, including by business users.
- Non-Materialized Query: results produced by dynamic or ad-hoc queries that are not persisted in storage.

The agent must be able to examine **Process Orchestration**, verifying the correct execution and sequencing of workflows, as well as compliance with logical and temporal dependencies. It must then analyse the **ETL Process**, checking data extraction, transformation, and loading operations, as well as the corresponding queries

and materialised tables. An additional check concerns the **Source Tables** from which the processed data originate, whose update status and integrity are essential to ensure data quality. The DQ Agent must also evaluate the **Information Delivery Process**, ensuring that data are properly distributed and interpretable by business users through reporting and visualisation tools. Finally, the agent may execute parts of the data pipeline in order to generate and inspect **Non-materialised queries**, i.e., dynamic, non-persistent query results that may provide further diagnostic insights. To determine which checks to activate without disrupting operational performance, the DQ Agent must also access the *monitoring system*, which provides visibility into process statuses, computational loads, logs, and past executions, enabling informed and efficient analysis. System-wide workload analysis is crucial to avoid critical interference with ongoing or scheduled data pipeline operations.

Once the root cause of the issue has been identified, the DQ Agent generates a report detailing the analysis and solutions proposed, which is subsequently forwarded to the DQ&AM team. If, however, the origin of the problem remains uncertain, the agent forwards the request to the same team, attaching a structured report documenting the diagnostic process carried out.

In the proposed model, the DQ Agent provides benefits both in operational efficiency and in knowledge management. The system contributes to reducing the average time required to analyse and address anomalies by automating preliminary diagnostic tasks. It filters out requests that fall outside the competence of the DQ&AM teams, preventing the misallocation of resources and ensuring that requests are appropriately addressed to the most relevant actors. Moreover, the DQ Agent ensures an autonomous and continuous initial handling of anomaly reports, maintaining service availability without interruption. A further advantage lies in the reduction of dependency on individual expertise, as the system operates on a continuously updated knowledge base. It provides consistent and structured access to technical and operational information, ensuring continuity in processes even in cases of staff turnover or the redistribution of responsibilities.

Finally, through integration with monitoring and orchestration systems, all solutions proposed by the DQ Agent are enriched with an evaluation of their potential impact on the data pipeline, thereby helping to preserve the efficiency, sustainability, and stability of both ongoing and scheduled processes. The system may be particularly suitable for the management of recurring or low-complexity anomalies, for which it is able to propose solutions based on historical cases, without requiring the direct intervention of experts. In more complex or specific cases, the system is a relevant support for the activities of the DQ&AM team, simplifying operations and helping to significantly reduce response times.

5 Conclusions

This study explores the potential of GenAI technologies, with a specific focus on LLMs, in optimizing data management and data quality processes within enterprise environments. Based on a conceptual analysis and insights gathered through discussions with industry experts, a conceptual framework has been developed to model the functioning of a DQ Agent capable of supporting user request handling and monitoring of enterprise data quality processes. The proposed logical architecture integrates natural language processing capabilities, document-based knowledge retrieval, and automated analysis of the processes composing the data pipeline. The model ensures a clear separation between the diagnostic phase, managed by the DQ Agent, and the operational phase, which remains the responsibility of the human team.

The integration of an LLM agent represents a strategic lever to enhance existing organisational knowledge, reduce critical dependency on individual expertise, and facilitate knowledge sharing within decision-making processes. The proposed model also contributes to overcoming the limitations faced by business users, promoting greater democratisation of access to data and data pipeline processes. This proposal provides a solid conceptual foundation for future applications that include technical investigations aimed at identifying the most suitable models, tools, and techniques, with the goal of empirically validating the framework and assessing its impact on organisational processes, both in terms of operational efficiency and knowledge management.

6 Ethics declaration

No ethical approval was required because the research did not involve human participants, experiments, or the collection of personal data.

7 AI declaration

During the preparation of this manuscript, the author(s) employed generative AI tools to enhance the language and clarity of the text. All content was subsequently reviewed and revised by the author(s), who assume full responsibility for the final version of the publication.

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Individual and Organizational Factors affecting the Adoption of GenAI in Creative Contexts: an Explorative Study

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Abstract

Recent developments of Generative Artificial Intelligence (GenAI) are profoundly impacting the creative contexts, offering innovative tools that redefine how artistic content is conceived, developed, and delivered. Across visual arts, design, music, and storytelling, GenAI is being embraced for its capacity to accelerate ideation, facilitate rapid prototyping, and democratize creative processes, so allowing both professionals and novices to produce high-quality outcomes. Its algorithmic creativity could augment human imagination and opens new frontiers for experimentation and collaborative creation.

However, while the GenAI tools are being celebrated, its adoption is not without reservations. Creatives express apprehension over issues such as loss of creative autonomy, potential homogenization of artistic outputs, and ethical concerns related to authorship and copyright infringement. The question of trust is pivotal: without transparency in AI processes and assurance over the originality of AI-generated content, users remain skeptical about relying on GenAI systems for meaningful creative work. Furthermore, aesthetic satisfaction plays a critical role, as artists seek not just functional outputs but final works that align with their personal and cultural values.

The study investigates the conceptual foundations underlying GenAI adoption in creative contexts. Existing theoretical frameworks such as the Technology Acceptance Model (TAM) provide useful foundations for examining user attitudes towards new technologies. However, these models originally developed in contexts of general-purpose technologies do not fully capture the emotional, aesthetic, and autonomy-related dimensions that characterize creative practices. As such, this paper critically explores their applicability to GenAI adoption in creative fields and identifies the need for further contextualization. Based on a systematic literature review of peer-reviewed articles sourced from Scopus and from existing AI governance frameworks (e.g. OECD and NIST), the paper identifies a set of constructs—including perceived usefulness, ease of use, trust, creative autonomy, aesthetic satisfaction, and behavioral intention—that can inform the future development of a tailored survey instrument. The relevance of the core constructs to education and artistic production is discussed. The contribution of the study is twofold: it offers an academically rigorous synthesis of current knowledge on GenAI adoption within creative domains and proposes a refined conceptual framework that can inform future empirical studies. By aligning established theoretical models with the distinctive needs of creative practice, the study provides a critical foundation for educators, researchers, and policymakers committed to supporting a responsible, ethical, and inspiring integration of AI technologies in the arts.

Keywords: Generative Artificial Intelligence, Business Processes, Creative Industry, Technology Acceptance Model, AI Classification Frameworks

Paper type: Academic Research Paper

1 Introduction

All creative contexts are undergoing a profound transformation propelled by the accelerating evolution of Generative Artificial Intelligence (GenAI). Traditionally, creative production has been deeply rooted in human originality and personal expression. Yet, the advent of GenAI is reshaping the landscape not only enhancing creative processes in terms of efficiency but are also enabling new forms of artistic experimentation that transcend human limitations.

While the promises of GenAI are substantial, its adoption within creative fields remains complex and irregular. Artists' acknowledge the benefits of accelerated ideation and increased access new technologies but also express concerns regarding the loss of creative autonomy and the risk of producing standardized outputs lacking human nuance (Permana and Fajar, 2024; van Niekerk et al., 2025). Moreover, trust in AI generated content and transparency in algorithmic decision making emerge as critical determinants of adoption, particularly in sectors where authenticity and originality are paramount. The ethical dimension further complicates the landscape. Questions about intellectual property, cultural appropriation, and algorithmic bias are increasingly central to the discourse on GenAI integration in creative practices (Greiner et al., 2023; Mourtajji and Arts-Chiss, 2024). These concerns are mirrored in academic research, which highlights the necessity of frameworks that ensure ethical compliance and foster user confidence (Mourtajji and Arts-Chiss, 2024).

This study is part of a broader research project aimed at investigating the individual and organisational factors that influence the adoption of Generative Artificial Intelligence (GenAI) in creative contexts. The

overarching goal is to develop a comprehensive understanding of how creatives engage with GenAI tools, and to design a survey to assess their acceptance and use starting from the students of Academy of Fine Arts and early career practitioners. To design the questionnaire to be administrated in the survey and determine which constructs should be measured, the study followed four main steps: (i) theoretical analysis of existing models of technology acceptance. The research focused on the Technology Acceptance Model (TAM) that provide structured frameworks for understanding the factors that influence individuals' adoption and use of new technologies. Among these, the Technology Acceptance Model (TAM), originally proposed by Davis based on the Theory of Reasoned Action (Ajzen, 1985; Davis, 1989), remains the most widely used models. Technology Acceptance Models It posits that users' behavioral intention to adopt a technology is primarily shaped by two constructs: *perceived usefulness* and *perceived ease of use*. In the present study, the mentioned TAM serves as the foundational model but is complemented by two other TAM that offer a broader perspective: the *OECD Framework for the Classification of AI Systems* (2022) and the *NIST AI Risk Management Framework* (2024). Such frameworks allow for the inclusion of additional dimensions—such as trustworthiness, transparency, and organizational conditions that are particularly relevant when addressing the deployment of AI technologies in complex social and educational settings. However, while valuable, also such frameworks exhibit limitations when applied to creative domains. Specifically, they often overlook the emotional, aesthetic, and identity-based aspects that are central to artistic practice. Future empirical validation may reveal the need to adapt or expand existing models, but this remains a potential implication rather than an immediate objective. A comprehensive literature search was conducted on Scopus to identify peer reviewed articles that explore the adoption of GenAI in creative contexts. The search query focused on the intersection between "generative AI" and "technology acceptance" and was limited to journal articles published in English. This process yielded 63 articles, which were then reviewed for relevance and thematic coherence: (iii) selection and analysis of a focused corpus of 26 papers. From the initial set of 63 articles, 26 were selected for in depth analysis based on their explicit focus on creative settings and the presence of theoretical constructs compatible with TAM frameworks. The triangulation of data collected from theoretical models, international guidelines, and empirical literature ensured a robust foundation for the development of the questionnaire; (iiii) design of a TAM based questionnaire. Based on the identified constructs, a draft questionnaire was formulated. It includes items measuring perceived usefulness, perceived ease of use, trust, creative autonomy, aesthetic satisfaction, and behavioral intention, as well as additional constructs emerging from the frameworks (e.g. facilitating conditions, emotional engagement). The questionnaire, that reflects the contextual specificities of artistic creation augmented by AI, will be administered to students in art and design related disciplines.

Looking ahead, future phases of the project will include discussion and refinement of the questionnaire through expert consultation, followed by a pilot test involving students from selected Art Academies. Successively the administration of the questionnaire will be extended to other artistic contexts.

The study contributes to both academic research and professional practice. From a research perspective, it advances current understanding of how Generative AI is perceived and adopted in creative domains by identifying and contextualizing a set of acceptance constructs specifically relevant to the contexts wherein artists are educated. On the practical side, the study supports educators, cultural institutions, and policymakers in making informed decisions regarding the responsible integration of GenAI tools in high education and professional contexts (Zhang and Hou, 2024).

2 Research methodology

The SLR was conducted following the PRISMA guidelines (Page et al., 2021) to ensure transparency and methodological rigor. The process included six sequential steps: (1) problem formulation, (2) query definition, (3) literature search, (4) screening and eligibility assessment, (5) thematic coding, and (6) synthesis and reporting (Ammirato et al., 2023; Donthu et al., 2021). Scopus was selected as the primary database due to its extensive coverage of interdisciplinary peer reviewed literature. The search strategy was designed to retrieve articles that explicitly address the intersection of Generative AI and technology acceptance, with particular attention to creative applications. A total of 63 articles were retrieved and screened. Of these, 26 were selected for in depth analysis based on their thematic relevance to the creative sector and alignment with the theoretical lens of technology acceptance. Bibliometric and semantic analyses were conducted to explore keyword frequencies and co-occurrences. The semantic analysis of abstracts was implemented using a text mining pipeline in R, including tokenisation, stop word removal, stemming, lemmatization, and frequency analysis. That allowed for the empirical identification of recurring terms and themes that informed the conceptual mapping (see Figure 5) and the preliminary selection of candidate constructs for the design of the questionnaire (Goyal and Kumar, 2021)

The methodological flow diagram is reported in Figure 1, which illustrates the sequential steps of the research design. The process begins with the problem definition, then, a query was developed and used to select papers from the Scopus database. The specific terms "generative AI", "technology acceptance", and related keywords were used, while limiting the results to "Article", "Journal", and "English". As mentioned, a total of 63 relevant papers were retrieved.

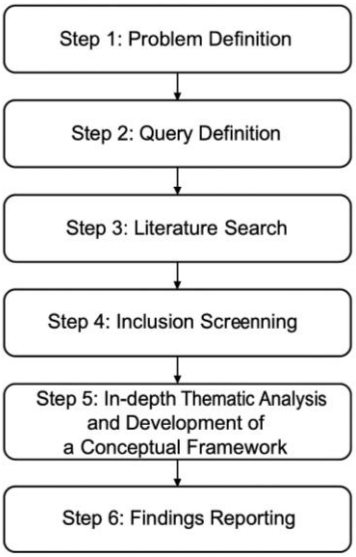


Figure 1. The sequential steps of the study.

The SLR was carefully designed to synthesize existing knowledge on the adoption of GenAI in creative contexts. The Scopus database, selected for its extensive coverage of peer reviewed journals, was utilized to ensure the inclusion of high quality studies across disciplines such as design, visual arts, education, and technology (Kanont et al., 2024).

The search strategy was meticulously crafted to retrieve articles focusing specifically on the intersection of generative AI technologies and technology acceptance, particularly in creative environments. The final query used in Scopus was as follows:

TITLE-ABS-KEY(("generative ai" OR "gen-ai" OR "gen ai") AND ("technology acceptance")) AND (LIMIT-TO (DOCTYPE,"ar")) AND (LIMIT-TO (SRCTYPE,"j")) AND (LIMIT-TO (LANGUAGE,"English")).

The search further filtered adopting the inclusion criteria document type "Article", source type “Journal", and language "English", yielded a total of 63 papers, of which 4 were published in 2023 and the remaining in 2024 and 2025. No further inclusion/exclusion criteria were applied. All 63 papers were fully considered in the analysis, so reflecting a deliberate choice to maintain a broad and inclusive scope given the novelty of the topic. The selected studies provided a rich foundation for identifying prevailing themes, including the critical roles of perceived usefulness, perceived ease of use, trust in AI systems, creative autonomy, aesthetic satisfaction, and behavioral intention (Wang et al., 2025). Alongside bibliometric insights, a content analysis was conducted to uncover the conceptual landscape of the field. A content analysis using lemmatization and frequency mapping of abstract keywords (using the R package “tidytext”) was conducted to identify recurring themes, concepts, and relationships relevant to the adoption of GenAI in creative domains. Through coding and thematic categorization, the analysis captured how scholars framed opportunities and challenges, mapped out user perceptions, and highlighted the factors influencing technology acceptance. Such an approach allowed for the identification of dominant narratives and emerging concerns across the literature, providing qualitative depth to the bibliometric findings. Based on the insights derived from the literature review, a questionnaire was developed to empirically explore the perceptions of students attending Art Academies, particularly those enrolled in courses dedicated to New Technologies of Art (Ebnali Harari et al., 2025). While our study focuses specifically on creative educational contexts, such as higher education institutions for the arts, it is embedded within a broader research agenda aimed at understanding GenAI adoption across diverse creative settings. These range from formative environments to professional creative contexts, where AI driven tools are increasingly shaping artistic production, distribution, and collaboration. The educational context is a particularly fertile ground for investigation, as it plays a crucial role in shaping the attitudes and competencies of future creative professionals. By examining the perceptions of students currently engaging with GenAI tools during their academic formation, this research provides valuable insights not only for educators and curriculum

designers, but also for software developers, cultural organizations, and policy makers aiming to foster responsible and meaningful integration of GenAI technologies across the wider creative ecosystem.

The survey design incorporated constructs validated in prior studies but adapted to capture dimensions crucial to creative contexts, such as creative autonomy and aesthetic satisfaction (Russo, 2024). Each construct was translated into multiple items to enhance the reliability of measurement, utilizing a 5-point Likert scale to capture degrees of agreement or disagreement.

3 Results and discussion

This section presents and discusses the results obtained from the study. The first paragraph (3.1 *Bibliometric analysis*) outlines the main findings derived from the bibliometric data associated with the selected publications. In the second paragraph (3.2 *In-depth thematic analysis*) the key themes emerging from the selected publications are organized into a conceptual framework structured around three thematic domains: Generative AI Dimensions, Creative Dimensions, and Constructs. The third paragraph (3.3 Constructs for GenAI acceptance in creative contexts) summarizes the constructs considered most relevant and instrumental for the subsequent development of tools aimed at assessing technology acceptance in creative settings.

3.1 Bibliometric analysis

The systematic analysis of the 63 selected articles revealed a complex and evolving landscape regarding the adoption of Generative AI in creative domains. The analysis showed the prominence of keywords such as creativity, autonomy, ethics, and collaboration, revealing how these concepts intersect in discussions of GenAI's role in creative practices (Mourtajji and Arts-Chiss, 2024). The semantic relationships underscored the importance of adapting established acceptance models to account for the unique priorities of creative users (Balaskas et al., 2025). What clearly emerged is that the discourse around GenAI is deeply intertwined with themes of empowerment and apprehension, reflecting both the enthusiasm for its creative potential and the caution surrounding its ethical and operational limitations (Zhang and Hou, 2024). A prominent finding from the literature is the perceived potential of GenAI to enhance creative processes, enabling unprecedented levels of ideation and content generation. Scholars highlight that GenAI systems, when appropriately integrated with other technologies, allow creators to transcend conventional barriers, offering tools that accelerate workflows and inspire novel forms of artistic expression.

The technologies facilitate rapid prototyping, provide instant feedback, and democratize access to sophisticated creative capabilities, making them particularly attractive to emerging artists and students. Figure 2 shows the exponential growth of publications in 2024 and 2025, indicating an intensified research focus on the theme. The Scopus research was carried out in March 2025.

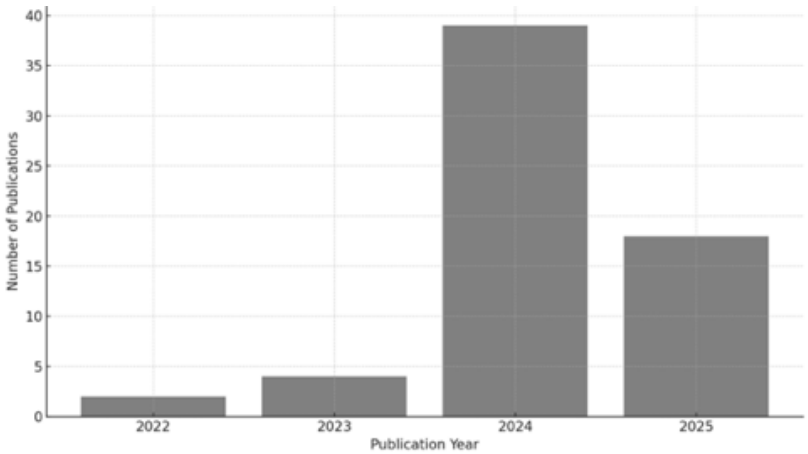


Figure 2. Scientific publications on Generative AI in creative sectors.

The adoption of GenAI across creative contexts remains highly fragmented. Numerous studies reveal persistent concerns about the dilution of creative autonomy and the fear of homogenization in outputs generated by AI systems (Chan and Zhou, 2023; Kim, 2025; van Niekerk et al., 2025). Creators often question whether reliance on generative systems might inadvertently lead to a convergence of styles and ideas, undermining the originality that defines artistic endeavor (Chan and Zhou, 2023; Wu et al., 2024). These concerns are amplified by the opacity of many GenAI algorithms, which complicates efforts to understand and

control the creative process. Further insights emerge from the geographical distribution of the studies analyzed, as shown in Figure 3, which highlights China and the United States as leading countries in research on GenAI for creative contexts, reflecting broader technological investments and academic engagement (Thüs et al., 2024).

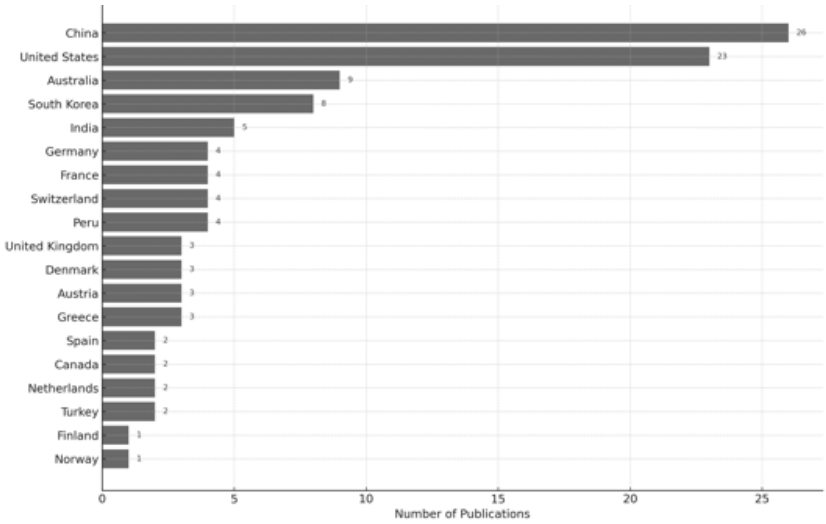


Figure 3. Geographical distribution of retrieved studies.

Trust in GenAI systems emerged as a decisive factor in determining user acceptance. Several studies emphasize that users are more likely to adopt GenAI tools when they perceive them as reliable, transparent, and capable of producing high quality outputs that align with their aesthetic values (Balaskas et al., 2025). Trust extends beyond technical performance, encompassing broader ethical considerations such as data provenance, authorship attribution, and fairness in algorithmic decision making. Additional layers of complexity were uncovered through a semantic analysis of keywords carried out in the abstracts of the 63 selected studies using VOSiewer (Figure 4).

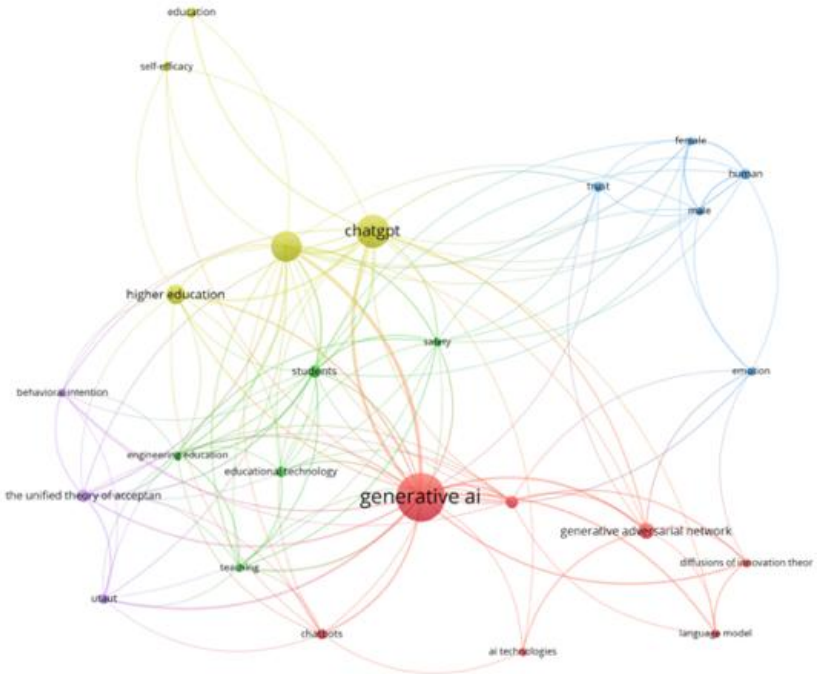


Figure 4. Co-occurrence network of keywords from selected studies on Generative AI and technology acceptance in creative sectors.

The co-occurrence map highlights clusters of terms such as "trust," "higher education," and "creative autonomy," indicating prevalent focal points in academic discussions and signaling areas requiring further empirical exploration.

3.2 In-depth thematic analysis

The conceptual framework presented in Figure 5 is the result of a multi-step thematic mapping process, aimed at organizing the main insights emerging from the literature. Such conceptual framework was developed by combining a semantic analysis of all 63 abstracts retrieved through the systematic literature review with an in-depth thematic coding of the 26 full text articles most relevant to creative contexts and technology acceptance.

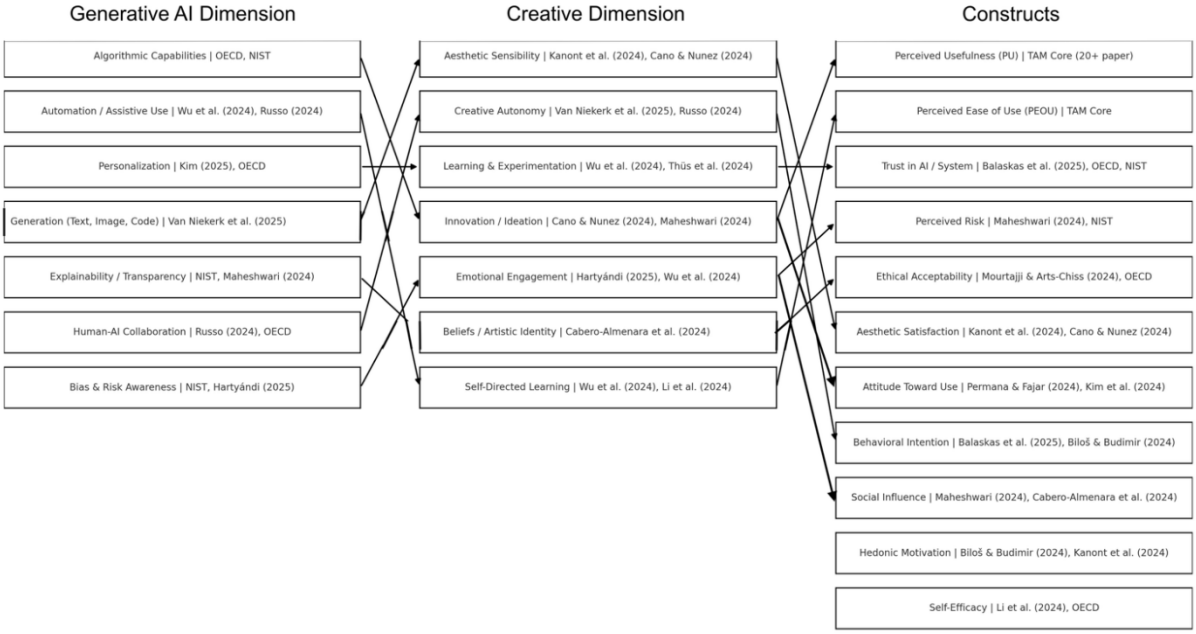


Figure 5. Conceptual framework of identified themes: connections between Generative AI dimensions, creative dimensions and Constructs.

The framework is structured into three **thematic domains**: *Generative AI Dimensions*, *Creative Dimensions*, and *Constructs.* Each group includes representative concepts or constructs, supported by specific literature sources. The connections between these elements were established manually based on patterns of co-occurrence in the abstracts and conceptual alignments observed in the full text papers.

Figure 5 report a conceptual framework that illustrates how specific technological features of GenAI (e.g. automation, explainability) relate to creative practices (e.g. innovation, self-directed learning), and how these, in turn, link to constructs mentioned in the retrieved papers to explain technology acceptance (e.g. perceived usefulness, trust, aesthetic satisfaction). This conceptual framework serves as a foundation for identifying and selecting the most relevant constructs for the subsequent development of the questionnaire to be administrated to potential GenAI creative tools users.

These linkages are visually represented by directional arrows in Figure 5, illustrating how technological features of GenAI interact with specific creative contexts and corresponding challenges or acceptance factors. Furthermore, extant literature underscores the increasing role of GenAI in educational settings, where it is employed to foster creative thinking, enhance learning outcomes, and prepare students for the evolving demands of the creative contexts (Chan and Zhou, 2023; Zhang and Hou, 2024). The analysis was implemented in R, a free and open-source software environment for statistical computing and graphics, widely used in academic and scientific research (Venables and Smith, 2025). Based on a text mining pipeline that included tokenisation, stop word removal, stemming, lemmatization, and frequency counting. The most recurrent terms ($n > 15$), visualized through a lemmatized frequency plot, provided the empirical basis for the thematic labels used in the conceptual mapping. It enables advanced data analysis, text mining, and the creation of high-quality visualizations through a vast ecosystem of specialized packages. In this study, R was employed to conduct semantic analysis on abstract data, supporting the identification of thematic constructs related to Generative AI adoption. The constructs listed under the “Constructs” were systematically derived through an in-depth thematic analysis of the 26 selected articles from the SLR. Each paper was examined to extract and classify all theoretical constructs explicitly or implicitly used to frame user acceptance of GenAI in creative dimensions. The extraction process followed a construct mapping approach: constructs were identified in the text. In addition, constructs were triangulated with those proposed in the NIST (2024) and OECD (2023) frameworks to ensure

conceptual alignment and to capture dimensions relevant to AI risk, trust, and organizational readiness. The final list includes both core TAM variables (e.g., perceived usefulness, perceived ease of use) and extended constructs (e.g., moral obligation, ethical acceptability), selected for their empirical relevance and contextual appropriateness (Ebnali Harari et al., 2025). The findings emerging from the study offer critical insights into the complexities surrounding the adoption of Generative AI in creative education and practice.

The insights not only inform the theoretical understanding of technology acceptance in creative fields but also may provide practical guidance for the design of GenAI tools and educational interventions aimed at fostering confident and critical engagement with generative technologies. For example, the identification of key acceptance constructs such as creative autonomy and aesthetic satisfaction can guide software developers in designing GenAI interfaces that allow users to customize algorithmic output, thus preserving personal expression. Likewise, educators in art academies can integrate modules on ethical AI use and critical digital literacy into their curricula, enabling students to engage with these tools not just as users, but as informed creators aware of both possibilities and limitations.

3.3 Constructs for GenAI acceptance in creative contexts

The insights gathered through the systematic literature review and the obtained conceptual framework constitutes a starting point for the development of tools (e.g. questionnaires, interview protocols) aimed at investigating the acceptance of GenAI among potential users in creative contexts.

Starting from the constructs identified in the conceptual framework (see Figure 4) the authors proceeded by grouping them, obtaining the results summarized in Table 1.

These results encompass both classical TAM constructs (e.g. perceived usefulness, perceived ease of use) and extensions particularly relevant to creative settings, such as trust, aesthetic satisfaction, and creative autonomy. At this stage the obtained constructs were furthered characterized according to their level of applicability (individual and/or organizational) including facilitating conditions and subjective norms, ensuring that the instrument reflects not only individual psychological drivers but also environmental and ethical factors.

Table 1. Constructs for assessing GenAI acceptance in creative contexts.

Constructs	Organizational	Individual	Definition	Source
Perceived Usefulness (PU)		X	The degree to which GenAI is perceived to enhance creative performance and output quality.	(Balaskas et al., 2025; Kim, 2025; OECD, 2022)
Perceived Ease of Use (PEOU)		X	The degree of ease associated with learning and using GenAI tools in creative practice.	(Chan and Zhou, 2023; NIST, 2024; Wu et al., 2024)
Trust in GenAI Systems	X	X	Confidence in the reliability, transparency, and fairness of GenAI outputs.	(Greiner et al., 2023; Kanont et al., 2024; NIST, 2024)
Creative Autonomy	X	X	Perception of control over the artistic process when using GenAI technologies.	(Mourtajji and Arts-Chiss, 2024; Zhang and Hou, 2024)
Aesthetic Satisfaction		X	Satisfaction with the aesthetic and cultural alignment of GenAI generated outputs.	(Cano and Nunez, 2024; Liu et al., 2024)
Facilitating Conditions	X		The degree to which users perceive that organizational or technical infrastructure exists to support the use of GenAI.	(Cabero-Almenara et al., 2024; Kim, 2025)
Attitude Toward Use		X	The degree to which users have a favorable or unfavorable evaluation of using GenAI tools.	(Kim, 2025; Permana and Fajar, 2024)
Subjective Norm		X	The perceived social pressure to use or not use GenAI tools in academic and creative practice.	(OECD, 2022; Zhang and Hou, 2024)
Behavioral Intention to Use		X	The likelihood of future use of GenAI tools in creative projects.	(Russo, 2024; Zhang and Hou, 2024)

Aesthetic satisfaction emerges as a crucial yet often overlooked factor in the adoption of GenAI tools. Creators engaged in artistic practices are not merely concerned with functional utility; they demand outputs that are emotionally resonant and culturally aligned with their creative identity. This aligns with the growing emphasis on aesthetic satisfaction as a relevant construct in creative education contexts, particularly when

GenAI is introduced into curricula that priorities experimentation and personal expression (Cano and Nunez, 2024; Liu et al., 2024). Similarly, the notion of creative autonomy is central to the discourse on GenAI integration. Several studies point to creators' desire to retain control over the artistic process, avoiding undue reliance on algorithmic outputs that might constrain originality (Mourtajji and Arts-Chiss, 2024; Zhang and Hou, 2024). These perspectives underscore the importance of complementing traditional TAM constructs—such as perceived usefulness and ease of use—with dimensions that reflect the emotive, cognitive, and ethical demands of creative disciplines. Building on these insights, a set of nine constructs has been identified through the systematic review and conceptual framework (see Figure 4). These are summarized and categorized in Table 1, which includes both individual and organizational dimensions. Alongside core TAM elements—such as perceived usefulness (PU), perceived ease of use (PEOU), and behavioral intention—the framework integrates extended factors like trust in GenAI systems, subjective norms, facilitating conditions, and attitudes toward use. This comprehensive view ensures that the proposed instrument does not limit itself to psychological readiness but also accounts for infrastructural support and normative expectations that shape the adoption process in creative educational settings. By doing so, the study not only clarifies which acceptance constructs are most relevant for GenAI in creative contexts but also offers a solid basis for the design of future survey instruments aimed at assessing their empirical validity. These tools may in turn guide educators, technology developers, and policymakers in aligning AI deployment with the needs and sensibilities of emerging creative professionals.

5 Conclusions

This study set out to explore the multifaceted dynamics underpinning the adoption of Generative Artificial Intelligence (GenAI) within creative contexts. Recognizing the potential of GenAI to enhance ideation, facilitate experimentation, and expand access to advanced creative tools, the research also acknowledges the complexity of integrating such technologies in domains where personal expression, aesthetic judgement, and authorial agency are central. By conducting a Systematic Literature Review of peer reviewed articles, the study offers an integrated perspective that bridges academic theory with the realities of creative practice (Balaskas et al., 2025; Zhang and Hou, 2024). The SLR findings confirm that GenAI technologies hold immense potential to redefine the creative landscape that could democratize access to sophisticated design tools and inspire novel forms of expression (Kim, 2025; Russo, 2024). The acceleration of ideation processes and the facilitation of rapid prototyping are consistently highlighted as key benefits, fostering new opportunities for experimentation and artistic growth (Cano and Nunez, 2024). The persistent concern over creative autonomy underscores the need for GenAI tools that empower rather than constrain human creativity. Creators are cautious of overreliance on algorithmic generation, fearing a potential homogenization of creative outputs and a dilution of personal expression (van Niekerk et al., 2025). Trust emerges as a critical determinant, not only in terms of technical reliability but also regarding the ethical dimensions of AI deployment. Transparent processes, respect for data integrity, and clear authorship attribution are essential to building user confidence and fostering responsible engagement with GenAI tools (Greiner et al., 2023; Mourtajji and Arts-Chiss, 2024).

Moreover, the aesthetic dimension of AI generated content proves pivotal. Creators expect outputs that do more than meet functional needs—they seek emotional resonance and alignment with their unique creative identities. This underscores the importance of designing GenAI systems that are not merely efficient, but also capable of producing outputs that evoke genuine artistic satisfaction (Ebnali Harari et al., 2025). The conceptual framework developed as part of this study (see Figure 4) served as a foundation for grouping and selecting a set of nine constructs considered most relevant for subsequent empirical investigation, as reported in Table 1. These constructs address both individual and organizational dimensions of acceptance, ensuring a comprehensive approach to future measurement efforts. The constructs selected—such as usefulness, ease of use, trust, creative autonomy, aesthetic satisfaction, behavioral intention, facilitating conditions, and subjective norms—were not chosen arbitrarily. Rather, they were systematically identified through an in-depth thematic analysis of 26 articles selected for their relevance to creative contexts and triangulated with frameworks such as the OECD Classification of AI Systems and the NIST AI Risk Management Framework. As discussed, such constructs provide a structured foundation to assess the multifaceted nature of GenAI acceptance in creative contexts. Future steps will include expert validation and pilot testing of the survey instrument, targeting students of Academy of Fine Arts to assess the reliability and construct validity of the proposed measurement model. This will enable the validation of the proposed constructs and offer deeper insight into the conditions that foster or hinder GenAI adoption. Comparative studies across cultural contexts and artistic disciplines would further enrich understanding, ensuring that the adoption of GenAI is not only technologically feasible but also culturally sensitive and ethically sound (Cabero-Almenara et al., 2024; Thüs et al., 2024).

Finally, the integration of GenAI into creative contexts offers transformative potential, if guided by thoughtful design, ethical integrity, and a deep respect for the human spirit of creativity. By synthesizing theoretical insights with practical tools, the research aspires to contribute meaningfully to GenAI, supporting a future in which technology complements, rather than replaces, the artist's hand and imagination.

6 Ethics Declaration

This study did not involve human participants, clinical trials, or personal data collection.

7 AI Declaration

No AI tool was used to develop this paper.

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Digital Solutions to Support Transition from Linear to Circular Manufacturing

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Abstract

The transition from linear to circular manufacturing systems (CMS) is essential for manufacturing firms aiming to enhance sustainability and mitigate resource depletion. Despite clear environmental and economic benefits, the adoption of circular economy (CE) principles within the manufacturing sector remains limited, largely due to significant technological, operational, and organisational barriers. This study addresses these issues by exploring the specific challenges that manufacturing companies face during their transition to CMS and proposes digital technologies to effectively overcome these barriers. Utilising an exploratory, qualitative, single-case study approach, we investigated a European white goods manufacturer implementing a refurbishment centre aimed at establishing circular practices within their laundry appliance segment. Through thematic analysis, we identified three primary challenges: uncertainty regarding the condition of returned appliances due to limited consumer data sharing, insufficient durability and longevity data from laboratory tests of new models, and operational inefficiencies due to inexperience with dismantling and refurbishing processes. To address these challenges, we propose advanced digital solutions leveraging Internet of Things (IoT), Artificial Intelligence (AI), and Augmented Reality (AR) technologies. Specifically, IoT and AI-based systems are recommended for comprehensive product tracking, real-time condition monitoring, predictive maintenance, and informed decision-making, significantly improving data availability and accuracy for refurbishment operations. Additionally, we suggest AR-enhanced workstations to assist workers in dismantling processes, enhancing operational efficiency, reducing error rates, and facilitating knowledge management across diverse product models. Our findings extend the current body of knowledge on CE barriers, particularly in relation to IoT capabilities and consumer data-sharing practices and highlight practical implications for manufacturers seeking effective digital interventions. This research underscores the critical role of technology integration and organisational readiness in achieving successful CMS transitions.

Keywords: Circular Manufacturing Systems (CMS), Circular Economy (CE), Digital Transformation

Paper type: Academic Research Paper

1 Introduction

The circular economy (CE) is being considered a transformative business and sustainability paradigm, grounded in recognising that natural resources are finite and that traditional linear production models are unsustainable (Geissdoerfer *et al.*, 2017; Jensen, 2023). Central to this paradigm, as outlined by the Ellen MacArthur Foundation (EMF, n.d.), are the principles of (i) eliminating waste and pollution, (ii) keeping products and materials in use at their highest value, and (iii) regenerating natural systems. These principles recognise the constraints of finite natural resources and degrading environmental conditions as major drivers for companies to become circular and sustainable. These CE principles are adopted by implementing different CE practices, which are increasingly enabled using digital technologies (Neri et al., 2023). The adoption of CE principles is even more important for the manufacturing sector to counter waste generation and increase the usability of products during their life cycle.

In manufacturing, the CE principles drive the development of Circular Manufacturing Systems (CMS), *designed intentionally for closing the loop of components or products, preferably in their original form, through multiple life cycles* (Rashid *et al.*, 2020, p. 345). The transition from linear to circular manufacturing is a complex, long-term initiative that linear companies usually undergo iteratively, focusing on three CMS pillars: product design, business model, and supply chains, which are enabled through ICT implementation and digital transformation. Companies usually pursue CMS through circular economy (CE) practices (Neri *et al.*, 2023). Despite the potential benefits of implementing CE, its adoption in linear manufacturing firms is still considered low. For example, the circular material use rate in the EU for 2023 was only 11.8% (EEA, 2025), indicating that the economy is primarily linear. To understand the reasons behind the slow adoption of CE, we explored the challenges that linear manufacturing companies face due to their current business model design, product design,

supply chain design, and existing ICT infrastructure. The research also explored the potential solutions to these challenges and the required knowledge and competencies.

To explore the challenges, we conducted an in-depth single case study of a European white goods manufacturer actively pursuing a transition towards CMS by establishing a dedicated return and refurbishment centre. This case was chosen because it reflects incumbent manufacturers' typical challenges when integrating CE practices into existing operations. Data were gathered for one year through a multi-method qualitative approach, including expert interviews, group interviews, focus groups and validation sessions. Subsequently, thematic analysis identified three challenges, and the participative design research approach generated potential ICT-based solutions.

This paper follows a standard structure, with theoretical background outlining the main theoretical concepts of this research, namely CMS, circular product design, circular business models, circular supply chains and digital support for CMS. Our qualitative methodology is described in the following chapter, focusing on data collection, thematic analysis, and a participatory design research approach. The identified challenges and the designed ICT-based solution are described in the results section. We contextualised our findings with respect to recent scientific developments in the discussion.

2 Theoretical background

The concept of CMS has finished the evolution of linear manufacturing from reverse approaches through closed-loop concepts, fuelled by the context of sustainability movements. The product design phase determines around 80% of the environmental impacts (European Commission, 2012) and is crucial for circularity as it determines the future reusability of the product. The most significant barriers hindering the transition towards circular product design are: financial constraints, inadequate infrastructure, government inaction, and global market barriers (Wang et al., 2022). If these barriers could be overcome, the design should focus on preserving product integrity, developing a longitudinal value proposition, and having a longitudinal business model (den Hollander, 2018). Including reducing, reusing, recovering, and rethinking principles into the product design phase (Tan et al., 2024) can dramatically reduce the environmental impact. These CE practices or principles could pave the way towards CMS (Neri et al., 2023). However, isolated implementation of CE practices or focus only on product design does not ensure transformation to CMS. The typical manufacturing pillars (product design, business model, supply chains, ICT) should be integrated and developed together (see Figure 1).

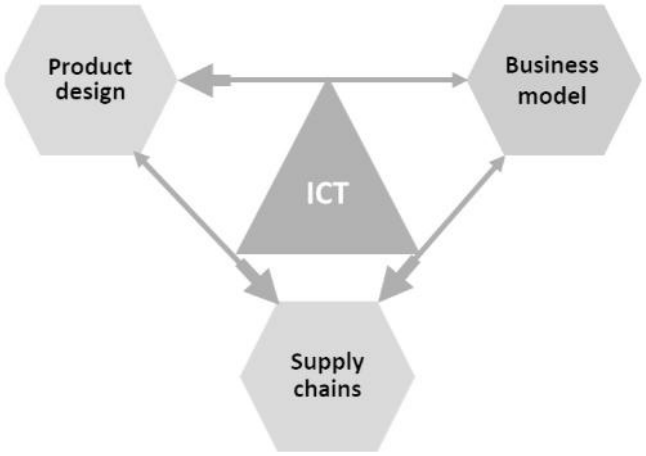


Figure 1: CMS framework (Rashid et al., 2020, p. 346)

The business model needs to evolve together with circular product design into a circular business model that could be understood as a business model that is cycling, extending, intensifying, and/or dematerialising material and energy loops to reduce the resource inputs into and the waste and emission leakage out of an organisational system. This comprises recycling measures (cycling), use phase extensions (extending), a more intense use phase (intensifying), and the substitution of products by service and software solutions (dematerialising) (Geissdoerfer *et al.*, 2020). Frishammar and Parida (2019) proposed a road map for circular business model transformation for linear companies, consisting from four phases i) analysing opportunities to initiate circular business model transformation; ii) review of current business model to identify gaps; iii) design and develop a revised business model based on the design elements of circular economy, iv) validate, implement and scale-up the circular

business model. Further integration of circular product design and business models with supply chain capabilities is needed.

The notion of circularity in supply chains emerged long before circularity became the central theme. Reverse logistics (Rogers and Tibben-Lembke, 2001; Tibben-Lembke and Rogers, 2002), or closed-loop supply chains (Guide and Van Wassenhove, 2006) have been studied for more than 20 years. However, these different concepts converged into circular supply chains (Wang *et al.*, 2022). The prevalence of linear manufacturing business models and thinking implies many barriers to successful circular supply chain implementation. For example, Taddei et al. (2024) identified seventeen barriers associated with circular supply chains. The authors ordered the barriers based on their importance, resulting in financial and economic barriers being the most important, followed by technical, legislative, political, organisational, and social barriers. In the recent study, Chen et al. (2025) identified factors affecting the implementation of circular supply chains. The immediate determinants were lower consumer costs, recycled raw material production, and energy conservation technology.

Technologies (mainly Industry 4.0) support all three pillars of CMS, as they play a significant role in the circularity transformation of supply chains, serving as enablers (Taddei *et al.*, 2024). Digital technologies were proven to support the circular economy strategies, especially in the areas of improving energy and resource efficiency, recycling, rethinking and reusing (Liu *et al.*, 2022). However, the same study highlighted that the repurpose strategy is the least supported by digital technologies. Digital technologies play a role of lower-order capability when supporting business performance through CE practices (Riggs *et al.*, 2024). This confirms the importance of digital technologies in CE initiatives, showing that digital technologies are a necessary but not sufficient condition for a successful CE initiative.

Some authors extended the focus on the four pillars (business model, product design, supply chain, ICT) by further areas. For example, Chirumalla et al. (2024) proposed a multi-level readiness framework to support the transition of manufacturing companies from linear to circular economy. They identified four key focus areas, each with five levels of progression: i) the ecosystem of external partners, ii) the customer and the business model, iii) the company's culture and internal capabilities, and iv) design and product development. The authors also identified four strategies for the successful transition to a circular economy: i) changing the mindset, ii) understanding of the circular economy concept and establishing own definition, iii) high-level planning and evaluation of scenarios, and iv) ensuring financial viability and environmental preservation.

3 Methodology

The goal of this research was to explore and describe the challenges of a manufacturing company aiming to transition from linear to circular manufacturing. The main research question this study addresses is: "What are the challenges that companies face when transitioning towards CMS, and how can digitalisation help address those challenges?" To answer this research question, we employed an exploratory, in-depth case study approach with features from design and action research strategies. The exploratory nature was derived from the lack of previous research that did not bring suitable testable outcomes. We chose the inductive qualitative approach because we wanted to provide details that could guide future confirmatory research. The design and action research elements were needed to answer the second part of the research question, as Company A could use the analysis of the barriers and our experience to design the solutions.

At the start of our research, we conducted several online interviews with relevant people from the organization. These interviews allowed us to understand the context of the company and its CMS transition initiatives. These interviews were recorded, and the transcripts were validated with the interviewees. After initial thematic analysis of the interviews, we designed a multiple-day focus group at the Company A facility to gather further data about the initial themes and ensure that we did not miss any themes during the initial interviews. The sample for the focus group was wider than the initial interviews, as we identified new respondents. The focus group was not recorded. However, multiple researchers were present during the focus group, and we created detailed notes that were validated after each session. The notes were used for further thematic analysis, both for conceptualising the existing themes further and identifying new themes. The themes were subsequently validated with relevant stakeholders through online interviews after the focus group.

After we concluded the thematic analysis, we designed another focus group that focused on exploring the design of digital solutions for overcoming the challenges. This focus group was conducted online using collaboration and co-creation tools both during and after the meeting to discuss and elaborate on different digital solutions. After the focus group, the authors prepared the circular flow diagram and mapped the digital solutions to different phases/stages of the circular value chain of the company (i.e., value use phase, reverse

logistics, and value recovery phase). Finally, the authors collected written feedback from the relevant people at the company on the need for different digital solutions and their design.

4 Findings

Company A operates in the white goods industry and manufactures a wide range of products that include refrigerators, freezers, washing machines, dishwashers, ovens, etc. For this research, only the business unit focusing on laundry appliances is considered, for which Company A is aiming to establish a refurbishment centre.

4.1 Current CMS maturity

Company A focused on CE activities and environmental awareness in the past decades by implementing an ISO-14001 environmental management system in 2000 and the EU Eco-Management and Audit Scheme (EMAS) in 2004. These activities helped reduce environmental impact in all the product life-cycle phases. Company A focuses on the long-term duration of appliances that support multiple lifecycles. The company tested a pay-per-use business model. Company A seeks to increase its value recovery activities by establishing and integrating refurbishment operations into its current processes. For this, Company A builds data infrastructure and data gathering capabilities through smart home features in their appliances, which are supported by IoT hardware to generate and gather data about the appliances.

To continue the transition to CMS, Company A wants to establish a refurbishment centre to refurbish appliances and harvest spare parts. Company A would like to use increased value recovery in the form of refurbished used parts to support their pay-per-use business model, to prepare to fulfil the future legislation about the right-to-repair, and to lower their costs on spare parts manufacturing. Therefore, Company A must ensure a sufficient volume of refurbished components and appliances, but it faces several challenges. The digital support for circularity remains limited. Company A also lacks the IT infrastructure to support the recovery and quality assessment of the used parts.

4.2 Challenges

During our thematic analysis, the following themes in the form of challenges emerged, which stand in the way towards CMS transformation:

- CHAL1 Uncertain condition of the appliance and its components
- CHAL2 Limited data about the longevity of the appliances for new models
- CHAL3 No experience with the dismantling process

The refurbishment centre will handle both unused and used appliances that have been returned. The first group will be easier to handle from the context of their condition. However, handling the used products will be challenging due to their uncertain condition (CHAL1). If the appliance has smart features, it could be connected, and Company A could have information (although usually impartial) about the use of the product. The real challenge will occur when there is no data about the use of the appliance online. The appliance stores a limited amount of data that could be retrieved and used for condition assessment; however, without further data that could be used to correlate the data from the appliance, it will be impossible to assess the appliance's condition.

Company A tests all models in a durability lab to check the average lifetime. The basic models take about eight months (non-stop usage) to test, whereas thoroughly testing the premium and heavy-duty models for their designed lifetime would take around seven years. This has two implications. First, some models cannot be adequately tested before entering the market. Second, Company A misses the data from testing for use in assessing the returned appliances. The extended testing time of the new models and limited data availability from their testing (although in laboratory conditions) make the efficiency of the refurbishment centre processes hard (CHAL2).

When establishing the new refurbishment initiative, the biggest challenge is the inexperience with the dismantling process and linear focus. The intake of many returned models contradicts the experience from linear manufacturing and complicates any (semi-) automation. Manual processes are prevalent and significantly depend on the expertise and knowledge of the inspection and dismantling workers. However, Company A has no extensive experience with these operations, and the lack of experience will result in errors and low efficiency of the inspection and dismantling processes (CHAL3).

4.3 Digital Solutions

We identified and designed two solutions (SOL) that are aimed at addressing the identified challenges. The first solution (SOL1) aims to enhance the IoT capability for tracing, tracking, and condition monitoring of washing

machines. It directly tackles CHAL1 and CHAL2 through Artificial Intelligence (AI) based decision support solutions with the aim to decrease testing time for new models of washing machines, increase uptime of washing machines during use phase, optimize reverse logistics of used appliances and parts, speed up end-of-life testing of used parts, and improve spare parts availability and inventory management. Table 1 provides a summary of IoT and AI-based digital solutions and their key requirements

Table 1: IoT & AI based circular support solutions and their key requirements

Area	Digital Solution	Key Requirements
Tracking & Tracing	Use of digital platform for collecting and storing operational data	a) 5 main data groups: settings, status, static, program status b) Cloud-based storage for long-term availability c) Requires enhanced firmware and software upgrades for cloud communication
Condition Monitoring of Critical Components	IoT-driven tracking of pump, heater, and motor performance	a) Monitoring of usage cycles, power consumption, and error codes b) Store data in a centralized data lake c) Data used for ML model training and maintenance forecasting
Durability Testing	Use of sensors for monitoring during lab testing	a) Custom firmware to read temperature and pressure sensors b) Streaming of raw sensor data (e.g., water temperature, pressure) c) IoT stack upgrade for low-latency, high-throughput data streaming
Reverse Logistics Decision Support	AI models to assess reuse and recovery decisions	a) Use of lifecycle data, error codes, and service logs b) ML pipeline using Apache Kafka and the Azure platform c) Support for end-of-life decision making (refurbish, recycle, buyback)
Predictive Maintenance	Machine learning for predicting component failures	a) Labelled training datasets from field failures b) Addressing the imbalance in data (rare failures) c) Use of supervised learning or anomaly detection d) Integration with historical error logs and operational patterns
AI Support for Durability Testing	Application of ML on lab testing data	a) Use of extended sensor logs b) Combination with historical technical data and component details c) Focus on improving label quality for model training
End-of-Life Testing	Data-based decision support for reuse or disassembly	a) ML models trained with sensor and statistical data b) Use of appliance and component-level information c) Labels such as “buyback” or “refurbish/recycle” guide decisions

The second solution (SOL2) should overcome CHAL3. To dismantle the appliances and recover the critical parts at the refurbishment centre, Company A will implement an AR-based solution to achieve a low error rate in value recovery of returned appliances. The proposed solution involves using an AR application in combination with a specific dismantling station to provide instructions for dismantling in a user-friendly manner.

Table 2: AR & AI-based digital solutions for disassembly and parts recovery

Area	Digital Solution	Key Requirements
Disassembly Support	AR-guided workstation for manual disassembly tasks	a) Physical station with camera setup and object tracking b) Adaptive instruction interface with text, images, videos, and 3D objects c) Latency under 40 ms for real-time response d) Validation of user interactions through object detection e) Offline mode capability f) Integration with Gorenje’s IT infrastructure and reverse logistics workflows

5 Conclusion

This study explored the challenges faced by manufacturing firms transitioning from linear to Circular Manufacturing Systems (CMS) and how digital technologies can address these challenges. Our research identified three key challenges: uncertain appliance condition due to limited user data sharing (CHAL1), inadequate product longevity data from laboratory tests (CHAL2), and operational inefficiencies arising from a lack of dismantling experience (CHAL3). We proposed advanced digital solutions, including IoT and AI for product tracking, condition monitoring, predictive maintenance, and decision support (SOL1), as well as augmented reality (AR) systems to assist manual disassembly processes (SOL2). These findings contribute to existing literature by expanding on identified barriers related to data complexity and IoT capability deficits (Ozkan-Ozen *et al.*, 2020). Specifically, we extended knowledge concerning user data-sharing barriers from supply chains into the white goods industry context. Additionally, our insights into operational inefficiencies due to workforce inexperience (see, Taddei *et al.*, 2024) align with social barriers identified in other sectors (Kazancoglu *et al.*, 2020), thereby broadening their applicability and relevance.

From a practical perspective, our study provides manufacturing firms with actionable insights into how digital transformation can facilitate the adoption of CMS. The integration of AI/ML and AR-assisted workstations represents a promising pathway to overcome existing challenges in data availability and operational inefficiencies. Such ICT-driven solutions improve the effectiveness of refurbishment processes and support the broader transition from linear to circular manufacturing models. For practitioners, the case study offers a replicable blueprint for designing and implementing refurbishment initiatives that are both technologically advanced and aligned with CE principles. This study contributes to the literature on digital transformation and circular manufacturing by exploring the challenges and opportunities associated with integrating ICT solutions in traditional manufacturing settings.

Our study provides actionable insights for practitioners aiming to transition toward circular manufacturing. Companies should invest in IoT technologies integrated with AI for real-time condition monitoring and predictive maintenance to improve decision-making in refurbishment operations. Manufacturing firms need to prioritise user-friendly Iot solutions to encourage consumer data sharing, addressing privacy concerns through transparent data management policies. Adoption of AR-guided workstations is recommended to enhance efficiency and accuracy in product disassembly and inspection processes.

Our findings underscore the importance of considering technological capabilities and organisational readiness when designing digital interventions. They also highlight the need for further confirmatory studies across diverse industrial sectors to assess the generalizability of the proposed solutions. Future research could extend our approach by incorporating multiple case studies, providing a more comprehensive understanding of how digital technologies can be leveraged to enhance CMS. Additionally, there is scope for investigating the socio-technical dimensions of digital transformation, particularly concerning workforce training and the user acceptance of smart technologies.

6 Acknowledgements

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7 Ethics declaration

The data collection in this paper did not have to be subject to ethical clearance; standard GDPR procedure was followed.

8 AI declarations

We used AI, namely Chatgpt Plus from Openai, to help with the quality of text. After the full draft of the paper was finished, we asked Chatgpt for critical feedback on our writing and used some of the suggestions for rewriting and improving the text.

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AI-driven Knowledge Futures: Digital Innovation in Cultural Heritage

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Abstract

The rapid advancement of digital technologies has opened new possibilities for cultural heritage institutions (CHIs), enabling digitization and AI-supported initiatives that improve preservation, accessibility, and public engagement. However, CHIs often face significant challenges in evaluating and selecting appropriate projects due to fragmented resources, institutional complexity, and existing decision-support frameworks prioritize financial and technical feasibility while neglecting cultural and social dimensions. This study addresses a critical gap by presenting a micro-level decision-support framework specifically designed to guide CHIs in the evaluation of digitization and AI-supported projects. The framework was constructed through a three-stage mixed-method research design that combined a systematic literature review (SLR), focus group discussions, and the Delphi technique. It draws on the expertise of professionals from the European cultural and creative industries, including representatives from CH institutions and ethnic minority groups. Their diverse perspectives ensured that the framework reflects both technical and cultural priorities. The process resulted in a validated set of 43 criteria, grouped into six categories: finance and investment, employment and personnel, market, accessibility, social impact, and cultural heritage object. The framework offers CHIs a comprehensive but context-sensitive tool to guide structured, evidence-based decision-making. It captures both tangible and intangible project dimensions and supports strategic planning that aligns with institutional missions and stakeholder expectations. The study contributes theoretically by operationalizing cultural value and institutional priorities in micro-level evaluation, addressing the limitations of market-oriented models. It also offers practical value by enabling CHIs to navigate trade-offs between innovation, feasibility, and cultural integrity. While grounded in project-level application, the framework also serves as a foundation for the application of multi-criteria decision-making (MCDM) methods and future research on institutional-level decision making. The findings improve CHI's ability to make informed, inclusive, and forward-looking investment decisions in a rapidly changing digital world.

Keywords: cultural heritage, digitization, AI-supported projects, decision making criteria, micro-level.

Paper type: Academic Research Paper

1 Introduction

The expansion of the digital economy has recently intensified interest in digital innovation within cultural heritage (CH), leading to advances in storage, creation, and dissemination (Lin & Li, 2023; Wen et al., 2023; Zhang et al., 2024). Technological advancements such as artificial intelligence (AI) and augmented and virtual reality drive digitization and expand audience engagement, particularly in tourism, where digital heritage attracts visitors and boosts economic activity. The emerging AI agenda in CH is crucial to understand both the possibility and the dilemma of pushing heritage institutions into the digitalization era.

Consequently, the rapid pace of technological change in the CH domain makes early identification and evaluation of promising digital technologies essential (Schuh et al., 2023). For CHIs, strategic decision making around digitization and AI-supported initiatives is becoming increasingly critical, as accelerated technological development demands more deliberate and forward-looking approaches to implementation. However, many CHIs lack long-term evidence-based agendas, resulting in fragmented initiatives and an absence of coherent direction that impedes the integration of digital innovation into broader institutional goals (Schuh et al., 2023). This challenge is further compounded by fragmented funding structures and a limited pool of digital expertise, both of which undermine the development of comprehensive digitization strategies and constrain the potential for broader socio-economic impact (Zemlickienė et al., 2018).

Furthermore, from the perspective of decision makers, incomplete information and significant uncertainties further complicate the process of selecting and adopting the most suitable digitization projects, particularly in the early stages of technological adoption (Lapinskaitė et al., 2024). Furthermore, current decision-support methodologies for CHIs fail to adequately capture the complexity of CH digitization and AI-supported projects. Existing frameworks often emphasize financial viability and technological feasibility while neglecting the cultural, social, and ethical dimensions central to CHI's missions (Schuh et al., 2023). As a result, decision-makers are frequently left navigating the digitization process with tools designed for commercial enterprises. This misalignment risks steering investments toward projects that prioritize short-term technological novelty over long-term cultural value.

To address these challenges, this paper presents a framework and decision-support methodology designed to help CHIs evaluate potential digitization and AI-supported projects and avoid non-productive investments ensuring that selected initiatives align with long-term institutional, societal, cultural, and economic objectives. The framework is grounded in a three-stage research strategy that combines qualitative and quantitative methods, including a systematic literature review (SLR), focus group discussions, and the Delphi technique. Unlike broader regional or policy-level approaches, our methodology emphasizes the specific characteristics, constraints, and intended outcomes of individual CH digitization projects. It offers an expert-driven, institution-centered assessment framework that reflects the distinctive mission of CHIs taking into account fragmented funding environments, internal limitations, and the cultural, social, and ethical dimensions of digital transformation.

This study is structured as follows. The next section outlines the background on decision-making related to CH digitization and AI-supported projects, followed by a description of the research design and applied methods. The results section presents the full set of decision-making criteria, and the conclusion synthesizes key insights, discusses their implications for institutional strategy, and identifies directions for future research in advancing digital innovation in cultural heritage.

2 Background

Technological innovations, digitization, and the growing use of AI present significant opportunities for CHIs. For example, digital collections can attract virtual tourists, support digital exhibitions, and contribute to the creative economy by inspiring new forms of art and media. In addition, digitization enhances the preservation and dissemination of cultural assets, fosters public engagement, and stimulates economic activity. Vuoto et al. (2024) emphasize the wide range of digital technologies used in the CH sector, including immersive tools like virtual and augmented reality, as well as 3D modeling, image reconstruction, laser scanning, and AI applications. These technologies aim to improve engagement, preserve heritage, and offer immersive experiences without compromising cultural integrity. In particular, AR and VR have been shown to shape visitor interactions and deepen engagement at heritage sites (Wen et al., 2023), while gamification and educational technologies increasingly support learning in virtual and mixed reality environments (Zhang et al., 2024). Furthermore, AI has also become central to CH digitization for image analysis and restoration, object classification, text transcription and translation, automatic content analysis, recommendation systems, and multimodal interpretation. In addition, AI tools can also support user-generated artistic expressions by manipulating virtual 3D objects, audio-visual materials, or spatial data.

Despite their potential, CH digitization and AI-supported initiatives face a number of challenges. While the economic potential is significant, the reuse of mass-digitized content reveals a complex network of issues. For instance, AI usage in CH faces significant challenges, such as lack of standardization, legal and ethical concerns, and economic or technological barriers. Tiribelli et al. (2024) note that the absence of unified standards complicates data integration across institutions. Additionally, some studies also point to mixed results in user experience, while digital tools often enhance engagement, they can also introduce drawbacks such as simulator sickness and increased distraction (Ye et al., 2025). As Marto et al. (2019) and Wen et al. (2023) observe, the effectiveness of these projects depends on their alignment with user expectations and their ability to preserve cultural authenticity. Thus, CHIs are challenged to balance traditional offerings with digital innovation, navigating tensions between modern engagement strategies and heritage conservation. In addition, the complexity of digital projects, resource limitations, incomplete information, and uncertainties surrounding technological impact continue to hinder the ability of CHIs to develop strategic, long-term, and evidence-based agendas.

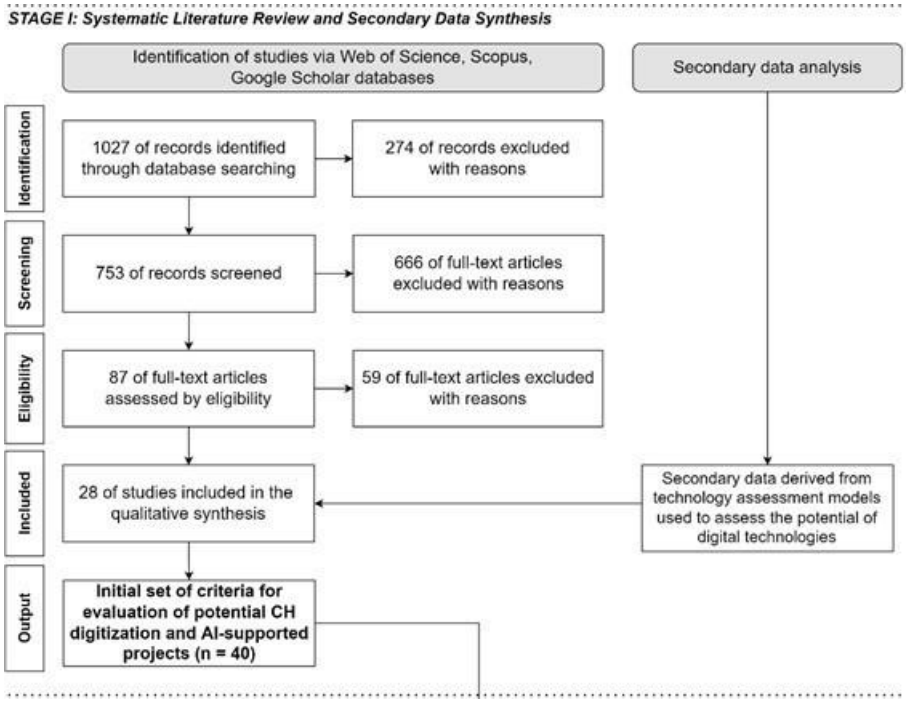
Therefore, a robust project-level decision support methodology is crucial for CHIs, as it provides a transparent and systematic approach to evaluate potential CH digitization and AI-supported projects. Technology assessment, as described by Liu et al. (2016), provides a framework for examining the implications of emerging technologies. It incorporates empirical methods, stakeholder engagement, and foresight analysis to reduce uncertainty and support informed decision-making. Understanding the life cycle and fundamentals of innovation, CHIs are able to adopt technologies that align with their institutional and socio-economic goals (Dereli & Altun, 2013). Although the commercial potential of new technologies is not the main concern for CHIs, it remains a relevant consideration. Effective decision-support tools help institutions avoid non-productive investments and ensure that adopted projects contribute to broader institutional and societal objectives (Zemlickienė et al., 2018).

Several methodologies have been developed to evaluate digitization and innovation projects, but their applicability to CHIs remains limited. For example, the STEP framework (Dereli & Altun, 2013) integrates technology, process, economic, market, perception and regulatory evaluations, yet lacks the nuance required to

address CH-specific concerns such as cultural significance and audience engagement. Similarly, IPscore® 3.01 (developed by European Patent Office) and WIPO's technology identification system (WIPO, 2010) offer structured approaches to assessing innovation. Still, they prioritize market-driven criteria that often sideline the broader societal impact of cultural heritage. Even frameworks that incorporate multi-criteria decision analysis (Zemlickienė et al., 2018) tend to underweight the values CHIs uphold, reducing their effectiveness in guiding strategic decision-making. However, a common consensus among these decision support methodologies emphasizes evaluating economic and market potential, stakeholder demands, and the integration of various assessment tools (Huang & Gu, 2009). These approaches highlight the importance of integrating multiple criteria to capture the diverse dimensions of the impact of the project. Since CHIs often face unique challenges that differ from purely commercial entities, existing tools may not adequately address multidimensional considerations, emphasizing the need for a problem-based approach that aligns with the specific needs of CHIs. Therefore, in this study we propose a methodology to aid CHI's decision-makers in evaluating potential CH digitization and AI-supported projects.

3 Research methodology

Our research design is guided by the following central research question (RQ): What are the relevant criteria for evaluating potential CH digitization and AI-supported projects? More specifically, the project level focuses on CHIs and organizations that implement digitization and AI-supported projects within specific institutional and community contexts. To answer the RQ and propose a decision support framework, we have employed a three-stage research strategy, integrating qualitative and quantitative methods for comprehensive data gathering and validation (Figure 1). This strategy provides distinct advantages through complementary methods and is built on previous studies (Lamoureaux et al., 2024; Rao et al., 2021; Tan et al., 2010) and methodological guidelines (Fathullah et al., 2023). Fathullah et al. (2023) highlight the benefits of combining systematic literature reviews (SLR), focus group discussions and the Delphi technique, and has been proven effective in previous research to consolidate baseline knowledge with expert-driven refinements.



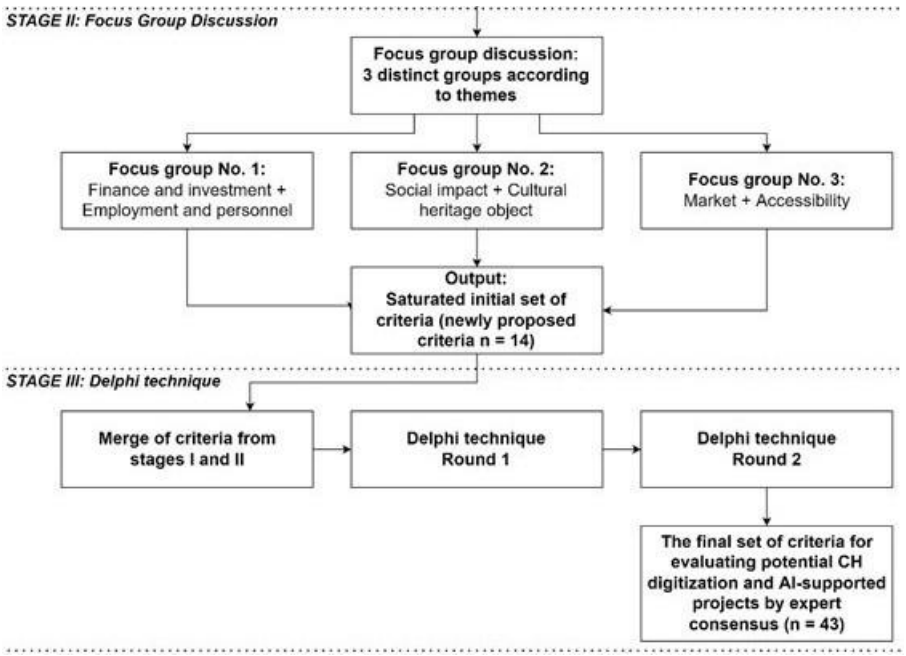


Figure 1: Research design to develop a decision support framework to evaluate potential CH digitization and AI-supported projects (Authors, 2025)

3.1 Systematic literature review and secondary data synthesis

The systematic literature review (SLR) formed the foundation for identifying decision-making criteria relevant to CH digitization at the institutional level. Studies were sourced from Web of Science, Scopus, and Google Scholar, selected based on their suitability as outlined by Pranckutė, (2021). The search strategy was structured around two streams: (1) cultural heritage and (2) decision-making. The second stream incorporated terms such as multi-criteria decision-making (MCDM), decision support, and prioritization frameworks to ensure methodological relevance.

An initial pool of 753 records was screened which included review of abstracts. Inclusion criteria were: (1) studies addressing decision-making processes related to CH digitization at the project level, and (2) studies presenting a defined set of criteria with clear descriptions. Exclusion criteria were: (1) studies focusing solely on selecting the best alternative without outlining underlying criteria; (2) topics unrelated to CH, such as biodiversity, construction, or restoration; (3) secondary research (e.g., SLRs, bibliometric analyses); (4) purely theoretical work lacking application to decision-making; (5) studies outside the institutional or geographical scope; and (6) papers lacking methodological transparency or sufficient description of decision-making criteria and context.

A total of 87 full-text articles were assessed for eligibility, and 59 were excluded due to: lack of project-specific criteria (n = 27), insufficient criterion descriptions (n = 8), topic irrelevance (n = 21), or minimal contribution (n = 3). These exclusions were possible only after full-text review due to insufficient detail at the abstract level. The final sample of 28 articles underwent qualitative synthesis, focusing on the applicability and clarity of decision-making criteria. To complement this analysis, a secondary data synthesis was conducted to examine existing technology and innovation assessment models and extract best practices. Following Cahyadi & Magda (2021) and Weston et al. (2019), these models were primarily derived from technology assessment literature. To structure the criteria, the generic technology potentials proposed by Schuh et al. (2023), including cost reduction, synergy, human impact, market potential and quality were adapted to the study context. This led to six final categories: (1) financial and investment (8 criteria), (2) employment and personnel (5 criteria), (3) market (4 criteria), (4) accessibility (7 criteria), (5) social impact (8 criteria), and (6) cultural heritage object (8 criteria). In total, 40 criteria were identified and used as input for the second stage of the research.

3.2 Focus group discussion

In the second stage, focus group discussions were used to integrate theoretical knowledge, namely, the criteria identified in the first stage, with expert insights, enriching, and refining the final set of criteria. Focus groups are particularly effective in exploratory research, offering a dynamic platform for capturing diverse perspectives, encouraging interactive dialogue, and facilitating the integration of multidisciplinary knowledge,

especially in complex decision-making contexts (Bandalos, 2018; Kramar et al., 2019; Prieto-Sandoval et al., 2019). We follow the methodological guidelines of Jacoby & Siminoff, (2007) and O.Nyumba et al. (2018). Three focus groups were organized as interactive workshops, each moderated by a dedicated facilitator and structured around themes derived from the initial criteria set. The first group addressed financial and investment criteria and employment and personnel criteria; the second focused on market and accessibility; and the third discussed social impact and cultural heritage object criteria. Experts were assigned based on their domain expertise, with 5–7 participants in each group. In total, 17 experts from the European cultural and creative industries, including representatives from CH institutions and ethnic minority groups, participated in this stage. Expert data are presented in Annex 2. The names of the experts are not disclosed due to privacy and legal rights, and experts have been codified with labels E1, E2, etc. Expert recruitment and surveying were carried out in September 2024.

The experts were presented with the central research question: What are the relevant criteria for evaluating potential CH digitization and AI-supported projects? An auxiliary question was also posed: What is important to consider when making decisions about the digitization of cultural heritage projects? These questions were explicitly formulated to saturate the set of criteria. The focus group setting proved highly informative, allowing participants to engage in nuanced discussions and share a wide range of perspectives. At the end of the sessions, each group proposed additional criteria that they believed should be incorporated. In total, 14 new criteria were suggested. After review, two were excluded because they fell outside the scope of the study, and three were merged with existing criteria due to overlap. As a result, nine new criteria were added to the initial pool and used as input for the third research stage.

3.3 Delphi technique

Finally, the Delphi technique was applied to refine and finalize the set of criteria, retaining only those deemed most important through expert consensus. The Delphi technique is a structured, multi-round survey process designed to facilitate consensus through iteration, controlled feedback, and aggregated responses (Schmalz et al., 2021). This study followed the methodological guidelines of (Afshari et al., 2012; Drumm et al., 2022), and previous applications in similar contexts (Schmalz et al., 2021)(Zavadskas et al., 2017).

A total of 20 experts participated in this third research stage. Expert data is presented in Annex 2. In the first round, all the criteria identified in stage one, along with those newly proposed during the focus groups, were merged and distributed to experts via a Delphi questionnaire. Experts were asked to evaluate each criterion's relevance on a 9-point scale (1 = “completely irrelevant”; 9 = “extremely relevant”) and were invited to select 3–4 criteria groups aligned with their area of expertise. They could also propose additional criteria or suggest refinements to existing definitions. Two auxiliary questions were included to guide expert judgment: (1) How relevant is the criterion when evaluating potential CH digitization and AI-supported projects? (2) What is important to consider when making decisions about the digitization project of CH? The responses were analyzed and criteria were advanced to the second round based on average relevance scores. Following the approach of Oroojeni Mohammad Javad et al. (2020), only criteria with a mean score of 7 or higher were retained. In the second round, a set of criteria, including newly added criteria, was returned to the experts to obtain consensus, and experts were asked again to evaluate the relevance of the criteria based on a scale of 1 to 9. Final consensus was reached at the end of this round, resulting in the validated set of decision-making criteria.

4 Results

The applied three-stage research strategy, integrating qualitative and quantitative methods, resulted in a final set of 43 criteria directly relevant for evaluating potential CH digitization and AI-supported projects (Figure 2). These criteria were classified into six thematic groups, drawing on the framework of generic technology potentials by Schuh et al. (2023) as an initial reference. While Schuh’s model offered a useful starting point, its orientation toward the private sector required adaptation to the distinct mission of CHIs. Through an iterative refinement process, the final grouping was developed to reflect the context of CHIs. The six resulting categories are: (1) Finance and investment (9 criteria), (2) Employment and personnel (6 criteria), (3) Market (4 criteria), (4) Accessibility (7 criteria) (5) Social impact (9 criteria), and (6) Cultural heritage object (8 criteria). The full list of criteria is provided in Annex 1.

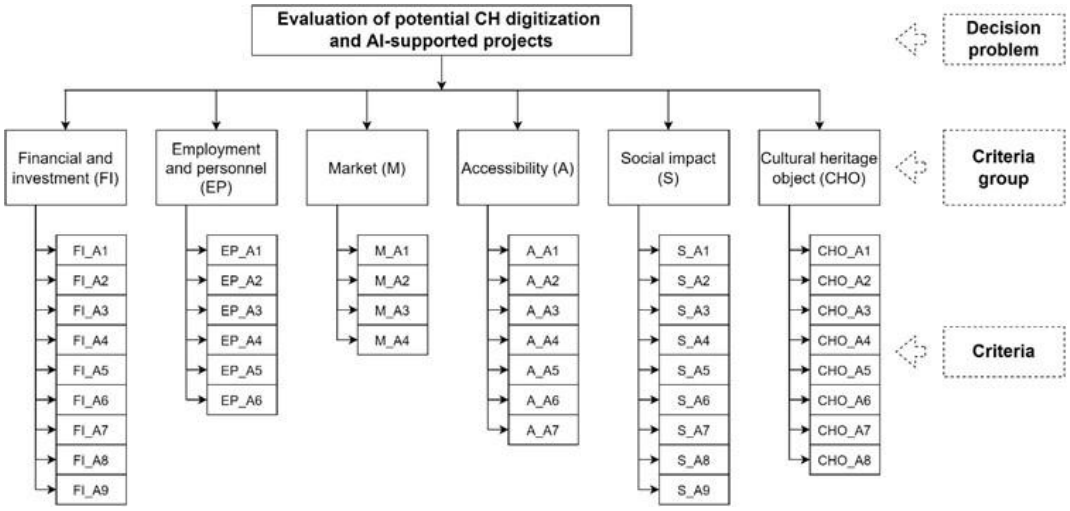


Figure 2: Hierarchical structure of the decision problem and framework to evaluate potential CH digitization and AI-supported projects (Authors, 2025)

4.1 Finance and investment criteria group

This group covers the economic dimensions of digitization projects, including financial feasibility, funding availability, and potential returns. It addresses both initial investment requirements and long-term financial commitments, including external funding, co-financing, and cost-efficiency. It also captures the potential for direct monetization or indirect savings, along with the broader economic implications for local communities.

4.2 Employment and personnel criteria group

This group covers the institutional readiness in terms of human resources and considers staff expertise in technology and cultural heritage, capacity for personnel allocation, and internal attitudes toward digitization. The group also accounts for job creation potential, workload distribution, and staff well-being, highlighting the organizational conditions required for successful implementation.

4.3 Market criteria group

The market group focuses on the project's positioning within the broader digital ecosystem. It evaluates readiness for public engagement, distinctiveness compared to similar initiatives, and both current and future demand. Technological maturity and growth potential are also considered, providing insight into a project's sustainability and relevance in a dynamic digital environment.

4.4 Accessibility criteria group

This group examines how users interact with and access digitized content. Key dimensions include user-friendliness, technological integration, and adaptability to future systems. It also addresses physical and remote access, technical support, and data security, ensuring that projects are inclusive, navigable, and resilient to changing user and infrastructure demands.

4.5 Social impact criteria group

Social impact criteria assess the alignment of projects with societal values, inclusivity, and educational potential. This includes public attitudes, social group responses, and the role of digitization in shaping cultural interpretation. It also captures contributions to public learning, international cooperation, and participatory design, reflecting the broader civic role of CHIs.

4.6 Cultural heritage object criteria group

This group focuses on the authenticity, quality, and preservation aspects of digitization. It considers the extent and fidelity of digital reproduction, the condition of the original object, and the potential risks or benefits to its conservation. The criteria also address the historical and symbolic significance of the object and the impact of digitization on its interpretation.

5 Conclusions

In this study, we present a robust project-level decision-support framework for CHIs and organizations implementing digitization and AI-supported projects within specific institutional and community contexts. Identifying micro-level evaluation criteria is a foundational step in enabling informed, strategic decision-making for CH digitization. The proposed classification offers a comprehensive and structured framework that captures the multifaceted nature of such projects. Each criteria group addresses critical factors influencing project feasibility, long-term sustainability, and broader socio-economic value. By integrating both qualitative and quantitative dimensions, the framework allows CHIs to assess tangible and intangible aspects of digitization, ensuring alignment with institutional priorities, stakeholder expectations, and available resources. In doing so, it enhances strategic planning while preserving cultural authenticity, promoting accessibility, and maximizing social benefit. This structured approach empowers CHIs to make well-informed, balanced and forward-looking decisions that reflect their unique missions and long-term objectives. Beyond the immediate scope of digitization projects, this framework contributes to a broader understanding of how cultural institutions can adapt technological innovation to serve public value rather than market imperatives. It offers a model for evaluating emerging technologies in ways that respect cultural specificity, institutional diversity, and community priorities.

5.1 Theoretical Implications

This study contributes to the theoretical discourse on decision-making related to digitization of cultural heritage by offering a domain-specific framework that addresses the limitations of market-oriented evaluation models. While existing methodologies often prioritize financial and technological feasibility, they frequently lack the nuance required to account for the cultural, ethical, and institutional dimensions unique to CHIs. This research introduces a micro-level classification of decision criteria that operationalizes these overlooked dimensions and can serve as a foundation for future studies in heritage informatics, cultural policy, and innovation governance. The framework also contributes to the creative economy literature by drawing attention to the strategic conditions under which cultural digitization projects are likely to produce sustainable, locally driven innovation. In addition, it invites further theoretical exploration of the extent to which cultural value can be meaningfully embedded in the assessment without reducing heritage to quantifiable metrics.

5.2 Practical Implications

For CHIs and organizations implementing digitization and AI-supported projects in specific institutional and community contexts, the findings offer a practical tool to guide structured evidence-based decision-making. The initial classification of criteria was grounded in a systematic literature review and informed by established decision-support models. More critically, the participation of experts from European cultural and creative industries, including representatives from CH institutions and ethnic minority groups, ensured that the framework was contextualized and responsive to real-world challenges. These expert insights helped refine criteria definitions and align the framework with the operational realities of CHIs, bridging the gap between technological feasibility and cultural sensitivity. This collaborative approach enhances the framework's applicability, enabling CHIs to manage and prioritize digitization projects in ways that reflect both institutional mandates and the expectations of cultural communities. However, as stakeholder priorities differ across institutional and cultural settings, project-level decision-making must also account for contextual variability. Digitization is not a uniform process; it is shaped by the values, constraints, and goals of distinct cultural groups. Therefore, effective implementation requires sensitivity to these differences and a commitment to inclusive and adaptive evaluation processes.

5.3 Limitations and agenda for future research

Although this study presents a robust and context-specific framework for evaluating CH digitization and AI-supported projects, several limitations should be acknowledged. First, the focus on European cultural and creative sector experts may limit the generalizability of the criteria across diverse geographical or institutional settings. Future research could expand the expert base to include perspectives from underrepresented regions and non-European cultural contexts. Second, while the Delphi method offered a structured approach to consensus building, the qualitative nuances of disagreement or divergence between experts were not explored in depth. Complementary qualitative methods, such as individual interviews or ethnographic case studies, could enrich understanding of context-dependent decision logics. Moreover, while the framework is developed for project-level evaluation, future research should explore its integration into multi-criteria decision-making

models, enabling CHIs to prioritize projects systematically under specific conditions. The finalized criteria set can serve as input for a range of MCDM techniques, such as AHP, BWM, TOPSIS, or PROMETHEE, to support structured decision processes.

6 Ethics declaration

Include a section at the end of your paper stating whether you needed ethical clearance for the research referred to in this paper and if you did provide a reference to the permission granted.

7 AI declaration

In developing the paper, AI tools were used exclusively to support language editing and facilitate textual refinement, with all outputs were reviewed and incorporated at the discretion of the authors.

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Annex 1: Full list of criteria to evaluate potential CH digitization and AI-supported projects

Criteria	Description
GROUP: Finance and investment (FI)	
Funding potential	External financial support and funding potential
Initial costs	Initial costs of a digitisation project
Long-term costs	Long-term financial obligations
Project duration	Projected duration of the implementation of the project
Project Longevity	Expected longevity of the project
Monetisation	Monetisation opportunities and potential for new revenue streams
Cost savings	Cost savings and avoidance due to project
Impact on local economic activities	Effects on local economic activities
Co-funding	Potential for securing additional funding through contributions by partners
GROUP: Employment and personnel (EP)	
Personnel technological competencies	Technological competencies of personnel
Personnel CH object competencies	Competencies of the personnel related to the cultural heritage object
Personnel capacity and availability	Allocation of sufficient human resources with required skills and time
Personnel hostility and attitude	Staff's openness, resistance, or hostility towards the project
Potential for creating new jobs	Ability to generate new employment opportunities
Personnel well-being	Physical health, mental well-being, and overall stress levels of the staff
GROUP: Market (M)	
Level of uniqueness	Uniqueness of the digital cultural heritage project in the market
Market readiness	Degree of market readiness
Current market demand	Current market demand and the number of potential users
Future market demand	The anticipated interest, and emerging trends
GROUP: Accessibility (A)	
Complexity of the technology	How challenging or advanced digital technology is for end-users
Technological dependencies	Extent to which the project relies on existing or technological infrastructure
Compatibility	How well the project integrates with existing digital platforms
User Engagement	Features of the project that enhance user engagement
Physical accessibility	Accessibility regarding physical location and availability

User support	Availability and quality of technical support and help resources for end-users
Security	Measures implemented to safeguard user data and ensure the security
GROUP: Social Impact (S)	
Social hostility and attitude	How well the project aligns with social attitudes and expectations
Socio-Cultural Impact	Affect the cultural authenticity and value of cultural heritage
Educational and research value	Potential contributions to educational and research activities
Use Restrictions	Limitations on fair use, including public accessibility
Social inclusion	Impact of the project on fostering social inclusion,
International relations	How effectively the project fosters international collaboration
Digital outreach	Extent to which the project facilitates the creation of new communities
Diverse audiences	How well the project caters to a wide range of demographic groups
Co-design principles	Extent to which the project incorporates co-design principles
GROUP: Cultural heritage object (CHO)	
Representation accuracy	Digital representation accurately of the cultural heritage object
Technological quality	Technological specifications (resolution, colour depth, file format, etc.)
Significance of the CH object	Uniqueness, cultural, symbolic, historical, artistic significance
Current preservation	Current preservation level of the cultural heritage object
Preservation needs	Preservation needs of the object in its current state
Physical condition	Physical condition of the cultural heritage object
Level of digitisation	Extent to which a cultural heritage object is digitised
Digitisation impact on CH	Extent of the effects that the digitisation process has on the CH object

Annex 2: Data of experts who participated in the Focus groups and Delphi

Expert	Country	Area of expertise	Participated in stage II	Participated in stage III
E1	Lithuania	market factors + accessibility	No	Yes
E2	Netherlands	market factors + accessibility	Yes	Yes
E3	Finland	social + cultural heritage object	Yes	Yes
E4	Germany	financial and investment + employment and personnel	Yes	Yes
E5	Italy	social + cultural heritage object	Yes	Yes
E6	Germany	social + cultural heritage object	Yes	Yes
E7	Lithuania	market factors + accessibility	No	Yes
E8	Finland	financial and investment + employment and personnel	Yes	Yes
E9	Lithuania	market factors + accessibility	No	Yes
E10	Belgium	social + cultural heritage object	Yes	Yes
E11	Finland	financial and investment + employment and personnel	Yes	Yes
E12	Lithuania	social + cultural heritage object	Yes	Yes
E13	Finland	financial and investment + employment and personnel	Yes	Yes
E14	Lithuania	market factors + accessibility	Yes	Yes
E15	Italy	social + cultural heritage object	Yes	Yes
E16	Italy	financial and investment + employment and personnel	Yes	Yes
E17	Netherlands	social + cultural heritage object	Yes	Yes
E18	Italy	market factors + accessibility	Yes	Yes
E19	Germany	financial and investment + employment and personnel	Yes	Yes
E20	Germany	market factors + accessibility	Yes	Yes

Transforming Hotel Innovation Management through Innovation Labs: Lessons from Spain

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Abstract

In this article, we will explore innovation management in such an important sector as tourism, focusing specifically on the hotel industry. Within the hotel industry, innovation has been a major focus for some years now, moving away from the popular phrase that traditionally circulates by word of mouth, "This has always been done this way." Proof of this is that highly important organizations in the sector such as ITH (Hotel Technology Institute in Spanish) are holding highly interesting events such as the one held in 2020: "Balance between technology and investment, common sense and people, key in ITH Hotel Virtual Innovation Lab". Because the current situation in the sector is changing, both for the hotelier and the customer, it is essential to be able to compare what has been studied so far with the current reality. In the past, guests would go to a hotel and find things they didn't have at home: a larger TV, a better mattress, a jacuzzi... this meant that innovation took a backseat to customer attraction. Nowadays, it's difficult to surprise guests with such basic items that they normally have at home that are just as good or better, so innovation has taken center stage and gained significant importance. We could say without fear of being wrong that today the hotel sector is one of the most interested in innovation in all its aspects (technological, marketing and processes) without a doubt. That's why we consider it important to conduct a study and see if the reality of the sector is surpassing the academic studies conducted on it. To contrast this reality, it is important to obtain information directly from the most relevant players in the sector and conduct as many interviews as possible.

Keywords: Innovation Lab, i-Lab, innovation, Hotel industry, Tourism

Paper type: Academic Research Paper

1 Introduction

The aim of this study is to analyse the management of innovation within a sector of great importance to the Spanish economy: the tourism industry, with a particular focus on the hotel sector.

According to data published by the Spanish National Statistics Institute (INE) on its website, the tourism sector accounted for 11.6% of Spain's Gross Domestic Product (GDP) in 2022. Within this sector, the hotel industry constitutes one of its key pillars, undergoing significant changes in recent years.

Historically, the hotel sector in Spain has been managed in a family-oriented manner, with varying levels of professionalism, and a common characteristic being the ownership of the properties operated. However, in recent years, new players have entered the market, including investment funds, external operators, and franchises.

This evolution has substantially transformed the sector, resulting in previously uncommon scenarios, such as the ownership of a property by an investment fund, its operation by an external manager, and its management under a franchise brand. These changes have made management more complex, with each case being unique.

This article will differ from a conventional article, because it will attempt to use two methodologies: a systematic reading of the literature and a case study.

With this particular structure we will try to compare the results obtained from the literature and those obtained from participants in the sector.

We will try to answer two basic questions from both points of view that give meaning to this article:

- *Is the management of innovation clearly defined within the hotel sector?*
- *Can an "Innovation Lab" be a useful tool for managing innovation?*

2 Theoretical foundations

Organizations are increasingly interested in creating dedicated physical spaces to foster innovation process. For more than ten years, universities, research institutes, incubators, accelerators, innovation centers, co-working spaces, start up spaces and more have grown at a considerable pace across the globe (Osorio et al., 2019). The concept of innovation lab, has grown in popularity in recent years, and, nowadays, a variety of

interaction spaces work with these principles in mind (e.g., 'living labs', 'hubs', 'fablabs') (Høegh-Guldberg et al., 2022).

This phenomenon is increasingly emerging in response to traditional Research and Development (R&D) centres' gaps in the digital age. Indeed, R&D labs, even when equipped with high-tech infrastructure and skilled personnel, cannot always sustain and improve the innovation capacity of companies. This is mainly because they are often still designed as monads, isolated from the rest of the company and where a highly technical language is spoken far from the rest of the company (Blank, 2007).

Innovation labs (or labs) in this study are collaborative innovation spaces that can be defined as 'physical or virtual spaces that enable and support the innovation (technological or otherwise) of those who participate in the space (Yati, 2024)

An innovation lab is mainly associated with an innovative space (Moultrie et al., 2007). One of the points that is gaining the most strength in terms of innovation labs is the use of a space dedicated and conceived exclusively for the purpose of facilitating innovation. Indeed, (Moultrie et al., 2007) suggest the physical space is essential for the innovation process in organizations.

As described in their article (van der Meer et al., 2021) we can classify innovation labs in to 4 types: Digital Enabler, Solution Insourcer, New Bussines Incubator and Joint Innovator.

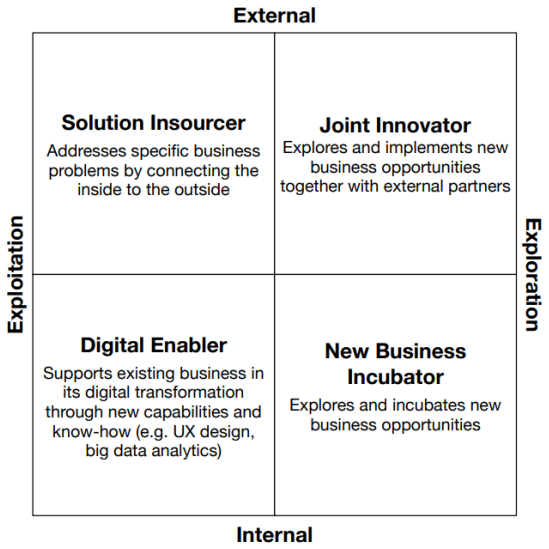


Figure 1. Innovation Labs Types identified by (van der Meer et al., 2021)

An Innovation Lab can be seen as an innovation management model based on three pillar dimensions distinguishing its structure: i) "atmosphere for innovation", i.e. the construction of an innovative space, which can be physical, virtual, hybrid, relational, promoting and supporting interactions and a context for innovation; ii) "time for exploration", i.e. the definition of time for creating and critical thinking spurring innovative ideas related to the challenges at hand; iii) "platform to experiment", i.e. the provision of tangible and intangible infrastructure and tools that can support the prototyping, experimentation and demonstration of possible innovative solutions. (Santarsiero et al., 2023)

3 Methodology

3.1 Systematic literature review

First of all, we conduct a systematic review of innovation labs in the hotel sector.

After an initial search of articles published in two of the most used databases; "Scopus" and "WOS", with different semantics, we observe that there are few publications on the topic in question.

3.1.1 Inclusion Criteria

It started with the search for the following string:

("Innovation Lab*" OR "Living Lab*") AND ("Tourism" OR "Hotel" OR "Lodge" OR "Accommodation" OR "Resort*")

In both databases, 72 documents were obtained in “Scopus” and 71 documents in “WOS”

We discarded publications that were not in Spanish or English this leaves us with a total of

62 documents in “Scopus” and 64 documents in “WOS”. Later we will stay with those that are in their final stage of publication leaving a total of 60 documents in “Sopus” and 64 documents in “WOS” because they don’t have this filter. Later we are left only with the documents catalogued as “articles”, 37 articles in “Scopus” and 43 articles in “WOS”.

We finally restrict the period to 10 years (2025-2025) giving us a total of 34 articles in “Scopus” and 41 articles in “WOS”.

Table 1**:** Resume

Initial documents	**Scopus**	**WOS**
	72	71
Filter 1, Language; English or Spanish	62	64
Filter 2, Publication stage: Final	60	---
Filter 3, Document type: Article	37	43
Filter 4, Range: 2015-2025	34	41

If we eliminate the duplicates in both databases, we are left with a total of 48 articles.

To the latter we added some articles that were very interesting from various magazines. This leaves us with a final result of a total of 51 articles to carry out the study.

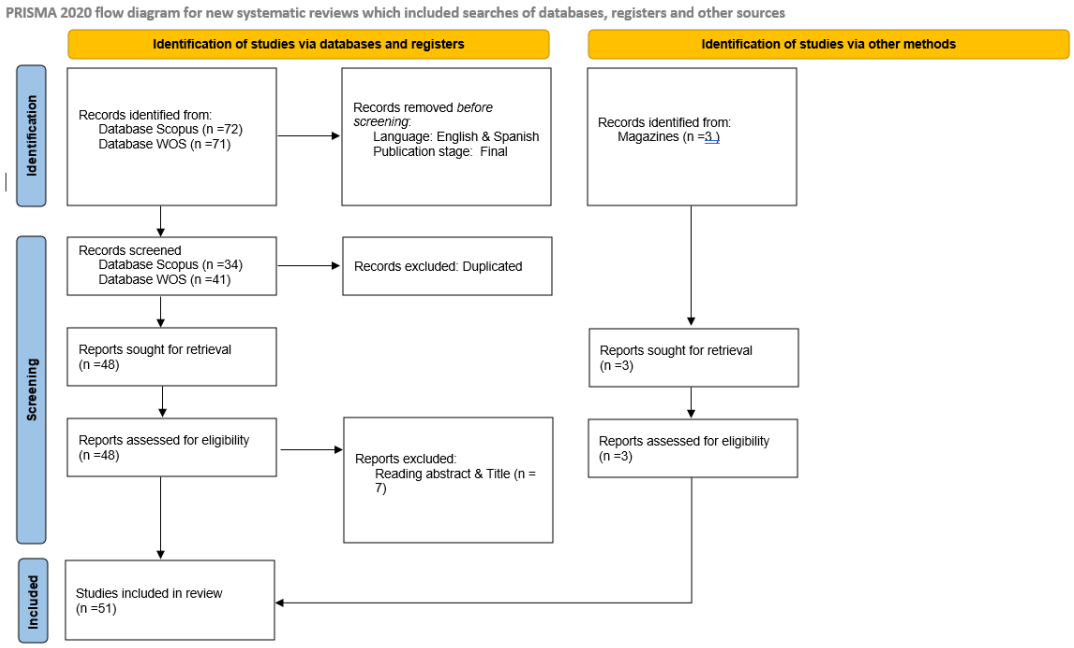


Figure 2. Prisma 2020. Flow diagram

3.1.2 Exclusion Criteria

A first reading of the title and the summary is carried out, and all articles that do not make direct reference to the indicated criteria, “Innovation Labs”, “Living Labs”, “Tourism” or “Hospitality”, are eliminated. 17 are discarded, leaving a total of 26 articles in this penultimate step.

3.2 Case study

As (Yin, 2014) defined, case study is “an empirical inquiry that investigates a contemporary phenomenon (the ‘case’) in depth and within its real-world context”.

We should start this chapter by compiling, according to various authors, the different types of case studies.

Table 2. Types of case studies

Initial documents	**Scopus**
	72
According to its purpose (Borges Méndez, 1995; Yin, 2014):	a) Pedagogical b) Clinical c) Investigative I.Explanatory II.Exploratory III.Descriptives
According to the number of cases (Yin, 2014):	a) Simple b) Multiple
According to the approach:	a) Quantitative b) Qualitative

In our case, we could categorize our study as an Investigative/Descriptive research study of a simple case using an intrinsic/qualitative approach.

Investigative, because we will seek to understand a specific phenomenon, the possible use of innovation labs. Descriptive, because the purpose is to examine and characterize the phenomenon.

Depending on the number of cases, if a single interview is initially conducted, it would be a simple type.

Finally, based on the approach, it would be a qualitative study, focusing on understanding the phenomenon, accepting the interviewee's subjectivity, and striving to interpret the research. It would also be intrinsic, due to the need to learn about the subject itself.

We have taken as references in this field the most renowned scholars of case studies, Robert Yin and Robert Stake.

To begin, we must assess whether the phenomenon we wish to study is a "case." For Stake, not everything is susceptible to being a case. To be considered a case, it must be something specific, with clear boundaries, and possessing a sense of identity and intentionality. However, the definition we believe best fits our particular case is the one described by Alonso G.(Alonso G., 2003): “A case study is a social science research strategy applied to a single, complex contemporary phenomenon, which is more specific than general in nature and which simultaneously represents a broader problematic situation. The research will seek to cover both the phenomenon and its real-life context in depth and will draw on multiple sources of evidence. It may aim to explain, describe, explore, evaluate, or diagnose.”

4 Results

4.1 From the systematic literature review.

After conducting a systematic literature review, we can observe, as the first and most important point, a small number of articles related to innovation labs and the hotel sector in particular.

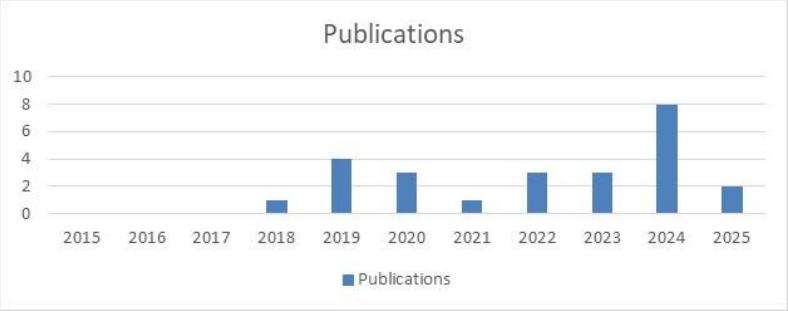


Figure 2. Publications by year

Almost all the articles found that deal with the topic start with the fact that the "innovation lab" is the appropriate tool, without really assessing whether it is or not and how innovation is initially managed.

Organizational culture and innovation today are components that together can be fruitful for the hotel sector, improving its profitability and, above all, contributing to the generation of innovative capabilities in human resources. Given the current competitive environment, it is imperative that they focus their attention on

strategies that allow them to grow and consolidate. In turn, the companies that will excel in the future will be those that make proper use of these components. (Padrón-Diaz de León et al., 2019)

The tourism sector's resistance to technological disruptions, which are integral to its offerings, has slowed the integration of Innovation Labs. Additionally, the prevalence of SMEs, often family-run, in the tourism and culture sector adds to the challenge. These SMEs face barriers to innovation and digital development due to limited economic and human resources, skills, cultural mindset, and dedicated time for innovation initiatives.(Najda-Janoszka and Kopera, 2014).

Innovation Labs have emerged as a valuable organizational practice that can help companies meet these needs by developing innovation strategies and promoting digital adoption.(Santarsiero et al., 2024)

There are also some articles that discuss "Living Labs" in the tourism sector, and since they are a derivative of an "innovation lab," they have been helpful in obtaining more information about alternatives in the sector.

Most of these articles based on "Living Labs" focus more on the general tourism sector and the destinations themselves in particular. This seems to be due to the fact that the members of a "living lab" are diverse and often include public administration among those involved.

(Osorio et al., 2019) Proposes an updated framework based on the experience of the projects described in his article. As has been shown, establishing a clear strategic intention at the early stage of the project is fundamental, and literature has actively evolved in that regard during the last few years. Among the other frameworks studied in this work, it is possible to identify common elements that define which aspects should be considered to set up the strategy for an innovation laboratory supported and shared by several stakeholders, such as companies, academics, open labs, factories, etc.

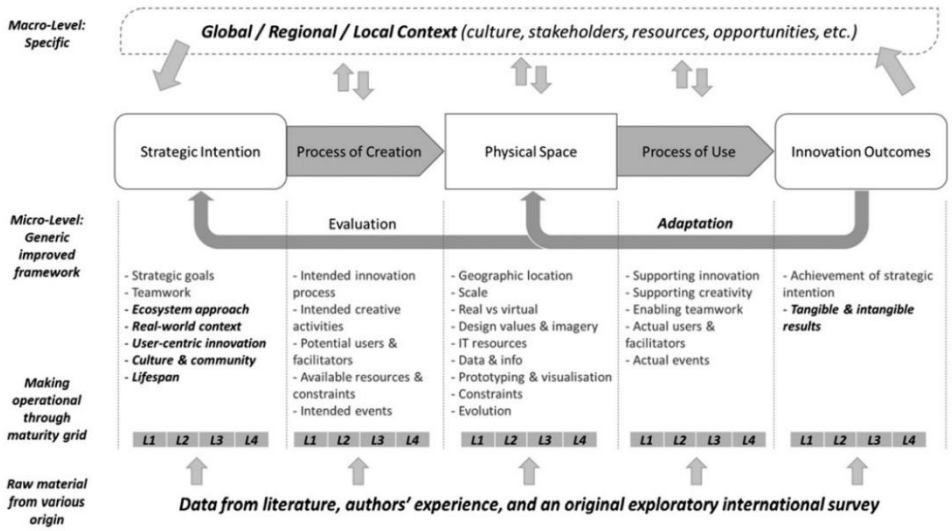


Figure 3. Updated framework based on (Osorio et al., 2019)

We can see that proper innovation management is crucial for the success of any new initiative. (Mellinas et al., 2016) describes how most Spanish hotels have adopted social media in recent years, but data indicate that many of them do it improperly, although a particularly intensive training for basic operation is not required.

Technology and innovation management is added to the relevant topics of technological innovation because one of the important issues in the innovation process is being able to measure them and evaluate their performance in this regard (Jiménez-Valero et al., 2012) They claim that there is no system of indicators that comprehensively evaluate GTI in the hotel industry.

Technological innovation, when used correctly, can be a very important point of connection with the customer, and Cardona (Cardona, 2016) demonstrates this in his study, where he analyzes the innovations implemented by Palladium Hotel Group in Spain for customer service, indicating which ones worked and which ones didn't.

Organizational culture and innovation today are components that, when combined, can be fruitful for the hotel sector, improving its profitability and, above all, contributing to the generation of innovative capabilities in human resources. Given the current competitive environment, it is imperative that they focus their attention on strategies that allow them to grow and consolidate. In turn, the companies that will excel in the future will be those that properly utilize these components. (Padrón-Diaz de León et al., 2019)

4.2 From the case study



Figure 4. Identified concepts

A parallel list of codes was created to assign to the concepts listed above, with the intention of evaluating the most important aspects. The list consisted of a total of 34 codes:



Figure 5. Identified codes

To summarize this first interview, we discussed how innovation is managed at the hotel chain where the interviewee worked. The interviewee mentioned that they are in the process of creating an "Innovation Lab" to channel innovative ideas. They currently do not have a physical space, so they plan to hold in-person meetings every four months. He emphasized that ideas can emerge from anywhere in the organization since the company's culture promotes creativity.

The interviewee explained that innovation is essential to differentiate themselves in a highly competitive sector, and although ideas initially come from senior management, any member of the organization can propose them.

To finance innovation projects, it is essential to present a short business plan along with the idea. Innovation is not limited to technology but also encompasses processes and services.

The barriers to innovation, according to the interviewee, are limited in his current organization but can be very significant in more traditional organizations. He points out that, in his view, measuring the success of ideas is based on three axes: generating new revenue, reducing costs, and improving the customer experience.

He considers the "Innovation Lab" vital for structuring the innovation process, enabling the creation of minimum viable products and the ability to scale these initiatives. The interviewee hopes to make innovation a habit in his organization and emphasized the importance of recognizing the people involved in these projects to foster a culture of innovation.

As we start in this investigation; Is the management of innovation clearly defined within the hotel sector? Can an "Innovation Lab" / "Living Lab" be a useful tool for managing innovation?

In response to these two main questions, we can say that innovation management does indeed appear to be clearly defined within the sector, and that an "Innovation Lab" is undoubtedly a useful tool for managing innovation in the hotel industry.

5 Discussion and conclusions

We can observe that the results of the literature surveyed, and the interviews conducted coincide on several relevant points, such as the fact that the sector has traditionally been reluctant to innovate, but that this is changing. In this case, they are completely in agreement, as an "Innovation Lab" is being implemented within the hotel chain studied. Interdepartmental communication and recognition of the members involved are essential if the company is to achieve long-term sustainability.

A crucial point to note is the importance of organizational culture within innovation and how this aspect significantly affects its development.

In addition to the contributions, this article has some limitations: The data for this study was obtained within the hotel sector in a global powerhouse such as Spain. Spain is a benchmark in the sector, and the various chains operating in Spain are international leaders, making the results highly valuable and a benchmark in other markets.

They were based only on the hotel sector, without considering other popular tourist activities such as “coliving”,” tourist apartments”, or “Hostels”.

This article has only included one interview, making it impossible to properly triangulate information.

The scope of the study, both in terms of proximity and ease of use, is limited to Spain; it should not be equivalent in other regions where both the way of working, and the organizational culture are different.

For future studies, other types of tourism business variants could be considered, such as “tourist apartments”, or even expanding the scope by evaluating chains in other geographical areas, of course, more interviews could be conducted to properly triangulate the results obtained.

6 Ethics declaration

To properly conduct and document this interview, an informed consent form was drawn up, which was accepted and signed by the interviewee. This document is filed with the transcript and recordings.

7 AI declaration

For this interview study, we used qualitative data analysis software that includes AI functionality. This software is Atlas.ti. The use given to this tool was basically the organization of information and generation of images.

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Assessing Digital Maturity in Rural Tourism: Insights from Pilot Areas in Basilicata

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Abstract

Building on a previously developed Digital Maturity Model (DMM) tailored for cultural tourism, this paper explores the application of the model in rural tourism contexts. While digital transformation (DT) is widely recognized as a strategic imperative, rural areas often face unique barriers—including limited infrastructure, digital skill gaps, and organizational inertia—that hinder their digital evolution. This study aims to assess the digital maturity of rural tourism operators in selected pilot areas in the Basilicata region, offering insights to guide targeted DT strategies.

The research adopts an empirical approach by applying the seven-dimensional DMM—comprising Strategy, Organization, Culture, Employee, Tourists, Technology, and Operations—to a sample of rural tourism and cultural operators. Data were collected through surveys and interviews conducted within pilot areas engaged in the Tech4You PNRR initiative.

The assessment reveals heterogeneous levels of digital maturity across rural operators. While strengths emerged in cultural orientation and visitor engagement, significant gaps were observed in areas such as strategic planning, technological infrastructure, and operational data use. These findings suggest a need for differentiated support policies and context-sensitive digital transformation roadmaps.

This paper extends the applicability of the DMM to rural tourism ecosystems, demonstrating its relevance beyond urban or institutionalized cultural tourism settings. It contributes empirical evidence to the literature on digital transformation in marginal areas, helping bridge the gap between maturity models and real-world application.

The study provides a diagnostic tool for local authorities, innovation agencies, and tourism stakeholders to map digital readiness, prioritize interventions, and co-design tailored DT strategies in rural contexts. It also opens pathways for replicability in other regions with similar territorial challenges.

Keywords: Digital Maturity; Rural Tourism; Cultural Heritage; Digital Transformation; Assessment Framework

Paper type: Academic Research Paper

1 Introduction

In today's rapidly evolving socio-economic context, the integration of digital tools and technologies has become a critical enabler for the resilience and competitiveness of organizations across all sectors, including rural and cultural tourism. Digital Transformation (DT) is no longer a strategic option but a necessity that requires rethinking processes, capabilities, and business models in alignment with emerging trends such as sustainability, personalization, and the digital experience economy (Gimpel & Westerman, 2012; Teichert, 2019).

Despite its recognized importance, the tourism sector—especially in rural contexts—faces persistent barriers to digital advancement. These include infrastructural gaps, digital skill shortages, and limited strategic vision. For organizations operating in rural tourism, which is often characterized by micro or family-run businesses deeply embedded in local cultural heritage, the transition to digital maturity presents unique challenges. Resistance to DT in such contexts is frequently rooted in concerns over standardization, loss of authenticity, and the complexity of integrating technology without disrupting the experiential essence of tourism (Guimont & Lapointe, 2016; Santarsiero et al., 2023).

Previous research has emphasized the importance of assessing digital maturity as a foundational step to guide strategic interventions and transformation efforts (Cantoni, 2020; Carlucci et al., 2023). In response, a Digital Maturity Model (DMM) specifically designed for cultural tourism organizations was developed and presented at IFKAD 2024. This framework identified seven core dimensions—Strategy, Organization, Culture, Employee, Tourists, Technology, and Operations—each articulated into specific sub-dimensions, offering a comprehensive basis for evaluating the digital readiness of tourism actors.

This paper builds upon that theoretical foundation by applying the DMM in a real-world context: selected rural pilot areas in the Basilicata region of Southern Italy. The goal is to empirically assess the digital maturity of tourism operators through field data collected as part of the PNRR Tech4You project. The study seeks to explore how the DMM performs in practice, what gaps and strengths emerge across dimensions, and how the findings can support context-sensitive strategies for digital innovation in rural ecosystems.

The paper is structured as follows. Section 2 provides a review of relevant literature on digital maturity and rural tourism transformation. Section 3 describes the research design and methodology. Section 4 presents and discusses the empirical results. Section 5 concludes with reflections on theoretical contributions, practical implications, and future research directions.

2 Theoretical background

Rural tourism has increasingly emerged as a driver of sustainable development, cultural valorization, and territorial reactivation. Yet, its potential is constrained by a range of structural and systemic challenges, particularly in relation to digital transformation (DT). Compared to urban or institutionalized tourism sectors, rural tourism contexts often suffer from a persistent digital divide (López-Carril et al., 2020), manifesting in limited access to broadband infrastructure, insufficient ICT services, and technological obsolescence. This infrastructural gap limits not only the adoption of digital solutions but also the capacity to develop data-driven services and marketing strategies (Wroblowska, 2016).

Rural tourism enterprises—often small, family-run, or community-based—are further hampered by resource scarcity, low digital literacy, and a general reluctance towards innovation (Dias & Patuleia, 2021). Operators frequently lack dedicated personnel for digital management, and investment capacity is limited. Moreover, cultural resistance persists: many stakeholders fear that digitization may undermine the authenticity and experiential quality that define rural tourism (Guimont & Lapointe, 2016; Santarsiero et al., 2023). These barriers collectively hinder the ability of rural tourism operators to engage with digital transformation processes in a structured and strategic way.

Nonetheless, digital transformation remains a critical enabler of visibility, competitiveness, and resilience in rural tourism. Digital tools can help mitigate geographical isolation, improve internal processes, and personalize visitor experiences. However, to unlock such benefits, operators must reach adequate levels of digital maturity—a concept that encapsulates not just technological readiness, but also cultural, organizational, and strategic alignment with digital innovation (Valdez-de-Leon, 2016).

The notion of digital maturity has gained traction in both academic and policy literature as a multidimensional construct that captures the degree to which digital technologies are integrated and strategically leveraged within organizations (Berghaus & Back, 2016). Maturity models—structured frameworks that define dimensions and levels of digital capabilities—have been extensively used to guide transformation processes. However, many existing models are overly generic or tailored to large enterprises, thus failing to account for the specificities of the tourism sector (de Bruin et al., 2005).

In 2024, a sector-specific Digital Maturity Model (DMM) for cultural tourism organizations was proposed (Santarsiero et al., 2024). This model was developed through a comparative analysis of existing DMMs across various industries and adapted to the operational realities of tourism enterprises rooted in cultural heritage. It identifies seven core dimensions—Strategy, Organization, Culture, Employee, Tourists, Technology, and Operations—each articulated through key sub-dimensions such as digital skills, brand management, and infrastructure. The model further defines a staged maturity progression, from basic to proactive integration of digital solutions.

This DMM not only provides a diagnostic tool but also acts as a strategic guide for organizations seeking to navigate their DT journey. It bridges a gap in the literature by incorporating both operational and experiential aspects of cultural tourism within a coherent digital assessment framework.

Building on this foundation, the present study aims to apply the DMM (Santarsiero et al., 2024) to rural tourism contexts, where infrastructural limitations, cultural particularities, and resource scarcity require a differentiated approach. While maintaining the model's seven dimensions, we interpret each through the lens of rural dynamics. For example, the "Technology" dimension includes considerations such as mobile coverage and public access points; the "Employee" dimension must reflect multi-tasking, often informally trained staff; and the "Tourists" dimension considers expectations shaped by offline traditions alongside online planning habits.

This extension represents both a conceptual and practical contribution: it tests the adaptability of the DMM to new territorial settings and generates evidence to inform policy and practice. Moreover, it aligns with recent calls in the literature for more granular and place-based approaches to digital transformation (Marín Díaz et al., 2023). As rural destinations face increasing pressure to innovate while preserving identity, a tailored maturity framework can serve as a lever for inclusive, resilient, and sustainable tourism development.

3 Methodology

The research adopts a mixed-methods approach aimed at empirically assessing the digital maturity of rural tourism organizations in the Basilicata region, Southern Italy. The methodology is rooted in the application of the DMM for cultural tourism introduced by Santarsiero et al. (2024), here adapted to the rural tourism context.

3.1 Research Context

The study was conducted as part of the broader Tech4You initiative (PNRR, Missione 4 - Componente 2), which supports the digital and ecological transition of Southern Italian regions. Specifically, the assessment was implemented in selected pilot areas characterized by a strong presence of cultural heritage assets and a predominantly rural tourism offer. These areas were chosen in collaboration with local authorities and development agencies, considering criteria such as remoteness, tourism intensity, and infrastructural readiness.

3.2 Instrument Design

The evaluation tool was structured around the seven dimensions of the DMM—Strategy, Organization, Culture, Employee, Tourists, Technology, and Operations. Each dimension was operationalized into three to five sub-dimensions, resulting in a total of 20 indicators. A structured questionnaire was developed based on these sub-dimensions, incorporating both Likert-scale items (ranging from 1 to 5) and binary questions to capture qualitative nuances.

The questionnaire was reviewed by domain experts and piloted with a small group of tourism operators for validation and clarity. To enrich the quantitative data, semi-structured interviews were also conducted with selected stakeholders, including public administrators, local tourism associations, and innovation facilitators.

3.3 Data Collection

The fieldwork took place between January and March 2025. The survey was distributed both digitally and in paper format, depending on the technological access of each participant. A total of 45 tourism operators participated in the survey, while 12 in-depth interviews were conducted across three pilot areas. Participation was voluntary and informed consent was obtained from all respondents.

3.4 Data Analysis

Survey responses were analyzed using descriptive statistics and cross-tabulations to explore variation in maturity across dimensions and territories. Maturity levels were calculated by aggregating scores per dimension and then categorizing results into four levels: Basic, Emerging, Structured, and Advanced. Qualitative data from interviews were thematically analyzed to contextualize quantitative findings and highlight perceived barriers, opportunities, and support needs.

This methodology allows not only for benchmarking digital maturity across pilot areas but also for capturing the lived experiences and structural limitations affecting digital transformation in rural tourism contexts. The integration of both quantitative and qualitative evidence ensures a robust and context-sensitive understanding of rural digital maturity dynamics.

4 Results

The results reveal a complex and fragmented picture of digital maturity across the surveyed rural tourism organizations. Overall, the majority of operators are positioned at an "Emerging" or low "Structured" level of maturity. Only a small minority demonstrate characteristics associated with the "Advanced" stage, suggesting that digital transformation remains at an early or transitional phase for most actors involved.

In terms of strategic orientation, very few organizations reported having a defined digital strategy. Most digital actions are reactive and lack integration within a broader vision, revealing a limited capacity for strategic planning in this domain. Governance models tend to be informal and often rely on individual initiative rather than structured organizational processes. Although some associations have introduced shared tools or platforms (e.g., centralized booking systems), such practices remain exceptions.

A generally positive attitude toward innovation emerged among respondents, particularly among younger operators. However, this openness often coexists with a cautious, risk-averse mindset. Interviewees highlighted that generational differences strongly influence the willingness to adopt and experiment with digital solutions. Skills gaps remain a critical issue: only 27% of participants reported having engaged in digital training activities

over the past year, with micro-enterprises facing the greatest difficulties in allocating time and resources for skill development.

From the customer engagement perspective, social media platforms—especially Facebook and Instagram—are widely used for visibility and promotion, but are rarely leveraged for more sophisticated purposes such as personalization, data analytics, or long-term relationship building. Internet infrastructure presents another major constraint: high-speed connectivity is available to only less of half of surveyed organizations, and very few have adopted more advanced technologies such as CRM systems, e-commerce platforms, or immersive media tools like AR/VR.

The "Operations" dimension recorded the lowest scores overall. Fewer than one in five respondents monitor performance through digital KPIs or systematically integrate technology into their daily operational practices. This indicates that, despite some advances in external communication and marketing, the internal digital transformation of rural tourism enterprises remains limited.

Geographically, the results show clear disparities among the three pilot areas. The most digitally mature operators were found in territories with more reliable broadband infrastructure and stronger institutional support for innovation. Conversely, the most peripheral and infrastructurally disadvantaged areas tended to exhibit the lowest maturity levels, especially in the Technology and Operations dimensions.

The qualitative insights gathered from interviews provide further context. Stakeholders identified several enablers that could facilitate digital development: the availability of targeted funding, access to training tailored for small enterprises, and the creation of peer-learning networks. On the other hand, major obstacles include time constraints, fear of losing authenticity, and the lack of an overarching territorial strategy to coordinate and support transformation efforts.

Altogether, the findings underscore the importance of adopting a multidimensional and context-sensitive approach when assessing digital maturity in rural tourism. They also confirm the need for place-based policies and capacity-building initiatives to overcome both technical and cultural barriers to transformation.

5 Discussion

The empirical findings offer valuable insights into the current state of digital maturity in rural tourism contexts and contribute to validating the applicability of the Digital Maturity Model (DMM) originally developed for cultural tourism. While the core structure of the model—centered around seven dimensions—proved to be sufficiently comprehensive, its application to rural settings reveals the necessity of contextual calibration. Infrastructural constraints, informal governance, and deeply rooted cultural dynamics significantly influence how each dimension manifests and interacts.

One of the most critical observations relates to the disconnect between digital intention and strategic integration. Many operators express a willingness to innovate but lack a formal strategy or structured process to do so. This confirms the assumption that digital transformation in rural contexts is often opportunistic rather than planned, and reinforces the need for tools and support mechanisms that not only assess maturity but also foster capacity building and strategic alignment.

The results further emphasize the importance of digital skills as both an enabler and a bottleneck. While the DMM accounts for human capital within the "Employee" dimension, the rural setting exacerbates the impact of limited access to training and professional development. This suggests that future iterations of the model could include an additional focus on local ecosystems of support—such as training networks, innovation hubs, and peer-to-peer learning communities—that compensate for the isolation typical of rural environments.

The variation across territories also highlights the interdependence between digital infrastructure and organizational readiness. In areas with more developed broadband coverage and stronger institutional engagement, operators exhibit higher levels of maturity, confirming the hypothesis that digital transformation is not only an organizational challenge but also a territorial one. This points to the need for coordinated, place-based digital policies that address both supply- and demand-side limitations.

Another key insight concerns the underutilization of digital tools for operational management and customer relationship building. Although visibility through social media is widespread, its use remains superficial and disconnected from deeper customer insights or data-driven practices. This reveals an untapped potential within the "Operations" and "Tourist" dimensions that, if activated, could enhance both competitiveness and sustainability.

Taken together, these findings support the broader argument that rural tourism's digital transformation cannot be achieved solely through individual entrepreneurial effort. It requires an enabling ecosystem that combines infrastructure, skills, vision, and collaboration. The DMM thus serves not only as a diagnostic tool but as a framework for guiding multi-stakeholder engagement in rural innovation processes. Its application here

confirms its adaptability, while also pointing to future directions for refinement that incorporate rural-specific dynamics and collective enablers of change. However, several limitations must be acknowledged. First, the research is geographically confined to selected pilot areas within the Basilicata region, which may limit the generalizability of findings to other rural territories with different socio-economic, cultural, or infrastructural characteristics. Second, the self-assessment nature of the survey instrument may have introduced response biases, particularly in the evaluation of intangible dimensions such as strategic vision or organizational culture. Third, while the qualitative interviews provided valuable depth, the number of interviews was relatively limited and may not fully capture the diversity of stakeholder perspectives.

Future research should aim to replicate and expand the application of the DMM across a broader range of rural regions, ideally incorporating longitudinal data to track transformation trajectories over time. Additional refinements to the model could explore integrating external factors such as policy environment, community engagement, and digital ecosystems. Moreover, participatory approaches involving co-design with local stakeholders could strengthen both the diagnostic accuracy and the practical utility of the maturity model in guiding place-based digital innovation strategies.

6 Acknowledgements

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7 Ethics declaration

This research did not require formal ethical clearance, as it involved non-sensitive data collection through voluntary surveys and interviews with adult participants operating in a professional capacity. Informed consent was obtained from all participants, and anonymity and confidentiality were ensured throughout the study. No personal or identifiable information was collected or stored.

8 AI declaration

No generative AI tools were used to produce, analyze, or revise the content of this paper. All data analysis, literature review, and writing processes were conducted by the authors using conventional academic methods.

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Models and Tools to Support Innovation Processes in Cultural Tourism Ecosystems: Evidences and Implications for Basilicata

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Abstract

This study explores the role of models and tools in supporting innovation processes and digital transformation within cultural tourism ecosystems. It emphasizes the need for a shift for cultural tourism organizations towards digital innovation and innovation processes and highlights the importance of collaborative networks that actively engage stakeholders in the co-creation of smart tourism solutions. The research identifies participatory methodologies, particularly participatory events, as strategic levers to foster innovation and digital awareness in the sector.

A qualitative research design was adopted, combining desk-based analysis of existing literature with a multiple case study methodology. A series of thematic focus groups held in the Basilicata region provided empirical insights into how participatory formats can support digital transformation and innovation in cultural tourism.

The findings reveal key challenges and opportunities for fostering digital transformation and innovation in cultural tourism. The study outlines emerging models, tools, and participatory formats that enhance stakeholder engagement and co-design processes, while also identifying structural barriers and enablers critical to success.

The paper contributes to the literature by systematizing participatory practices as catalysts for digital transformation and innovation in cultural tourism. It offers practical guidelines and raises new questions for future research on innovation dynamics in rural tourism ecosystems.

Keywords: Digital transformation, cultural tourism, innovation, participatory events, co-creation lab

Paper type: Academic Research Paper

1 Introduction

Cultural tourism has gained increasing attention in recent decades from both scholars and practitioners, reflecting its growing significance within the broader tourism landscape. The convergence of tourism and culture offers not only economic opportunities but also rich, multifaceted experiences rooted in heritage, arts, lifestyle, and contemporary creativity (Lerro et al., 2023). The complexity of this convergence has made cultural tourism difficult to define, with various interpretations emerging (Michalkó and Rátz, 2011). However, as cultural tourism continues to evolve, a more nuanced understanding of its dynamics is required that encompasses not only what is consumed but also how it is experienced, interpreted, and co-created. In this context, innovation and digital transformation are no longer optional but essential. They are strategic levers for achieving smarter, more sustainable, and inclusive forms of tourism, enhancing the sector's competitiveness and resilience (Gretzel & Koo, 2021; Buhalis & Amaranggana, 2015). Nevertheless, the adoption of innovation and digital transformation in cultural tourism is often fragmented and uneven (Cavalheiro et al., 2019). Structural barriers, including resistance to change, and concerns over standardization, hinder progress. The sector's reliance on human-centered, differentiated experiences further complicates the integration of digital tools. To overcome these obstacles, organizations and destinations must adopt models and frameworks that support effective innovation management, digital literacy, leadership development, and stakeholder engagement (Elia et al., 2022; 2024). However, the success of digital transformation depends on the alignment of these strategies with the specific characteristics of local territories. This includes fostering a participatory culture in which tourists, citizens, and entrepreneurs are not merely passive recipients but active co-creators of value. In this scenario, co-creation, participatory design, and shared innovation processes are emerging as powerful approaches for reimagining destination development and governance (Tussyadiah and Zach, 2013; Mehraliyev et al., 2020). However, there is still limited evidence on how such approaches can be translated into operational models, practices, and tools. This study seeks to fill this gap by examining the design and the development co-participatory events, such as focus groups and co-creation labs, as tools to foster digital innovation in cultural tourism ecosystems with particular attention to experiences held within the Basilicata region, in Italy.

2 Theoretical background

2.1. Trends, challenges and opportunities for innovation and digital transformation in cultural tourism

In recent decades, cultural tourism has attracted growing interest from both academics and practitioners. **However, there is no single, universally accepted definition of cultural tourism; instead, various researchers have proposed their own interpretations to capture its multifaceted nature (**UN Tourism General Assembly, 2017; **Michalkó and Rátz, 2011;** European Travel Commission's 2024; Stebbins, 1996; Richards, 2003). For sake of simplicity, a useful definition of cultural tourism is provided by Richards and Pereiro (2006, p.1) in terms of "*the movement of persons to cultural attractions away from their normal place of residence, with the intention to gather new information and experiences to satisfy their cultural needs*" and as "*all movements of persons to specific cultural attractions, such as heritage sides, artistic and cultural manifestations, arts and drama outside their normal place of residence".* As the cultural tourism industry continues to grow and evolve, understanding its peculiarities demands a multidimensional approach that encompasses not only what is consumed but also how it is experienced and interpreted. Consequently**, innovation and digital transformation are pivotal to achieve smart, sustainable, authentic and inclusive tourism development (Calza et al., 2022; Jiang et al., 2019**; Guimont and Lapointe, 2016**). On the other hand, by incorporating technologies into their operations, tourism stakeholders can create unique, personalized experiences that enhance customer loyalty and drive sustainable growth.**

Despite their importance, their integration is far from linear and often presents significant challenges and risks (Psomadaki et al., 2019).

To address these gaps, on one side, it is important to seed digital and leadership skills and the adoption of new models, and tools to effectively lead the processes of digital transformation and business model innovation (Elia et al., 2024; 2022). On the other side, the creation of awareness and orientation towards a digital innovation culture and a business and entrepreneurial education recently emerges as a significant element to be considered as well as the role and the relevance that new forms of involvement of the stakeholders may play in activating and supporting these dynamics.

This requires not only meeting the needs of citizens, stakeholders, and tourists but actively involving them in the innovation process, positioning them as crucial playersAccordingly, the role of the participatory design and related participatory events has gained great relevance in the scientific and policy debate (Tussyadiah and Zach 2013).

2.2. The Participatory Events (PEs): aims, typologies, characteristics, actors

Participatory Events (PEs) are conceptually part of the wider theoretical research stream of the Participatory Design (PD), sometimes called also collaborative design and co-design. They are object of interest both by the managerial and the social sciences and aim to build a paradigm in which, in order to make a program/project/initiative as comprehensive as possible, all those who have an interest in it are involved in its elaboration and development (Sadd-Sulonen et al., 2018).

Along the time, scholarship has analysed different aspects of the PEs: purposes (Bossen et al., 2010), principles, rationale and values (Dalsgaard, 2012), characterizing elements (Di Salvo et al., 2012; NICE, 2008; Nicoli and Zani, 1998; Nicoli et al., 2010), actors involved (Bobbio, 2004; Dahl and Sharma, 2022), main areas of application (Dahl and Sharma, 2022): in particular, regarding these latter, the healthcare and the environmental issues, the security, and the urban planning sector (with a focus on the urban regeneration phenomena) have been identified as significant and consolidated areas of application.

More recently, it is possible to observe an increasing attention and application of the PD and, consequently, of PEs, in tourism, and specifically in the cultural tourism sector. This emergent trend finds significant roots in the industrial features of the cultural industries and of the cultural tourism as well as in the personal and social traits of the cultural tourist (Chiabai et al., 2013; Bole et al., 2017; Ashworth and Dietvorst, 1995). In fact, the wide range of assets and resources comprised in the notion of cultural tourism - ranging from archaeological sites and museums up to valuable architectural elements (ruins, buildings, cities), to various artistic elements (painting, sculpture, crafts, galleries, festivals, events), theatrical, film and drama events, and even language and literature studies, religious holidays, pilgrimages and folk culture) – determine a significative number of actors and stakeholders involved in preserving and managing them and, consequently, an increasing need to identify and develop new and effective "spaces" and "times" in order to balance their different, and often struggling, objectives, wants and orientations (Richards, 2018). The full understanding of the relationship that is established between the methods and the tools characterizing the PD and the development of PEs related to cultural tourism obviously requires, first, the identification and the analysis of the main PD-related methods, tools and

techniques. Secondly, it is important to evaluate their applicability, in order to figure out the empirical advantages for the specific sector under investigation, also and above all in accordance with the underlying digital transformation and innovation processes increasingly characterizing their elaboration and implementation. In the following paragraphs and sub-paragraphs, an analysis of the focus group method whose use is desirable from a digital innovation culture and innovation processes perspective will be carried out, trying to understand which tools are most consistent with the previously analyzed purposes of PD.

2.3 The focus groups

Focus groups represent a mature methodology, and have historically been used in managerial and marketing sciences for market research over the last few decades (Nyumba et al., 2018). As its name suggests, informally expressed with the meaning of "discussion group", its primary objective is to implement a "focus" on a specific topic, in order to implement the decision-making process, on the basis of the most precise possible understanding of a collective trend. The focus is implemented starting from the creation of small groups, typically made up of a number of participants ranging from six to twelve and previously selected using specific sampling techniques aimed at representing a specific market or interest-related segment. Considered as one of the most dynamic and flexible research methods (Kumer and Urbanc, 2019), it can be theorized in relation to PD, with respect to which it has the undoubted merit of implementing an active involvement of the participants. The usability of the focus groups on tourism and digitalization issues has been widely experienced (Maisarah et al., 2023; Strielkowski et al., 2012). The focus group methodology follows a structured process composed of several phases, each playing a crucial role in achieving the research objectives (Dickinger and Kolomoyets, 2024). The focus group thus provides a valuable foundation for decision-making by offering a deeper understanding of participants' views and perspectives (Li et al., 2020). In the following paragraph it explained how this methodology was extensively implemented within a multiple case study focused on cultural tourism organizations across the rural territories of Basilicata.

3 Methodology

From a methodological point of view, a multiple case study approach (Yin, 2009; 2013) has been rigorously elaborated and developed to provide empirical insights supporting the evidences emerging from the above proposed notions.

A series of thematic focus groups were systematically organized and analysed across various sample areas within the Basilicata region, aimed at collecting data through open discussions, interviews and participatory observations where participants were freely to express their views while ensuring thematic coherence across all sessions. This initiative aligns with broader objectives of facilitating organizational adaptation to digital technologies, enhancing knowledge exchange, and catalyzing systemic transformation within the cultural tourism sector. All the data collected were codified and transcribed, resulting in a reliable information base that perfectly reflected the interviewees' thoughts. Concerning the data analysis, an open coding process was applied to the transcripts to identify recurring concepts, phrases, and patterns across the four areas. Codes were grouped into broader themes through iterative comparison, allowing for both within-case and cross-case analysis. Thematic categories emerged inductively from the data, reflecting stakeholders' views. In the following, the findings derived from the workshops are presented and discussed.

4 Findings

The analysis focused on four sample areas, all located in rural parts of the Basilicata region: Vulture Melfese, Val d'Agri, Collina Materana, and the area of Tito and Satriano. Each focus group was meticulously structured around a participatory and co-design methodology, informed by participatory events and focus group practices discussed above. This methodology ensured an inclusive, hands-on approach, facilitating the active participation of stakeholders and ensuring that the focus groups were both contextually relevant and practical. The first step was to set common specific goals for the focus groups, specifically aimed at: *i)* exploring challenges and opportunities that digital transformation offers within the cultural tourism sector in the sample areas analysed; *ii)* activating engagement of cultural tourism organisations, involving local stakeholders in structured dialogues and collaborative exchanges, allowing for the sharing of best practices and fostering a culture of continuous improvement; *iii)* implementing practical tools and strategic models, to introduce actionable tools and frameworks that could guide organizations through the complexities of digital strategy development; *iv)* facilitating networking and synergies among local actors, including public and private stakeholders, and external experts; *v)* stimulating innovation through the presentation of impactful case studies, use cases, and digital

solutions that exemplify successful strategies and applications of digital technologies within cultural tourism contexts. Then, the preparation of activities and questions and the selection of moderators was essential. The facilitator team included five experts with specialized academic knowledge about digital innovation and cultural tourism, and each session also involved four professionals with practical experience in areas such as digital innovation, sustainability, and cultural tourism to enrich the discussion. Concerning the selection of participants, the focus groups included session with 15 heterogeneous participants and a knowledgeable group of stakeholders, from four different Basilicata rural areas. This approach not only ensured the relevance of the discussion but also facilitated the collection of valuable insights, particularly regarding the intersection of cultural heritage and digital innovation in tourism. The sampling process was aimed at ensuring a balanced and representative sample that accurately reflected the diverse stakeholders within the cultural tourism ecosystem. In this phase, participants were carefully analysed and chosen. Specifically, the selection process involved organizations from key areas of the cultural tourism landscape, including hospitality, tourism promotion, heritage preservation, local cultural organizations, youth advocacy, gastronomy, the performing arts, and inbound tourism services. This diverse representation was essential for capturing a wide range of perspectives and experiences related to the integration of digital innovation in the sector. The participants' recruitment began with formal invitations sent via email, where the focus group's objectives, expected contributions, and the significance of each participant's input were clearly outlined. This ensured that all invitees were well-informed about the purpose and scope of the discussion. Follow-up communications were then tailored to the individual needs of each participant, often involving personalized phone calls or additional emails that provided more detailed context, preparatory materials, and a clearer understanding of the topics to be discussed. The conduction of the discussion was organized into five distinct phases, each serving a unique function in promoting engagement, reflection, and collaboration. In the following table the phases implemented in the focus groups are summarized.

Table 1. Focus group's design

Welcome and Introduction	The workshop began by setting the stage, articulating the session's goals, and framing the broader contextual challenges and opportunities related to digital transformation in the cultural tourism sector. This introduction provided participants with a comprehensive overview of the workshop's scope and objectives.
Inspiration Space	This segment featured expert contributions from thought leaders, practitioners, and entrepreneurs, who shared best practices, innovative digital solutions, and real-world applications of digital technologies in cultural tourism. These presentations offered tangible examples of how digital tools could be leveraged to enhance visitor experiences, improve organizational efficiency, and promote sustainability within the sector.
Debate Space	The debate phase facilitated an interactive Q&A session, where speakers and participants engaged in open dialogue about the challenges and opportunities presented by digital transformation. This session was designed to foster critical reflection, enabling participants to exchange ideas and perspectives on the implementation of digital strategies in their own contexts.
Networking Space	An informal segment dedicated to fostering connections and dialogue among workshop participants. This space encouraged attendees to engage in peer-to-peer exchanges, share insights, and explore potential collaborations that could extend beyond the workshop setting.
Co-creation session	The final segment of each workshop provided participants with the opportunity to engage in facilitated co-creation activities. These activities were designed to address localized challenges, allowing participants to work together to develop actionable digital strategies and solutions tailored to their specific needs and objectives. This participatory approach ensured that the strategies developed were contextually grounded and relevant to the local realities of each organization. Specifically, the workshop incorporated a substantial co-creation phase, aimed at engaging participants in hands-on, problem-solving activities designed to address specific challenges within the cultural tourism sector. The facilitator team, including experts with specialized experience in digital innovation and cultural tourism, introduced the methodology for the session. Participants were presented with a set of nine plastic plates, each containing challenges written on cards of various colors. These challenges, specifically related to different aspects of the cultural tourism sector, were categorized into thematic areas such as: Engagement & Empowerment, Accessibility, Ecosystem, Booking & Flow Management, Sustainability, Data, Smart Tourism Information, Integration with the Local Economy, and Mobility. Each category was visually represented on a large display with a guided explanation of its relevance to the broader tourism ecosystem. Participants selected a card corresponding to one of the identified challenges, and based on the chosen issue, they were prompted to draw inspiration from a series of keywords projected on a

	slide. This served to stimulate creative thinking and support the development of innovative solutions to the challenges identified. The co-creation space aimed to foster collaborative problem-solving and generate actionable ideas, contributing to the overall goal of enhancing the digital transformation of the cultural tourism sector. Following the co-creation session, participants shared their developed solutions in a brief presentation format. This discussion phase was structured to provide an opportunity for the exchange of ideas and collective reflection on the problem-solving process. Participants were guided through a structured tool designed to facilitate the implementation of their solutions, focusing on identifying the necessary resources for execution. This included financial, human, infrastructural, and intangible assets, as well as a focus on communication strategies to improve visibility and outreach. This part of the workshop was crucial for ensuring that the co-created solutions were not only innovative but also feasible and practical in the context of the local tourism ecosystem. Through this structured approach, the workshop sought to promote both the generation of ideas and their practical application within the cultural tourism sector, encouraging participants to consider the holistic requirements for successful implementation and scalability.

The last phases concerned the analysis of results, to examine the data gathered during the discussion, identifying recurring patterns or trends, and extracting meaningful insights. Specifically, some key insights emerging from the sessions included: *i)* Heterogeneous level of digital maturity: a significant variance in the digital maturity levels across organizations was observed. While certain entities demonstrated a relatively high degree of familiarity with digital tools and strategies, many others exhibited a fragmented, reactive approach to digitalization. This disparity was often exacerbated by limitations in technical skills, inadequate human resources, and the absence of a coherent strategic vision for digital transformation. The findings highlight the need for tailored digital interventions that account for the diverse starting points of organisations; *ii)* Strong demand for capacity-building and peer learning: participants consistently expressed a desire for further capacity-building opportunities, particularly in areas such as digital marketing, data-driven decision-making, immersive technologies, and online visibility. This finding highlights the need for ongoing education and professional development programs to equip organizations with the requisite skills to harness the full potential of digital tools; *iii)* Structural barriers to innovation: across the focus groups, common structural barriers to innovation emerged. These included issues such as inadequate infrastructure (especially in rural areas with limited connectivity), bureaucratic constraints, and a lack of coordinated governance. These barriers highlighted the need for targeted policy interventions that address both infrastructural gaps and the need for more effective governance frameworks that facilitate digital transformation within the cultural tourism sector; *iv)* Value of storytelling and local identity: a recurring theme across the focus groups was the importance of leveraging storytelling and digital narratives to enhance the visibility of lesser-known destinations. Many cultural tourism stakeholders emphasized the potential of digital tools to showcase intangible heritage and local identity. The findings suggest also that digital storytelling could play a pivotal role in increasing the attractiveness and competitiveness of cultural tourism offerings, especially in regions with rich, yet underexploited, cultural assets; *v)* Emerging leadership roles: in several cases, innovation within the participating organizations was driven by individuals or small teams with high motivation, vision, and a proactive approach to digitalization. These individuals often acted as change agents, catalyzing innovation within their communities or organizations. This result highlights the critical importance of empowering local leaders to drive digital transformation, as they possess the necessary motivation and contextual understanding to implement effective change.

5 Conclusions and implications

This study examined how participatory events can support the digital transformation and innovation of cultural tourism organisations, with a specific focus on the Basilicata region. Through a combination of insights derived by desk research and empirical on-field research conducted through the organization and the development of structured focus groups, the research sheds light on the enabling conditions for fostering a digital innovation culture in cultural tourism. The findings address the importance of the stakeholder involvement in the co-design processes, particularly in contexts marked by fragmented innovation capabilities and limited digital maturity. Participatory events have proven to be valuable mechanisms not only for engaging local actors but also for generating context-specific, actionable solutions. These insights reinforce the value of co-creation methodologies in facilitating innovation and digital transformation processes in cultural tourism development. From a **managerial perspective**, the study provides practical guidance for cultural tourism organizations and policymakers. Specifically, this paper systematizes participatory practices as catalysts for

digital transformation and innovation in cultural tourism, with a focus on rural areas. It enhance the importance of structuring and codifying the steps and organization of focus groups, such as the selection of participants, thematic framing, and facilitation techniques, while maintaining a degree of flexibility that allows these practices to be adapted to the specific characteristics of local communities. This balance between structure and adaptability is essential for ensuring that participatory methods are both methodologically sound and locally meaningful, enabling more effective and inclusive digital innovation processes. From a **theoretical viewpoint**, the study contributes to the ongoing debate on innovation digital transformation in tourism by linking participatory design practices with innovation management in the cultural tourism sector. It also broadens the understanding of how innovation processes unfold in rural and peripheral tourism contexts. Despite its contributions, the study is not without limitations. First, the empirical analysis is geographically limited to the Basilicata region, which may affect the generalizability of the findings. Future research should consider comparative case studies across multiple regions or countries to validate the applicability of the proposed models and tools in different cultural and institutional settings. Second, while the focus groups offered rich qualitative insights, the absence of quantitative measures limits the ability to assess the long-term impact of participatory interventions on organizational performance or innovation outcomes. Future studies could integrate mixed-method approaches to capture both the qualitative dynamics and measurable effects of digital transformation strategies.

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7 Ethics declaration

This research did not require formal ethical clearance, as it involved non-sensitive data collection through voluntary surveys and interviews with adult participants operating in a professional capacity. Informed consent was obtained from all participants, and anonymity and confidentiality were ensured throughout the study. No personal or identifiable information was collected or stored.

8 AI declaration

No generative AI tools were used to produce, analyze, or revise the content of this paper. All data analysis, literature review, and writing processes were conducted by the authors using conventional academic methods.

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Digital Transformation in Rural Cultural Tourism: Insights from a SWOT Analysis in Basilicata

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Abstract

This study investigates the dynamics of digital transformation in rural cultural tourism. It explores how rural territories can engage with digital innovation through context-specific strategies that enhance cultural heritage, territorial identity, and stakeholder collaboration.

The research adopts a qualitative methodology based on a SWOT analysis, drawing from semi structured interviews, participatory workshops, field observations, and desk research. This approach allows for a critical assessment of internal and external factors influencing digital transformation processes in rural tourism areas.

The analysis highlights a series of structural challenges, including limited digital infrastructure and skills gaps, but also identifies unique opportunities tied to community cohesion, authentic local narratives, and the potential for slow, sustainable tourism models. The findings emphasize the importance of bottom-up approaches and multi-actor engagement in shaping digital strategies that are both place-sensitive and innovation-oriented.

The paper contributes both to literature and to managerial and policy practices by offering a grounded perspective on rural digital transformation, moving beyond generalized frameworks to focus on localized innovation pathways. It positions cultural heritage not as a constraint but as a resource for co-creating digital solutions tailored to rural tourism contexts.

Keywords: rural cultural tourism, digital transformation, cultural heritage, SWOT analysis, innovation, participatory events

Paper type: Academic research paper

1 Introduction

Over the past decade, the integration of digital technologies in tourism has become a central concern for scholars and practitioners. Within this transformative landscape, rural cultural tourism presents unique challenges and opportunities. On one hand, it is rooted in rich local identities and heritage; on the other, it often lacks the digital infrastructure, competencies, and strategic coordination required for smart and sustainable innovation (Zhao et al., 2023). While urban destinations may benefit from economies of scale and robust digital ecosystems, rural areas face greater difficulty in attracting investment, developing digital skills, and coordinating fragmented tourism (Pasa, 2025). Digital transformation in tourism is receiving growing attention from both scholars and practitioners, however, existing literature tends to focus predominantly on technologically advanced destinations, where digital ecosystems are more mature and infrastructure is well-established. There is a relative scarcity of research that examines rural cultural tourism, particularly from the perspective of practitioners and professionals operating within these territories (Sainaghi, 2017).

In this vein, this paper seeks to fill this gap by adopting a SWOT analysis approach to explore the internal and external factors influencing the digital transformation of rural cultural tourism in Basilicata. This research draws upon qualitative insights from professionals and practitioners operating in the field. The goal of this article is not only to map existing strengths, weaknesses, opportunities, and threats, but also to understand the cultural, organizational, and governance dimensions shaping the digital evolution of this sector. Specifically, the study aims to identify the main drivers and barriers influencing the adoption of digital tools and innovation practices as well as to offer strategic, contextual recommendations to lead future digital innovation in rural cultural areas. This paper contributes to the ongoing discourse on digital innovation in cultural tourism providing a grounded, experience-based perspective from a rural area. Accordingly, it presents strategic insights for regional authorities, destination managers, and cultural tourism operators aiming to foster digital transformation in a socially inclusive and territorially embedded way.

2 Theoretical background

In recent decades, cultural tourism has attracted growing interest from both academics and practitioners. Generally, cultural tourism is considered as “the movement of persons to cultural attractions away from their

normal place of residence, with the intention to gather new information and experiences to satisfy their cultural needs" which encompasses all movements to heritage sites, artistic events, and cultural manifestations (Richards and Pereiro, 2006, p.1).

As the cultural tourism industry continues to grow and evolve, understanding its peculiarities demands a multidimensional approach that encompasses not only what is consumed but also how it is experienced and interpreted. In this context, innovation and digital transformation are pivotal to achieving a smart, sustainable, authentic, and inclusive model of tourism development. These processes are not only strategic levers for competitiveness but also essential for ensuring relevance in a rapidly changing and digitally mediated global tourism landscape (Bekele and Raj, 2025).

The concept of digital transformation in cultural tourism refers to the comprehensive integration of digital technologies into all areas of the tourism experience, including marketing, service delivery, customer interaction, and back-end operations. In the context of cultural tourism, digital transformation is not merely about adopting new tools, but about rethinking how cultural value is created, communicated, and consumed (Gretzel et al., 2015).

Specifically, digital transformation may allow tourism to offer personalized, immersive, and interactive experiences that foster visitor engagement and loyalty. From digital storytelling to augmented reality applications, technology can significantly enhance cultural value propositions, particularly in terms of heritage-driven storytelling, community engagement, and authenticity of experience (Trunfio et al., 2022).

However, the integration of digital tools in the cultural tourism sector is often non-linear and faces many challenges. These challenges are due to several structural and cultural characteristics: a high reliance on human labor, the uniqueness of local experiential offerings, and a deeply embedded emphasis on authenticity. There is also a widespread resistance to digital transformation, driven by concerns that standardization and technological mediation may weaken the uniqueness and emotional richness of cultural experiences (Psomadaki et al., 2019). These challenges are even more evident in rural areas, where there are specific obstacles such as infrastructural deficits, skills gaps, fragmented governance, and resistance to change (Salemink et al., 2017; Cavalheiro et al., 2019).

According to Elia et al. (2022; 2024), successful digital transformation requires the adoption of appropriate organisational models, business tools, and leadership competencies to guide change effectively. Moreover, the promotion of digital culture through training, entrepreneurship education, and stakeholder engagement is also crucial.

This calls for an integrated approach that aligns technological innovation with territorial identity and local socio-economic dynamics. Instead of imposing external models, digital transformation should be co-designed with local stakeholders, tailored to the cultural and institutional context of each destination (Gill and Larson, 2014).

In this vein, a growing body of literature emphasizes the importance of stakeholder involvement and participatory governance in driving digital transformation in cultural tourism (Borseková et al., 2019). The use of co-design, living labs, and participatory foresight exercises has been identified as a way to foster innovation ecosystems that are inclusive and place-based (Dredge & Jenkins, 2011; Baggio et al., 2010). In this regard, SWOT analysis can be a useful strategic planning tool, implemented during the participatory practices, to capture diverse stakeholder perceptions and to identify areas for coordinated action and for mapping complex change environments. A SWOT Analysis is a useful and simple tool that can give a snapshot of key digital transformation issues perceived in the areas investigated target, i.e. enterprises and institutions operating in cultural tourism based on cultural heritage. Through the SWOT analysis it is possible to map and evaluate the internal factors (Strengths and Weaknesses) and external factors (Opportunities and Threats) that can impact the decision of embarking in a digital transformation journey as well as the digital transformation implementation per se. It is especially useful when embedded within participatory processes, where it can serve not only as an analytical tool but also as a means of activating reflection and shared sense-making (Wasike, 2010).

3 Methodology

This study adopts a qualitative, participatory approach to investigate the enablers and barriers of digital transformation in the context of rural cultural tourism. The methodological framework applied is a SWOT analysis, designed and implemented as part of a broader analysis involving cultural tourism organizations and professionals operating in the Basilicata region, Southern Italy (Wasike, 2010).

The rationale for choosing the SWOT framework lies in its capacity to offer a structured yet flexible tool for identifying and organizing key issues affecting digital transformation patterns in cultural tourism. Unlike traditional diagnostic models that rely heavily on quantitative performance indicators, the SWOT approach

allows for a subjective, experience-based mapping of internal and external factors that shape digital innovation within small and rural cultural tourism organizations.

The SWOT analysis was integrated into a series of participatory events facilitated by researchers and moderators with expertise in cultural heritage, digital strategy, and organizational development. During these sessions, participants – such as local tourism operators, cultural heritage managers, and freelance professionals – working individually and as groups, were engaged in interviews, guided reflections and team-building exercises aimed at stimulating critical thinking about their current practices, challenges, and aspirations related to digitalization (Namugenyi et al. 2019). The group composition was intentionally heterogeneous in order to capture a broad spectrum of insights and to encourage peer learning. The sessions were designed around four thematic blocks corresponding to the SWOT quadrants: Strengths, Weaknesses, Opportunities, and Threats. For each quadrant, participants responded to a predefined set of key-questions related to digital assets, strategic orientation, infrastructure, skills, communication practices, and stakeholder relationships (Eastwood et al., 2016). Specifically, the set of specific objectives and key-questions related to each block are defined and reported in the following tables.

Table 1. SWOT Analysis framework for Digital Transformation in Rural Tourism

STRENGHTS (S)	**WEAKNESSES (W)**
Strengths identify issues where the organizations/institutions think to excel and can further grow to drive digital transformation. Strengths can come in many forms. Examples provided for the discussion were: • Digital assets and capabilities: This issue refers to the organization's existing digital infrastructure, such as its website, social media presence, and e-commerce platforms. It also includes the organization's capabilities to adopt and implement new digital technologies. • Talent pool: This issue includes the organization's employees, skills and experience, and ability to adapt to change. A capable and tech-savvy workforce can be a significant strength in driving digital transformation. • Brand reputation: This issue refers to the organization's reputation and credibility. A strong brand reputation can help build trust and credibility with customers and stakeholders during digital transformation. • Financial stability: This issue includes the organization's financial strength and stability. A solid financial foundation can provide the essential resources to invest in digital transformation initiatives. • Partnerships or collaborations: This issue refers to partnerships or collaborations that would Facilitate digital transformation.	The organizations evaluate the features that could be hindering their digital transformation journey. Mapping weaknesses allows to identify the issues where the organizations need to improve and take steps to address these weaknesses. Examples provided for the discussion were: • Legacy systems: This issue includes outdated technology or processes that are no longer powerful in the digital landscape. These legacy systems can gradual down digital transformation initiatives. • Lack of skills or expertise: This issue refers to the organization's lack of skills or expertise in digital marketing, data analytics, or user experience design, etc. Without the needed skills, the organization may struggle to execute its digital transformation strategy effectively. • Resistance to change: This issue includes the organization's culture or mindset, which may be hesitant or resistant to change to adopt new technologies or processes. This resistance can slow down digital transformation initiatives and make it difficult to achieve buy-in from employees and stakeholders. • Limited resources: This issue refers to the organization's limited financial or human resources, which may make it difficult to invest in digital transformation initiatives or hire the necessary expertise to implement them.
OPPORTUNITIES (O)	**THREATS (T)**
Identifying opportunities is about assessing external factors that might help digital transformation. The goal is identifying the issues where organizations can leverage external factors to its advantage and achieve digital transformation objectives. . Examples provided for the discussion were: • Customer/customers behavior: Due to numerous technological advancements, customers' behavior keeps changing. By understanding and adapting to changes in customer/user behavior, the organisation can better meet the needs of its customers/uses and drive virtual transformation. • Partnership opportunities consist of partnering with other organisations to leverage their expertise, resources, or technology. The business enterprise can boost up its digital transformation initiatives by means of forming strategic partnerships.	The goal is to identify the issues where the organizations could face challenges or obstacles in achieving digital transformation goals. Examples provided for the discussion were: • Cybersecurity threats: This area refers to the threat of cyberattacks or data breaches, which could compromise the organization's data, systems, or reputation. Organizations need strong cybersecurity measures to mitigate these threats and protect their digital assets. • Changes in technology: This includes changes in technology that could make the organization's existing technology or processes out of date. The organization needs to stay informed about emergent technologies and adapt to these changes to stay relevant in the digital landscape. • Economic and political factors: This consists of economic and political factors such as recessions, changes in government regulations, or trade policies, which could impact the organization's digital transformation initiatives.

The qualitative data collected from these sessions, through semi structured interviews and guided reflection, were organized into a cognitive map, highlighting patterns and linkages between enabling and hampering factors.

Concerning the data analysis, the process started by adopting a mixed approach, deductive and inductive, through a thematic analysis. Braun and Clarke (2006) defined thematic analysis as a method for identifying, analyzing and reporting patterns, within data that organizes and describes data sets in detail.

The coding process supported the identification of unforeseen areas (Karlsson, 2016; Charmaz et al., 2006). Specifically, first, all data obtained from participatory events, stakeholder interviews, and project documentation were first transcribed and organized. Then, a two-step coding process was applied. In the first phase, open coding was used to identify initial concepts and recurring expressions related to digital transformation, innovation challenges, stakeholder engagement, and cultural value. In the second phase, coding was employed to group similar codes and explore relationships between them, allowing for the construction of broader thematic categories. After that, the derived codes have been revised to identify patterns and develop initial themes within which codes have been clustered. Following the coding, a thematic analysis was conducted to systematically interpret and synthesize the data into core themes. This involved identifying patterns that reflected participants' perceptions of strengths, weaknesses, opportunities, and threats (SWOT) regarding digital transformation in the cultural tourism sector in their organizations and territory. This process-oriented approach to SWOT was not only diagnostic but also generative: it served as a shared cognitive exercise through which participants could identify priorities, prioritize unspoken challenges, and begin to envision strategic directions collaboratively. The findings from this analysis are presented in the following paragraphs.

4 Insights

The research questions driving this empirical investigation focus on identifying and analyzing the internal strengths and weaknesses, as well as the external opportunities and threats, that influence the digital transformation of rural cultural tourism in Basilicata. The main insights that emerging from the empirical analysis are presented in the following table and then discussed in the next paragraph.

Table 2. Main insights deriving from the SWOT Analysis framework for Digital Transformation in Rural Tourism in Basilicata

S	The cultural tourism sector in Basilicata exhibits several important strengths that can support digital transformation. First of all, there is the strong sense of belonging and deep cultural identity that pervades the region. This provides fertile ground for heritage-based storytelling and immersive digital content. Some operators have already experimented digital tools to narrate local history, traditions, and folklore, thus creating emotionally engaging visitor experiences. Moreover, a growing network of motivated professionals, though still fragmented, demonstrates interest in innovation and experimentation. These actors, often driven by personal commitment and community values, can serve as catalysts for broader digital adoption, provided they are supported by targeted training and institutional recognition.
W	Several critical weaknesses emerged from the analysis. Most organizations lack a coherent digital strategy and struggle to align technology use with long-term objectives. Brand management and communication are often inconsistent, with low visibility on social media and limited ability to control the destination's digital image. Relationship management is similarly weak, with few structured efforts to build partnerships or leverage digital tools for network creation. On the organizational side, there is a general lack of planning, and digital goals are often vague or poorly communicated. Cultural resistance to change is common, particularly in associations involving several volunteers. There is a widespread lack of digital mindset, compounded by insufficient training opportunities and limited awareness of digital tools' potential. Concerning a more technical perspective, digital infrastructure is outdated or lacking altogether, and there is minimal capacity for data collection and use, at the same time, human resources are often under-qualified for digital roles, and financial limitations restrict investment in digital innovation.
O	It emerges that various opportunities can be leveraged in rural areas such as Basilicata to accelerate digital transformation. Digital technologies offer new ways to enhance the tourist experience through storytelling, augmented reality, and interactive platforms. These tools can make cultural content more accessible and emotionally resonant. Bottom-up innovation processes, such as co-creation and participatory planning, can also be activated through digital means, fostering stronger community engagement and ownership. External resources, such as online training and funding opportunities, are increasingly available and can support capacity-building. Collaboration with digital professionals can help bridge internal skills gaps, and outsourcing specific tasks can improve efficiency. Finally, open data and digital tools can facilitate more informed decision-making and innovation in tourism offerings, such as themed itineraries and integrated visitor services.
T	Through the empirical research, a number of external threats emerge as hindering digital transformation and innovation processes. The first one is the lack of territorial coordination, with fragmented governance structures impeding the development of shared digital strategies. Moreover, training programs for digital skills are limited, poorly promoted, or inaccessible to small-scale operators. There are also cultural risks associated with digitalization, including concerns about losing the authenticity of the experience and reducing social interactions. Additionally, many tourists, especially older or less experienced individuals, may struggle to interact with digital content, reducing its impact and accessibility. In conclusion, persistent infrastructural deficits, such as slow internet connections and lack of access to modern hardware, further exacerbate the challenge. These barriers highlight the need for targeted investments and inclusive digital policies.

5 Discussion

The SWOT analysis reveals a complex picture in which cultural strengths and innovation potential coexist with structural fragilities and systemic gaps. The findings confirm previous research on the challenges of digital transformation in rural areas (Gretzel & Koo, 2021), but also introduce a more nuanced understanding of the role of professionals and community-based values.

On the one hand, the region's strong sense of belonging and distinctive cultural identity constitutes powerful endogenous strengths. These intangible assets create fertile ground for innovative digital storytelling and immersive experiences that can emotionally engage visitors and differentiate Basilicata from more mainstream destinations. In line with Trunfio et al. (2022), leveraging heritage-driven narratives via augmented reality or interactive platforms can, in turn, leverage regional identity to create immersive experiences.

However, these strengths coexist with significant weaknesses in strategic planning, digital skills, and infrastructure. This recalls the findings of Cavalheiro et al. (2019), who note that fragmented governance and skill gaps are key barriers in rural tourism digitalization. Without clear digital objectives, consistent brand management, and sufficient training opportunities, local organizations cannot capitalize on their narrative potential.

The lack of a coherent digital strategy and the prevalence of outdated systems obstacles the region's ability to translate cultural capital into sustainable digital services. Moreover, the lack of strategic alignment between digital tools and organizational vision emphasizes the need for training programs that go beyond technical skills to include strategic thinking and change management.

The opportunities identified - such as bottom-up co-creation processes, open data, and external funding schemes -point toward actionable pathways for overcoming internal weaknesses. For example, participatory events can simultaneously build digital competencies and foster a shared vision, mitigating resistance to change (Tussyadiah & Zach, 2013). Similarly. collaboration with digital professionals and universities can deliver targeted up-skilling and support the development of thematic digital itineraries, aligning with Élă et al.'s (2024) emphasis on capacity building.

Finally, the analysis also uncovers the threats emerged, for example infrastructural shortfalls, limited access to training for small-scale operators, and risks to experiential authenticity. In this context, policy interventions are therefore required to upgrade rural broadband and to subsidize hardware investments, ensuring that digital initiatives do not deepen existing disparities

6 Conclusions and Implications

This study has provided an in-depth analysis of the factors shaping digital transformation in rural cultural tourism, using the Basilicata region as a case study. Through a SWOT analysis, internal capabilities and external conditions that affect the adoption of digital tools and strategies have been identified and discussed.

This study offers both theoretical insights and practical takeaways for understanding digital transformation in rural cultural tourism, particularly in rural areas.

Theoretically, the study expands the understanding of digital transformation by framing it as a place-based process that, in rural contexts, is shaped by the interplay between cultural heritage, community engagement, and territorial identity. It suggests that rural areas are not passive recipients of innovation but active agents capable of developing digital pathways that reflect their specific socio-cultural configurations. This perspective invites a rethinking of digitalization as a process that can originate from local values and assets rather than being externally imposed. Moreover, the SWOT analysis used proves useful not only as a strategic tool but also as a conceptual framework to interpret local capacities and constraints in a structured way. It encourages a broader academic reflection on how cultural tourism, often perceived as resistant to change, can become a space of experimentation and adaptation when approached through a digital lens. Practically, the findings highlight the importance of designing digital transformation strategies that are aligned with the specific characteristics and needs of rural territories. Policymakers and practitioners should prioritize approaches that leverage local heritage, foster community participation, and support the development of digital skills within local networks. In sum, the findings enhance the urgency of creating tailored digital strategies that align with the cultural and social peculiarities of rural destinations.

Concerning the limitations of the study, while the SWOT analysis provided valuable insights, it also has limitations. The findings are context-specific and may not be generalized to other regions. Moreover, the subjective nature of the method means that some findings bay be biased. Future research could include comparative case studies across different rural regions, as well as longitudinal analyses to track the impact of digital initiatives over time.

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8 Ethics declaration

This research did not require formal ethical clearance, as it involved non-sensitive data collection through voluntary surveys and interviews with adult participants operating in a professional capacity. Informed consent was obtained from all participants, and anonymity and confidentiality were ensured throughout the study. No personal or identifiable information was collected or stored.

9 AI declaration

No generative AI tools were used to produce, analyze, or revise the content of this paper. All data analysis, literature review, and writing processes were conducted by the authors using conventional academic methods.

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The Role of Incubators in the Innovation Ecosystem

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Abstract

In this paper, we rely on multiple correspondence analysis (MCA) to explore a complex ecosystem of Italian innovative enterprises. In this respect, we analyze more than 11.000 innovative SMEs and start-ups. We find that the Italian innovation ecosystem is mainly structured along two dimensions. The first and most significant dimension emphasizes the opposition between structured institutional elements that are typical of SMEs and leaner, more flexible arrangements closer to the start-ups. The second axis is that of social inclusiveness and innovation as opposed to sociocultural sedimentation, which is more representative of well-established SMEs in the industrial/artisanal sector. An additional analysis of concentration ellipses revealed that start-ups are prone to rely on higher female representation and are closer to the service sector category. If we treat the latter as a proxy category for incubators, which were all designated as services, then the unfortunate conclusion is that Italian innovative enterprises tend to lose their social innovativeness aspects, which include but are not limited to social inclusivity, once past the start-up phase. The ramifications of these dynamics are yet to be sufficiently understood in relation to the broader ability of enterprises to innovate.

Keywords: innovation, start-ups, SMEs, incubators, social inclusivity, MCA

Paper type: I a Practical Paper

1 Introduction

This study aims to investigate the complex arrangements within the Italian innovation ecosystem to understand how innovative start-ups and SMEs are structured in terms of their social, economic, and legal composition while also considering how these relate to incubators. For the in-depth exploration of the ecosystem of innovative Italian enterprises, we rely on multiple correspondence analysis (MCA), a technique designed to explore relationships between categorical variables (Clausen, 1998). This method is particularly useful for synthesizing large nominal data sets, representing them graphically in a few dimensions, and allowing an intuitive representation of associations between variables (Hoffmann and Franke, 1986).

Through the MCA, we analyze the complex relations between structural characteristics of start-ups and innovative SMEs in order to explore the internal field dynamics with regard to the two categories of enterprise. The study aims to identify common and diverging characteristics between successful start-ups and innovative SMEs, considering variables related to their activities, social composition, and institutional-legal arrangement. The results are an integrated overview of the innovation ecosystem in Italy, providing useful indications for improving their functioning, especially as related to their primary goal—i.e., how to become and remain innovative.

2 A brief overview of innovation ecosystems

An innovation ecosystem describes a network of structures, individuals, entities, and resources used to develop new ideas, systems, products, and methods. The rationale is to promote innovation in regional contexts and industries to maximize the creation of shared value (Adner, 2006; Cooke, 2016; Dedehayir et al., 2018; Jacobides et al., 2018). Ecosystems, consisting of research institutions, corporate inventors, industry clusters, marketplaces, infrastructure, government and academic institutions, customers, and investors, can be seen as a support system for the development of innovative and creative business ideas (Clarysse et al., 2014; Meng and Ma 2018; Peterková et al., 2022). Such organizations also include co-working centers, incubators, and science and technology parks (Popkova et al., 2020; Peterková et al., 2022), which are indicative of a functioning ecosystem (Audretsch et al., 2018).

Each component of the ecosystem creates a network of symbiotic relationships, which collectively keeps the system efficient (Granstrand and Holgersson 2020). On the one hand, the goal of the ecosystem is to accelerate the birth and development of start-ups and SMEs by fostering a widespread entrepreneurial culture (Roman et al., 2020). On the other hand, the goal of these actors is to innovate in order to solve emerging and existing problems affecting businesses and markets (Thurik & Wennekers, 2016). Indeed, the innovation ecosystem is based on value creation through customer-oriented collaborations (Adner, 2006). In fact, there is a symbiotic

relationship between entrepreneurship and innovation ecosystems. Alvarez et al. (2018) highlight that the former focuses on generating new products, services, and ideas to solve everyday problems by identifying gaps in the market. Moreover, an innovation ecosystem provides the necessary support structures for entrepreneurial activities. Innovation is harnessed as a factor that promotes entrepreneurship and builds synergies between actors (Mago and Van der Merwe, 2023). On the one hand, innovation provides resources to entrepreneurship through workspaces, accelerators, incubators, and funding networks; on the other hand, entrepreneurship requires resources such as talent, mentoring, capital, and infrastructure (Bruns et al., 2017). In this context, it is essential to promote open innovation through a collaborative approach that allows companies to access knowledge, technologies, and resources from outside while leveraging their own expertise to create value (Chesbrough, 2003).In this regard, incubators embody the principles of open innovation by offering not only access to physical and financial resources but also to networks of contacts and strategic expertise that accelerate the innovation process (Chesbrough et al., 2006; West and Gallagher, 2006; Colombelli et al., 2017; O'Connor and Ayers, 2005; Barile et al., 2024). Therefore, the purpose of incubators is to support start-ups in their early stages with different strategies (Grimaldi and Grandi, 2005; Mian et al., 2016). The resources made available by incubators, such as space, technology, and mentorship, are crucial for the competitive advantage of incubated enterprises, especially as seen from the Resource Based View perspective (Penrose, 1959; Barney, 2001).

3 Methodology

As anticipated in the Introduction, we have used MCA for the exploratory purposes of our study. MCA is a multivariate analysis technique used for exploring relationships between categorical variables, widely used to identify latent structures in qualitative data (Abdi & Valentin, 2007; Hoffman & De Leeuw, 1992; Vlacic et al., 2021). It constitutes an extension of simple correspondence analysis (CA), specifically designed to explore associations between multiple categorical variables (Clausen, 1998) in an n-dimensional space. As such, it can be considered a qualitative counterpart of principal component analysis for nominal variables (Abdi & Valentin, 2007). MCA is useful for synthesizing large nominal datasets, offering their geometric representation in a low-dimensional space that allows an intuitive analysis of associations between modalities and observations (Hoffman & Franke, 1986). The MCA was initially conceived to analyze cross tables and frequency matrices (Benzécri et al., 1973) but now also finds application in fields such as marketing and social sciences, where it is used to map thematic relationships and understand complex conceptual structures (Parchomenko et al., 2019; Vlacic et al., 2021).

The basic principle of MCA is the barycentric property, according to which observations are attracted to the local "centers of gravity" of the modalities to which they belong, thus allowing for a shared representation in factorial space (Hoffman & De Leeuw, 1992). Distances between points are calculated using the χ^2 metric, and the space obtained through the singular value decomposition allows for the representation of relationships between modalities and statistical units based on their proximity. Additionally, since the MCA tends to underestimate the inertia explained by the dimensions, it is necessary to correct the eigenvalues to obtain reliable interpretations (Abdi & Valentin, 2007; Hjellbrekke, 2018). The quality of a mode's representation is measured by means of squared cosines, while relative contributions indicate how much each mode influences the formation of principal axes (Greenacre, 1986). Active variables participate directly in the construction of the geometric space, while additional variables can be projected onto space (without contributing to its definition) to improve interpretation (Le Roux & Rouanet, 2010; Blasius & Thiessen, 2001). MCA results are represented on proximity maps, where spatial proximity between categories and observations reflects significant similarities in answer profiles (Hoffman & Franke, 1986; Abdi & Valentin, 2007). To further facilitate reading, graphical tools such as star plots and line plots are often used (Hoffman & De Leeuw, 1992).

3.1 Sample

The present study is based on a compound dataset updated to 2025, which collects information on incubators, start-ups, and innovative small and medium-sized enterprises (SMEs) operating in Italy. The data were obtained from official and public sources and organized so as to allow the application of MCA, favoring variables of a categorical nature with relatively few well-represented modalities.

In the case of incubators and SMEs, the categorical variables chosen as supplementary include the economic sector to which they belong, the production class referring to the last year, the size class in terms of employees, and the share capital class. Indeed, when these were included as active variables, the resulting geometric space was mainly structured by the respective size of an enterprise along one of the first two axes, hence precluding the deeper understanding of the nested dynamics within the innovation ecosystem.

In addition, eight categorical variables were retained as active variables (i.e., the ones that actively participated in the construction of the space). Among these, to capture certain socio-cultural-demographic characteristics of the space, three categorical variables were included to indicate whether (and to what degree) the enterprise has a female, youth, or foreign prevalence within the corporate structure, with reference respectively to the majority presence of women, persons under 35 years of age, or persons of non-Italian origin among partners and founders.

For each enterprise, the "type" categorical variable was also coded, denoting whether the single observation is a start-up or an SME. Additionally, a categorical variable indicating the activity sector was also treated as active. This has also solved the issue of incompatibility of the "incubators" observations with the remaining two categories (SMEs and start-ups) since these did not share the profile structure with incubators. In this regard, as all incubators in the original data were coded as "service," the *sector* variable acted as a proxy of sorts, allowing certain conclusions also in relation to incubators even if these did not make it to the final dataset.

In addition to the data listed above, three specific requirements for recognition as an innovative enterprise were treated as binary variables (yes/no). When it comes to start-ups, the first requirement consists of allocating at least 15 percent of the higher of costs and total production value to research and development activities. The second requires that at least two-thirds of the team be composed of personnel with a master's degree or at least one-third of PhD students, PhDs, or graduates with at least three years of certified experience in research activities. The third criterion refers to the ownership or licensing of an industrial patent or the registration of software. For SMEs, although the data structure was shared, the innovative requirements have different thresholds. In particular, the first requirement is that at least three percent of the higher of costs and value of production must be allocated to research and development activities. The second requires that at least one-third of the team possesses a master's degree, or at least one-fifth consists of doctoral students, PhDs, or graduates with at least three years of documented experience in research activities. Also, for SMEs, the third requirement concerns the presence of an industrial patent or software registered in the company's name.

After combining the two datasets (SMEs and start-ups), in order to not destabilize the analyses, all the individual observations for which one or more modalities were not available in the active set were eliminated. This allowed the preparation of the dataset for processing by MCA, facilitating the identification of latent configurations, the visualization of the relationships between structural and innovative characteristics of firms, and the analysis of sectorial differences within the Italian entrepreneurial fabric. In total, 14159 enterprises were analyzed.

4 Analysis of results

The MCA made it possible to construct a geometric space in which start-ups and SMEs are placed according to a series of categorical variables/their modalities. These include the activity sector, the presence of formal requirements for their identification, and the female, youth and/or foreign component. The two main dimensions that emerged from the analysis together explain 88% of the variance (according to the modified rates), of which 73% is attributed to the first dimension and 15% to the second. The result is substantial and allows us to clearly read the main lines of opposition between the entrepreneurial profiles observed. Moreover, the cloud of individuals (Figure 1) turned out to be regularly shaped, with no significant abnormalities around the origin, indicating no opposition on the axes beyond the second that could have significantly influenced the cloud.

The MCA produced a geometric space in which start-ups and SMEs are distributed according to differentiation logic related to the requirements for access to their respective legal qualifications. The first dimension (Figure 2), which alone explains more than 70% of the variance, shows a clear opposition between two groups of companies: on the one hand, innovative SMEs, which are characterized by the fulfillment of the second and third requirements, i.e. the presence of a team qualified for at least one third with a master's degree or doctorate, and the possession or use of intellectual property rights or registered software; on the other hand, start-ups, which are characterized by the fulfillment of the first requirement only, i.e. an R&D expenditure intensity of at least 15% of the greater of costs and production, but which are generally lacking patent assets and a consolidated organizational structure (requirement 1 and 2). This configuration suggests that the first dimension reflects the degree of organizational maturity and legal and technological consolidation, distinguishing firms that are already endowed with strategic intangible assets (formalized human and intellectual capital) from younger or start-up firms that focus mainly on R&D investment intensity but have not yet developed structural and protectable assets.

The second dimension (Figure 3), which explains a further 15% of the variance, shows an internal differentiation between companies adopting hybrid configurations of requirements. This includes, for example,

companies that fulfill the second requirement but have not yet consolidated investments in R&D or IP protection or, conversely, companies with patent assets that do not have formally qualified human capital. In addition, a greater female presence in start-ups than in SMEs clearly emerges. This data suggests a prevailing orientation of women towards leaner forms of enterprise, less structured according to traditional formal criteria, and with greater flexibility in organizational models.

Overall, the two-dimensional space described by the MCA allows a coherent map of different entrepreneurial trajectories to be drawn. The axis of structuration (first dimension) distinguishes enterprises according to the degree of formalization and consolidation, while the axis of inclusiveness and social innovation (second dimension) differentiates organizational and cultural models. The presence of these intermediate configurations suggests that the pathways towards formal recognition (as SMEs or innovative start-ups) are neither univocal nor simultaneous with respect to the three requirements but follow differentiated equifinal sequences dictated by internal factors (available resources, strategic objectives) or external factors (sector, access to protective instruments or specialized human capital).

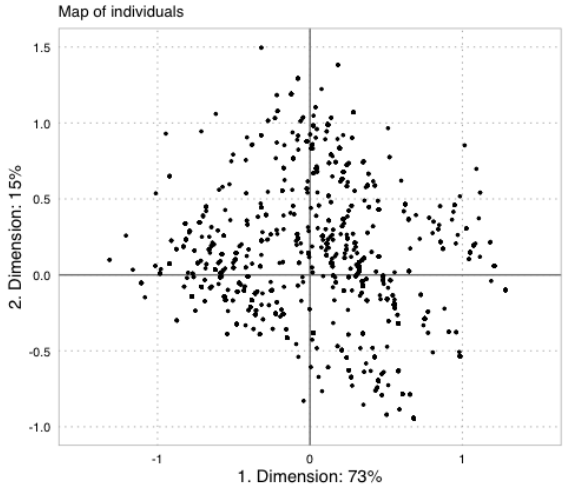


Figure 1: Distribution of Start-ups and SMEs in the Factorial Space

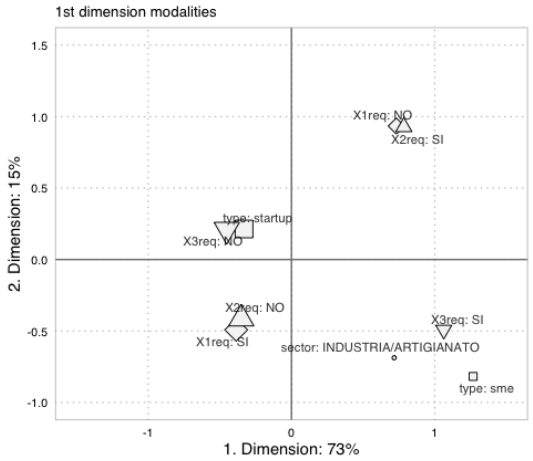


Figure 2: Modalities with higher than average contribution. First dimension

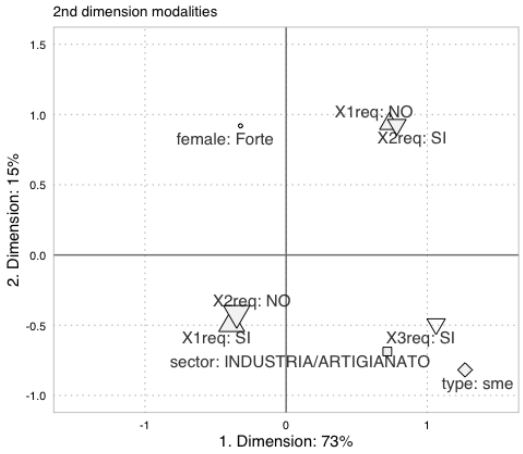


Figure 3: Modalities with higher-than-average contribution. Second dimension

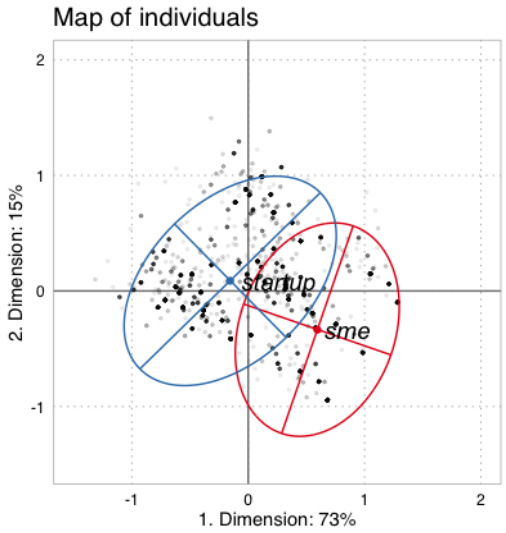


Figure 4: Concentration Ellipses by Legal Form: Start-up vs SME

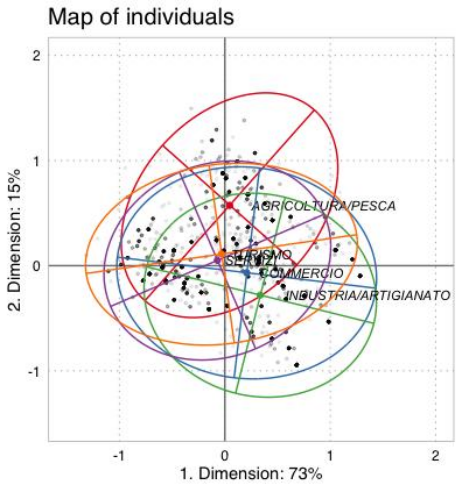


Figure 5: Concentration Ellipses by Sector of Activity

5 Discussion

The results of the analysis are not limited to distinguishing between companies that “are” or “are not” in possession of the requirements but allow us to grasp the logic through which these requirements combine and manifest themselves in business models that differ in structure, strategy, and degree of consolidation. Positioning in the space of Italian innovative companies thus reflects not only legal-institutional conformity but

also the way in which companies build their legitimacy as innovation subjects over time. This makes the analysis particularly useful from a prospective viewpoint to understand which trajectories turn out to be more frequent, which configurations remain marginal, and which could benefit from targeted policy interventions to accelerate access to full innovative firm status.

Fig. 4 emphasizes the distribution of start-ups and SMEs in relation to their local barycenters; in fact, the concentration ellipse allows a clear visualization of the structural differences between the two groups. The ellipses enclose about 85% of the observations belonging to each group, thus representing an effective summary of the internal variability with respect to the category to which they belong. A particularly noteworthy element is the distinct position of the central points (barycenter) of the two ellipses: the “average” profile of the start-up is located on the left-hand side of the factorial plane, corresponding to negative coordinates on the first dimension, while the “average” profile of the SME is clearly on the right-hand side. This distance between the central points is not only geometric but also substantial, reflecting the opposition between the two organizational models. The first, represented by SMEs, is characterized by high internal structuring, often linked to the presence of qualified human capital and intellectual property protection instruments (second and third requirements). The second, associated with start-ups, tends to be less compliant from a regulatory point of view while presenting an intensity of investment in research and development (first requirement), indicating a propensity for innovation. The broader shape of the start-up ellipse highlights a greater heterogeneity of the group, consistent with the idea that start-ups go through different stages of development and adopt varying strategic configurations.

Figure 5 highlights the sectors that enterprises belong to and shows how the distribution of companies in the space reflects not only their organizational configuration but also the economic sector in which they operate. Enterprises active in the industry/craft sector are predominantly SMEs and are concentrated in an area of the plane associated with a high degree of structuring, in line with the fulfillment of the more complex requirements for innovative enterprises, such as the presence of highly qualified human capital and the ownership of intellectual assets. In contrast, the services, trade, and tourism sectors include a combination of start-ups and SMEs but are characterized by greater internal heterogeneity and less overall adherence to more structured requirements. In these sectors, it is common to find companies that only partially meet the regulatory criteria or are in the early stages of formalization, often with a predominant orientation towards R&D investment but without full consolidation of the other requirements. Finally, the agriculture/fisheries sector has companies that are generally located peripheral to the main axes, indicating a low incidence of requirements, regardless of legal form.

6 Implications and conclusion

Our study is of interest to managers and researchers who strive to better understand the dynamics of institutional structuring of a complex innovation ecosystem, in particular, within Italian context and contexts that are, in part, isomorphic to Italian (like that of EU). Overall, the results indicate that the economic sector conditions the degree of business structuring and the internal composition apropos a variety of legal aspects: in the more regulated and manufacturing-oriented sectors, consolidated SMEs prevail, while in the more flexible and dynamic sectors, like that of services, the coexistence of start-ups and SMEs, often with less formalized profiles, can frequently be observed.

This remark is in line with the consideration that all the incubators in the original dataset belonged to the service sector. Moreover, since it is closer to the local barycenter, denoting a strong female presence, a tentative conclusion is that, when they are still a part of incubators, start-ups are usually more socially innovative in terms of their workforce composition. However, once they move toward full-fledged SMEs, two things tend to happen: 1) the strong female presence is no longer there, and 2) the enterprise moves from the service sector toward the industry/craft. This is unfortunate since a degree of social innovation is lost in the move. This, in turn, might also humper other forms of innovation and diversity once the enterprise becomes more institutionally consolidated.

7 Ethics declaration

This work did not require ethical approval, as it does not involve human participants, animal subjects, or sensitive personal data. Therefore, no ethical authorization was necessary.

8 AI declaration

No generative artificial intelligence tools, including ChatGPT or ChatGPT-6, were used in the development of this paper. All content has been independently produced by the author(s) without the assistance of AI-based tools.

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Resilience of Entrepreneurial Ecosystems (EEs) in Switzerland: Diversity, Coherence, and Digitalization

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Abstract

This paper investigates the factors that shape the resilience of entrepreneurial ecosystems (EEs) in the context of long-term structural and technological change. Drawing on a longitudinal dataset from the Global Entrepreneurship Monitor (GEM) for Switzerland (2003–2023), we examine how ecosystem diversity, coherence, and digitalization influence adaptive capacity in the face of external shocks. Building on recent literature, we conceptualize ecosystem resilience as the ability to sustain early-stage entrepreneurial activity over time, and explore whether digitalization contributes to resilience outcomes. We construct composite indexes for diversity, coherence, and digitalization, and estimate a series of linear regression models including interaction effects. Our results confirm that diversity has a significant positive impact on resilience, and that digitalization contributes independently and strongly to resilience as well. However, we find no significant interaction between diversity and coherence, suggesting that alignment and diversity do not always produce synergistic effects. Notably, we identify a negative and statistically significant interaction between coherence and digitalization, indicating that in ecosystems with high institutional alignment, the use of digital tools may be associated with reduced flexibility and adaptability. These findings contribute to the emerging body of research on entrepreneurial ecosystem resilience by introducing digital infrastructure as a dynamic moderating variable. The study also provides one of the few longitudinal assessments of ecosystem resilience in a European context, offering new insights into the interplay between diversity, institutional alignment, and technological capacity.

We discuss the implications for theory, highlighting the conditional nature of resilience mechanisms and the need to account for ecosystem maturity and saturation effects. For policymakers, the results suggest that coherence-building and digitalization strategies should not be treated as universally beneficial, especially in already well-structured ecosystems. Instead, interventions should aim to balance structure with openness, and stability with experimentation, in order to enhance long-term ecosystem resilience.

Keywords: Entrepreneurial Ecosystems, Resilience, Global Entrepreneurship Monitor (GEM), Digitalization, Switzerland.

Paper type: Academic Research Paper

1 Introduction

Entrepreneurial ecosystems (EEs) are conceptualized as networks of interconnected and interdependent actors and resources that collaborate to foster productive entrepreneurship (Stam, 2015). In the wake of recent external shocks, such as the COVID-19 pandemic, and technological disruptions, including the widespread adoption of generative artificial intelligence, there has been growing scholarly interest in the resilience of EEs (Cannice et al., 2023; Iacobucci and Perugini, 2021; Khurana et al., 2022; Santoro et al., 2020). Resilience, in this context, is defined as the capacity of EEs to recover from external shocks and adapt to internal pressures (Cadenasso et al., 2006).

Much of the existing research emphasizes spatial heterogeneity, investigating how different regional ecosystems vary in their composition and capacity for resilience (e.g., Brown and Mason, 2017). In contrast, this study adopts a temporal perspective, examining how a single entrepreneurial ecosystem evolves over time in response to long-term structural and technological change. This approach enables a dynamic understanding of ecosystem resilience by capturing its evolution rather than treating it as a static attribute.

Building on Roundy et al. (2017), we analyze how the key structural and institutional dimensions of EEs — diversity, coherence, and digitalization — contribute to resilience when observed longitudinally. We propose a comprehensive framework, integrating three key EE characteristics:

Diversity: Degree of variety within the EE (e.g., stakeholders' characteristics, industries, venture types)

Coherence: Degree of alignment and connectivity among EE actors in terms of broad intentions and goals, behaviours and activities, common outcomes, values, and cultural rule sets.

Digitalization: Degree of use of digital technologies to generate value-creation opportunities among the EE actors.

While these dimensions independently may enhance resilience, their dynamic interactions are posited to create synergies that amplify their collective impact, resulting in more adaptive and robust ecosystems. For

instance, diversity expands an ecosystem's adaptive capacity by increasing the variety of resources and perspectives available. Coherence, on the other hand, facilitates the alignment of these resources toward shared goals, thereby minimizing inefficiencies and reducing fragmentation (Morris et al., 2015; Motoyama and Knowlton, 2017). Digitalization complements and enhances these processes by providing technological tools and platforms that facilitate coordination, foster innovation, and enable scalability (Autio et al., 2018; Zahra et al., 2023). While diversity and coherence are widely acknowledged as critical to entrepreneurial ecosystem resilience (Acs et al., 2017; Roundy et al., 2017), the role of digitalization in these interactions remains underexplored. By examining the interplay among diversity, coherence, and digitalization, this study offers a more holistic perspective on the drivers of entrepreneurial ecosystem resilience. By leveraging longitudinal data from the Global Entrepreneurship Monitor (GEM) spanning 2003–2023, this study explores how the evolution of these dimensions influences Switzerland's capacity to sustain entrepreneurial activity in the face of ongoing change. In doing so, we contribute to a more dynamic and temporally grounded understanding of EE resilience.

The remainder of the paper is organized as follows. Section 2 develops the research hypotheses, grounding them in existing literature on ecosystem structure, institutional alignment, and digitalization. Section 3 describes the data, index construction, and empirical strategy, including the use of longitudinal regression models. Section 4 presents the main results and statistical analysis. Section 5 discusses the findings in relation to existing theory and explores potential explanations for observed interaction effects. Finally, Section 6 outlines the main conclusions, implications for, and directions for future research.

2 Research Hypotheses

From the perspective of complex systems theory, entrepreneurial ecosystems can be conceptualized as complex adaptive systems characterized by diverse agents interacting non-linearly (Roundy et al., 2017). Portfolio theory suggests that *diversity* promotes resilience by increasing the range of responses available to a system under stress (Frenken et al., 2007; Markowitz, 2009) In the context of EEs, higher diversity in their composition improves the survival and adaptability of ventures during crises where cross-industry collaborations become essential (Boyd and Folke, 2011; Chaffin and Gunderson, 2016). Diverse ecosystems draw on a broader knowledge-base and provide more innovative solutions to adapt to shocks (Boyd and Folke, 2011). Diversity, therefore, broadens the ecosystem's knowledge base, enhances adaptability, and fosters innovative responses to crises. Based on these insights, we propose:

- *H1: Entrepreneurial ecosystems with higher diversity exhibit greater resilience.*

However, diversity alone may lead to fragmentation or inefficiency if it is not aligned with shared goals and collaborative behaviors among an EE's actors. Coherence has been argued to mitigate these potential inefficiencies by aligning actors through shared goals, values, and behavioral norms in socio-technical systems (Brown and Mason, 2017; Mack and Mayer, 2015). Drawing on institutional and social capital theories, coherence is deemed to facilitate cohesiveness and collective outcomes (Motoyama and Knowlton, 2017; Putnam, 2000). In the context of EEs, high coherence allows entrepreneurial ecosystems to fully realize the benefits of diversity by fostering alignment, reducing inefficiencies, and promoting collaboration (Roundy et al., 2017). Based on these insights, we propose:

- *H2: Entrepreneurial ecosystems with higher coherence exhibit a stronger positive relationship between diversity and resilience.*

Despite high levels of diversity and coherence, EEs may still face limitations in their adaptability, particularly when constrained by geographic, institutional, or resource-related constraints (Autio et al., 2018; Feldman et al., 2022). Scholars have shown how digital platforms and tools allow ecosystems to overcome traditional barriers, such as lock-in phenomena, and foster virtual collaboration and innovation (Nambisan, 2017). Therefore, in EEs with low diversity, digitalization may introduce external perspectives and expand the knowledge base by connecting regional actors to global networks (Chen et al., 2023; Zahra et al., 2011). Similarly, in EEs with low coherence, digital tools provide alignment mechanisms, enabling regional actors to coordinate effectively even without shared values or cultural norms. Collaboration platforms, data-sharing tools, and digital marketplaces, for example, facilitate efficient resource allocation and enhance ecosystem-wide coordination. Therefore, we propose:

- *H3a: Digitalization substitutes for diversity in fostering resilience in ecosystems with low diversity.*
- *H3b: Digitalization substitutes for coherence in fostering resilience in ecosystems with low coherence.*

3 Methodology

To test our hypotheses, we use longitudinal data from the Global Entrepreneurship Monitor (GEM) Adult Population Survey (APS) and National Expert Survey (NES) for Switzerland, covering the period 2003 to 2024. The analysis focuses on how diversity among ecosystem actors relates to entrepreneurial ecosystem (EE) resilience, and how coherence and digitalization influence this relationship over time.

To operationalize the key variables in our model, we construct four composite indices. The Entrepreneurial Ecosystem Resilience Index (EERI) is calculated as the five-year compound annual growth rate (CAGR) of the Total Early-stage Entrepreneurial Activity (TEA) rate. TEA, provided directly by GEM, captures the percentage of adults (18–64) engaged in nascent entrepreneurship or managing a new business under 42 months old. This indicator serves as a proxy for the ecosystem's capacity to regenerate entrepreneurial activity after disruptions. EERI is calculated as:

$$EERI_t = \left(\frac{TEA_t}{TEA_{t-n}}\right)^{\frac{1}{n}} - 1$$

where TEA_t represents the total early-stage entrepreneurial activity at year *t*.

The Diversity Index is computed as the mean of three Simpson Indices capturing diversity in age, gender, and sectoral distributions of early-stage entrepreneurs. Each Simpson Index is defined as

$$D = 1 - \sum_{i=1}^{n} p_i^2$$

where p_i is the share of entrepreneurs in category i (e.g., a specific age group or sector). The Diversity Index, is defined as:

$$DIV_t = \frac{D_{age,t} + D_{sector,t} + D_{gender,t}}{3}$$

To capture institutional alignment within Switzerland's entrepreneurial ecosystem, we constructed a Coherence Index (COH_t) using selected variables from the GEM National Expert Survey (NES). The initial pool included indicators related to government policy, infrastructure, and public–private collaboration. An exploratory factor analysis (EFA) was conducted to retain only those variables with strong loadings (≥ 0.6) on a dominant factor and internal consistency (verified via Cronbach's alpha). Retained items were standardized (z-scores), and the index was computed as:

$$COH_t = \frac{1}{k}\sum_{i=1}^{k} z_{it}$$

Where z_{it} is the standardized score of variable *i* in year *t*, and *k* is the number of retained variables. This index reflects the extent to which ecosystem institutions and support structures are coherent and aligned across time.

Finally, the Digitalization Index is the average of standardized scores on three NES items: NES_E02 (technology access), NES_E01 (knowledge transfer), and NES_H01 (infrastructure quality), computed as

$$DIG = \frac{1}{3}(z_{E02} + z_{E01} + z_{H01})$$

Tables 1 and 2 provide an overview of the variable construction process and data sources used in the analysis.

Table 1. Index variables and sources

	Description	Components	Data Source
Resilience Index - EERI	5-year CAGR of TEA	TEA % (Total Early-stage Entrepreneurial Activity, ages 18–64)	APS
Diversity Index - DIV	Average of Simpson Indices across age, gender, and sector	TEA by age group, gender, and sector-level participation	APS
Coherence Index - COH	Factor score capturing institutional and cultural alignment	PCA on NES_B, NES_E, NES_G, NES_H, NES_I variables (e.g. policy, collaboration, infrastructure)	NES
Digitalization Index - DIG	Composite z-score reflecting tech access and infrastructure	z(NES_E02), z(NES_E01), z(NES_H01) – technology access, knowledge transfer, infrastructure quality	NES

Table 2. Index sub-components and sources

	Sub-components	Calculation Method
Diversity Index	Simpson Index for Age Diversity (TEA by age 18–24, 25–34, 35–44, 45–54, 55–64)	$S = 1 - \sum p_i^2$
	Simpson Index for Gender Diversity (TEA by male/female)	
	Simpson Index for Sector Diversity (TEA by industry/sector categories)	
Coherence Index	NES_B: Government policy; NES_E: Entrepreneurial culture; NES_G–I: Infrastructure, Collaboration	PCA with varimax rotation
Digitalization Index	NES_E02: Equal access to new technology	Standardized (z-score), then averaged
	NES_E01: Knowledge transfer from universities	
	NES_H01: Physical infrastructure quality	

3.1 Model Specification

We estimate a series of linear regression models (OLS) to test the hypotheses H1 through H3b. Each model builds progressively by adding variables and interaction terms to assess both main effects and moderating influences of ecosystem characteristics. All variables were mean-centered to facilitate interpretation and reduce multicollinearity. Year was included as a control variable in all models to account for time-specific effects such as macroeconomic trends or policy changes. The general structure of the models can be expressed as:

$$EERI_t = \beta_0 + \beta_1 * DIV_t + \beta_2 * COH_t + \beta_3 * (DIV_t * COH_t) + \beta_4 * YEAR_t + \varepsilon_t$$

The individual models are specified sequentially to test each hypothesis. Model 1 estimates the baseline effect of diversity on ecosystem resilience (H1). Model 2 introduces coherence and the interaction between diversity and coherence, allowing us to assess whether institutional alignment moderates the relationship between diversity and resilience (H2). Model 3 incorporates digitalization and its interaction with diversity to examine whether digital infrastructure substitutes for or amplifies diversity in fostering resilience (H3a). Finally, Model 4 includes the interaction between coherence and digitalization to evaluate whether digitalization can compensate for low institutional coherence in enhancing ecosystem resilience (H3b). All models were estimated using ordinary least squares regression with robust standard errors. Their statistical significance and explanatory power were assessed via R^2 and F-tests.

4 Results

Table 3 presents the descriptive statistics for the variables used in the longitudinal analysis of Switzerland's entrepreneurial ecosystem from 2003 to 2023. All indices exhibit sufficient variability over time. The mean value of the Resilience Index is moderately negative, indicating a modest decline in early-stage entrepreneurial activity over this period. The Diversity Index shows relatively high diversity across the period, with an average score of 0.62 on a scale from 0 to 1. A categorized version of this index indicates that in most years, Switzerland's ecosystem exhibited high diversity (coded as 3). The Coherence Index averages 3.33 on a 1–5 scale, suggesting moderately high coherence in ecosystem structures and actor alignment. Its categorized version indicates that in most years, the coherence level was moderate (category 2). The average value of the Digitalization Index is approximately zero, indicating a balanced digital infrastructure trajectory during the period observed.

Table 3. Descriptive Statistics of Key Variables (2003–2023)

Variable	N	Min	Max	Mean	Std. Dev.
EERI	17	-9,56	1,75	-0,81	3,03
DIV (Diversity Index)	18	0,54	0,64	0,62	0,02
Categorized Diversity Index	18	2,00	3,00	2,94	0,23
COH (Coherence Index)	18	2,81	3,63	3,32	0,23
Categorized Coherence Index	18	2,00	3,00	2,17	0,38
DIG (Digitalization Index)	17	-1,61	1,27	-0,0	0,70
Categorized Digitalization Index	17	1,0	3,0	_	_
TEA (TEA proxy)	18	5,04	10,29	7,67	1,45
Year	18	2003	2023		

Note: EERI values are calculated as 5-year CAGR of TEA. Diversity and Coherence categorical variables range from 1 (low) to 3 (high). N for EERI is 17 due to the 5-year window required for CAGR computation.

Table 4 shows that all predictor variables are positively correlated with ecosystem resilience. The analysis reveals a significant positive correlation between the Entrepreneurial Ecosystem Resilience Index (EERI) and the General Diversity Index (r = 0,491, p = 0,046), supporting Hypothesis 1: diversity contributes to ecosystem resilience. Similarly, Coherence Index shows a strong and significant positive correlation with EERI (r = 0,689, p = 0,002), suggesting that higher alignment and institutional consistency are associated with increased ecosystem adaptability.

Additionally, a strong positive correlation exists between diversity and coherence (r = 0,717, p < 0,001), indicating that these two constructs may reinforce each other. Digitalization has a moderate correlation with resilience (r = 0,61), and is also highly correlated with coherence (r = 0,79), highlighting potential interaction effects. No multicollinearity concerns were detected, as no pairwise correlation exceeds 0,80. However, multicollinearity diagnostics suggest they remain distinct enough to be used in interaction analysis. The Year variable is also significantly correlated with EERI (r = 0,766, p < 0,001), reflecting general time trends in the data, and is therefore included as a control variable in the regression models.

Table 4. Correlation matrix

Variable	EERI	DIV	COH	DIG	Year
EERI	1	0,491* /(0,046)	0,689** / (.002)	0,606**/ (0,010)	0,766***/(<0,001)
DIV	0,491*/(0,046)	1	0,579*/ (.015)	0,539*/ (0,025)	0,447/ (0,063)
COH	0,689**/ (0,002)	0,579*/ (0,015)	1	0,790***/ (<0,001)	0,548*/ (0,019)
DIG	0,606**/ (0,010)	0,539*/ (0,025)	0,790***/ (<0,001)	1	0,470*/ (0,050)
Year	0,766***/ (<0,001)	0,447/ (0,063)	0,548*/ (0,019)	0,470*/ (0,050)	1

Notes: Pearson correlation coefficients shown. *p < 0,05, **p < 0,01, ***p < 0,001
N = 17 for EERI; N = 18 for other variables (listwise deletion applied for missing values).

Table 5 summarizes the results of four linear regression models testing the impact of diversity, coherence, and digitalization on entrepreneurial ecosystem resilience. **Model 1** confirms Hypothesis 1, showing that diversity has a significant positive effect on resilience. **Model 2** introduces coherence and its interaction with diversity (H2), but the interaction term is not significant, suggesting that coherence does not strengthen the diversity–resilience link in this context.

Model 3 tests the moderating role of digitalization (H3a). Digitalization alone significantly enhances resilience, but its interaction with diversity is not significant, indicating no clear substitution or amplification effect. Finally, **Model 4** (H3b) reveals a significant negative interaction between digitalization and coherence. This suggests that while digital infrastructure boosts resilience on its own, in highly coherent ecosystems it may reduce flexibility and adaptability.

Table 5. Linear Regression Models Testing the Effects of Diversity, Coherence, and Digitalization on Ecosystem Resilience

Predictor	Model 1 (H1)	Model 2 (H2)	Model 3 (H3a)	Model 4 (H3b)
Diversity	69,16 (< 0,05)	26,25 (< 0,05)	6,29 (n.s.)	
Coherence		3,78 (<0,05)		-0,76 (0,312)
Digitalization			2,1 (0,004)	1,95 (0,028)
Diversity × Coherence		-139,5 (n.s.)		
Diversity × Digitalization			-46,54 (0,181)	
Coherence × Digitalization				-5,92 (0,049)
R^2	0,73	0,81	0,88	0,89

Note: β coefficients shown with p-values in parentheses. n.s. = not significant.

5 Discussions

The findings confirm that diversity exerts a statistically significant and positive effect on entrepreneurial ecosystem resilience, reinforcing the notion that heterogeneous environments are better equipped to absorb shocks and adapt to changing conditions. This aligns with portfolio and complexity theories (Frenken et al., 2007; Boyd and Folke, 2011), which suggest that variety in actors, industries, and perspectives enhances systemic robustness by expanding the repertoire of responses available during crises.

Similarly, digitalization emerges as a strong and consistent enabler of ecosystem adaptability. The positive effect of digital infrastructure across models underscores its role in facilitating coordination, enabling access to

knowledge, and lowering barriers to innovation and collaboration—especially in geographically bounded or resource-constrained settings (Autio et al., 2018; Zahra et al., 2023). Digital tools thus appear to offer critical affordances for entrepreneurial renewal, especially in the face of systemic disruptions.

However, the interaction effects point to a more nuanced and conditional understanding of ecosystem resilience. The non-significant interaction between diversity and coherence challenges prevailing assumptions from institutional and social capital theories, which posit that institutional alignment should help integrate diverse elements into a cohesive and effective whole (Putnam, 2000; Motoyama and Knowlton, 2017). In the Swiss context, where baseline levels of institutional coherence are already high, additional alignment may yield diminishing returns. This could indicate a saturation effect, where further increases in coherence no longer contribute meaningfully to ecosystem adaptability—or worse, risk stifling the creative frictions that diversity is supposed to promote.

Most notably, the negative and statistically significant interaction between coherence and digitalization points to a potential trade-off that complicates conventional assumptions. While both factors independently support resilience, their combination appears to reduce adaptability under certain conditions. One plausible explanation is that digital tools, when implemented in already tightly structured and rule-bound environments, may reinforce existing routines and centralized control, thereby limiting flexibility and hindering experimentation. This interpretation is consistent with the warnings of Nambisan (2017) and Autio et al. (2018), who argue that the value of digitalization is not inherent but contingent on the ecosystem's institutional configuration.

Rather than acting as a universally beneficial force, digitalization may function as a double-edged sword: empowering adaptation in loosely structured systems while amplifying rigidity in ecosystems that are already institutionally aligned. In this sense, digital tools may inadvertently lock ecosystems into path-dependent trajectories, making them less responsive to unexpected challenges. These findings highlight the importance of viewing digitalization not as a one-size-fits-all solution, but as a context-sensitive mechanism whose effects are mediated by the broader institutional architecture in which it is embedded.

Overall, these results suggest that fostering resilience requires a careful balancing act between structure and openness, and between technological advancement and institutional flexibility. Ecosystem builders and policymakers should be cautious not to assume that more coherence or more digitalization will always lead to better outcomes. Instead, strategic attention must be paid to the interaction effects among ecosystem dimensions—and to the risk that well-intentioned interventions may produce unintended rigidity in ecosystems that are already highly structured and governed by well-established institutional arrangements.

6 Conclusions

This study set out to explore how diversity, coherence, and digitalization interact to shape the resilience of entrepreneurial ecosystems (EEs), using longitudinal data from Switzerland between 2003 and 2023. Building on prior theoretical work, we proposed a model in which diversity and coherence represent structural and institutional capacities, while digitalization serves as a moderating force capable of amplifying or substituting these effects.The empirical analysis confirms that both diversity and digitalization exert a positive and independent influence on ecosystem resilience. However, the interaction between diversity and coherence was found to be non-significant, suggesting that their complementarity may be context-dependent or subject to saturation effects in already mature ecosystems. Most notably, the interaction between coherence and digitalization was negative and statistically significant, implying that digital infrastructure—while beneficial in isolation—may reduce adaptive capacity in ecosystems that are already highly structured. The study makes several contributions to the entrepreneurial ecosystem literature. First, it introduces a dynamic, interaction-based view of ecosystem resilience that incorporates both structural diversity and technological readiness. Second, it offers rare longitudinal evidence from a European context, as most existing studies focus predominantly on Anglo-American or global metropolitan contexts. Third, it refines the understanding of digitalization's role, highlighting its potential downsides when combined with strong institutional alignment. Nonetheless, the study is not without limitations. The sample size constrains statistical power and generalizability. The indexes, while theoretically grounded, rely on secondary data and perception-based measures, which may not fully capture on-the-ground dynamics. Furthermore, the use of linear models may oversimplify what are likely to be non-linear and complex interactions. Future research should build on this work by employing mixed-method designs that combine quantitative analysis with case studies of ecosystems undergoing structural or digital transitions. Longitudinal studies with higher temporal resolution, or comparisons across countries with varying degrees of maturity and digital infrastructure, would also be valuable. In addition, future models might incorporate more granular data on innovation types, sectoral shifts, or entrepreneurial

demographics to better understand how different forms of diversity interact with coherence and technology. From a policy perspective, the findings suggest a need for nuanced consideration when promoting coherence and digitalization as levers of ecosystem resilience. In settings where institutional alignment is already relatively high, further efforts to enhance coherence might yield limited benefits—or, in some cases, could be associated with reduced adaptability if not accompanied by sufficient diversity and openness. Rather than treating coordination-heavy or technology-driven interventions as universally beneficial, policymakers and ecosystem builders may benefit from reflecting on the maturity and structural characteristics of their ecosystems. Approaches that emphasize flexibility, inclusiveness, and opportunities for experimentation could be more effective in fostering long-term resilience in certain contexts.

7 Ethics declaration

No ethical clearance was required for this study as it used publicly available secondary data.

8 AI declaration

AI tools were used to support linguistic editing of this manuscript. All substantive content were generated by the authors.

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Leveraging External Knowledge: How Business Incubators Facilitate Open Innovation in Start-ups

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Abstract

Start-ups represent one of the main sources of innovation and, consequently, national competitiveness. However, due to their limited size, they face several challenges, such as the scarcity of technical and financial resources, which significantly constrain their innovation capacity. To overcome these challenges, start-ups should engage in the adoption of open innovation (OI) processes, which enable them to collaborate with external organizations and exchange resources and knowledge. The effectiveness of such processes is amplified when start-ups are embedded in solid innovation ecosystems. Among the various actors that compose these ecosystems, innovation intermediaries — such as business incubators (BIs) — play a key role. BIs, through targeted networking services, enable incubated start-ups to more easily develop OI collaborations, either with one another or with external organizations. This study aims to explore the role of BIs as OI intermediaries — a topic that has received limited attention in the literature — by identifying the main operational strategies implemented to foster the openness of their incubated start-ups. To achieve this objective, a case study was conducted on the incubator of the University of Calabria (UniCal), "*TechNest*". The findings reveal a strong commitment by TechNest to supporting the development of both internal and external innovation networks. However, some limitations were observed in terms of openness among start-ups operating within the academic context. This research provides valuable implications. On a theoretical level, it contributes to the limited body of literature on the topic. On a practical level, it highlights the importance for incubator managers to integrate an OI perspective into their incubation programs, while also emphasizing the need for managers of incubated start-ups to open their innovation processes to external collaborations. At the same time, policymakers should work to improve innovation policies, providing greater support to incubators and, more generally, to local and national innovation ecosystems.

Keywords: Open innovation, Business incubators, Start-ups, Innovation ecosystems, Case study

Paper type: Academic Research Paper

1 Introduction

Start-ups are increasingly recognized as a crucial driver of national competitiveness. Their flexibility, risk-taking propensity, and ability to explore new market opportunities position them as key players in economic and technological development. Defined as a firm, a partnership, or a temporary organization designed to search for a repeatable and scalable business model (Blank, 2010), start-ups have the potential to create new industries and generate significant economic and social impacts (Audretsch *et al.*, 2020). However, these firms often encounter substantial challenges in developing and commercializing innovations due to their small size and limited resources, knowledge, and capabilities (Spender *et al.*, 2017). Therefore, start-ups should adopt OI practices to overcome these constraints by engaging with external entities and organizations (Bereczki, 2019; Bogers, 2011; Primario *et al.*, 2024; Spender *et al.*, 2017). Moreover, the adoption of OI processes is more effective when start-ups are part of a genuine "*innovation ecosystem*," comprising various agents, such as firms, universities, research centers, governments, intermediaries, and financial institutions, all interacting to foster innovation (e.g., Adner, 2006; Costa and Matias, 2020; Wei *et al.*, 2021). Within these ecosystems, innovation intermediaries play a pivotal role by connecting "*searchers*" (organizations facing an OI challenge) with "*solvers*" (individuals or entities providing potential solutions) (Chesbrough and Brunswicker, 2014). A prominent example of innovation intermediaries is business incubators (BIs) (Conroy *et al.*, 2023), which foster the adoption of OI processes by their incubated start-ups offering targeted networking services (e.g., Hansen *et al.*, 2000; Scillitoe and Chakrabarti, 2010; Soetanto and Jack, 2013). These services promote knowledge exchange and the creation of technological and market partnerships (Hansen *et al.*, 2000), both with external organizations and with other start-ups incubated within the same facility (Bøllingtoft and Ulhøi, 2005; Soetanto and Jack, 2013). As "*knowledge hubs*," incubators facilitate the development of new entrepreneurial ideas and the subsequent dissemination of knowledge and innovative technologies to market-oriented firms (Gassmann and Becker, 2006). However, the literature on OI collaborations between start-ups and other organizations, such as small and medium-sized enterprises (SMEs) (Mercandetti *et al.*, 2017) and large firms (Barile *et al.*, 2024) remains relatively underexplored. Similarly, research on incubators as OI intermediaries is still in its early stages (Leitão

et al., 2022; Theodoraki *et al.*, 2022). Indeed, there is a lack of detailed studies creating a theoretical basis for the use of the OI approach within BIs, which often leads to its implementation being unstructured and unintentional (Cirule and Uvarova, 2022). Therefore, the question of how these organizations can effectively facilitate the adoption of OI practices by their incubated start-ups remains unresolved (Leitão *et al.*, 2022).

Consequently, this research primarily aims to understand the key processes implemented by BIs to foster OI relationships between incubated start-ups and external organizations.

- *RQ_1 - How do business incubators facilitate the adoption of OI processes by start-ups?*

Moreover, this study aims to understand the actual outcomes achieved by incubators through the provision of these services, particularly in terms of increased openness of the innovation processes of the incubated start-ups.

- *RQ_2 – Do incubated start-ups effectively adopt OI processes?*

To address the research questions and contribute to the limited body of knowledge on this topic, a descriptive-exploratory case study was conducted. The selected case is the incubator of the University of Calabria (UniCal), "*TechNest*".

The paper is structured as follows. Following this introduction, the second section offers an overview of the theoretical framework. The third section describes the methodology employed in the study. In the fourth section, the case study findings are presented and analysed. Finally, the article concludes by discussing the main implications, as well as the limitations and future developments of the research.

2 Theoretical background

2.1 Open Innovation

The OI paradigm, introduced by Chesbrough in 2003, is based on firms' deliberate use of both inflows and outflows of knowledge and technology to accelerate internal innovation and expand markets for external innovation exploitation (Chesbrough *et al.*, 2006; Chesbrough, 2003). This approach contrasts with the Closed Innovation model, in which firms conduct R&D projects internally without engaging external partners (Chesbrough *et al.*, 2006; Chesbrough, 2003). As highlighted by Chesbrough *et al.* (2006), in a typical OI process, R&D projects can be launched using the firm's technological base and, at the same time, external technological sources. New technologies from outside can be introduced into the development process not only in the initial phase but also in subsequent ones. Finally, technological innovations (new technologies and/or innovative technological know-how) developed by the firm can be disseminated in markets through various channels (e.g., firm's marketing and sales channels; out-licensing; creation of new technological spin-offs).

2.2 Business incubators

The incubation process can be described as "*an interactive development process where the aim is to encourage people to start their own business and to support start-up companies in the development of innovative products. (…) Besides accommodation, an incubator should offer services such as hands-on management, access to finance (…), legal advice, operational know-how and access to new markets*" (Aernoudt, 2004, p. 127). The concept of business incubation is evolving and presents several knowledge gaps (Sohail *et al.*, 2023). Based on the contribute of Abduh et al. (2007), the services provided by BIs can be classified as follows: (i) facilities related services; (ii) counselling and business assistance related services; (iii) accessibility to internal and external incubator networks. Among the various classifications proposed in academic literature, the one by Grimaldi and Grandi (2005) identifies four main types of incubators: (i) BIC (Business Innovation Centers): established in 1984 through an initiative of the European Commission, they focus on offering basic services such as access to physical spaces, information on financing opportunities, administrative support, visibility, etc.; (ii) UBI (University Business Incubators): founded by universities, they promote the development, combination, and dissemination of new scientific and technological knowledge. UBIs offer specific services linked to the academic environment, including consultancy from professors, access to libraries, research laboratories, scientific infrastructure, R&D activities, and technology transfer programs (Mian, 1996); (iii) IPI (Independent Private Incubators): established by individuals or groups of investors (which may include firms) who acquire equity in start-ups with the goal of fostering their growth. They are often referred to as accelerators, as they typically support start-ups that have already launched their operations and require capital or know-how injection; (iv) CPI (Corporate Private Incubators): established by large corporations to develop new business ventures derived from internal projects that cannot be pursued within the parent company.

BICs and UBIs are typically non-profit organizations, as they are founded by public entities with the objective of promoting local economic development. As private incubators, the opposite holds true for IPIs and CPIs. Typically, UBIs and CPIs host business ideas originating from their parent organizations (universities and corporations, respectively), whereas BICs and IPIs support business ideas coming from external sources.

2.3 Business Incubators as promoters of OI among start-ups

Given the scarcity of resources and knowledge that typically characterizes start-ups, the implementation of OI processes is of fundamental importance for becoming part of a robust "*innovation ecosystem*," where various actors - such as firms, universities, research centres, governments, intermediaries, and financial institutions - interact to foster innovation (e.g., Adner, 2006; Costa and Matias, 2020; Wei *et al.*, 2021). Among these actors, BIs play a fundamental role as innovation intermediaries (Conroy *et al.*, 2023), providing targeted networking services that facilitate the adoption of OI processes by their incubated firms (e.g., Hansen *et al.*, 2000; Scillitoe and Chakrabarti, 2010; Soetanto and Jack, 2013). These services promote inter-firm collaboration, knowledge exchange, and the formation of technological and market partnerships (Hansen *et al.*, 2000). The networking services are primarily provided by private incubators and UBIs, whereas BICs tend to focus mainly on the delivery of more traditional services (Grimaldi and Grandi, 2005). Therefore, incubators facilitate start-ups' engagement with external organizations, such as SMEs, large firms, and universities (external innovation networks), while simultaneously fostering internal knowledge exchange among the incubated firms (internal innovation networks) (Bøllingtoft and Ulhøi, 2005; Cirule and Uvarova, 2022; Soetanto and Jack, 2013).

3 Methodology

To address the research questions, a case study was conducted. Specifically, a descriptive-exploratory study was carried out to thoroughly examine the topic and establish a solid foundation for future research, given the limited literature on the subject (Yin, 2018). The selection of the incubator was guided by two key criteria: (i) it had to be either a UBI or a private one, as these ensure extensive networks both within the facility, as well as with external organizations; (ii) it had to be located in a socio-economically disadvantaged area. Although the research does not explicitly focus on territorial development, this allows for the analysis of the main difficulties and positive outcomes associated with incubators operating in contexts characterized by limited access to resources, weaker entrepreneurial ecosystems, and structural barriers to innovation.

Based on these criteria, the selected case is the incubator of the UniCal, "*TechNest*". TechNest operates in a challenging territory characterized by structural difficulties (e.g., Eurostat, 2024), and it stands out for its strong commitment to fostering an OI culture among firms by offering targeted networking services that connect start-ups with both local and national innovation ecosystems.

The use of a single case study is particularly appropriate for exploratory research (McCutcheon and Meredith, 1993), especially when the phenomenon under investigation is dynamic and potentially uncertain (Yin, 2009) and enables the exploration of '*how*' and '*why*' questions concerning a set of contemporary events (Yin, 2009).

Multiple data collection methods were employed to expand the available information base and enhance data diversity, ultimately aiming to reduce biases (Patton, 2002). Accordingly, data were gathered from various sources, including a semi-structured interview of approximately 40 minutes with a TechNest's manager, a questionnaire sent via Google Forms to TechNest, incubator documents, online resources (e.g., the official website), and press articles. Building on the literature review, a specific analytical protocol was developed to facilitate the aggregation and discussion of the collected data (Battistella *et al.*, 2017). This protocol consisted of the following sections: (i) descriptive analysis about TechNest, including its main objectives, organizational structure, and services offered; (ii) analysis of the strategies adopted by TechNest to support the implementation of OI practices among incubated start-ups and of the latter's ability to effectively leverage this support; (iii) assessment of TechNest's contribution to the socio-economic development of the local ecosystem.

4 Results and discussion

4.1 Descriptive analysis

TechNest was inaugurated on November 30, 2010 and currently hosts 12 innovative start-ups (primarily operating in the ICT sector), with a total of approximately 40 start-ups supported throughout its history. Access to TechNest is reserved for spin-offs from the UniCal, start-ups emerging from entrepreneurial training programs established by the university (such as the Contamination Lab initiative known as "*UniCalLab*"), and start-ups that have won the regional entrepreneurship competition, "*StartCup Calabria*." TechNest offers access to both

physical and virtual incubation and pre-incubation programs. In addition to providing facilities-related services (e.g., access to dedicated equipped private offices, coworking areas, and other shared spaces, such as seminar rooms, meeting rooms, and laboratories), TechNest offers administrative and professional services, including intellectual property management, commercial channel activation, and internationalization support through research, feasibility analysis, and similar activities. It offers dedicated mentoring and training programs (e.g., in business management, strategic planning, business plan development, IP management, technology transfer, etc.), along with meetings with specialized tutors to analyse critical issues in the entrepreneurial idea and identify possible solutions. TechNest facilitates start-ups' access to public and private funding sources. TechNest ensures access to both internal and external incubator networks, thereby fostering the opening of the innovation boundaries of its incubated start-ups. TechNest provides additional specialized university services, such as access to the university's laboratories and libraries, the organization of training events open to both the academic community and start-ups, and the establishment of partnerships between the UniCal and incubated start-ups for joint research projects. According to contractual agreements, the incubation process should not exceed five years. However, if there are available spaces that are not needed to accommodate new applicants, firms may remain beyond this period. Once the incubation phase ends, TechNest aims to continue supporting the firms. Nevertheless, a dedicated post-incubation support program has not yet been formally established.

4.2 The strategies adopted by TechNest to support the implementation of OI practices among incubated start-ups

The analysis of the collected data clearly highlights TechNest's continuous commitment to adopting practices aimed at fostering the dissemination of OI among its incubated start-ups. Indeed, the manager stated that "*what we do most of all is constantly create networks among enterprises*". TechNest promotes the diffusion of OI processes facilitating the development of internal and external innovation networks. TechNest: (i) organizes networking events both internally, among incubated start-ups, and externally, with potential clients, partners, and investors; (ii) provides dedicated coworking spaces to facilitate knowledge sharing among start-ups incubated in the same facility; (iii) assists in scouting and connecting with potential external partners; (iv) offers partnership programs with external organizations for innovation development; (v) leverages its status as a university incubator to engage start-ups in research collaborations with the UniCal to develop joint research projects; (vi) supports the outbound flow of knowledge and technologies by providing incubated start-ups with specialized assistance in drafting business plans and pitch decks for presenting innovations to potential partners.

Beyond merely facilitating these connections, TechNest plays a crucial role in helping its incubated start-ups integrate OI principles into their growth and innovation processes through specialized training and mentoring activities. These initiatives help start-ups understand the importance and dynamics of technology transfer, fostering an open approach to external collaborations.

4.2.1 Incubator's external partners: an overview

TechNest connects its start-ups with: (i) established SMEs and large enterprises, particularly in the ICT sector; (ii) banks, financial institutions, and other investors; (iii) universities and research centres; (iv) institutional intermediaries in the entrepreneurial ecosystem; (v) national development and innovation agencies; (vi) public and governmental entities; (vii) other incubators, accelerators, and innovation players. The geographical reach of TechNest's networking activities extends beyond local boundaries, with strong national and even international connections.

The manager highlighted the success story of a start-up, specialized in advanced indoor localization technologies and applications. After winning the StartCup Calabria competition and being incubated at TechNest, it successfully established numerous OI projects with external organizations at local, national, and especially international levels, including collaborations in Japan and the United States.

TechNest manages relationships with numerous high-level entities, leveraging various projects promoted by the university as well. One example is the "*Tech4You*" project, which aims to establish a innovation ecosystem between Calabria and Basilicata and to stimulate innovation activities with a focus on developing sustainable products to mitigate climate change issues and improve the quality of life for local population.

4.2.2 The future incubation strategy

The interview revealed a radical shift in the incubation strategy. Alongside TechNest, which will continue to function as a first-level incubator supporting early-stage start-ups, a second-level incubator (named "Palazzo dell'Innovazione") will be created to assist already established start-ups seeking growth and scalability. It is expected to become operational by 2026. Access to second-level incubator will be granted through a dedicated

call for applications, open also to start-ups external to the university ecosystem. This new incubation strategy aims to preserve the entrepreneurial assets developed over the years, building a hybrid university innovation ecosystem composed of: (i) early-stage start-ups incubated in TechNest; (ii) firms in a more advanced development stage, previously incubated in TechNest and are currently located within TechNest or other UniCal premises; (iii) firms external to the university ecosystem.

Figure 1 provides an overview of the future innovation ecosystem of the UniCal.

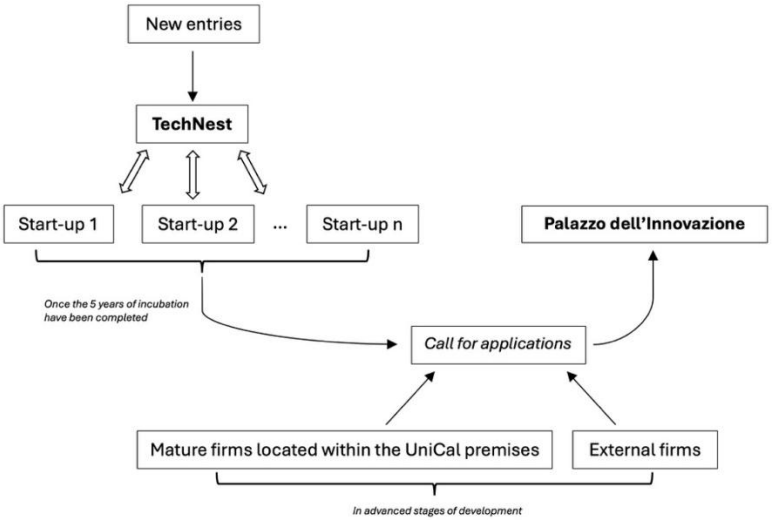


Figure 1: Future UniCal's Innovation Ecosystem (authors' elaboration)

4.2.3 A synthesis framework

Figure 2 graphically outlines the entire discussion conducted. The red rectangle encompasses the process through which TechNest fosters the development of external innovation networks, interconnecting its start-ups with external organizations, including potential firms from outside the university's innovation ecosystem, which will be hosted in the upcoming "*Palazzo dell'Innovazione*". At the same time, the firms that will be incubated within the second-level incubator could also establish connections with external organizations, expanding the external innovation network. The blue circle represents the process through which TechNest facilitates the development of internal innovation networks, enabling start-ups to interconnect and collaborate with each other. Finally, the green circle illustrates the process by which TechNest fosters hybrid innovation networks. This involves not only connecting its start-ups with other firms within the UniCal's innovation ecosystem but also linking them with external firms that will be located in the "*Palazzo dell'Innovazione*".

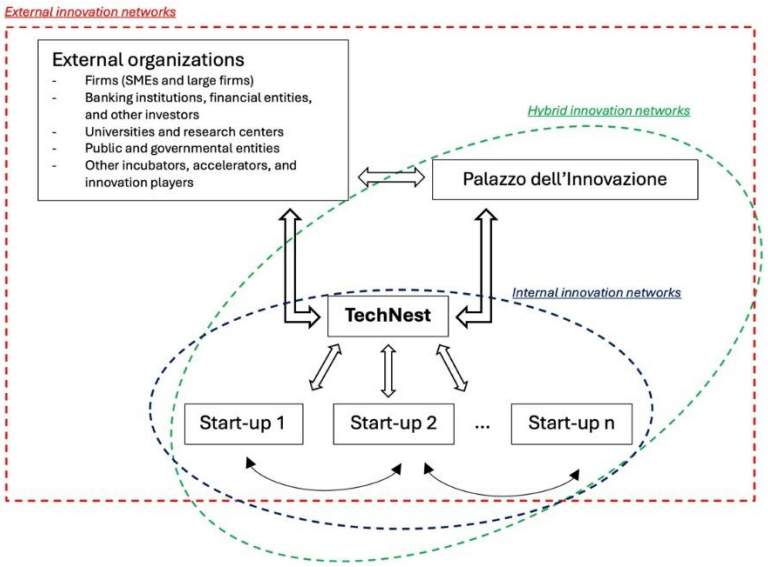


Figure 2: The process of OI diffusion by TechNest (authors' elaboration)

4.3 Limitations to overcome and untapped opportunities

Based on the collected data, incubated start-ups actively leverage the networking services provided by TechNest and demonstrate a growing inclination to open their innovation boundaries. This increasing openness is a significant trend, as the interview revealed that academic entrepreneurship start-ups are significantly affected by the "*Not-Invented-Here*" syndrome, a major barrier to OI adoption among Italian firms (Politecnico di Milano, 2024). This attitude leads firms to underestimate the products and ideas of other firms, considering them qualitatively inferior to those developed or potentially developable internally. As a result, establishing new partnerships for innovation development becomes more challenging. Consequently, TechNest start-ups often utilize networking opportunities to establish commercial collaboration agreements to compensate for their typical lack of marketing expertise, rather than engaging in pure OI projects. Our findings appear to align with previous studies, which have indicated that the OI approach is not entirely familiar to university spin-offs (Shutyak, 2016). Indeed, these firms often apply it unconsciously, by default (Shutyak, 2016). Specifically, as emphasized by van Geenhuizen and Soetanto (2012), such firms tend to develop highly closed innovation networks, as they primarily engage with a limited number of well-established actors, mostly at the local level. This, in turn, restricts their access to new knowledge and external resources.

Returning to our case study, in instances where OI projects have been implemented, the experiences have been overwhelmingly positive, with no major issues related to partner opportunism. This has been attributed both to the small firm's willingness to engage in an open manner and to the collaborative approach adopted by the external partner. As the manager remarked, "*this aspect is fundamental, because behaving in this way always leads to a win–win outcome for both parties*". Additionally, it was observed that start-ups engaging in OI achieved higher performance levels and revenue growth.

4.4 The challenges of operating in a disadvantaged region

TechNest's operations are significantly influenced by the regional economic and social context. Operating in an economically disadvantaged area presents numerous challenges, particularly in spreading OI processes among enterprises. The absence of major industrial hubs and large local players complicates efforts to integrate start-ups with the surrounding innovation ecosystem. While globalization alleviates some of these issues, the lack of investors remains a critical challenge. Unlike incubators in more developed regions such as Northern Italy—where venture capitalists routinely engage with start-ups—TechNest must actively seek out investors. To enhance Southern Italy's attractiveness for innovation investments, the manager advocates for policy improvements rather than new legislative measures. For instance, integrating targeted strategies within the Regional Operational Program could help sustain and finance incubators in the region. Despite these challenges, TechNest's achievements, although modest in absolute terms compared to incubators in more developed areas, are significant in relative terms within the regional context. Managing an ecosystem of firms generating millions in revenue underscores its success in fostering sustainable entrepreneurial growth in a challenging environment.

5 Conclusions

This research, through the case study of the UniCal's incubator "*TechNest*," investigates the role of BIs as OI intermediaries. Our findings confirm the crucial role played by incubators in promoting the adoption of OI processes by their incubated start-ups, thereby contributing to the development of both local and national innovation ecosystems. However, the analysis also reveals that start-ups operating in academic contexts tend to be more closed and less inclined to adopt pure OI processes in their innovation development. Furthermore, BIs emerge as key actors in fostering regional development, particularly in disadvantaged areas.

5.1 Theoretical and practical implications

From a theoretical perspective, this research contributes to the limited literature on the role of BIs as OI intermediaries, highlighting the operational strategies implemented by them to promoting the adoption of OI processes by their incubated start-ups.

Significant implications are provided for: (i) incubator managers, who should strategically implement specific activities in their incubation programs aimed at promoting the diffusion of OI among firms, as this services increasingly influence the attractiveness and competitiveness of incubators; (ii) managers of incubated start-ups, especially in academic context, who, by leveraging the networking activities provided by the hosting incubator, should open up to more partnerships with external organizations, as this can enhance their performance and thus their growth; (iii) policymakers, who should adopt actions that ensure the development of local and national innovation ecosystems, as this helps increase the level of innovations developed and thus

the country's competitiveness. Through specific changes in policy management, they should seek to increase funding for BIs, which are fundamental actors in the development of these ecosystems and, above all, in ensuring the growth of the entrepreneurial fabric of regions, particularly in disadvantaged areas. Moreover, they should look for ways to provide incentives to encourage start-ups and established firms to adopt partnerships for innovation development.

5.2 Limitations and future development of the study

The main limitation of this study lies in the fact that it analyzed only the perspective of a single incubator, without considering the viewpoint of the incubated start-ups. Therefore, this research represents only a starting point, as we intend to select and interview a sample of start-ups incubated in TechNest in the future to gain a more detailed understanding of their perspective on the adoption of OI processes, to identify the main motivations that drive them to establish or not establish collaborations. Moreover, for start-ups that report adopting OI processes, we aim to understand the main benefits and challenges they face throughout these types of relationships.

6 Acknowledgements

The authors would like to thank the managers of TechNest for their generous willingness to contribute to the development of this research.

7 Ethics declaration

This study does not require an Ethics Committee Approval.

8 AI declaration

The authors used AI-based tools to support a more accurate translation of the text.

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The Impact of Digitalization and Open Innovation on the Performance of Innovative Startups: A Systematic Literature Review

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Abstract

In a fast-changing and hyper-connected business environment, startups are increasingly challenged to innovate, scale efficiently, and remain competitive despite limited internal resources. This paper investigates how digitalisation and open innovation (OI) jointly impact the performance of innovative startups, with a particular focus on how digital technologies enable open innovation processes. To address this, the study adopts a systematic literature review (SLR) methodology, analysing 42 peer-reviewed articles retrieved from the Scopus database. The selected studies span various industries and geographic regions, although the majority are concentrated in developed economies and ICT-intensive sectors. The review identifies a growing interest in the role of technologies such as Artificial Intelligence (AI), Big Data Analytics (BDA), Internet of Things (IoT), Blockchain, and Cloud Computing as key enablers of both inbound (e.g., external knowledge sourcing) and outbound (e.g., licensing, platform participation) open innovation activities. Findings show that while digitalisation and OI are often studied in isolation, few models offer an integrated, startup-specific perspective. Moreover, most existing frameworks focus on financial performance, neglecting sustainable performance metrics such as environmental and social value creation. The analysis highlights several theoretical gaps, including a lack of longitudinal and cross-sectoral studies, and limited exploration of digital open innovation dynamics in early-stage firms. From a theoretical standpoint, the study maps the most frequently adopted frameworks—Resource-Based View (RBV), Dynamic Capabilities Theory (DCT), Knowledge-Based View (KBV), and Open Innovation theory—and proposes a conceptual model linking digital technology adoption, open innovation practices, and dual performance outcomes (financial and sustainable). This model provides a foundation for future empirical testing and theoretical refinement. On the managerial side, the paper offers practical insights for startup founders, innovation managers, and ecosystem developers, suggesting how digital tools can be strategically combined with open innovation practices to enhance agility, reduce costs, and drive long-term value creation. Overall, this study contributes to the literature by clarifying conceptual relationships, identifying key constructs, and outlining directions for future research at the intersection of digital transformation and collaborative innovation in startups.

Keywords: Digitalization, Digital technologies, Open innovation, Innovative Startups, Systematic Literature Review

Paper type: Academic Research Paper

1 Introduction

In an increasingly dynamic and interconnected business environment, organisations are under growing pressure to innovate continuously, adapt to market shifts, and leverage external sources of knowledge to sustain competitiveness. In this context, two concepts have emerged as central pillars of modern innovation strategies: digitalisation and open innovation (OI) (Wu et al., 2022). Digitalisation integrates digital technologies like AI, Big Data, IoT, Blockchain, Cloud Computing and digital platforms into business models and processes. These technologies enhance flexibility, improve data-driven decision-making and create pathways for innovation. (Hanelt et al., 2021; Wu et al., 2022). Open innovation, as described by Chesbrough (2003), involves using external knowledge to augment internal R&D and accelerate value creation. This approach involves actively seeking external resources (e.g. knowledge, technologies, ideas) through "outside-in" and "inside-out" processes (Holgersson et al., 2024). The former involves integrating external inputs (e.g. feedback, research, partnerships) to fuel internal innovation, while the latter allows companies to share their innovations with the external world, fostering new market opportunities and co-creation (Kraus et al., 2021). This stimulates product and service development, enhancing organisational adaptability and competitiveness. Digital transformation connects companies to external stakeholders, facilitating innovation. This integration fosters a dynamic, collaborative process. Customers can co-develop products and services, providing feedback (Gassmann et al., 2010), and suppliers and partners contribute expertise and innovations (Wu et al., 2022). Digital technologies therefore not only enable innovation but also expand the innovation ecosystem by facilitating collaboration.

Startups, by their very nature, operate in resource-constrained environments that often preclude large-scale internal R&D. This makes them particularly reliant on digital tools to scale efficiently and on external collaboration to develop and commercialise new products or services. Indeed, prior studies suggest that digital technologies can play a critical role in enabling startups to engage in open innovation practices, thereby reducing innovation costs, increasing speed to market, and enhancing performance (Del Bosco et al., 2021; Audretsch et al., 2023). Yet, the literature remains fragmented, with few studies offering a comprehensive framework that integrates these dimensions or focuses explicitly on early-stage firms. Against this backdrop, this paper seeks to answer the following research questions:

- *RQ1: How can the increasing pressure to adopt new digital technologies enable startups to open their boundaries for external collaboration?*
- *RQ2: How and to what extent does digitalization impact open innovation and startup performance?*

To address these questions, our study employs a SLR focusing on peer-reviewed publications analysing the intersection of digitalisation, open innovation and performance in startup contexts. It synthesises the theoretical insights of 42 selected articles to highlight research gaps and develop a model of digital technology adoption, open innovation and performance in innovative startups.

2 Methodology

This study conducted a SLR to examine how digitalisation drives open innovation and influences startup performance, adopting adopting a consolidated approach, the PRISMA Protocol (Page, 2021). This method primarily involves the planning, identification and appraisal of studies for the purpose of extracting and synthesising data from the literature (Tranfield et al., 2003). The protocol starts with defining how to identify and select articles for review. We retrieved the articles using a SCOPUS search query, as this database provides a comprehensive portfolio of scientific journals and is widely used in academic research (Filippelli, 2024). The query1 included variations of the term digitalisation and the keyword open innovation, to ensure the inclusion of a broad set of relevant documents. The initial search returned 118 results, which were subsequently filtered based on access to full-text articles and alignment with the research scope, in accordance with PRISMA protocol. This screening process led to the selection of 42 articles deemed most relevant to the investigation.

All the bibliographic information from the sample was exported into an Excel spreadsheet. The dataset was then enriched with additional variables aligned with the objectives of the review, to support a comprehensive coding process. We identified and applied a set of classification dimensions (e.g., year, journal, geographical scope, digital technologies, type of open innovation, performance indicators, methodological approach, theoretical frameworks, industry focus, firm type, main variables, and research objectives) that allowed us to systematically analyse and compare the 42 selected articles.

3 Bibliographic analysis

This analysis aimed to map the structure and characteristics of the literature, providing insights into the technologies discussed, temporal publication trends, geographical distribution, and journal coverage.

3.1 Publication by years

We analysed publications volume over time (Figure 1). The earliest publication was in 2005, with a rise in scholarly attention starting in 2015, reflecting industry digital transformation and open innovation (Hanelt et al., 2021). A peak in publications in 2023 is due to post-pandemic digital acceleration and new models (Jabeen et al., 2023). The slight drop in 2024 is due to data covering only the first four months of the year.

[1] (TITLE-ABS-KEY ("digitalization" OR "digitization" OR "digitalisation" OR "digitisation" OR "digital transformation" OR "digital technolog*") AND TITLE-ABS-KEY ("open innovation")) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (SUBJAREA , "BUSI")) AND (LIMIT-TO (LANGUAGE , "English")).

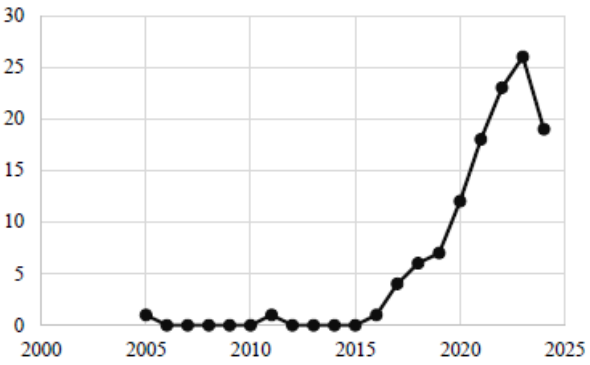


Figure 1: Publishing trend.

3.2 Publication by journal

Figure 2 illustrates the distribution of publications across journals. The European Journal of Innovation Management led the list with 8 articles, indicating its prominence in this domain. Technovation followed with 6 articles, while Journal of Business Research, Technological Forecasting and Social Change, IEEE Transactions on Engineering Management, Journal of Knowledge Management, and International Journal of Innovation and Technology Management each contributed 4 articles.

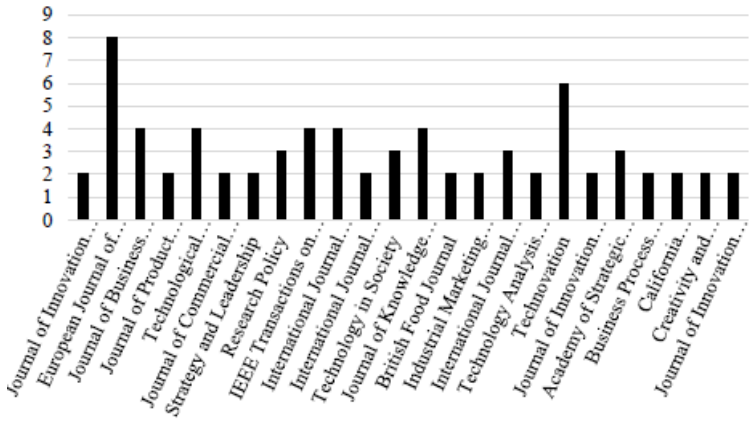


Figure 2: Publications by journals.

3.3 Country analysis

We analysed the geographical distribution of papers to understand global research trends at the intersection of digitalisation, open innovation and startup performance (Figure 3). While it's hard to assign a single country to each study, we can get an overview by considering the nationality of the corresponding author. This highlights the most active countries in the research and allows us to infer the impact of national innovation ecosystems on scholarly output. The United Kingdom led the field with 35 publications, reflecting its innovation ecosystem and strong institutions. The United States followed with 32 publications, likely driven by its global leadership in investment and infrastructure. The Netherlands ranked third, with 28 contributions, underscoring its startup environment, favourable regulations, and public-private collaboration. Singapore, Germany, and Switzerland also contributed significantly, benefiting from research infrastructures and policy support. These findings suggest that national policies and innovation ecosystems play a pivotal role in research output. Strong digital infrastructure and R&D investment leads to more impactful research.

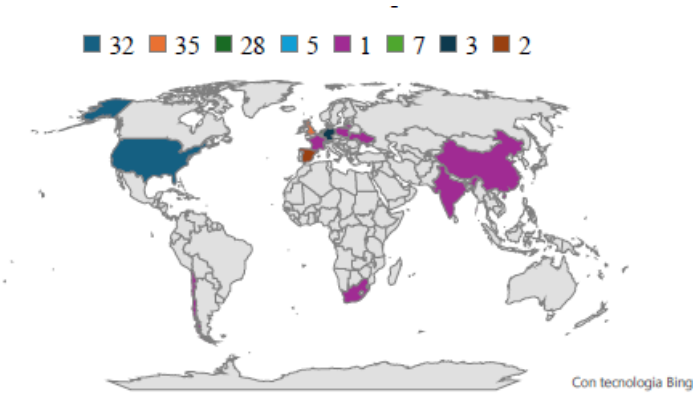


Figure 3: Paper distribution per country.

3.4 Mapping digital technologies

We tracked technologies across all 42 articles, identifying which ones were mentioned. Technologies such as AI, Big Data, IoT, Cloud Computing etc. were included, although not all articles explicitly referenced them. The resulting data mapped where digitalisation is being used in various contexts. Figure 4 shows the relative frequency of each technology. Big Data and Artificial Intelligence are the most frequently cited, highlighting their role in data-driven decision-making and automation. IoT is commonly linked to predictive maintenance and logistics, while Blockchain, Cloud Computing and Digital Platforms support secure, scalable and collaborative innovation. Robots are used less frequently and more specially.

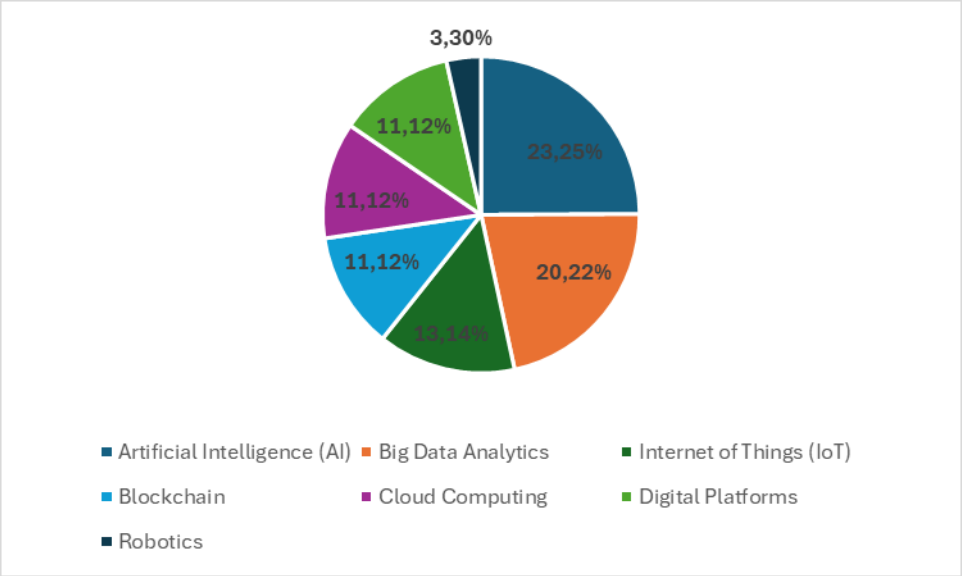


Figure 4: Frequence of technologies.

4 Content analysis

4.1 Thematic clusters and research objectives

The critical content analysis revealed that the 42 selected studies pursue three main research objectives, which form the basis of our categorisation:

- Assessing the impact of digital technologies on innovation performance: many studies investigate how technologies such as AI, IoT, BDA, and blockchain enhance firms' capabilities to innovate, collaborate, and remain competitive (e.g., Rialti et al., 2022; Oduro and De Nisco, 2023).
- Exploring the enablers and mechanisms of open innovation in digital contexts: several contributions focus on understanding the conditions under which open innovation flourishes in digitally advanced environments, identifying factors such as organisational culture, absorptive capacity, and digital maturity (e.g., Marshall et al., 2021; Bertello et al., 2024).

- Examining the interplay between internal resources and external knowledge sourcing: this stream of research delves into how firms balance internal innovation efforts with the integration of external knowledge, often through collaborative platforms or ecosystems (e.g., Bogers et al., 2018: Appio et al., 2024). To further structure the review, each article was also classified into one or more thematic clusters based on the technological focus and organisational context addressed.

The analysis led to the identification of eight key research domains, detailed in Table 1.

Table 1: Main research clusters.

Research cluster	Description	References
Management and strategy	Focus on how digital tools reshape organisational capabilities, innovation processes, and leadership models	e.g., Granig and Hilgarted, 2022; Yun et al., 2023
Industry 4.0 and manufacturing	Focus on smart factories, cyber-physical systems, and integrated production systems leveraging IoT, AI, and BDA	e.g., Crupi et al., 2020; Oduro and De Nisco, 2024
Digital Platforms and ICT	Address the role of digital ecosystems, platform-based business models, and virtual collaboration environments	e.g., Arias-Pérez et al., 2022; Appio et al., 2024
Startups and SMEs	Examine how small firms adopt digitalisation and open innovation to overcome resource constraints and accelerate growth	e.g., Jabeen et al., 2023; Tallarico et al., 2024
Agri-food and traceability	Investigate blockchain-enabled transparency, supply chain integration, and digital food safety systems	e.g., Bigliardi and Filippelli, 2022; Kafetzopoulos et al., 2023
Banking and finance	Explore digital financial services, open banking models, and the role of APIs in collaborative innovation	e.g., Stefanelli and Manta, 2023
Health and e-Health	Focus on remote healthcare services, health data sharing, and e-health platforms	e.g., Ghasemzadeh et al., 2022
Tourism and Smart Cities	Study co-creation in tourism, digital experiences, and smart infrastructure	e.g., Ferràs et al., 2020; Han, 2024

4.2 Theoretical frameworks and key variables

To ensure a systematic and comparable analysis of key theories, theoretical frameworks and variables, detailed information from the quantitative studies was coded across a set of specific dimensions. Each article was reviewed to extract theoretical frameworks and reference models, operationalised constructs (i.e. analysed variables) and formulated hypotheses about construct relationships.

4.2.1 Key theories

As far as the theoretical foundation is concerned, the most frequently encountered frameworks include:

- Resource-Based View (RBV) (Barney, 1991) is one of the most frequently used theoretical frameworks, particularly in studies assessing how digital technologies serve as valuable, rare, inimitable, and non-substitutable (VRIN) resources. Digital capabilities, such as data analytics and AI, are seen as strategic assets that enhance a firm's ability to exploit external knowledge and generate competitive advantage through innovation (e.g., Arias-Pérez et al., 2022).
- Dynamic Capabilities Theory (DCT) (Teece, 2007) extends RBV by focusing on a firm's capacity to sense, seize, and reconfigure internal and external competencies in rapidly changing environments. Many reviewed articles use DCT to explain how digital technologies facilitate the continuous renewal of innovation capabilities and support effective knowledge integration through open innovation practices (e.g., Čirjevskis 2022).
- Knowledge-Based View (KBV), a branch of RBV, regards knowledge as the most strategically significant resource of the firm. This perspective is often adopted in studies exploring the mechanisms by which digital infrastructures (e.g., platforms, data systems) support the capture, transformation, and application of external knowledge in open innovation processes (e.g., Crupi et al. 2020)
- Technology-Organisation-Environment (TOE) Framework (Tornatzky and Fleischer, 1990) to explain the factors influencing technology adoption. Within this view, digitalisation is shaped by the interaction between technological capabilities, organisational readiness, and environmental pressures. This

framework is particularly relevant in startup contexts where external conditions (e.g., ecosystem maturity, regulatory support) play a key role in shaping innovation strategies (e.g., Wang et al., 2025).

4.2.2 Key variables

Five core constructs were consistently found across the literature, though often studied in isolation or within limited scopes:

- Adoption of Digital Technologies (ADT): most commonly measured through the extent to which firms integrate AI, BDA, IoT, blockchain, cloud computing, and digital platforms. ADT is often framed as an enabler of organisational flexibility, innovation responsiveness, and knowledge management (e.g., Lorenz et al., 2020).
- Inbound Open Innovation (IOI): this refers to the firm's capacity to source external knowledge, collaborate with partners, or co-develop solutions with stakeholders. Measures often include R&D partnerships, customer involvement, and academic collaborations (e.g., Sisodiya et al., 2013; Lee and Roh, 2023).
- Outbound Open Innovation (OOI): less frequently studied, this involves the external exploitation of internal knowledge through licensing, spin-offs, or platform-based dissemination. When present, this construct was frequently operationalised in studies of ecosystems and platform strategies (e.g. Lee and Roh, 2023).
- Financial Performance (FP): commonly assessed through growth metrics, ROI, profitability, and innovation output. These were typically self-reported in survey-based studies, though a few used secondary financial data for validation (e.g., Arias-Pérez et al., 2022).
- Sustainable Performance (SP): an emerging dimension in the literature, this includes environmental outcomes, social responsibility, and long-term stakeholder value. While less developed than financial metrics, it is gaining importance as a criterion for measuring innovation success in broader terms (e.g., Danarahmanto et al., 2020; Lee and Roh, 2023; Autio et al., 2024).

4.3 Research gaps and future directions

Despite growing academic interest and methodological richness, the critical analysis revealed gaps and limitations that constrain understanding of how digitalisation and open innovation influence firm performance, particularly in the context of start-ups.

A recurring issue in the literature is the fragmented nature of models, with many studies analysing partial relationships in isolation. However, very few studies integrate all key dimensions into a single framework. This lack of integration makes it difficult to understand how digital tools and collaborative innovation affect business outcomes. As a result, there is insufficient insight into the effects of digitalisation on open innovation efficiency and how performance influences future innovation strategies.

Secondly, while several studies mention startups in a generic sense, very few articles adopt a startup-specific lens in their research design (Cirule and Uvarova, 2022). The majority of the reviewed literature focuses on general Small and Medium Enterprises (SMEs) or large corporations, particularly in the manufacturing and ICT sectors. Startups, however, differ substantially from both SMEs and large firms in terms of resource constraints (e.g., limited funding and staff), organisational structure (e.g., flat hierarchies, high flexibility) and strategic focus (Spender et al., 2017). These structural differences suggest that findings derived from SMEs or corporates may not be directly transferable to startups. Moreover, startups often exhibit Greater reliance on external networks for innovation (Marcon ad Ribeiro, 2021), higher adoption rates of digital tools for agility (Gonçalves et al., 2022) and distinct performance metrics, including survival rate, scalability and ecosystem fit (Kulkarni et al., 2023).

Thirdly, although sustainability has emerged as a critical business imperative, especially in European policy and ESG frameworks, very few studies treat sustainable performance as a primary outcome in models connecting digitalisation and open innovation in startups.

Another observed limitation is the lack of diversity in geographical and sectoral scope. The majority of reviewed studies are conducted in developed economies (e.g., UK, US, Netherlands, Germany), focused on manufacturing or ICT-intensive industries. This concentration limits the generalizability of findings to other contexts, particularly emerging markets, where digital infrastructure and regulatory environments differ. Moreover, few studies offer cross-country comparisons or longitudinal views, making it difficult to assess how institutional environments shape the adoption of digital technologies and OI practices.

5 Conclusion

The aim of this study was to deepen the understanding of the relationship between digitalisation, open innovation (OI), and the performance of innovative startups through a systematic literature review (SLR). By analysing 42 peer-reviewed articles, the research has made several contributions to both the theoretical and practical discourse on how emerging enterprises can leverage digital tools and collaborative approaches to enhance their innovation capabilities and performance outcomes.

The findings confirm that digital technologies, such as Artificial Intelligence, Big Data Analytics, Internet of Things, blockchain, and cloud computing, play a pivotal role in enabling open innovation processes. These technologies not only improve startups' internal operational efficiency but also facilitate external knowledge exchange, reduce transaction costs, and allow for greater scalability. In particular, digitalisation acts as a bridge that connects startups with broader innovation ecosystems, allowing them to compensate for their typical resource constraints. Moreover, the review highlights that open innovation, when enabled by digital capabilities, can significantly impact two main performance dimensions: financial performance, by improving time-to-market, customer responsiveness, and innovation return on investment, and sustainable performance, by supporting longer-term value creation, stakeholder engagement, and socially responsible innovation, though this second dimension is still under-represented in empirical models.

5.1 Theoretical and managerial implications

From a theoretical standpoint, the review contributes by mapping the dominant theoretical frameworks used in the field, such as the Resource-Based View (RBV), Dynamic Capabilities Theory (DCT), Knowledge-Based View (KBV), and the Open Innovation paradigm. This allows scholars to understand which perspectives are shaping the discourse and where overlaps or blind spots exist. Moreover, it highlights a lack of integrative models that combine digitalisation, open innovation (inbound and outbound), and dual performance outcomes (financial and sustainable). Most studies tend to adopt single-theory approaches and examine partial relationships, indicating the need for more holistic, multi-theoretical frameworks in future research. Finally, it identifies the underrepresentation of startup-specific theories. While general innovation or strategic management theories are frequently applied, few studies tailor their models to reflect the distinctive characteristics of early-stage ventures, such as agility, external dependence, or scalability potential. This gap calls for the development of startup-sensitive theoretical models in future research.

For practitioners, particularly startup founders, innovation managers, and ecosystem developers, this study offers several practical insights derived from the aggregated academic evidence. The review highlights the technologies most frequently associated with successful innovation strategies (particularly AI, BDA, IoT, and cloud computing) which can help managers prioritise digital investments aligned with collaborative innovation goals. By identifying how digitalisation enables open innovation practices, the paper shows that digital tools are not merely enablers of internal efficiency but also crucial facilitators of external collaboration. Startups can use this insight to design more effective partnership strategies, reduce innovation costs, and speed up product development cycles. The findings suggest that outbound open innovation, though less studied, holds untapped potential for startups aiming to monetise internal capabilities or integrate into larger platforms and ecosystems. The emphasis on sustainable performance in emerging literature encourages managers to broaden their KPIs beyond financial growth, considering long-term value creation, environmental responsibility, and stakeholder impact, which are dimensions increasingly important for investors and policy frameworks.

5.2 Limitations and future research directions

Despite the contributions made by this study in systematising and conceptualising the relationship between digitalisation, open innovation, and startup performance, several limitations should be acknowledged. These limitations offer useful guidance for future research directions aiming to expand, test, or refine the framework proposed.

Firstly, the study is based exclusively on publications available in the Scopus database and written in the English language. While this ensures a level of academic rigour and peer-review quality, it may also introduce a language and indexing bias, potentially excluding valuable research conducted in local contexts or published in non-English academic journals. For instance, regional innovation ecosystems, particularly in Latin America, Africa, or Asia, may be underrepresented despite exhibiting unique models of digital adoption and collaborative practices. Future reviews could integrate other databases (e.g., Web of Science) and include multilingual sources to provide a more comprehensive global picture.

A second limitation lies in the cross-sectional nature of most studies included in the review. Innovation processes and digital adoption strategies are dynamic and evolve over time. A startup's maturity level, funding stage, or market positioning can significantly influence its ability to engage in open innovation and scale through digital tools. Consequently, longitudinal studies are needed to capture the temporal evolution of digital and collaborative capabilities, providing a more nuanced understanding of their impact on long-term performance and sustainability.

Lastly, while financial performance remains the most commonly used outcome variable, sustainable and ESG-related performance metrics are still largely neglected. As the role of startups in shaping responsible innovation and contributing to socio-environmental goals becomes more prominent, future research should integrate non-financial indicators, such as environmental sustainability (e.g., carbon footprint reduction, circular business models), social impact (e.g., inclusion, well-being, ethical innovation) and governance quality (e.g., transparency, stakeholder engagement). This would allow for a multi-dimensional assessment of startup performance, aligned with the evolving priorities of investors, institutions, and society.

6 Ethical Statement

This research did not require ethical approval, as it did not involve human participants, nor the collection of personal data, nor any other elements that would have required review by an ethics committee.

7 AI Statement

ChatGPT (OpenAI) was used solely to assist with language-related tasks such as translating and editing the manuscript into English. All AI-generated content was carefully reviewed and edited by the author to ensure accuracy and consistency with the scientific objectives of the study.

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Enabling and Hindering Factors in the Collaboration Between Startups and Big Enterprises within Innovation Ecosystems: A Focus on Sustainability and Digitization

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Abstract

The concept of Innovation Ecosystem has taken on a central role in corporate innovation strategies and industrial policies, representing a key element for competitiveness and economic growth. Innovation Ecosystems differ from traditional ecosystems due to their emphasis on cross-sector cooperation and the integration of heterogeneous skills, facilitating the alignment of supply and demand for innovation and fostering knowledge dissemination. In this context, startups emerge as key players thanks to their agility, experimentation capabilities, and focus on technological discontinuity.

However, startups face numerous challenges, including a high risk of failure, technological and market uncertainty, and difficulties in accessing financial resources and strategic networks. To overcome these obstacles, they often engage in collaborations with established companies within an Innovation Ecosystem, in line with the Open Innovation paradigm. Despite the growing attention to these ecosystems, the startup perspective remains underexplored in academic literature.

This study aims to analyze the main factors influencing the success or failure of startups in Innovation Ecosystems, with a particular focus on the role of collaborations with large companies, sustainability, and digitalization. To achieve this goal, the research framework is structured into three main phases: (1) a systematic literature review to identify key variables and build a solid theoretical foundation; (2) the design of a questionnaire and a structured interview protocol based on the literature review findings; (3) an empirical analysis conducted through interviews with innovative startups operating in Innovation Ecosystems. The methodological approach combines quantitative and qualitative tools, enabling an in-depth understanding of collaboration dynamics.

The proposed analysis will contribute to expanding knowledge on interactions between startups and established companies, highlighting the necessary conditions for effective collaboration and the strategic role of digitalization and sustainability. The findings will provide valuable insights for both theory and practice, supporting businesses and policymakers in designing more effective and inclusive innovation ecosystems.

Keywords: Innovation Ecosystem (IE), Start-Ups, Open Innovation (OI), Digitalization, Sustainability

Paper type: Academic Research Paper

1 Introduction

In recent years, the concept of Innovation Ecosystem has become central in academic research and industrial strategies, promoting innovation and economic growth (Adner, 2006; Granstrand & Holgersson, 2020). These ecosystems comprise a network of actors, resources, and institutions that facilitate the innovation process (Jacobides et al., 2018), distinguishing themselves from traditional ecosystems through their emphasis on cross-sector collaboration, the integration of diverse competencies, and value co-creation (Kapoor, 2018).

Open Innovation (Chesbrough, 2003) has reinforced the role of Innovation Ecosystems by highlighting the importance of external collaborations in overcoming the limitations of closed innovation. Large corporations, research institutions, and startups are part of these ecosystems, leveraging knowledge sharing and technological advancements to accelerate innovation (Xiong et al., 2022). Startups play a crucial role due to their agility and disruptive potential (Spender et al., 2017), yet they face challenges such as financial constraints, limited access to strategic networks, and scalability difficulties (Gimenez-Fernandez et al., 2020).

Collaborations between startups and established companies present both opportunities and challenges: on the one hand, they provide access to resources and expertise; on the other hand, they may lead to dependency, strategic misalignment, and limitations on innovative autonomy (Polidoro & Yang, 2021). While research on Innovation Ecosystems has focused on their structure and benefits, it often lacks an analysis of dynamics from the startup perspective (Wang, 2021). Existing literature emphasizes the positive aspects of corporate-startup collaborations (Bereczki, 2019; Urbaniec & Żur, 2021), whereas more recent studies highlight critical issues such as power imbalances and the restrictive influence of large corporations on startups (Polidoro & Yang, 2021).

To address this gap, this study analyzes the enabling and constraining factors for startups within Innovation Ecosystems, with a particular focus on collaborations with established companies, sustainability, and digitalization.

The key research questions are:

- *What are the enabling and constraining factors in collaborations between startups and established companies within an Innovation Ecosystem?*
- *How do digitalization and sustainability influence these collaborations?*

The research adopts a mixed-method approach, including a systematic literature review, structured interviews, and case studies on startups operating within Innovation Ecosystems.

2 Method

The research methodology was structured into three main phases (Bigliardi et al., 2012). The first phase focused on a mixed-method analysis of existing literature, combining quantitative techniques such as bibliometric analysis with qualitative methods like a systematic literature review (Tranfield et al., 2003). This dual approach provided both a broad bibliographic overview and an in-depth understanding of key themes. Relevant articles were identified through a computerized search in Scopus and Web of Science (WoS), using keywords such as *start-up*, *entrepreneurial venture*, *new venture*, *young company*, *innovation ecosystem*, and *sustainable innovation ecosystem*. The search initially produced 254 results from Scopus and 114 from WoS.

After removing duplicates and applying a two-stage screening process, excluding incomplete records, unavailable full texts, and irrelevant content, the final dataset comprised 108 relevant articles. In the second phase, a questionnaire and a list of structured questions were developed based on the main issues identified in the literature. These tools formed the basis of a case study protocol designed to guide interviews. Finally, the third phase involved conducting structured interviews with innovative startups embedded in an innovation ecosystem. A case study approach, following Voss et al. (2002), was chosen to enrich and validate insights from the literature review through a deeper, context-specific exploration of innovation dynamics.

3 Description of Results

This section presents the results obtained from the data analysis, applying the previously described methodologies. First, the bibliometric analysis of the literature conducted on the examined sample of articles is explained. Then, the main findings of the systematic literature review are presented.

3.1 Bibliometric Analysis

This section presents the results of several bibliometric analyses conducted on a sample of 210 scientific articles. The scientific community's interest in this topic has been steadily growing, with a notable peak in publications recorded in 2023 (53 scientific contributions).

To conduct the keyword co-occurrence analysis, the open-access software VOSviewer was used, a specialized tool for the graphical representation of bibliometric maps. The resulting networks illustrate the connections between keywords, where node size is correlated with the number of articles each author has published on the topic or the frequency with which a keyword has been used. Figure 1 shows the keyword co-occurrence network, highlighting five main clusters.

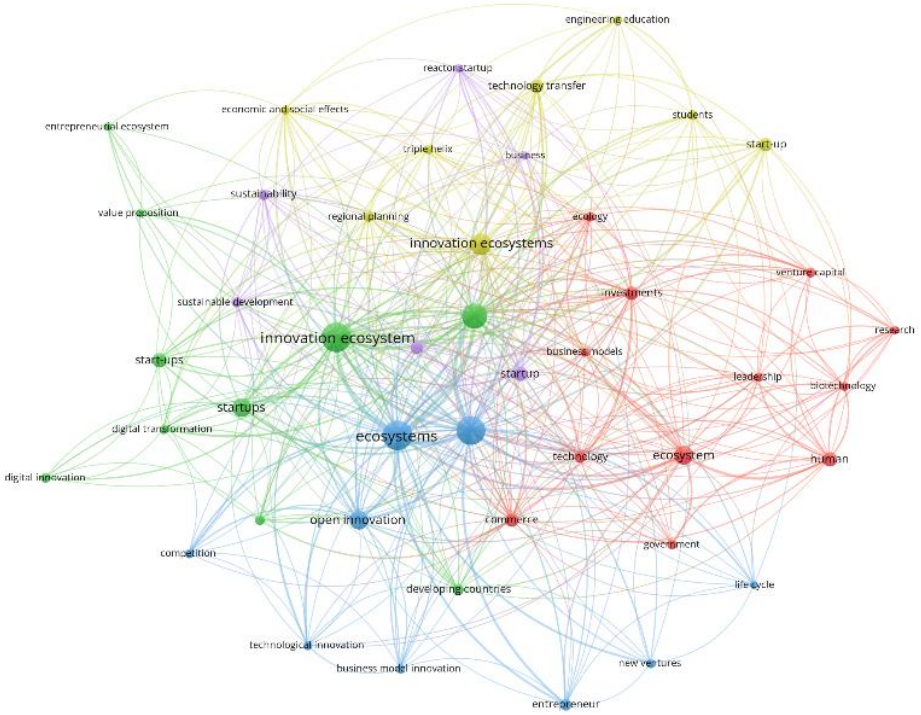


Figure 1: Co-occurence of keywords network carried out with VOSviewer.

The macro-areas investigated are easily identifiable thanks to the use of different colors in the network, while the nodes represent the keywords, and their size is proportional to the frequency of the keywords in the analyzed dataset. The content of the five identified clusters was carefully examined. The labels assigned to each cluster are reported in Table 1.

Table 1: Keywords co-occurence analysis

Keywords co-occurence analysis		
Color of the clusters	Name of the clusters	Main keywords included
Green	Digitalization	Innovation ecosystem; Digital transformation; Digital innovation; Entrepreneurship; Entrepreneurial ecosystem; Startup
Blue	Open Innovation	Open Innovation; Innovation; Business model innovation; Competition; New ventures
Purple	Sustainability Circular Economy	Sustainability; Sustainable Development; Startup; Business; Reactor startup
Yellow	Triple Helix	Triple Helix; Technology transfer; Startup; Innovation ecosystem; Regional planning; Economic and social effects
Red	Ecosystem Business Dynamics	Ecosystem; Venture capital; Leadership; Business model; Investment

3.2 Systematic Literature Review Analysis

The results of the sample article analysis, conducted following the methodology proposed by Gioia et al. (2013), are presented below. The adoption of this methodology made it possible to identify the main enabling factors, which facilitate the consolidation and growth of startups, as well as the hindering factors, which represent barriers and challenges in collaboration with established companies, the digitalization process, and the implementation of sustainable practices.

3.2.1 Risks and enabling factors for collaborations

In the innovation ecosystem, collaboration between different entities is a crucial challenge, as it involves the simultaneous sharing of various knowledge flows. Startups often find themselves needing to collaborate with established companies to access crucial expertise not available internally. However, such collaboration presents significant risks that can undermine the success of startups within the context of innovation ecosystems

(Kosorukova et al., 2023; Corvello et al., 2023). The results of the risk analysis for collaborations are summarized in Table 2.

Table 2: Risk analysis for collaborations

Risks analysis for collaborations	
First order concepts	Second order concepts
Complex integration within corporate goals; Continuous support from the innovation partners is critical; Ineffective use of underutilized incumbent resources; Organizational proximity embeds joint agreements between organizations; Short time for establishment	OPERATIONAL
Loss of IP control; IP risk exposure; knowledge transfer; Loss of autonomy; IP appropriation, Loss of control over their IP; Cocreation (sharing of intellectual property); Cooperation and exchange	IP
Conflict from diverging goals; Vision and goal misalignment	CONFLICT OF INTEREST
Limited resources; Extremely limited budgetary state funding; Financial instability; Large capital requirements; Limited resource	FINANCIAL
Risk of loss of autonomy due to premature acquisition by a larger company; Co-Existence; Co-Specialization; Heterogenous views; High level of interaction with other actor of ecosystem; Interdependence during collaboration; working cooperatively and competitively with other companies in order to co-evolve capabilities; Sharing goals; General risk of loss of autonomy within the collaboration; Imbalance of power that may lead to domination by the larger company; Operational autonomy hampered by dependence on the resources of the larger company; Collaboration should also be honest and transparent	LOSS OF AUTONOMY AND CONTROL
Absence of shared vision; Coordianational and organizational; Cross network alignment; Diverging interest and goals; Insufficient network leaderiship; Integration risk; Demoralisation of staff; Loss of support for the startup due to closure of critical outposts; Failure of collaboration without benefits to the startup; Minimal support of the incumbent due to underestimation of the startup's innovation; Misalignment of the solution with the requirements of the established company; Startup ideas are lost because the multinational company fails to develop or commercialize them	COLLABORATION
Loss of talent to established companies	RETENTION OF RESOURCE

At the same time, as previously mentioned, collaborations between large companies and startups promote the consolidation and growth of the latter. Being young entities with limited resources, collaboration with large companies allows startups to overcome this limitation, gaining access to global markets and strategic resources that would be difficult to reach on their own (Gupta et. al, 2021). The results of the enablers analysis for collaborations are summarized in Table 3.

Table 3: Enablers analysis for collaborations

Enablers analysis for collaborations	
First order concepts	Second order concepts
Having the opportunity to collaborate with leading companies provides access to markets and important resources, such as complementary technologies, complementary skills, funding, research and development, and research synergies; Creating platforms to attract investments in research development; Increasing access to venture capital, investment funds, and other necessary sources of financing to develop and expand technological activities.	RESOURCE
Having the opportunity to collaborate with leading companies provides access to markets and important resources, such as complementary technologies, complementary skills, funding, research and development, and research synergies; Assistance in technology transfer; Increased capacity to produce new methods and products; Being part of an innovation ecosystem can provide access to advanced technological resources that might otherwise be out of reach for a single startup; … a faster flow of innovative ideas, collaborative problem-solving, and sharing of best practices,	TECHNOLOGICAL
Having the opportunity to collaborate with leading companies provides access to markets and important resources, such as complementary technologies, complementary skills, funding, research and development, and research synergies; Creating links and alliances between actors; improved collaboration and sharing of goals; increased investment in R&D.	HUMAN COMPETENCE AND EXPERIENCE

Enablers analysis for collaborations	
First order concepts	Second order concepts
Collaboration has a significant effect on survival; Social networks and a collective dimension open to the "new"; Interaction with suppliers, customers, and organizations offering complementary services to stimulate innovation; Collaboration offers the opportunity to connect with a network of people and organizations, increasing the chances of future partnerships and relationship-building,	EXTERNAL INTERACTIONS
Increase in the number of patents.	IP
A successful innovation ecosystem is characterized by a well-organized, collaborative, and supportive environment, with vibrant exchanges among ecosystem members.	ORGANIZATIONAL

3.2.2 Risks and enabling factors for digitalization

Below, in tables 4 and 5 the factors that enable and hinder the digitization process, which profoundly influences the way startups and large companies operate, innovate, and interact with each other, will be analyzed (Chekanov, 2022; Felicetti et. al, 2023).

Table 4: Risk analysis for digitalization

Risk analysis for digitalization	
First order concepts	Second order concepts
Perception of risk; Administrative and legal barriers limiting the adoption of digital solutions; Fragmented ecosystem; Lack of support from the ecosystem.	GOVERNMENTAL
Rigidity of organizational structures; Complexity and rigidity of established companies; Need for physical interactions; Network limitations; External dependency; Limited functional connections.	OPERATIONAL
Cyber-attacks; Limited access to information; Data privacy issues.	IP
Uncertainty and lack of trust among potential partners; Power imbalance; Information asymmetry.	CONFLICT OF INTEREST
Limited resources and capabilities; High funding requirements and development costs.	FINANCIAL
Resistance to change from established companies; Coexistence; Co-specialization; Heterogeneous visions; Power imbalance that may lead to dominance by the larger company; Operational autonomy hindered by dependence on the larger company's resources; Collaboration should also be honest and transparent.	LOSS OF AUTONOMY AND CONTROL
Difficulties in collaborating with new entities such as startups; Inadequate collaboration among stakeholders; Lack of a shared vision; Diverging interests and objectives; Insufficient network leadership; Demoralization of personnel; Loss of support for the startup due to the closure of critical outposts; Failure of collaboration without benefits for the startup; Minimal support from the incumbent due to underestimation of the startup's innovation; Misalignment of the solution with the requirements of the established company.	COLLABORATION
Loss of talent to established companies; Disparity in access to digital technologies between large and small companies; Lack of awareness; Lack of technological skills; Difficulty in hiring employees with strong digital skills.	RETENTION OF RESOURCE

Table 5: Enablers analysis for digitalization

Enablers analysis for digitalization	
First order concepts	Second order concepts
Need for investments; Support for market access	RESOURCE
Technology integration; Structured phases of digital innovation	TECHNOLOGICAL
Access to digital skills; Training and Talent Development; Resilience and capabilities; Teaching and mentorship; Use of creativity and experience of end users; Support from leaders; Design Thinking	HUMAN COMPETENCE AND EXPERIENCE
Accelerators and incubators; Relationships with universities, startups, and research centers; Government support; Public-Private collaborations; Corporate engagement; Connections and relationships; Support for local networks and complementary resources; Collaborations with established companies	EXTERNAL INTERACTIONS
Cultural and physical spaces; Alignment among stakeholders; Facilitation by mediators; Creation of a collaborative ecosystem; High speed in innovation cycles; Lean methodology; Open Innovation ecosystem; Good openness in maintenance activities; Social Network structures; Integration of external stakeholders	ORGANIZATIONAL

3.2.3 Risks and enabling factors for sustainability

The integration of sustainable practices in companies and startups can be a complex process due to numerous obstacles that slow down their adoption and diffusion (Audretsch et. al, 2018). Table 6 presents the main obstacles to the implementation of sustainable practices.

Table 6: Risk analysis for sustainability

Risk analysis for sustainability	
First order concepts	Second order concepts
Standard organizations; Pollution issues; Climate change; Regulatory constraints; High taxes	GOVERNMENTAL
Distance between mature and growing ecosystems; Complexity in the food ecosystem; Changes in the supply chain	OPERATIONAL
Intellectual property issues; Disruptive technologies; Offices and patents	IP
Risk of greenwashing; High competitiveness	CONFLICT OF INTEREST
Financial conflicts; Economic crises; Limited access to funds for sustainable innovation; High costs; Financial and market constraints; High capital requirements; Insufficient competitive models	FINANCIAL
Cultural resistance	LOSS OF AUTONOMY AND CONTROL
Lack of customer interest; Lack of consumer information	COLLABORATION
Limited resources; Lack of skills	RETENTION OF RESOURCE

Startups show a greater inclination towards sustainable models, frequently adopting circular strategies inspired by the principles of Circular Economy to develop their business models (Bigliardi and Filippelli, 2021). Table 7 presents the main enabling factors for sustainability.

Table 7: Enablers analysis for sustainability

Enablers analysis for sustainability	
First order concepts	Second order concepts
Set of incubators and accelerators; Sustained business growth; Universities and research	RESOURCE
Innovative technologies	TECHNOLOGICAL
Entrepreneurial leadership; Long-term thinking; Management support	HUMAN COMPETENCE AND EXPERIENCE
Companies that stimulate knowledge variation; Growth in demand for sustainable products	EXTERNAL INTERACTIONS
Collaborations between entities; Pollution reduction; Diversification into the right market with an innovative product; Mission focused on innovation; Initiatives that support the innovation ecosystem; Transparency; Alignment in the value chain	ORGANIZATIONAL

4 Case Studies

This section presents two case studies of innovative Italian startups, based on semi-structured interviews that examine collaboration dynamics with large companies. The analysis focuses on the influence of digitalization and sustainability, aiming to identify key enablers, barriers, and the role of regulations and emerging technologies in supporting these partnerships.

4.1 The AgerTech case

AgerTech is an innovative Italian startup based in Turin, founded in 2024, and active in the Agrifood sector and artificial intelligence. Its core product, AgerIX, is a WhatsApp-based digital assistant that automates the collection and organization of business data. Through an intuitive dashboard, agronomists can manage farms and generate detailed reports, improving efficiency and communication with producers.

“Innovation ecosystems have been a key element for us, not only to receive feedback but also to build a solid network,” says Mara Verri, CEO and Founder of AgerTech.

After three years of activity, the company has pivoted to better align with market needs. While it is currently receiving positive feedback and expects substantial growth, it still faces major challenges such as intellectual property protection and cost management. Support from incubators and accelerators, such as Le Village, has

been “crucial in addressing these challenges, providing networking opportunities and facilitating entry into new markets.”

On a local level, AgerTech has leveraged innovation ecosystems to build collaborations with various institutions, allowing the company to adapt its solutions to the specific needs of different agricultural contexts.

4.1.1 Collaborations with Big Enterprises

Partnerships with large companies and incubators represent a key element for AgerTech. In addition to financial support, these collaborations offer business matching opportunities and access to new markets. Belonging to an innovation ecosystem facilitates strategic connections and enables the sharing of material and financial resources, reducing operational costs.

One of the crucial aspects of AgerTech's strategy is the protection of intellectual property: while collaborating with large companies, the startup aims to maintain its autonomy in product development and customization. "*Although large companies often seek more control, autonomy is non-negotiable for us: we want to innovate and compete without compromises*," explains the founder.

Thanks to partnerships with established players, AgerTech has developed strategic relationships that allow it to access new markets and strengthen its competitive position. However, for emerging startups, the risk of becoming overly dependent on large companies remains a challenge that must be managed carefully.

4.1.2 Digitalization

Digitalization is AgerTech's main strength, operating in a market with a growing demand for innovative technological solutions. However, the startup faces bureaucratic and regulatory obstacles that slow down the integration of their technologies. To overcome these barriers, AgerTech relies on specialized consultants and offers digital tools to simplify agricultural data management.

Despite the added value of their solutions, the startup does not receive adequate government support to foster the digitalization of the sector. "*A state intervention could make a difference, for example, by incentivizing companies that collaborate with startups*," suggests the founder. Such measures would help overcome difficulties related to high costs, training times, and a lack of digital skills, facilitating the technological transformation of Italian agriculture.

The adoption of new technologies in the agricultural sector represents an opportunity not only to optimize data management but also to improve the quality of the final product and the sustainability of the entire production process. However, the change requires a strong commitment from both institutions and companies in the sector, so that innovative solutions can be implemented on a large scale.

4.1.3 Sustainability

Sustainability is another central element in AgerTech's vision. The company is committed to developing solutions that not only improve operational efficiency but also promote more sustainable agricultural practices. Through the digitalization of processes, AgerTech helps agricultural businesses reduce waste of resources such as water and fertilizers, optimizing the use of agricultural inputs through intelligent data monitoring.

"*We have created a tool that enables more informed decision-making, with both economic and environmental benefits*," says the CEO. However, the transition to more sustainable agricultural practices is still hindered by resistance to change and the lack of specific incentives. AgerTech hopes for greater support from institutions to encourage widespread adoption of new sustainable technologies in the agricultural sector.

For AgerTech, sustainability is not limited to waste reduction: the startup is also committed to optimizing the agricultural supply chain, reducing emissions related to transportation and logistics. "*Making the supply chain more efficient means not only saving on costs but also reducing environmental impact*," emphasizes the CEO.

Furthermore, digitalization can promote the use of regenerative agricultural practices, helping farmers implement environmentally friendly cultivation techniques. AgerTech aims to become a reference point for those who want to innovate without compromising the sustainability of their production model.

4.2 The HumanWE case

Founded in 2023 and based in Emilia-Romagna, HumanWE is a startup in the Early Growth phase, currently employing five people. Operating in the environmental sustainability sector, it has developed ESGAnalytics, a software platform that automates sustainability reporting. The tool provides a centralized, reliable data repository, helping companies save time on manual tasks and focus on analyzing ESG goals and shaping sustainable business strategies.

4.2.1 Collaborations with Big Enterprises

HumanWE has built a strategic network of collaborations with incubators, universities, and major companies, such as Le Village and the RES.m HUB of Università Cattolica in Piacenza, gaining access to funding, scientific expertise, and business opportunities. A key partnership with the University of Parma has supported research on AI applied to ESG regulation.

"I strongly believe in collaborations with universities, especially in the scientific field," says CEO Antonello Bartolone. "Our first meeting with the University of Parma was based entirely on an exchange of ideas… with no financial request from the university. This shows there is a strong interest in developing innovative solutions together."

The startup has also partnered with large companies in tech and environmental sectors to enhance ESG data analytics. "We found companies willing to believe in our vision and actively collaborate to improve sustainability management in businesses," Bartolone notes. Still, he acknowledges the difficulties of working with large firms: "A mindset change is needed to value small innovative companies."

4.2.2 Digitalization

HumanWE invests in digitalization through the strategic use of Artificial Intelligence, collaborating with academic institutions to develop advanced algorithms. The company is also exploring the use of emerging technologies such as blockchain for ESG data certification and Big Data Analytics to improve the management of business information.

"*Artificial Intelligence should not just be a trend, but a real added value," emphasizes Bartolone. "We decided not to limit ourselves to integrating existing chatbots, but to develop proprietary algorithms capable of effectively supporting companies in managing their ESG strategies. Our goal is to provide an intelligent tool that can interpret data and guide managers in decision-making*."

HumanWE has also invested in automating internal business processes, reducing the time needed to process ESG reports and improving the accuracy of analyzed data. Digitalization must be a concrete support for companies, not an obstacle. For this reason, HumanWE develops user-friendly tools that facilitate the adoption of new technologies.

Despite the potential of digitalization, the startup faces difficulties in accessing funding for technological innovation. "*Funding opportunities for innovative startups exist, but they are often difficult to access. The application process is complex, and the available resources are not always sufficient to support large-scale technology adoption*," explains the CEO.

4.2.3 Sustainability

HumanWE is a benefit company committed to integrating sustainability into every aspect of its operations. "*Being sustainable is not just an obligation; it is our mission*," says Bartolone. The company uses data centers powered exclusively by renewable sources and adopts energy-efficient technological infrastructures.

HumanWE has also introduced corporate policies aimed at promoting diversity and inclusion because it firmly believes that sustainability is not just environmental but also social. In fact, "*an inclusive and diverse work environment contributes to creating a more cohesive and innovative team*."

However, HumanWE faces several challenges in pursuing its sustainable business model. The main obstacles include the high costs of sustainable practices and the need for adequate funding. Adopting sustainable practices involves significant initial investment. Therefore, it is essential for institutions and investors to recognize the value of sustainability and support companies that choose this path.

In this context, HumanWE has joined the GRI Community (Global Reporting Initiative), the leading international organization for sustainability reporting. "*Joining the GRI Community is a strategic step for us. It allows us to stay updated on regulatory developments and to develop solutions that are increasingly in line with the needs of companies*," says Bartolone. HumanWE's experience demonstrates that sustainability and digitalization can be drivers of growth for startups, provided there is a favorable ecosystem, made up of investments, collaboration, and an appropriate regulatory framework.

5 Conclusion

This research aimed to analyze the role of startups within Innovation Ecosystems, with a particular focus on enabling and hindering factors that influence digitalization, sustainability, and strategic collaborations with large companies. Starting from a literature review and a study based on a Multiple Case Study analysis, the paper provided a clear framework of the dynamics characterizing these interactions.

In terms of future developments, this research suggests several possible directions. In particular, it would be useful to focus on (i) the motivations for startups to enter into collaborative relationships, providing strategic information on how these collaborations can be effective and efficient; (ii) further studies could investigate the impact of specific digital technologies (such as artificial intelligence or blockchain) on the dynamics of Innovation Ecosystems; (iii) it would be useful to expand the sample of analysis by including startups from different industrial sectors and geographical areas to better understand the contextual variables influencing the success of strategic collaborations.

This approach will provide a more comprehensive and detailed understanding of the challenges and opportunities that startups face in innovation ecosystems, helping to develop more focused and sustainable strategies for their long-term success. In conclusion, this research provides useful insights both for the academic world and for businesses, offering tools to strengthen collaborations between startups and large companies and promote a more integrated and resilient innovation ecosystem.

6 Ethics declaration

This research is based on the analysis of two business cases using publicly available information and voluntary interactions with company representatives. No personal or sensitive data were collected, and no procedures were carried out that required approval from an ethics committee. Therefore, no formal ethical clearance was sought or obtained.

7 AI declaration

ChatGPT (OpenAI) was used exclusively as a language support tool for translating and revising the manuscript into English. All content generated by this AI tool was carefully reviewed and adapted by the author to ensure accuracy and alignment with the scientific objectives of the research.

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Mental Models for Entrepreneurial Ecosystems: A Simulation Experiment

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Abstract

Entrepreneurial ecosystems are increasingly seen as complex, dynamic environments requiring effective coordination by ecosystem orchestrators. While prior research has focused on structural and institutional elements, little is known about the cognitive processes guiding orchestrators' decisions. This study addresses this gap by examining how mental models influence ecosystem performance. The study analyzes three key attributes of mental models: complexity, centrality, and accuracy. Data were collected through a simulation environment where eleven teams played the role of orchestrators across ten rounds of strategic decision-making. Using a fuzzy-set Qualitative Comparative Analysis (fsQCA), the study identifies two causal configurations sufficient for high performance: one based on high centrality and the other on high complexity, both combined with low accuracy. The findings suggest that orchestrators can adopt different cognitive strategies to achieve strong outcomes, challenging the assumed importance of accuracy. The study contributes to the literature on entrepreneurial ecosystems and managerial cognition, offering practical insights for those aiming to enhance ecosystem performance through cognitive and strategic design.

Keywords: entrepreneurial ecosystem; mental model; decision making

Paper type: Academic Research Paper

1 Introduction

Entrepreneurial ecosystems have enriched entrepreneurship theory by offering a systemic approach to support the creation and growth of new ventures (Cavallo, Ghezzi, and Balocco, 2019). Entrepreneurial ecosystem theory highlights the importance of a supportive environment for new ventures and entrepreneurs (Acs, Autio, and Szerb, 2014). The existing literature has expanded significantly, offering various educational frameworks to guide policymakers and strategists in creating or fostering entrepreneurial ecosystems in the real environment. These frameworks provide tools to interpret or manage ecosystems by focusing on actors and resources (Isenberg, 2010, 2011; Stam and Van de Ven, 2021) or governance structures (Colombo et al., 2019). However, due to the diversity of actors and resources involved in entrepreneurship, ecosystem managers—better referred to as orchestrators, i.e., those who perform orchestration activities that influence the network and its members (Hurmelinna-Laukkanen and Nätti, 2018)—often face challenges in managing innovation networks and identifying key actions or measures to effectively promote entrepreneurship (Jung, Eun, and Lee, 2017). While prior research has identified critical drivers and metrics to inform and guide orchestrators (Cavallo, Ghezzi, and Sanasi, 2021) or explored the roles orchestrators assume and their related capabilities (Hurmelinna-Laukkanen and Nätti, 2018; Tabas, Nätti, and Komulainen, 2023), the literature has not examined factors that influence orchestrators' decisions. Specifically, no studies have investigated how theoretical knowledge, experience, or entrenched assumptions affect their decision-making processes within entrepreneurial ecosystems.

This paper introduces a novel perspective by analyzing how ecosystem orchestrators interpret and apply theoretical knowledge in their decision-making—particularly how theories on entrepreneurial ecosystems guide their efforts to coordinate complex systems of actors and achieve positive performance. The analysis focuses on a micro-level perspective that analyse key concepts and schemas that guide decisions in complex contexts such as that of entrepreneurial ecosystem. A field not yet explored by any researchers.

Drawing on behavioral decision-making literature (Guiette and Vandenbempt, 2013; Schwab, 2007; Gavetti et al., 2012) and managerial cognition studies (Blettner, 2011; Gary, Wood, and Pillinge, 2012), this study examines how theories shape managerial mental models. Managerial mental models are defined as "*models that managers use to map the competitive landscape of their industries and rationalize their strategic decisions*" (Yang et al., 2016, p. 899).

While previous literature has primarily focused on firm-level decision-making and its impact on performance (Nadkarni and Narayanan, 2007), investigating the net effects of mental model variables on firm outcomes, this

study addresses a double gap. First, mental model theory has not yet been applied to the analysis of decision-making processes and performance in the context of entrepreneurial ecosystem managers. Second, whereas traditional research typically investigates linear relationships between variables, this study adopts a configurational perspective to explore how different combinations of mental model characteristics relate to ecosystem performance.

More precisely, it examines how orchestrators' mental models of entrepreneurial ecosystems influence ecosystem-level outcomes, by addressing the following research question: *How do different configurations of mental model attributes shape the performance of entrepreneurial ecosystems?*

Recognizing that top-level decisions are typically made by teams rather than individuals (Klimoski and Mohammed, 1994), we assess mental models at the team level. Managing ecosystems requires dialogue and negotiation among diverse stakeholders, each representing unique entrepreneurial perspectives. This research employs a simulation-based experimental design using The Entrepreneurial Ecosystem Game (TEEG), a web-based simulation tool designed to model the dynamics of entrepreneurial ecosystems. Participants, in the role of ecosystem orchestrators, played the game over ten rounds, making strategic decisions to manage ecosystem development. Each of the eleven teams aimed to maximize startup creation while navigating resource scarcity, competition, and causal ambiguity—key features of real-world ecosystem management. TEEG provides a high level of realism through mechanisms such as temporal delays, feedback loops, and uncertainty, making it a suitable environment for observing how mental models influence strategic decisions and ecosystem-level outcomes.

The mental models were captured through conceptual maps, reconstructed from the strategic declarations of participants. Building on the literature in managerial cognition, we analyzed three key characteristics of these mental models: complexity (Bogner and Barr, 2000), centrality (Kiss and Barr, 2015), and accuracy (Denrell, Fang, and Levinthal, 2004; Gary and Wood, 2011). Ecosystem performance was measured by the number of startups created. The simulation environment allowed us to systematically track team strategies, performance trajectories, and the feedback they received over time, enabling full data collection for each case.

Given the exploratory nature of the study and the small number of cases (n = 11), we employed a fuzzy-set Qualitative Comparative Analysis (fsQCA) to uncover causal configurations that link mental model characteristics to ecosystem outcomes.

The results offer a new lens for understanding entrepreneurial ecosystems by connecting orchestrators' cognitive structures to performance outcomes. Specifically, we find that variations in mental models lead to differences in ecosystem performance. Notably, high levels of centrality or complexity appear to be sufficient conditions for high performance, while accuracy does not emerge as a necessary condition, either alone or in combination.

These findings contribute to both the entrepreneurial ecosystems and managerial cognition literatures, while offering practical implications for policy-makers and educators interested in fostering high-performing entrepreneurial ecosystems.

2 Theoretical Background

2.1 Entrepreneurial Ecosystems: toward a new lens of analysis

The literature on entrepreneurial ecosystems can be considered widely discussed (see Saxenian, 1994; Cohen, 2006; Isenberg, 2010; Feld, 2012). Entrepreneurial ecosystems have emerged as a relevant academic field that has helped explain how the external environment can impact individual entrepreneurship and the economic development of local configurations. The entrepreneurial ecosystem concept has provided a more evolutionary, non-linear, and socially interactive explanation of entrepreneurial dynamics (Colombelli, Paolucci, and Ughetto, 2017). It argues that entrepreneurship occurs within a community of interdependent actors situated in a specific area (Isenberg, 2010; Malecki, 2011). The literature has devoted considerable attention to defining entrepreneurial ecosystems and identifying their key attributes (Roundy et al., 2017). Some scholars have focused on the antecedents of ecosystems, drawing from strategy and regional development literatures (Yun et al., 2017; Erina et al., 2017), while others have proposed frameworks identifying the principal components of entrepreneurial ecosystems. Most frameworks have adopted an actor-centric approach, listing the main—primarily economic—actors characterizing an ecosystem. Further streams of research have discussed measures for evaluating the performance of entrepreneurial ecosystems (Jung, Eun, and Lee, 2017). Additionally, a body of literature has explored governance mechanisms, aiming to move beyond the static perspectives provided by earlier studies and introducing dynamic considerations regarding the evolving role of actors within ecosystems (Colombo et al., 2019; Borissenko and Boschma, 2017).

Despite the variety of topics already addressed, the literature on entrepreneurial ecosystems still offers room for further investigation (Cavallo, Ghezzi, and Balocco, 2019). Cavallo, Ghezzi, and Balocco (2019) call for a deeper understanding of several aspects, including the effects of digitalization on entrepreneurial ecosystems and a more precise identification of the critical components that significantly impact ecosystem performance. The latter point represents fuel for thought. Beyond identifying which components affect performance, it is also important to explore which components are perceived as critical by decision-makers themselves. This perspective introduces a novel lens through which to interpret entrepreneurial ecosystems—one that focuses on the behavior of orchestrators and the cognitive schemas guiding their strategic choices.

This exploration of cognitive schemas and critical ecosystem elements, as perceived by orchestrators, will be conducted through the theoretical lens of mental models.

2.2 Mental Models

Decision-makers, and humans more generally, possess limited capacity for information processing. To navigate this limitation, they rely on simplified knowledge schemas or representations of how the world operates (March and Simon, 1958). These cognitive structures play a critical role in shaping the strategic choices of managers. The literature on managerial cognition has explored how managers' interpretations influence their decisions, giving rise to an extensive body of research on managerial mental models (Porac et al., 1995). Managerial mental models are defined as schemas or "models that managers use to map the competitive landscape of their industries and rationalize their strategic decisions" (Yang et al., 2016, p. 899). In other words, they function as lenses through which strategic decision-makers interpret information and translate it into organizational actions (Huff, 1982). Mental models are heterogeneous, and a significant portion of the literature has examined how information is classified and organized within cognitive frameworks (Barr et al., 1992). Among the various characteristics explored, three have gained particular prominence: complexity, centrality, and accuracy. Complexity refers to the degree of differentiation and integration within a strategic framework, reflecting the richness of concepts and relationships incorporated into the model (Bogner & Barr, 2000). Centrality concerns the extent to which a mental model is focused and hierarchical, often revolving around a central actor or resource. Accuracy pertains to the model's capacity to correctly link actions to outcomes (Denrell et al., 2004; Gary and Wood, 2011). Research has investigated how these characteristics influence decision-making effectiveness and firm performance. According to Nadkarni and Narayanan (2007) and Manral (2011), greater complexity enhances the amount of information perceived, generates alternative solutions, and fosters flexibility in the decision-making process - all factors positively associated with superior performance. Regarding centrality, scholars such as Kiss and Barr (2015) argue that managers often develop mental models centered around key concepts, thereby facilitating efficient decision-making and improving organizational outcomes. As for accuracy, although some authors question whether highly accurate mental models consistently enhance performance (Sutcliffe, 1994; Weick, 1990), other studies (e.g., Gary and Wood, 2011) have shown that accuracy in understanding key firm principles is positively related to organizational success.

Beyond individual-level cognition, scholars have increasingly recognized that strategic decisions often emerge at the group level. This insight has spurred extensive research on team mental models (Klimoski and Mohammed, 1994). Team mental models extend the concept of cognitive schemas to collective settings, emphasizing the need for consensus and shared understanding among team members. When team members hold similar mental models, they are better able to anticipate one another's actions and coordinate effectively, particularly under conditions that limit overt communication and debate (Mathieu et al., 2000). Much of this literature primarily focuses on team dynamics and task-specific effectiveness (see Yang et al., 2016).

Building on these insights, our study adopts a different perspective. While drawing on the concept of team mental models, we do not focus on team dynamics or intra-team performance per se. Instead, we examine the characteristics of mental models and investigate their combination and their relationship with the performance of ecosystems.

3 Methodology

3.1 The empirical setting

The simulation experiment was conducted using The Entrepreneurial Ecosystem Game (TEEG), a live, web-based simulation developed by Parthenope University of Naples. TEEG explores the dynamics of entrepreneurial ecosystems and aims to simulate the conditions necessary for the creation and survival of start-ups over time.

The primary goal of the game is to foster start-up creation, and to achieve this, players must design and implement a feasible entrepreneurship policy mix.

Players define and execute an ecosystem development strategy using three types of tools across ten rounds: analytical tools, meta-organizational tools, and intervention tools. In every round, teams can decide on specific interventions, such as financing resources or actors, selecting data for monitoring, and implementing coordination mechanisms. Through these instruments, teams make strategic decisions to enhance resource availability within the entrepreneurial ecosystem and to build trust among actors with diverse objectives. Their decisions are subject to a budget constraint spread over the ten rounds. At the end of each round, teams receive feedback on budget status and simulation results, particularly the number of start-ups created. This feedback mechanism encourages competition among teams.

Players are asked to articulate their strategic plan prior to starting the game and then revisit and revise it after five rounds (corresponding to five simulated years). More precisely, before playing, participants are required to write a detailed strategy aimed at stimulating start-up creation. While the strategy can be adjusted based on performance feedback, any revisions must be documented through textual annotations, preserving a trace of changes made to the original plan.

The TEEG simulation provides a high level of complexity, mimicking real-world conditions such as time delays, resource competition, scarcity, and causal ambiguity. Due to its realistic dynamics, TEEG has been adopted as both a research and pedagogical tool in universities and public and private institutions.

TEEG is particularly well suited to the purposes of this study for several reasons. First, it is a dynamic and competitive decision-making environment where participants act as a team, receive real-time feedback, and iteratively refine their strategy. Second, the complex algorithms underlying TEEG make the relationships between decisions and outcomes highly non-linear and unpredictable, thereby introducing meaningful complexity and uncertainty. Third, the simulation offers a controlled setting for tracking the evolution of strategists' mental models, with traceable decision data and performance feedback over time (Lant & Hewlin, 2002).

3.2 Data collection and analysis

A longitudinal dataset was collected from eleven teams acting as strategic decision-makers. The teams were composed of master's students in Innovation Management and Startup Management, who were considered knowledgeable rather than novice in the field of entrepreneurial ecosystems. Their academic programs include modules focused on innovation and ecosystem-related topics. Student simulations provide a valid environment for studying strategic decision-making processes (Lant & Hewlin, 2002; Gary & Wood, 2011). More specifically, we collected and analyzed team mental models for two main reasons: first, decisions within ecosystems are often made through group discussions; second, the complexity of the TEEG simulation requires the participation of more than one player.

Teams (hereafter referred to as "players") received the same instructions and were encouraged to take the simulation seriously, as game performance contributed to their final course evaluation. Data from the game sessions were collected via the TEEG platform, which includes a master dashboard that accurately tracks all decisions made during the game. Additional data were gathered through supporting materials in which players were required to explain the motivations behind their decisions. Each team submitted a file detailing their strategy, which they were free to describe in as much detail as they deemed appropriate. These written descriptions formed the basis for mapping mental models, while the TEEG dashboard data were used to assess strategic actions and ecosystem performance. We used causal mapping to capture mental models. Causal maps are a type of cognitive map that represent key concepts and the relationships among them, tracing the rationale behind decisions (Curşeu et al., 2010; Narayanan & Armstrong, 2005). In the first stage of analysis, the authors identified statements, key concepts, and causal links - i.e., phrases indicating cause-effect relationships. In the second stage, the cognitive maps were constructed using Draw.io. The maps were enriched with raw statements to support and contextualize the relationships among elements (Narayanan & Fahey, 1990).

In line with the purpose of our paper, cognitive maps were analyzed according to three characteristics: complexity (Bogner & Barr, 2000), centrality (Kiss & Barr, 2015), and accuracy (Denrell et al., 2004; Gary & Wood, 2011). In the context of entrepreneurial ecosystems, a complex mental model reflects the inclusion of a wide range of ecosystem resources (e.g., talent, services, funding, and technology) and actors (e.g., universities, corporations, governments, accelerators, incubators, and research centers). Centrality captures the presence of a hierarchical concept around which decisions revolve (e.g. centrality around actors or resources). Accuracy assesses the extent to which actions targeting ecosystem actors or resources are logically linked to desired outcomes, such as ecosystem growth. Each variable was measured on a 5-point Likert scale by each author, and

the average score was then calculated. Ecosystem performance is operationalized as the number of start-ups created, as reported on the TEEG dashboard. This numerical value was converted into a Likert scale for comparison purposes.

Given the exploratory nature of the study and the small number of cases (n = 11), we employed a fuzzy-set Qualitative Comparative Analysis (fsQCA) to uncover causal configurations (Ragin, 2008) that link mental model characteristics to ecosystem outcomes**.** This method is particularly well-suited to examining causal complexity, allowing for the identification of multiple, potentially non-symmetric combinations of conditions that lead to a given outcome.

All conditions were calibrated using the direct method, transforming original scores into fuzzy-set membership values ranging from 0 (full non-membership) to 1 (full membership). The midpoint value of 0.5 was treated as the crossover point, representing maximum ambiguity regarding set membership. Calibration was theory-driven and based on the distribution of empirical values across the cases. The analysis focused on identifying both sufficient and necessary conditions for high ecosystem performance.

The full analysis (including calibration, construction of the truth table, and calculation of consistency and coverage) was conducted manually using Microsoft Excel. While Excel does not automate fsQCA procedures, it enabled full control over the steps of the analysis and transparency in the logic of minimization. A consistency threshold of 0.8 was applied to identify sufficient configurations, in line with established methodological standards (Ragin, 2008). Solutions were interpreted by examining both raw and unique coverage values to understand the explanatory contribution of each configuration.

4 Preliminary Results and conclusions

The results of the fuzzy-set Qualitative Comparative Analysis (fsQCA) identified two distinct causal configurations as sufficient for achieving high levels of ecosystem performance.

The first configuration includes high centrality, combined with low complexity and low accuracy (0 1 0), while the second involves high complexity, low centrality, and low accuracy (1 0 0). These findings suggest that different cognitive strategies- each centered on either complexity or centrality- can independently support high performance, even in the presence of low accuracy (Table 1).

Table 1: Sufficient Configurations for High Ecosystem Performance

Configuration	Complexity	Centrality	Accuracy	Performance	Consistency	Coverage
1	0	1	0	1	1	0,16
2	1	1	0	1	1	0,16

In practical terms, ecosystem orchestrators who leverage complexity may attempt to stimulate entrepreneurship by involving a wide and diverse set of actors, embracing the systemic nature of the ecosystem. In contrast, orchestrators emphasizing centrality may rely on clear prioritization principles, giving prominence to selected actors and resources to coordinate collective action more efficiently. These results align with prior literature: they support Nadkarni and Narayanan (2007) and Manral (2011) regarding the relevance of complexity in strategic thinking, and Kiss and Barr (2015) in highlighting the role of centrality in cognitive structures. However, the results challenge the findings of Gary and Wood (2011), as accuracy did not emerge as a relevant or necessary condition for high performance in this context.

Importantly, the analysis did not identify any single condition as necessary, reinforcing the configurational logic of fsQCA, which assumes equifinality - the possibility of achieving the same outcome through different causal paths.Although the overall coverage of the solutions is relatively low, this is consistent with the exploratory and work-in-progress nature of the study. The limited number of cases and the simulation-based design aim to generate initial insights rather than generalizable claims. Nonetheless, these preliminary findings offer a valuable lens through which to explore how mental model configurations can shape ecosystem outcomes under uncertainty.

From a practical standpoint, the findings suggest that attempting to be highly accurate - that is, controlling all actors and relationships in a complex ecosystem - does not necessarily lead to better performance.

On the contrary, decision-makers may benefit more from adopting a complex perspective, which considers a broad array of actors and adapts to evolving conditions, or from asserting central coordination principles to structure collective behavior, even in fluid environments.

This study has several limitations. First, the sample size is limited and needs to be expanded with additional observations. Second, the conceptualization of mental model characteristics could be further refined, and future

research may explore additional cognitive dimensions that more fully capture mental models within entrepreneurial ecosystems.

Ethics Declaration

The ethical clearance was not required for the research.

AI Declaration

No AI tools were used for the creation of the paper.

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Orchestrating Digital Innovation Ecosystems: A Case Study on Asymmetric Collaborations in Pharma Logistics

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Abstract

The emergence of Digital Innovation Ecosystems (DIEs) is reshaping how innovation is generated, diffused, and scaled across sectors, especially within highly regulated domains such as pharmaceutical logistics. These ecosystems bring together startups, corporations, research institutions, and intermediaries to co-create digital solutions. However, such collaborations are inherently asymmetric—startups and corporates differ vastly in resources, legitimacy, and influence—posing challenges related to power imbalances, cultural misalignments, and governance.

This paper investigates how asymmetric collaborations are orchestrated within DIEs, drawing on a single in-depth case study: *Logi-farma*, a digital platform project aiming to optimize pharmaceutical distribution through AI, automation, blockchain, and data analytics. The case involves a large ICT corporation, an innovative SME, a logistics specialist, and a university research center. Guided by a conceptual framework derived from a prior systematic literature review on asymmetric collaborations, this study explores how stakeholders with diverging capabilities and motivations coordinate innovation efforts and mitigate power asymmetries.

Using semi-structured interviews, document analysis, and comparative assessments of digital innovation models, we investigate the governance mechanisms, collaboration dynamics, and innovation outcomes within the project. Findings are structured through a 6W-based framework—exploring who the actors are, how they collaborate and integrate technology, why they engage, and where/when the processes unfold. The analysis reveals that while startups benefit from legitimacy and scale, corporates leverage agility and niche expertise. However, unresolved asymmetries around data ownership, IP, and decision-making risk undermining trust and long-term viability.

This paper contributes to both theory and practice. Theoretically, it advances open innovation and ecosystem literature by integrating asymmetry as a structural component and proposing a novel conceptual lens for analyzing goal-oriented, multi-actor innovation networks. Practically, it offers guidance for ecosystem orchestrators, policymakers, and innovation managers on how to design inclusive governance structures that support fair value co-creation. The case study illustrates how digital health innovation can be scaled through collaborative orchestration, provided that power differentials are addressed and trust is actively managed. Ultimately, this work underscores the potential of orchestrated asymmetric collaborations to drive digital transformation and sustainability in complex, high-stakes sectors.

Keywords: Digital Innovation Ecosystem; Startup-Corporate Collaboration; Open Innovation; Case Study

Paper type: Academic Research Paper

1 Introduction

In the current landscape of technological transformation and increasing regulatory complexity, the role of Digital Innovation Ecosystems (DIEs) has become central to organizational competitiveness and industry evolution. These ecosystems, defined by the interdependent collaboration of diverse actors—including startups, incumbents, universities, and intermediaries—facilitate the co-creation and diffusion of digital innovation through shared technological infrastructures, resources, and knowledge flows (Adner, 2006; Jacobides et al., 2018; Grandstrand & Holgersson, 2020). Within such ecosystems, startups bring agility, niche expertise, and disruptive innovation capabilities, while large corporations offer market access, capital, and infrastructural support (Chesbrough, 2003; Steiber, 2020; Kurpjuweit et al., 2021).

Despite this complementarity, collaborations between startups and corporates are inherently asymmetric, marked by imbalances in power, resources, organizational culture, and institutional legitimacy (Polidoro & Yang, 2021; Allmendinger & Berger, 2020). These asymmetries can create both synergies and tensions—startups may benefit from visibility and scale, but risk dependency and appropriation of intellectual property, while corporates might leverage innovation but struggle with cultural integration and trust-building (Spender et al., 2017; Steiber & Alänge, 2021).

This issue is especially pronounced in regulated industries such as pharmaceutical logistics, where digital innovation efforts are tightly constrained by compliance requirements, data governance, and stakeholder accountability (Bressanelli et al., 2019; Polidoro & Yang, 2021). While existing research has explored open innovation and collaborative strategies (Chesbrough, 2017; Corvello et al., 2023), few empirical studies have

investigated how these asymmetric partnerships are orchestrated in multi-actor, goal-oriented digital ecosystems within highly regulated contexts.

This paper addresses this gap by presenting a single in-depth case study of Logi-farma[1]—a collaborative innovation project involving a large ICT corporation, an innovative SME, a logistics specialist, and a university research center. Logi-farma aims to develop an integrated digital platform for pharmaceutical distribution, leveraging artificial intelligence (AI), big data, IoT, blockchain, and automation technologies.

Drawing on the 6W conceptual framework developed through a prior Systematic Literature Review (SLR) (Felicetti et al., 2025), this study explores the dynamics of asymmetric collaborations within a digital ecosystem. The research is guided by the following question:

How did a Big Corporation organize its Digital Innovation Ecosystem, and what are the functional roles, influence, and coordination mechanisms of the various actors involved in the project?

By analyzing Logi-farma through the lenses of actor roles, collaborative processes, digital technologies, motivations, and outcomes, this study contributes to a more nuanced understanding of how startup-corporate asymmetries are negotiated, mitigated, and transformed into sustainable innovation strategies.

Ultimately, the findings provide both theoretical insights for the evolving literature on DIEs and asymmetric partnerships, and practical guidance for orchestrating digital innovation in high-stakes, regulated environments.

2 Theoretical Background

Collaborations between startups and large corporations have emerged as a strategic response to the increasing demand for agility, innovation, and responsiveness in complex and fast-changing environments. These inter-organizational partnerships enable a blending of complementary resources: startups provide novel technologies, experimentation capabilities, and entrepreneurial energy, while corporates contribute market access, infrastructure, and institutional legitimacy. However, these relationships are rarely balanced. When actors with significantly different sizes, resources, organizational maturity, and strategic goals collaborate, the result is often an asymmetric partnership, where power, knowledge, and risk are unevenly distributed (Allmendinger & Berger, 2020; Felicetti et al., 2024).

The literature describes such asymmetries as both a source of value creation and a source of relational friction. On one hand, startups can accelerate innovation by leveraging the corporates' resources and networks, enabling faster market entry and scalability (Salvato et al., 2017; Virdi & Sinha, 2025). On the other hand, these same partnerships may generate dependency, loss of autonomy, and exposure to opportunism—especially when formal governance mechanisms and trust-building processes are weak (Sears et al., 2022; Prashantham & Madhok, 2023).

Scholars have applied a range of theories to interpret the dynamics of these collaborations. Transaction Cost Economics (Williamson, 1981) explains partnerships as cost-minimizing responses to uncertainty and asset specificity, while the Resource-Based View (Barney, 1991) emphasizes the strategic importance of accessing complementary capabilities. Institutional Theory (DiMaggio & Powell, 1983) adds a legitimacy perspective, where startups conform to the dominant norms and routines of corporate partners to gain acceptance and survival opportunities. Collective Action Theory (Olson, 1965) and Collaborative Network Theory (Camarinha-Matos & Afsarmanesh, 2005) further highlight the role of shared interests, relational embeddedness, and dynamic coordination across networked organizations.

Innovation Ecosystems have emerged as a new form for organizing innovations, often driven by large organizations that seek to establish alliances with complementary organizations such as startups, suppliers, and spin-offs to achieve mutual benefits (Konietzko et al., 2020; Ritala et al., 2013). These partnerships help integrate products and services through digital technology platforms, enabling value creation and collaboration (Dedehayir et al., 2018; Jacobides et al., 2018).

Existing literature on digital innovation ecosystems and startup-corporate collaborations highlights the potential of digital platforms, artificial intelligence (AI), and automated systems in optimizing supply chains. However, previous studies often focus on single-actor innovations rather than multi-stakeholder, goal-oriented networks in regulated industries. Furthermore, prior research primarily assumes positive outcomes from these collaborations, overlooking the potential risks and limitations, such as power asymmetries, resource control, and technology lock-in (Polidoro and Yang, 2021). Startups, despite their agility and innovative capabilities, face challenges related to credibility, resource constraints, and market access, which impact their ability to thrive within corporate-led innovation ecosystems (Spender et al., 2017; Inekwe, 2019). There is a need to understand better how collaboration lifecycle models evolve in startup-corporate partnerships, particularly in

[1] *"Logi-Farma" is a confidential project name used for anonymization purposes. It does not refer to any existing company or commercial initiative.*

pharmaceutical logistics, and how digital technologies shape integration efforts in such ecosystems (Baldwin, 2012).

Importantly, as these collaborations increasingly occur within Digital Innovation Ecosystems—interconnected environments mediated by digital technologies such as AI, IoT, and data platforms—the nature of asymmetry is further amplified. The digital layer introduces new forms of platform-based control, data asymmetries, and coordination challenges, particularly in regulated sectors such as healthcare and pharmaceuticals (Giglio et al., 2023; Corvello et al., 2023). In such contexts, large firms may dominate technological standards, control access to user data, and shape the pace and direction of innovation, limiting the startup's capacity to influence strategic decisions (Polidoro & Yang, 2021).

Although a growing body of literature investigates startup–corporate collaboration, significant gaps remain. Many studies overlook the startup's perspective, or focus exclusively on dyadic interactions, neglecting the broader ecosystemic configurations and the structural asymmetries embedded in these arrangements. Furthermore, conceptual overlap between related constructs—such as innovation ecosystems, digital ecosystems, and open innovation platforms—contributes to fragmentation and theoretical ambiguity.

In light of this, a deeper understanding of how asymmetries shape collaborative innovation—especially in multi-actor, digitally mediated, and regulated ecosystems—is both timely and necessary. It allows us to move beyond generic models of value co-creation, toward a more realistic portrayal of the tensions, trade-offs, and governance challenges that define asymmetric partnerships in digital transformation contexts.

3 Methodology

This research employs a qualitative, single-case study design (Yin, 2009) to investigate how asymmetric collaborations between startups and large corporations are orchestrated within Digital Innovation Ecosystems (DIEs). The case study approach is appropriate given the exploratory nature of the research and the aim to capture the complexity of a real-world, multi-actor innovation initiative in a regulated context.

3.1 Case selection

The Logi-farma project was selected through purposive sampling based on its relevance to the research objectives. It represents a digitally enabled innovation ecosystem involving:

- A large ICT corporation acting as the orchestrator;
- An AI-focused SME responsible for platform development;
- A SME acting as a logistics operator active in the pharmaceutical sector;
- A university research center offering technological validation and methodological support.

The project was funded by a public-private initiative and aims to develop a data-driven, AI-enabled digital platform for optimizing pharmaceutical logistics and distribution. Logi-farma provides a rich empirical setting to explore how diverse actors—characterized by unequal resources, influence, and expertise—interact and co-create innovation within a digital ecosystem.

3.2 Data collection

Multiple data sources were used to ensure triangulation and increase the robustness of findings (Eisenhardt, 1989; Gibbert et al., 2008):

- Seven semi-structured interviews were conducted with representatives of each participating organization, focusing on their roles, motivations, expectations, and experiences within the ecosystem.
- Project documentation, including partnership agreements, technical platform specifications, grant proposals, meeting minutes, and internal memos, was analyzed.
- Secondary materials, such as policy documents, press releases, and public communications, were used to complement and contextualize primary data.

Data were collected from semi-structured interviews with project stakeholders, archival documents, and comparative assessments of digital innovation models, spanning from June to December 2024. This dual-method approach broadens the scope of our analysis, offering a comprehensive view of Logi-farma's multi-actor ecosystem.

This approach allowed us to analyse the governance mechanisms, success factors, and innovation outcomes that emerge when an established ICT leader engages with innovative small enterprises to start a cooperative innovation project.

3.3 Data analysis

The analysis was conducted using a theory-driven coding strategy, grounded in the 6W Framework developed through the authors' prior systematic literature review (Felicetti et al., 2025). The 6W framework—Who, What, Why, Where, How, and When—provided an analytical lens to categorize and interpret data systematically across the following dimensions:

- What: Focuses on key themes such as market entry, innovation transfer, and strategic partnerships, emphasizing how startups and corporates exchange value to support innovation ecosystems (Chesbrough, 2003; Corvello et al., 2023).
- Who: Identifies core actors—startups, corporates, intermediaries, universities, and investors—each contributing specific resources, capabilities, and roles in collaboration (Giglio et al., 2023; Dos Santos & Benneworth, 2019).
- Why: Highlights motivations like funding, credibility, and agility for startups; and innovation, resilience, and sustainability for corporates—framed within the broader context of the digital and green transitions (Ricciardi et al., 2022; Geissdoerfer et al., 2018).
- How: Describes engagement mechanisms such as accelerators, venture capital, and orchestration by intermediaries. Success depends on effective coordination, resource sharing, and cultural alignment (Schepis et al., 2021; Steiber & Alänge, 2021).
- Where: Refers to physical hubs (labs, incubators) and digital platforms, which together enable real-time, scalable, and inclusive collaboration (Bereczki et al., 2022).
- When: Considers the timing of collaboration phases, from entry to scale-up, stressing the need for synchronization between startup agility and corporate innovation cycles (Wadhwa & Basu, 2013).

Emergent findings were discussed in relation to existing literature and validated through follow-up conversations with two project participants.

This approach enabled a structured yet flexible analysis of the Logi-farma project, allowing the study to surface both the commonalities and tensions inherent to asymmetric collaborations within digital innovation ecosystems.

4 Findings

The Logi-farma project represents a digitally enabled innovation ecosystem in the domain of pharmaceutical logistics, aiming to improve the traceability, efficiency, and sustainability of the drug distribution process through a collaborative digital platform. The ecosystem brings together a large ICT corporation (orchestrator), two technology-oriented startups, a logistics service provider, and a university research center acting as intermediary and methodological support. The initiative was funded through a regional innovation policy program supporting public–private partnerships, with a specific focus on the digital and green transitions in healthcare.

The project leverages technologies such as AI, IoT, automation, data analytics, and blockchain, integrated into a platform designed to manage the end-to-end flow of pharmaceutical products from wholesalers to pharmacies and hospitals. While the large corporate led the platform architecture and funding coordination, the startups contributed modules for real-time tracking and predictive analytics, and the logistics provider enabled operational piloting.

Despite strong complementarities among the actors, the collaboration was characterized by asymmetries in terms of organizational size, influence, and technological maturity. These asymmetries influenced how roles were distributed, how decisions were made, and how value was perceived and appropriated.

The collaboration targeted three innovation areas:

1. automation of warehouse and delivery processes;
2. data-driven traceability and condition monitoring of pharmaceutical products;
3. predictive analytics for demand planning.

These areas reflected strategic priorities for all actors—startups aimed to validate technologies in a real-world setting, while the corporate sought to integrate modular solutions into its platform-based service offering. These goals aligned with broader ecosystem needs related to efficiency, transparency, and compliance in regulated logistics.

Who: Key Actors and Their Roles

The ICT corporation acts as the orchestrator of the ecosystem, leading project governance, providing funding and infrastructure, and setting the technical direction of the platform. Its central position allows it to define timelines and coordinate partner contributions.

The AI-focused SME contributes advanced digital capabilities such as real-time tracking, demand forecasting, and IoT-based monitoring. They bring agility, rapid experimentation, and solution prototyping into the ecosystem, complementing the corporate's scale with technological niche expertise.

The logistics partner enables real-world piloting, providing access to warehousing and distribution operations, and ensuring regulatory compliance for pharmaceutical product delivery.

The university research center serves as a neutral intermediary and knowledge broker. It offers process modeling, validation of AI-based tools, and impact assessment. It also supports methodological rigor, trust-building, and alignment of expectations.

Although the ecosystem presents structural asymmetries in power, resources, and decision-making capacity, the university helps mitigate potential dominance by the corporate actor and reinforces a shared commitment to co-creation and research-based development.

Why: Motivations and Value Expectations

Motivations vary across actors but remain strategically complementary.

- The ICT corporation seeks to expand its portfolio in the digital health domain by integrating AI-driven logistics solutions. It also aims to enhance its position in public-private healthcare innovation and to develop scalable service models.
- The startups aim to gain market access, technological validation, and visibility. They benefit from the corporate's infrastructure, funding, and institutional credibility.
- The logistics partner participates to modernize its operations, experiment with automation and predictive analytics, and improve competitiveness in a tightly regulated market.
- The university engages to apply academic research to real-world challenges and to strengthen its role in regional innovation and knowledge transfer.

All actors share a common interest in contributing to the Twin Transition—aligning digital innovation with environmental sustainability. However, their differing strategic horizons and organizational speeds generate tensions that require continuous coordination.

How: Modes of Collaboration and Governance

The collaboration follows a hybrid governance model. Formal agreements define roles, funding flows, and intellectual property arrangements, while informal mechanisms—such as co-creation workshops, design sprints, and iterative prototyping—enable flexibility and mutual learning.

Three main collaboration types emerge:

- Co-creation and joint development of platform modules;
- Startup supplier integration, where the SME delivers AI solutions embedded in the corporate's infrastructure;
- Mentorship and knowledge exchange, supported by the university, which fosters alignment and methodological coherence.

The presence of the university as intermediary reduces transaction costs and manages asymmetries. However, challenges persist, particularly around:

- Data ownership and interoperability;
- Decision-making authority, with the corporate occasionally asserting control;
- Technological integration across partners.

Despite these issues, trust develops gradually through transparent communication, shared goals, and iterative validation.

Where: Collaboration Spaces

The collaboration unfolds across both physical and digital environments. Early engagement takes place in innovation labs and co-working spaces, enabling relationship building and co-design. As the project progresses, partners rely on digital tools and cloud platforms for remote coordination, data sharing, and development activities.

This hybrid setting provides flexibility but also generates occasional friction, especially during team onboarding or parallel project iterations. Nonetheless, the digital infrastructure proves essential for enabling distributed innovation and cross-organizational collaboration.

When: Timing and Development Stage

The Logi-Farma project remains in a very early stage. The current focus lies on partner alignment, ecosystem configuration, and the initial design of platform functionalities.

While collaboration agreements are in place and some exploratory work has started, operational deployment and full technological integration are still under development. This early phase offers insight into the challenges of initial orchestration, such as:

- Aligning timelines and expectations across diverse actors;
- Defining governance mechanisms in the absence of tested routines;
- Balancing flexibility with the need for clarity in roles and contributions.

The following table summarizes our findings:

Table 1. Summary of Findings from the Logi-Farma Case Study, according to the 6W Framework

Dimension	Categories	Description
Who	**Actors and roles**	**Big Corporate:** Orchestrates the innovation ecosystem, provides financial resources and ICT expertise. **Innovative SME:** Develops AI-driven software for logistics optimization. **Logistics Specialist:** Ensures supply chain efficiency and regulatory compliance. **Research Institution:** Provides research expertise, process modeling, AI validation, and impact assessment.
How	**Technologies**	**AI & Machine Learning:** Demand forecasting, stock optimization. **Big Data Analytics:** Real-time insights into pharmaceutical consumption. **Cloud Computing & IoT:** Smart inventory tracking and data exchange **Blockchain:** Secure drug traceability and compliance. **Automation & Robotics:** Smart dispensing units for last-mile distribution.
	Collaboration types	**Co-Creation & Joint Development:** Corporate and startup co-develop the digital platform. **Startup Supplier Program:** SME provides AI-driven solutions to corporate. **Mentorship & Knowledge Exchange:** Research Institution facilitates research integration.
	Collaboration Process	**Opportunity Detection:** Identifying inefficiencies in rural pharmaceutical distribution **Partner Search:** Selecting AI and logistics partners. **Design & Set-Up:** Developing AI-powered stock management tools.
	Collaboration Characteristics	**Duration:** Goal-oriented network. **Geographical Distance:** All partners operate within the same region. **Degree of Structuration:** Defined roles for corporates, startups, intermediaries, and research institutions. **Presence of Intermediaries:** Research institution acts as a neutral knowledge broker. **Funding & Reimbursement:** Corporate investment and public research grants.
WHY	**Motivations for Collaboration**	**Big Corporate:** Aims to expand its digital healthcare portfolio by integrating AI-driven logistics and automation solutions into pharmaceutical distribution. **Innovative SME**: Seeks market access and scalability, leveraging the corporate's resources and network. **Logistics Expert**: Participates to modernize and optimize its logistics operations, gaining access to cutting-edge solutions. **Research Institution**: Engages in the project to apply theoretical research to real-world challenges
	Challenges	**Power Asymmetries:** Corporate dominance in decision-making. **Regulatory Compliance:** Adapting AI models to strict pharmaceutical regulations. **Data Ownership & Integration:** Ensuring seamless interoperability between partners' systems

Dimension	Categories	Description
WHERE	**Domain and Context**	**Initial Deployment:** Regional pharmaceutical distribution **Scalability Potential:** National and international expansion to hospitals, global pharma logistics, and medical device tracking
WHEN	**Timing and development stage**	**Current Stage**: Very early stage of collaboration. Focus is on partner alignment, ecosystem design, and initial technological scoping. No full deployment yet; processes and governance mechanisms are still under development.

5 Discussion and conclusions

The findings from the Logi-Farma case study confirm that multi-actor collaborations, even when structurally asymmetric, can become powerful enablers of scalable digital innovation in regulated domains such as pharmaceutical logistics. By leveraging a structured and phased collaboration process—from opportunity detection to ecosystem design—Logi-Farma integrates advanced technologies including AI, blockchain, IoT, and automation to address inefficiencies in drug distribution, improve inventory management, and enhance patient adherence.

The collaboration in this study is marked by clear power asymmetries: the ICT corporation exercises control over project funding, strategic direction, and technological architecture, whereas the startups operate in a more reactive, executional role. This is consistent with literature indicating that such asymmetries can hinder trust and compromise innovation potential (Allmendinger & Berger, 2020; Polidoro & Yang, 2021). However, the presence of a neutral intermediary—in this case, the university research center—acts as a governance stabilizer, validating the SLR's emphasis on the role of intermediaries in moderating imbalances, aligning expectations, and promoting fairness within the ecosystem (Giglio et al., 2023).

The research institution plays a dual role: as a knowledge broker and a process facilitator.

The research institution plays a dual role: as a knowledge broker and a process facilitator. As a knowledge broker, it connects academic expertise with real-world challenges, translating theoretical models into actionable tools for logistics optimization (Howells, 2006; Dos Santos & Benneworth, 2019). As a process facilitator, it mediates between stakeholders with differing goals and capabilities, helping to structure collaboration workflows, align expectations, and maintain communication across organizational boundaries (Giglio et al., 2023; Schepis et al., 2021). This reflects the literature on Virtual Breeding Environments (VBEs) and Goal-Oriented Networks (GONs) (Camarinha-Matos & Afsarmanesh, 2005), where intermediaries enhance mutual understanding, reduce coordination costs, and bridge the logic gap between corporates and startups. The findings thus reinforce the theoretical claim that intermediaries are essential to managing complexity and ensuring continuity in asymmetric innovation ecosystems.

Logi-Farma illustrates how co-creation processes—such as joint development of platform modules, design sprints, and agile prototyping—can enable mutual value creation despite divergent incentives. As evidenced in previous research, motivations are often asymmetric but complementary: startups seek legitimacy, scale, and resource access; corporates pursue agility, innovation sourcing, and resilience; research institutions aim to apply and validate theoretical models. The key lies in creating a collaborative structure that allows these diverse goals to coexist and converge around a shared innovation agenda (Ricciardi et al., 2022).

Finally, the Logi-Farma ecosystem represents a goal-oriented, project-based network, a configuration particularly well-suited to contexts of uncertainty and regulatory constraint. The ecosystem is temporary, modular, and locally embedded, but designed with scalability in mind. This aligns with the concept of ecosystem fluidity and the shift from hierarchical integration to networked coordination in digital innovation (Jacobides et al., 2018). The case illustrates how such configurations support experimentation, risk sharing, and technological validation in early stages—while preserving optionality for future growth.

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7 Ethics declaration

All interview participants were informed about the objectives of the study. No sensitive personal data were collected, and confidentiality has been ensured throughout the analysis and reporting process. Given the nature of the research—focused on organizational practices in a public-private partnership project—no formal approval from an ethics committee was required

8 AI declaration

Artificial Intelligence (AI) tools were utilized in the preparation of this manuscript to support language refinement, citation formatting, and proofreading

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Stress Management and Organizational Strategies: Promoting Well-Being and Innovation in Healthcare Systems

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Abstract

The healthcare sector is characterized by intense emotional, cognitive, and physical demands that expose professionals to chronic stress, with significant consequences for their well-being and performance. Despite growing scholarly attention to stress in healthcare, little is known about the specific coping strategies that professionals employ and the organizational factors that facilitate or hinder these approaches. This study addresses this gap by examining how healthcare workers navigate daily stressors and how organizational structures can support or undermine their coping mechanisms.

Based on a qualitative research design, the study involved 41 semi-structured interviews with healthcare professionals—including doctors, nurses, psychologists, and other staff—operating in various settings. The findings reveal that organizational support plays a crucial mediating role between job demands and perceived job control. In particular, participants who reported supportive leadership, accessible resources, and open communication channels were better equipped to handle high workloads and emotional fatigue, even in contexts with limited formal autonomy.

The concept of perceived control emerges as a central theme, expanding traditional models of occupational stress. The study demonstrates that the subjective perception of being able to influence one's work environment—fostered by empathetic leadership and inclusive organizational culture—can significantly enhance resilience and reduce burnout risk. Moreover, the diversity of professional experiences in the sample underscores the importance of tailored organizational strategies that reflect the unique stressors and coping needs of different roles within the healthcare system.

By integrating insights from organizational behavior, human resource management, and health psychology, this research contributes to the development of more resilient and supportive healthcare organizations. The findings offer practical recommendations for policy-makers and managers seeking to promote employee well-being, improve job satisfaction, and sustain innovation in complex healthcare environments, particularly in the face of ongoing global health challenges.

Keywords: Stress management, Coping strategies, Healthcare, Organizational support, Professional development.

Paper type: Academic Research Paper

1 Introduction

The healthcare sector stands as one of the most demanding and high-pressure work environments in the modern world. Professionals in this field face unique stressors—ranging from the need to make swift, critical decisions, to the constant exposure to human suffering and illness, and the heavy responsibility tied to patient care (Fiabane, Giorgi, Sguazzin, & Argentero, 2013; Wang et al., 2021). Adding to this intrinsic burden are external factors, such as irregular working hours, long shifts, lack of sleep, and the unceasing need for professional updates (Shemtob, Good, Ferris, Asanati, & Majeed, 2022). These circumstances create a perfect storm, where burnout and emotional exhaustion can thrive. Furthermore, emergency situations, which are frequent in the healthcare field, exacerbate the mental and physical demands on professionals (Hijazi et al., 2022; Mirzaei, Mozaffari, & Soola, 2022).

It is within this complex environment that healthcare professionals operate daily, exposed to immense physical, emotional, and psychological stress (Søvold et al., 2021). In the long run, unmitigated stress can lead to severe consequences, affecting the mental health and well-being of these workers (Weinberg & Creed, 2000). Stress in healthcare is further compounded by chronic understaffing, which places additional workloads on already strained professionals (Cogin, Ng, & Lee, 2016; Dyrbye et al., 2017). This structural deficiency becomes more pronounced in times of global health crises, such as the COVID-19 pandemic, where resources are stretched thin, leading to higher levels of professional stress (Yusefi, Sharifi Nasabi, Rezabeigi Davarani, & Bastani, 2022).

Yet, despite the growing body of research on stress in healthcare, there is a notable gap in understanding the specific coping mechanisms that professionals employ to handle these stressors. Existing studies often focus on the general stressors of healthcare work but fail to delve deeply into the intricacies of how professionals,

individually and collectively, navigate such pressures. This lack of research is particularly pronounced when exploring the relationship between organizational structures and the efficacy of coping strategies.

While many studies have documented the stressors inherent in healthcare (Rollins et al., 2021), there is less comprehensive research into the specific strategies that professionals use to cope with these stressors and how organizations can better support these strategies. Most existing literature on coping strategies, particularly in high-stress environments, tends to generalize findings without addressing the experiences of healthcare workers.

This research aims to address the aforementioned gaps by taking a closer look at the coping strategies employed by healthcare professionals and how these strategies are supported or hindered by organizational structures. Specifically, we explore how healthcare professionals navigate their daily stressors, what strategies they find most effective, and how organizational policies can be adapted to support their well-being.

Our research seeks to answer the following questions: What are the main sources of stress for healthcare professionals? What coping strategies are most commonly employed, and how effective are they? How do organizational structures support or impede these strategies? By exploring these questions, this study aims to contribute to the growing body of literature on organizational well-being and stress management in healthcare, offering practical recommendations for improving the work environment for healthcare professionals.

This study is particularly relevant in light of the ongoing global health challenges that have placed unprecedented strain on healthcare systems. By understanding the specific coping strategies used by healthcare workers and how these strategies can be supported, healthcare organizations can make informed decisions to reduce stress, improve job satisfaction, and ultimately enhance the quality of care provided to patients. Through this research, we hope to provide actionable insights that bridge the gap between individual coping and organizational responsibility, offering a pathway toward more resilient healthcare systems.

2 Theoretical Background

Stress is a pervasive and critical issue within the healthcare sector, posing substantial risks to both the psychological well-being of healthcare professionals and the overall effectiveness of healthcare organizations. The complex and emotionally demanding nature of healthcare work frequently exposes workers to chronic stressors, which, if unaddressed, can lead to burnout, high turnover, and diminished quality of care. The Job Demands-Resources (JD-R) model (Demerouti et al., 2011) serves as a comprehensive theoretical framework for understanding how specific job characteristics contribute to these outcomes. Central to this model is the premise that each occupation is defined by a unique combination of job demands and job resources, which interact to influence employee health, motivation, and performance. In healthcare, job demands often manifest as heavy workloads, time pressure, emotional labor, and staff shortages. These demands require sustained physical or psychological effort and are associated with significant physiological and emotional costs (Bakker & Demerouti, 2017).

When these demands are not adequately balanced by job resources—defined as the physical, psychological, social, or organizational aspects of the job that support goal achievement, reduce job demands, or stimulate personal growth—the likelihood of stress-related outcomes increases significantly. Such outcomes may include emotional exhaustion, depersonalization, reduced professional efficacy, and overall dissatisfaction with one's work. On the other hand, the presence of job resources such as supportive leadership, effective communication, access to professional development, and organizational policies promoting well-being can buffer the impact of high demands. These resources not only mitigate the adverse effects of stress but also enhance motivation, engagement, and resilience among healthcare workers (Kinman et al., 2020).

The JD-R model also highlights the role of coping mechanisms in mediating the relationship between job characteristics and employee outcomes. In resource-rich environments, healthcare professionals are more likely to adopt adaptive coping strategies, including problem-solving, task prioritization, and time management. These strategies enable them to manage their workload more effectively and sustain their performance over time. Conversely, in environments where resources are lacking, workers may resort to maladaptive, emotion-focused coping mechanisms such as disengagement or emotional detachment, which may offer short-term relief but can ultimately contribute to long-term burnout (Bakker & Sanz-Vergel, 2013). This dynamic underscores the importance of organizational commitment to fostering a resource-enriched environment where healthcare workers are empowered to meet the demands of their roles.

Moreover, organizational support—particularly through leadership practices—is increasingly recognized as a critical job resource within the JD-R framework. Leaders who acknowledge the challenges faced by healthcare staff, provide emotional and instrumental support, and advocate for adequate staffing and professional development opportunities play a pivotal role in reducing occupational stress. Interventions such as resilience

training programs, mentorship initiatives, and stress management workshops can further enhance individual coping capacities and promote a healthier work culture. Through the lens of the JD-R model, it becomes clear that strategically investing in job resources is essential not only for improving employee well-being but also for ensuring the sustainability of healthcare systems. By addressing both the demands placed on workers and the supports available to them, healthcare organizations can better safeguard staff health, improve care quality, and maintain high levels of organizational performance.

3 Method

3.1 Research Design

This qualitative study explores coping strategies among healthcare professionals and how organizational structures influence them. Semi-structured interviews were used to examine stress perceptions and responses in high-pressure healthcare environments.

The sample included 41 healthcare professionals (15 doctors, 15 nurses, 6 psychologists, 5 others), selected via purposive sampling. The average age was 42, with 15 years of experience. Fifteen held managerial roles; all had at least one year in their current position.

3.2 Data Collection

Interviews lasted around 40 minutes, conducted in person or online. Questions focused on stress sources, coping strategies (problem- or emotion-focused), and available organizational support.

3.3 Data Analysis

Thematic analysis was conducted using ATLAS software in six steps, identifying key themes: (1) stress sources, (2) common coping strategies, and (3) role of organizational support. Staffing shortages and problem-focused strategies were prominent findings.

3.4 Ethical Considerations

Ethical standards were followed, including informed consent, anonymity, right to withdraw, and data protection.

3.5 Trustworthiness and Rigor

Research rigor was ensured through data triangulation, member checking, and peer debriefing with experts. that aim to respond to these gaps and guide future empirical inquiry.

4 Findings

The analysis of the interviews with 41 healthcare professionals uncovered three primary themes: sources of work-related stress, coping strategies, and the role of organizational support. These findings shed light on the day-to-day pressures healthcare professionals face, the strategies they use to manage stress, and the extent to which organizational structures support or undermine these efforts.

4.1 Sources of Work-Related Stress

A dominant theme emerging from the interviews was the range of stressors inherent to the healthcare profession. Participants frequently highlighted several critical factors contributing to their stress, and these can be grouped into three main subthemes.

4.2 Workload and Time Pressure

The overwhelming workload and time pressure were universally cited as major sources of stress. Participants reported having to care for an excessive number of patients, often under tight deadlines and high expectations. This constant rush not only left them feeling physically and mentally drained but also created a sense of ongoing pressure to perform flawlessly.

- *"The workload is really heavy, and we're always running against time. It's exhausting, both mentally and physically."* (Participant 12, nurse)

This quote reflects the almost inescapable feeling of being overwhelmed that many healthcare professionals experience. The repeated reference to exhaustion highlights how the cumulative impact of continuous high pressure leads to burnout, a common issue in the sector. Healthcare professionals are expected to manage multiple patients with complex needs, all while maintaining high standards of care, which is unsustainable in the long run. This exhaustion often compromises their mental well-being and their capacity to perform effectively.

4.3 Staff Shortages

Many participants identified staff shortages as a critical stressor that exacerbates their workload. With fewer staff to share the load, professionals found themselves juggling multiple tasks, which not only increased their workload but also heightened their emotional stress. The chronic lack of personnel in healthcare institutions made it difficult to ensure quality care, leading to feelings of frustration and helplessness.

- *"We're always understaffed, and it makes everything harder. You can't give your best when you're stretched so thin."* (Participant 21, doctor)

This statement powerfully conveys the sense of helplessness that comes from trying to provide optimal care in suboptimal conditions. The metaphor of being "stretched thin" illustrates the emotional toll that understaffing takes on healthcare workers, as they are forced to compromise the quality of care they can deliver. This not only affects their professional identity but also their sense of fulfillment, as many healthcare professionals enter the field with a desire to help, which becomes difficult when resources are scarce.

4.4 Emotional Pressure and Responsibility

Beyond the physical workload, the emotional pressure associated with patient care was a key source of stress. Healthcare professionals frequently deal with life-and-death situations, which naturally creates a significant emotional burden. The responsibility to provide high-quality care, often in emotionally charged situations, left many feeling psychologically strained.

- *"The hardest part is the emotional toll. You deal with people in pain every day, and it's hard not to take that home with you."* (Participant 8, psychologist)

This statement captures the intense emotional labor that healthcare professionals must manage. The phrase "take that home with you" poignantly illustrates how the boundaries between work and personal life blur, making it difficult to mentally disengage from the pain and suffering encountered at work. This emotional spillover can contribute to compassion fatigue, where professionals struggle to remain empathetic because they themselves are emotionally drained.

4.5 Coping Strategies

Healthcare professionals employ a variety of coping strategies to manage their stress. The interviews revealed two main categories of coping strategies—problem-focused and emotion-focused—as well as instances where participants used a combination of the two.

4.6 Problem-Focused Coping

The majority of participants preferred problem-focused coping, which involves actively addressing the causes of stress. This approach allowed them to feel more in control of their workload and gave them a sense of accomplishment by tackling problems head-on. For example, professionals emphasized the importance of task organization and time management to cope with their daily responsibilities.

- "*I always make a to-do list and prioritize the most critical tasks. It helps me stay on top of things."* (Participant 33, nurse)

This quote illustrates how organizational skills can be a powerful tool in managing overwhelming workloads. By creating a structured approach to tasks, participants felt they could regain some control over their work environment, reducing feelings of chaos. This proactive strategy contrasts with more passive approaches, allowing individuals to mitigate the sources of stress directly rather than only managing their emotional responses to it.

4.7 Emotion-Focused Coping

Some participants also engaged in emotion-focused coping to manage their emotional responses to stress. Although this approach did not necessarily reduce the actual workload, it helped individuals handle the emotional aspects of their job more effectively, especially in highly stressful or traumatic situations.

- *"I meditate for 10 minutes during my break just to clear my mind and reset."* (Participant 6, psychologist)

This excerpt highlights how techniques like meditation serve as emotional "resets" in the midst of stressful workdays. Such strategies help healthcare workers regain emotional equilibrium, allowing them to continue their tasks with a calmer mindset. While this coping method may not directly address the root causes of stress (such as high workload or emotional strain), it provides temporary relief, which is essential for maintaining psychological resilience over time.

4.8 Mixed Coping Strategies

A notable group of participants used mixed coping strategies, combining both problem-focused and emotion-focused techniques. These professionals understood that while organizing tasks was crucial, they also needed to manage their emotional well-being.

- *"I try to balance both. I focus on organizing my tasks but also make time for some deep breathing exercises during my shift to manage the emotional stress."* (Participant 29, doctor)

This response reflects a broad approach to coping, acknowledging that managing stress in healthcare requires attention to both practical and emotional dimensions. The balance between action-oriented coping (task organization) and self-care (deep breathing exercises) demonstrates an understanding of stress management, where both the mind and tasks need attention to sustain long-term well-being.

4.9 Role of Organizational Support

The role of organizational support emerged as a critical factor influencing how effectively healthcare professionals could manage their stress. Participants frequently mentioned that their coping success was strongly tied to the level of support provided by their organizations, particularly in terms of leadership, policies, and available resources.

4.10 Supportive Leadership

Many participants expressed that supportive leadership was essential in mitigating stress. Leaders who were approachable, empathetic, and involved in addressing the challenges faced by healthcare workers were seen as key allies in creating a less stressful work environment.

- *"When the leadership is supportive, it makes a huge difference. You feel like you're not alone in dealing with the stress."* (Participant 19, nurse)

This statement underscores the psychological relief that comes from knowing leadership is present and actively supportive. Feeling "not alone" in managing stress creates a sense of shared responsibility, reducing feelings of isolation and fostering a more collaborative environment. Leadership that is engaged in problem-solving can significantly reduce the burden healthcare professionals face, particularly when it comes to systemic issues like understaffing or resource shortages.

4.11 Professional Development and Training

Participants also valued opportunities for professional development and training, as these programs provided tools and techniques for managing stress and improving their skills in high-pressure situations.

- *"We have access to continuous training, and that's been really helpful. It helps you feel more equipped to handle the pressures."* (Participant 11, doctor)

This quote highlights the importance of professional growth in building resilience. Training programs not only equip healthcare workers with better tools to handle stress but also empower them by increasing their competence and confidence. Feeling "equipped" suggests that training gives professionals the mental tools they need to stay calm and effective under pressure, which can mitigate the negative effects of stress.

4.12 Inadequate Organizational Support

On the other hand, many participants felt that their organizations did not provide adequate support. They cited issues like lack of staffing, poor communication, and insufficient attention to worker well-being as exacerbating factors for their stress.

- *"We don't get the support we need from the administration. They know we're understaffed, but nothing changes."* (Participant 25, psychologist)

This quote encapsulates the frustration many healthcare professionals feel when their concerns are not addressed by the administration. The acknowledgement that leadership is aware of the problems but fails to act

intensifies feelings of powerlessness, leading to further stress. When organizations do not provide adequate support, it creates an unsustainable work environment, where workers are left to cope with systemic issues on their own.

4.13 Impact on Well-being and Performance

Effective coping strategies, particularly when supported by strong organizational frameworks, had a direct impact on the well-being and performance of healthcare professionals. Those who reported using effective strategies in conjunction with a supportive work environment noted improvements in their mental health, job satisfaction, and overall quality of care.

- *"When I feel supported, I'm able to manage my stress better, and that reflects in the quality of care I give."* (Participant 10, doctor)

This statement highlights the virtuous cycle of support and performance: when healthcare professionals feel supported, they manage their stress more effectively, which in turn enhances their ability to provide high-quality care. The link between organizational support and patient care outcomes underscores the importance of institutional responsibility in managing healthcare worker stress.

On the flip side, participants who felt unsupported or overwhelmed by stress reported diminished job satisfaction, higher levels of burnout, and a corresponding decline in their performance.

- *"The constant stress and lack of support have made me consider leaving the profession altogether."* (Participant 14, nurse)

This quote is a stark reminder of the real consequences of inadequate stress management. The consideration of leaving the profession altogether is a clear indicator of burnout, and it reflects the broader systemic issue of retaining healthcare talent in the face of mounting pressures.

5 Discussion

The primary objective of this study was to explore the coping strategies used by healthcare professionals to manage work-related stress, and to understand how organizational support structures influence these strategies. Through in-depth interviews with 41 healthcare professionals, we sought to identify the main sources of stress, examine the coping mechanisms employed by individuals, and assess the role of organizational frameworks in mitigating or exacerbating stress. The study provides new insights into the practical strategies that healthcare professionals use to navigate the high-pressure environments in which they work, while also highlighting significant gaps in organizational support.

The findings revealed several key stressors, including excessive workloads, staff shortages, and the emotional burden of caring for critically ill patients. Coping strategies employed by participants were predominantly problem-focused, such as task prioritization and time management, though emotion-focused coping strategies, like relaxation techniques and seeking social support, were also commonly used. The effectiveness of these coping strategies was heavily influenced by the level of organizational support provided, particularly in terms of leadership involvement and access to professional development resources. Conversely, inadequate organizational support, especially regarding staffing and resource allocation, often exacerbated stress levels.

6 Theoretical Implications

This study enhances the existing literature on stress and coping by applying the JD-R model (Demerouti *et al.*, 2011) specifically to the healthcare sector, a context characterized by unique demands and resource constraints (Fiabane *et al.*, 2013; Wang *et al.*, 2021). By examining the relationship between job demands, resources, and coping mechanisms, this study provides a clearer understanding of how organizational structures interact with individual strategies to mitigate or exacerbate work-related stress. The findings contribute to JD-R literature by reaffirming that resources play a buffering role against job demands (Bakker and Demerouti, 2017), while also extending the model to include relational and psychological resources as critical to managing stress in high-stakes healthcare environments.

In line with previous studies, this research identifies workload, emotional burden, and time pressure as primary job demands that intensify stress and burnout among healthcare professionals (Cogin *et al.*, 2016; Dyrbye *et al.*, 2017). The JD-R model posits that such high demands deplete employees' energy, leading to stress and burnout when left unmitigated (Bakker and Demerouti, 2017). Our findings corroborate this perspective and add depth by showing that these demands are exacerbated by chronic understaffing and the emotional toll associated with patient care (Søvold *et al.*, 2021). This study thus contributes to the growing evidence that specific healthcare stressors demand tailored resources, as outlined in the JD-R framework (Bakker *et al.*, 2014).

The buffering role of job resources is a core component of the JD-R model, as demonstrated in previous research showing that supportive leadership, professional development, and resource allocation are essential in reducing stress (Kinman, *et al.*, 2020; Strauss *et al.*, 2021). This study supports these findings by illustrating that resources like accessible leadership, continuous training, and adequate staffing not only reduce stress but also enable healthcare professionals to employ problem-focused coping strategies effectively. These insights expand on the JD-R model's assertion that resources foster resilience and job satisfaction (Bakker, 2011) by highlighting how resources tailored to healthcare can improve coping efficacy and, consequently, organizational outcomes such as patient care quality and job retention.

While the JD-R model traditionally emphasizes tangible job resources, our findings suggest that relational and psychological resources, such as perceived support from leadership and team cohesion, are equally important in high-demand settings like healthcare (Strauss *et al.*, 2021; Saha *et al.*, 2011). Healthcare professionals reported that supportive leadership enhanced their perceived control and mitigated feelings of helplessness, which aligns with the findings of Carrillo-García *et al.*, (2018) regarding the influence of perceived control on stress levels. This study suggests that integrating these relational and psychological resources into the JD-R framework could refine its applicability in high-stakes environments by recognizing that perceived support can buffer job demands effectively, even when formal autonomy is limited (Urbanetto *et al.*, 2013).

Consistent with Warr's (1994) Organizational Well-being Model, our findings reinforce that healthcare organizations need to align job demands with resource availability to reduce stress effectively. This study contributes to the JD-R framework by demonstrating that resource allocation strategies, such as improved staffing and training opportunities, are vital in high-pressure settings (Brand *et al.*, 2017). Aligning with the insights of Siegrist *et al.*, (2019), our research further suggests that organizations should implement both tangible and intangible resource strategies to maintain job satisfaction and engagement. The JD-R model can therefore guide healthcare organizations in making targeted resource investments to alleviate the demands associated with healthcare roles.

Finally, this study extends the JD-R model by emphasizing its relevance in healthcare and proposing its applicability across other high-stress professions. The findings suggest that relational and psychological resources—such as peer support, leadership empathy, and recognition—can buffer job demands effectively in high-stakes environments where traditional autonomy is limited (Kinman *et al.*, 2020; Strauss *et al.*, 2021). Future theoretical work could further refine the JD-R model to include relational resources, providing a more comprehensive framework for stress management in high-demand sectors where teamwork and leadership engagement are central (Bakker *et al.*, 2014).

7 Ethics Declaration

This research involved human participants and followed all institutional and national ethical standards. Participation was voluntary, and informed consent was obtained from all individuals involved. No personal or sensitive data have been disclosed.

8 AI Declaration

No generative artificial intelligence tools were used in the preparation of this manuscript.

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A Randomized Controlled Field Trial: A Gamified Training Course on Workplace Health and Safety Prevention for Middle School Students – "Let's Play 81!"

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Abstract

Workplace safety is increasingly recognized not only as a matter of regulatory compliance but as a collective, knowledge-based infrastructure that must be cultivated early and systemically. In response to this challenge, the "Let's Play 81!" project introduces a school-based, game-driven educational pathway aimed at promoting occupational safety awareness among students aged 8 to 13. Developed in alignment with Italy's updated safety legislation (Legislative Decree 81/2008, reform 2024), the project reframes prevention as a civic competence rooted in shared knowledge, care, and responsibility.

The initiative was piloted in four public schools in central Italy, involving 198 students, 20 teachers, and 4 certified safety trainers. It employs analog games—developed and validated by occupational health experts—as tools to activate learning through play. Three distinct games simulate safety challenges in fictional yet relatable settings. These tools enable students to interact with roles, rules, and consequences, encouraging reflection, dialogue, and collective problem-solving.

The study adopts a mixed-methods approach. Quantitatively, it measures knowledge acquisition using a pre/post quiz (81Questionnaire), revealing a significant improvement in the intervention group (+4.43 points on average, $p < 0.001$). Qualitative data from teacher and trainer feedback underscore increased engagement, emotional involvement, and transversal learning outcomes (e.g., collaboration, attention, civic sense).

From a knowledge management perspective, the project demonstrates how structured play can serve as a conduit for transmitting tacit and explicit knowledge in early education contexts. It also fosters interinstitutional collaboration among schools, Universities, and training bodies, suggesting a model for distributed governance in prevention.

"Let's Play 81!" offers a replicable framework to embed safety culture through experiential, inclusive, and cognitively rich learning. It contributes to the broader discourse on how public value can be co-generated through educational innovation and how knowledge-intensive processes—like risk awareness and prevention—can be activated far beyond the boundaries of formal workplaces.

Keywords: Safety Culture, Gamification, Knowledge Transfer, Preventive Education, Public Value Creation

Paper type: Academic Research Paper

1 Introduction

Workplace safety is a foundational component of social and economic sustainability. It is not only a matter of regulatory enforcement, but a cultural and educational issue that requires long-term investment in people, systems, and communities. The promotion of a shared safety culture is increasingly seen as a collective responsibility, to be cultivated throughout the life course, starting from early educational stages.

In Italy, this perspective has been reinforced by the recent reform of Legislative Decree 81/2008, approved in 2024, which expands institutional accountability and underlines the importance of preventive education (Quotidiano Sanità, 2024). The updated regulatory framework encourages the involvement of schools and local authorities in disseminating safety-related knowledge and values, in line with international recommendations promoting prevention as a civic competence and a shared ethical duty.

Within this context, the project "Let's Play 81!" introduces a structured and gamified approach to workplace safety education in primary and lower secondary schools. The initiative takes its name from the core Italian law on occupational health and safety (D.lgs. 81/08), but its objectives are pedagogical rather than juridical. Developed within a regional pilot framework, the project aims to promote risk awareness, responsibility, and care among children aged 8 to 13, through playful and accessible formats.

The activities are designed and implemented by certified safety educators, in collaboration with schools, institutional stakeholders, and local authorities. The tools used in the project—such as board games and interactive materials—are grounded in recognized pedagogical principles and validated content. They are meant to engage students emotionally and cognitively, helping them to internalize basic concepts of prevention and safety as part of their everyday experience.

"Let's Play 81!" responds to the evolving educational and legislative landscape by proposing an innovative yet grounded intervention model. It aims to contribute to a broader process of safety culture formation, in which schools play a proactive and strategic role in shaping future citizens who are not only aware of risks, but capable of managing them collectively.

2 Theoretical framework

The promotion of occupational health and safety (OHS) as a lifelong competence requires the integration of educational, cultural, and regulatory dimensions. In recent years, a growing body of literature has emphasized that safety culture cannot be reduced to procedural compliance; rather, it emerges through situated learning, social interaction, and value-based communication (Gherardi, 2006; Reason, 2000). In this view, schools are not merely preparatory spaces for future work—they are active contexts in which foundational attitudes toward prevention, responsibility, and care can be developed.

A key contribution to this approach comes from experiential learning theory, which highlights the role of direct engagement in consolidating both conceptual understanding and personal meaning (Kolb & Kolb, 2010). Educational experiences that combine action, reflection, and emotional involvement help learners construct durable knowledge structures and increase their sense of agency. These principles are particularly relevant in the context of safety education, where behavioural awareness and practical judgement are as important as factual knowledge.

Learning through play, especially in structured educational settings, has also been widely recognized as a valid pedagogical strategy (Singer et al., 2006; Barnett, 2007). Play enables learners to simulate real-life situations, manage emotional responses, and explore complex dynamics such as risk and interdependence in a safe and controlled environment. This is especially important for children, who benefit from multimodal, emotionally rich formats that sustain attention and foster retention.

From a policy and organizational standpoint, the integration of safety education in schools aligns with international strategies that promote prevention as a shared cognitive and civic infrastructure, rather than a task delegated only to employers and adult workers. In this context, the revised Italian law on OHS (D.lgs. 81/08, updated in 2024) explicitly invites schools and local institutions to play an active role in disseminating a culture of safety, with a focus on early educational engagement (Quotidiano Sanità, 2024).

This framework justifies the development of targeted interventions such as "Let's Play 81!", which aims to build knowledge and awareness around workplace safety by using methods that are pedagogically appropriate and emotionally resonant. It also underlines the strategic role of educational innovation in supporting national and regional policy objectives related to health, prevention, and social responsibility...

3 Project Overview: Let's Play 81!

"Let's Play 81!" is a pilot initiative that promotes early education in occupational health and safety (OHS) through playful, age-appropriate methods. It is addressed to students aged 8 to 13 and implemented in selected primary and lower secondary schools in central Italy. The project takes its name from Legislative Decree 81/2008—the cornerstone of Italian workplace safety regulation—and responds to recent normative developments that emphasize the involvement of educational institutions in the promotion of a shared culture of prevention (Quotidiano Sanità, 2024).

The initiative is promoted by a partnership of three Universities, Universitas Mercatorum, _University "San Raffaele" and Sapienza University of Rome, with professionals specialized in occupational safety. It was developed within a public call for proposals and funded as a regional pilot action, in line with broader educational and health promotion strategies at the local level.

The project aims to foster the acquisition of basic knowledge and attitudes related to workplace safety, risk awareness, and mutual care, using non-formal and game-based educational tools. The materials used—such as board games and printed resources—were designed and validated by certified OHS professionals to ensure pedagogical appropriateness and technical accuracy. These tools present safety concepts in an accessible and engaging way, adapted to children's cognitive and emotional development.

The intervention consists of classroom-based sessions led by qualified trainers, in collaboration with teachers. Each session is structured around the use of a game as a catalyst for reflection, discussion, and

participatory learning. The experience is further supported by an educational “toolkit” that includes visual aids and reference materials, designed to reinforce key prevention messages.

Beyond the educational activities, the project also facilitates collaboration among schools, local authorities, and training institutions, creating a network-based approach to safety education. Insights from the pilot schools are being analysed to inform future scaling and possible integration into broader civic education programmes.

4 Methodology

The “Let’s Play 81!” project adopts a structured pedagogical methodology based on experiential and active learning principles. The intervention aims to convey foundational messages related to occupational health and safety (OHS) to children aged 8 to 13 using analog, game-based tools designed specifically for educational contexts. The sessions are led by certified safety trainers in collaboration with classroom teachers.

The use of games as educational devices is supported by research on learning through play and engagement (Singer et al., 2006; Barnett, 2007). Structured gameplay facilitates memory, reflection, emotional involvement, and peer interaction—critical factors in internalizing complex concepts such as risk, responsibility, and prevention.

The study was conducted following CONSORT guidelines ().

A teaching kit was created, consisting of a box (30×20×10cm) containing an operational manual and the materials necessary for three different types of games: a role-playing game ("81 si gira!"), a board game ("Riduci il premio"), and a card game ("Mettici la mano").

81 Action! (81 si gira!) is a role-playing game in which each player takes on a character involved in workplace safety (e.g., employer, prevention officer, inspector, workers’ representative). Players collectively address safety scenarios presented through “story cards” and engage in dialogic problem-solving based on their assigned responsibilities. The game encourages cooperative reflection, active listening, and contextualized reasoning within safety frameworks.

Reduce the Premium! (Riduci il premio!) is a board game inspired by Monopoly mechanics, where each player represents a company seeking to reduce its insurance premium. Players navigate a board with 30 squares and interact with “True/False” questions, “Credits” knowledge tests, and “Action” cards representing correct or incorrect safety behaviours. Game dynamics simulate INAIL’s incentive system (“oscillation for prevention”) to enhance understanding of cost-risk relationships in prevention strategies.

Your Hand on It! (Mettici la mano!) is based on the Italian card game “Tappo”, this game uses character-based decks and reflex dynamics. Players attempt to collect four identical character cards and then quickly place their hands on the table to answer a safety-related question. Speed, memory, and correct responses determine the winner. The game reinforces vocabulary, roles, and basic concepts of responsibility in a competitive yet playful format.

Each activity is accompanied by an educational “toolkit” including printed materials, visual aids, and question decks. Trainers facilitate gameplay and support classroom discussions on key messages. Teachers help contextualize the content within broader civic and health education curricula.

Feedback was collected qualitatively through observation sheets and reflections from both students and teachers. The modular format of the activities allowed for local adaptation without compromising educational consistency. All materials were aligned with the content and spirit of Legislative Decree 81/2008 and updated guidelines on prevention in educational settings.

5 Preliminary results and observations

The field trial of the “Let’s Play 81!” gamified training course was conducted in three lower secondary schools in Rome. Ten third-year classes were invited to participate (n = 226 students, 100% adherence rate). On the day of the intervention, 36 students were absent, leading to 190 students actually participating (mean age: 13.08 ± 0.36 years; 49.5% female). Students were randomly divided into two arms: Intervention Group (IG, n = 97) and Control Group (CG, n = 93). Three students from the CG were later excluded due to incomplete questionnaires, resulting in n = 90 analyzable CG participants.

The learning outcome was measured using the Score81 tool, a 15-question multiple-choice test administered pre- and post-intervention (T0, T1). The quiz was validated in previous research (Cronbach’s $\alpha > 0.70$).

Statistical analysis showed:

- At T0 (baseline), no significant difference in Score81 between IG and CG ($p = 0.597$)
- At T1, IG showed a significant increase in knowledge: from 4.87 ± 2.41 to 9.30 ± 2.89 ($p < 0.001$)

while CG remained unchanged: from 4.69 ± 2.14 to 4.60 ± 2.41 ($p = 0.617$)

Δ Score81 (mean increase):

- IG: +4.43 points (SD = 2.98, $p < 0.001$)
- CG: +0.09 points (SD = 1.68, $p = 0.617$)

These results are summarized in the following table:

Table 1 – Score81 results: Comparison between Intervention Group (IG) and Control Group (CG)

Group	T0 Mean ± SD	T1 Mean ± SD	Δ (T1 – T0)	p (within group)
CG (n = 90)	4.69 ± 2.14	4.60 ± 2.41	+0.09	0.617
IG (n = 97)	4.87 ± 2.41	9.30 ± 2.89	+4.43	< 0.001

Legend: T0 = pre-intervention; T1 = post-intervention; p = paired t-test.

Qualitative observations collected by trainers and teachers indicated strong student engagement during the sessions. Feedback highlighted the games' capacity to stimulate memory, collaboration, and emotional connection to content. Teachers also noted improvements in cooperative behavior and class cohesion. These transversal benefits are consistent with the broader aims of civic education.

While promising, the results must be interpreted considering certain limitations: no long-term follow-up was conducted, the sample was limited to Roman schools, and randomization occurred at class level, not individual. These factors may limit generalizability but confirm feasibility and impact in school-based prevention education.

6 Policy and practical implications

The results of the "Let's Play 81!" pilot intervention underscore the strategic value of integrating occupational health and safety (OHS) education into the formal school curriculum, starting from lower secondary levels. The observed increase in safety-related knowledge among students in the intervention group, combined with positive feedback from teachers and trainers, points to the efficacy and relevance of non-formal, game-based methods in promoting a preventive mindset from an early age.

This educational approach aligns with the evolving normative framework at the national level. The 2024 amendment to Legislative Decree 81/2008 has explicitly strengthened the role of educational institutions in cultivating safety culture, emphasizing the need for early engagement, active methodologies, and territorial partnerships (Quotidiano Sanità, 2024). "Let's Play 81!" anticipates and operationalizes this policy direction, offering a concrete example of how schools, municipalities, and certified OHS trainers can collaborate to disseminate prevention principles in accessible and sustainable formats.

The implications of this model are both practical and systemic:

- Educational innovation: The project demonstrates that analog, low-tech games can be powerful tools for teaching complex safety concepts. This is particularly relevant in under-resourced contexts where digital infrastructures are limited.
- Scalability and replicability: The modular design of the toolkit and the structured delivery method enable adaptation across different school levels and regional contexts. The experience of "Let's Play 81!" can inform the development of regional or national guidelines for integrating safety into civic education.
- Transversal competencies: Beyond safety knowledge, the intervention supported broader learning outcomes, including collaboration, communication, and responsibility—skills that are central to both education for sustainable development (ESD) and lifelong learning agendas.
- Institutional coordination: The project illustrates the importance of cross-sectoral governance in health promotion. By involving schools, municipalities, and training bodies, it fosters an integrated approach consistent with international health and safety strategies (e.g., WHO, ILO).

These findings suggest that gamified OHS education can serve not only as a learning innovation, but also as a policy instrument to reinforce a systemic, community-based culture of prevention. Further development, including long-term evaluation and broader stakeholder engagement, could support its institutionalization within national educational frameworks.

7 Conclusions

The "Let's Play 81!" project represents a concrete and innovative response to the growing institutional and societal demand for the early promotion of a safety culture. By combining non-formal learning, analog gamification, and school-based delivery, the initiative has proven both feasible and effective in enhancing students' understanding of occupational health and safety (OHS) principles.

Quantitative results confirm a statistically significant improvement in students' knowledge following participation in the intervention, while qualitative feedback highlights strong engagement, emotional

involvement, and relevance to broader educational goals. These findings demonstrate that playful, interactive approaches—when pedagogically structured—can be powerful vehicles for developing civic responsibility and risk awareness.

At a policy level, the project aligns with the 2024 update to Legislative Decree 81/2008, which reinforces the educational sector's role in prevention. "Let's Play 81!" anticipates this shift by offering a practical model for inter-institutional cooperation and early intervention in the development of safety competencies.

Looking ahead, several areas of development are envisioned:

- Long-term evaluation: Future studies will assess knowledge retention, behavior change, and transversal impact over time, including follow-up with teachers and families.
- Toolkit optimization: Based on pilot feedback, the game materials and facilitation strategies will be refined to improve clarity, inclusivity, and alignment with curricular objectives.
- Broader dissemination: Institutional partnerships will support the scaling of the initiative to other regions, potentially integrating it into national health promotion or civic education programs.
- Research integration: Opportunities exist to expand the scientific evidence base on gamified prevention strategies in schools, contributing to interdisciplinary knowledge on health education and learning innovation.

In sum, "Let's Play 81!" affirms that promoting workplace safety is not solely a matter of compliance or training—it is a cultural investment that begins in school, through methods that are participatory, inclusive, and cognitively rich.

8 Ethics declaration

Ethical approval was obtained from Universitas Mercatorum Ethical Committee on March 13, 2025 (Prot. 0617). The study adheres to the principles outlined in the Helsinki Declaration of 1975, as revised in 2000 (The world medical association, 2008).

9 AI declaration

The authors declare they did not use AI tools in developing the paper .

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Digital Transformation, Board of Directors and Environmental Performance: Evidence from Italian Listed Companies

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Abstract

Digital transformation, board characteristics, and environmental performance are increasingly significant in the realm of corporate sustainability. Numerous scholars assert that digital transformation can serve as a powerful catalyst for sustainable corporate development, delivering substantial benefits to both businesses and society. Digital transformation refers to the process through which companies evolve from traditional industrial stages to the Industry 5.0 paradigm, which integrates technological innovation with human-centric approaches.

According to the stakeholder theory, firms operate within an interconnected system encompassing economic, social, environmental and political dimensions, and enhancing corporate profitability has become an essential requirement for stakeholders. In this context, digital transformation can substantially boost corporate productivity and contribute to achieving sustainable development goals, thereby acting as a primary factor through which stakeholders can compel firms to initiate transformation processes.

Furthermore, companies are increasingly subjected to pressures from stakeholders who are placing greater emphasis on environmental issues, compelling them to adopt proactive environmental governance strategies. However, despite the extensive development of literature on digital transformation and environmental performance, studies analyzing the potential moderating role of board characteristics remain limited. This paper aims to bridge this gap by exploring the relationship between digital transformation and environmental performance, considering the specificities of board characteristics.

The existing empirical literature often employs textual analysis to quantify the extent and quality of digital transformation. Similarly, in this study, the construction of the digital transformation indicator is achieved through keywords selected based on prior literature, including: big data, informatization, intelligence, robotics, Internet of Things, blockchain, automation, digitization, and cloud computing.

Based on this method to measure the digital transformation efforts, we investigated the potential moderating effect of board gender diversity on the relationship between digitalization and corporate environmental performance, using data from Italian publicly listed companies for the year 2023.

The results of the empirical analysis indicate that 1) digital transformation has a positive and significant impact on corporate environmental performance, and 2) that impact of digital transformation on environmental performance is reinforced by a higher presence of female directors on corporate boards.

These findings provide potentially valuable insights to a diverse audience. Firstly, to companies engaged in digitalization processes. Secondly, to developing countries still in the Industry 3.0 or Industry 4.0 phase. Thirdly, to governments of developed countries, to promote national technological growth, monitor companies, and establish appropriate regulatory frameworks for the digital era.

Keywords: digital transformation, female directors, critical mass, CSR performance

Paper type: Academic Research Paper.

1 Introduction

In recent decades, driven by the progress of industrialization, Italy has established itself as one of the leading global economies, with a strong manufacturing sector that has secured its position in major international markets (Ministry of Economic Development, 2018). As of 2019, Italy accounted for approximately 2.3% of global GDP and was the second-largest manufacturing economy in Europe, after Germany. However, industrial growth has also posed significant environmental challenges, with the industrial sector remaining one of the primary sources of CO_2 emissions (Ministry of the Environment, 2020). These figures underscore a critical challenge for Italian industry: how to reconcile economic development with environmental sustainability.

Within this framework, Italy's digitalization and Industry 4.0 transition policies play a pivotal role in ensuring that the industrial sector can effectively address sustainability challenges. Like other European countries, Italy has embraced the Industry 4.0 paradigm. The Italian government launched the National Industry 4.0 Plan to foster the digitalization of the manufacturing sector, aiming to modernize firms through the adoption of advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), and robotics (Ministry of Economic Development, 2018). Through the Transition 4.0 Plan, which later evolved into the Transition 5.0 Plan,

fiscal incentives were introduced to encourage the adoption of technologies capable of reducing energy consumption and enhancing firms' production efficiency.

However, several studies emphasize that, despite the growth in investment, Italian firms – while benefiting from public funding – frequently fail to introduce substantial strategic changes. Instead, these firms often prioritize utilizing the funds to secure short-term tax benefits, rather than pursuing meaningful enhancements in their production processes or business models (Bocci et al. 2023; Bronzini and Piselli 2016; Czarnitzki and Lopes-Bento 2014).

In the evolutionary transition toward the next phase of industrial development, Industry 5.0 (I5.0) emerges as a new paradigm that integrates technological innovation with human-centric approaches, aiming to overcome the limitations of Industry 4.0 (I4.0) and to foster sustainability across its economic, environmental, and social dimensions (Sarkar et al. 2024). This paradigm represents an advanced stage of industrial progress in which the synergy between technological capabilities and human creativity enables the implementation of highly customized, efficient, and sustainable Smart Manufacturing (SM) solutions (Grabowska, 2022).

Industry 5.0 is grounded in the integration of emerging technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), collaborative robotics (cobots), and advanced big data analytics.

Unlike I4.0, which focused on automation and data-driven efficiency, I5.0 emphasizes the centrality of human involvement in production systems, promotes mass customization models, and advances a systemic commitment to sustainability.

Digital transformation has significantly increased the volume of data available to firms. In this context, technological innovations such as the Internet of Things (IoT), cyber-physical systems, and artificial intelligence are increasingly integrated with traditional enterprise information systems (Garzella, 2018), enabling the collection and analysis of large volumes of data to convert them into actionable insights that support decision-making processes (Nielsen and Montemari, 2021).

Corporate governance theory posits that the board of directors plays a critical role in aligning corporate strategy and promoting sustainable business development (Sahar et al. 2018). Moreover, the board can offer valuable support through technological expertise and experience, thereby helping to mitigate the risks associated with digital transformation (Davis and Cobb, 2010).

According to recent studies, the effectiveness of digitalization in improving corporate environmental performance may be influenced by the characteristics of the board of directors and top management (Sahar et al. 2018; Westerman and Bonnet, 2015; Orazalin and Baydauletov 2020). Corporate governance theory and resource dependence theory suggest that a diverse board in terms of age, gender, education and political ties can facilitate digital transformation, reduce the associated risks and enhance environmental performance (Cabeza-García et al. 2019; Song et al. 2020; Sarto et al. 2019)

However, the findings from empirical studies examining the relationship between board structure and corporate environmental performance (CEP) remain inconclusive (Beji et al. 2021; Khan et al. 2013). The existing research predominantly investigates the direct impact of board structure on either environmental performance or digital transformation, but tends to overlook the potential moderating role of board structure in both domains. This research aims to fill this gap, specifically by investigating the moderating role of board gender diversity. In order to do so, we performed a multiple regression (OLS) analysis on a sample of Italian listed firms.

The empirical findings suggest that digital transformation has a positive impact on environmental performance and that firms with a higher representation of women on their boards of directors appear more inclined to adopt digital transformation initiatives that enhance environmental performance. These results contribute in several ways to the existing research on digital transformation and environmental performance.

First, while previous studies have examined the impact of digital transformation on corporate sustainability, they have often relied on literature reviews and conceptual frameworks (Zhu et al. 2021). Instead, our study adopts a textual analysis approach to quantify the level of digital transformation and empirically assess its impact on environmental performance (Zhai et al. 2022). Second, we examine the interaction effect of board structure and digital transformation on environmental performance, thus verifying the strategic role of the board in shaping decisions related to the adoption of digital transformation initiatives.

The remainder of this paper is structured as follows: the *Literature Review* section presents prior research on digital transformation, corporate environmental performance (CEP), and the moderating role of board structure; the *Variable Description and Methodology* section outlines the data sources and econometric methods used; the *Regression Results and Discussion* section presents the empirical findings and their interpretation; and finally, the *Conclusion and Policy Implications* section summarizes the study, discusses practical implications and the study's limitations, while also outlining future research directions.

2 Literature review and hypotheses development

2.1 Digital transformation and Corporate Environmental Performance (CEP)

A growing body of scholarly research posits that digital transformation serves as a strategic enabler for corporate sustainable development, generating substantial value for both businesses and broader society (Shabur, 2025). According to stakeholder theory (Waheed et al. 2020), firms operate within complex and interrelated economic, social, environmental, and political domains, where enhancing corporate profitability has emerged as a core expectation among stakeholders (Iyigün 2015).

Within this framework, digital transformation is increasingly recognized as a critical driver for improving organizational productivity and advancing sustainability goals, thereby motivating firms to embrace digital technologies in response to stakeholder pressures (Bertani et al. 2020; Dyatlov et al. 2019).

Furthermore, drawing on information processing theory (Premkumar et al. 2005), digital technologies are understood to enhance the efficiency of information management processes, thereby improving organizational responsiveness and reinforcing competitive advantage (Khin and Ho 2019; Chen et al. 2015). By enabling real-time visibility into operational activities and facilitating more effective resource allocation, digital transformation supports agile and data-driven decision-making aligned with sustainable business practices.

Moreover, digital transformation enhances transparency in business management and operations toward stakeholders, contributing to building trust (Kyaw et al. 2022). In fact, companies are facing increasing pressure from various stakeholders—especially those focused on environmental issues—pushing firms to adopt proactive environmental governance strategies. These strategies are not only environmentally effective but also financially beneficial, attracting external capital (Cronkleton et al. 2008).

Based on the theoretical analysis above, we propose the following hypothesis:

- *Hypothesis 1. Digital transformation can improve corporate environmental performance.*

2.2 The moderating effect of board structure

Several studies have investigated how board diversity influences environmental and sustainability practices, examining aspects such as board diversity, greenhouse gas disclosures, and the presence of environmental committees (Liao, 2015), female directorship and corporate sustainability (Galbreath et al. 2011), and compliance-oriented approaches to sustainability practices (Nadeem et al. 2017).

Some research highlights that women tend to be more sensitive to environmental and social protection (Post et al. 2015). Other studies point to a direct impact of board diversity on actual environmental performance (Glass et al., 2016) and emphasize the relationship between board composition and corporate sustainability performance (Naciti et al. 2019). The presence of female board members has also been shown to facilitate communication and the dissemination of information, which in turn supports strategic innovation within the firm (Smulowitz and Smulowitz, 2024; Song et al. 2020; Sarto et al. 2019).

Furthermore, with the evolution of information technologies, more women are increasingly participating in corporate decision-making processes (Cabeza-García et al. 2019). Based on the above theoretical analysis, we propose the following hypothesis:

- *Hypothesis 2. Female directors can strengthen the positive relationship between digital transformation and environmental performance.*

3 Research methodology

3.1 Sample

Our initial sample comprised all firms listed in the Italian stock exchange in the year 2023. Data were collected from multiple sources. The ESG scores were collected from the Refinitiv Eikon database, now LSEG Data & Analytics. Financial and accounting data were sourced by AIDA. Corporate governance data such as the number of female directors, and board size were hand-collected from the corporate governance reports.

After removing firms with missing data and financial firms we were left with a final sample of 90 firms. This is mainly due to the limited number of ESG scores available on Refinitiv Eikon for Italian listed firms.

3.2 Variable measurement

The corporate environmental performance is measured using the environmental score provided from the Refinitiv Eikon database. This score measures firms' environmental performance based on public information

data, taking into account comparability, data availability, and industry relevance, ranging from a minimum of 0 to a maximum of 100.

The independent variables of interest in this study are digital transformation (DT) and board gender diversity as measured by the percentage of female directors on the board.

In order to measure digital transformation, this study builds upon previous empirical work, which established and validated a digitalization dictionary that identifies the words that a qualified public (made up of professors, PhD students, graduate and undergraduate students) associates with firms' digitalization efforts (Hossnofsky and Junge 2019). This study summarizes and organizes keywords related to digital transformation and uses Nvivo software to match text content in companies' annual reports to determine the number of words related to digital transformation, wherein more times words related to digital transformation appear in an annual report, the higher the degree of digital transformation is for that enterprise. To reduce statistical errors, we excluded judgmental words, such as none, not, and no, before and after the word field. Thus, we came up for each firm with the total number of digital transformation-related words, as a measure for the degree of firm digitalization.

As additional control variables at firm level, we include firm size, the debt-to-equity ratio and the return-on-assets (ROA) ratio. The control for firm size is particularly important because ESG scores can be subject to firm size bias (Drempetic et al. 2020) as bigger firms may use economies of scale to enhance ESG performance. We use the natural logarithm of employee number as a proxy for firm size. The debt-to-equity ratio is used as a proxy for firm leverage to control for the impact of financial risk on firm ESG performance (Simnett et al. 2009). As more profitable firms are more likely to have better ESG performance, we also control for firm profitability using the ROA ratio (Liang and Renneboog 2017). Industry effects are also accounted for.

Table 1 summarizes the definition and measurement of all the variables used in the econometric analysis.

Table 1. Variables definition and measurement

Variable	Description	Source
CEP	Corporate Environmental score	Refinitiv Eikon
DT	Number of digitalization related words in annual reports	Company annual Report
BGD	Percentage of female directors on the board	Corporate Governance Report
Lev	Leverage ratio	AIDA Database
Cash	Cash ratio	AIDA Database
Firm size	Log-transformed of number of employees	Corporate Governance Report
ROA	The percentage of return on assets	AIDA Database
Leverage	Total debt/total assets	AIDA Database

4 Results

In order to test our hypotheses, we estimate the following model by using an ordinary least squares (OLS) regression, where the digital transformation variable (DT), the percentage of women on board (BGD) and their interaction term (DT*BGD) are the main variables of interest:

CEP Performance (CEP) = b_0 + b_1DT + b_2 DT*BGD b_3 + b_4Firm size + $b_5$cash ratio + b_6Leverage + Industry + ε

Table 2 presents the descriptives statistics and pairwise correlations between the variables. The average value of the CEP performance is 64.74 with a standard deviation of 16.20 which indicates a large variation in this performance measure. The boards of Italian listed firms are composed on everage for the 39% by female directors.

The results of the correlation analysis show that the independent variable of interest, the percentage of female directors, has a positive and significant association with the CEP variable, providing some initial support to our first research hypothesis. Furthermore, as the variance inflation factors (VIF) values are well below the warning value of 10 (Myers 1990), we can conclude there are no significant multicollinearity issues in our regression.

Table 2. Means, standard deviations, VIF and pairwise correlations

	Mean	SD	VIF	1	2	3	4	5	6	7
1. CEP	54.8	16.9		1.00						
2. DT	2.31	1.44	1.88	0.271*	1.00					
3. BGD	38.72	12.14	2.87	0.484*	0.089	1.00				
4. Firm size	6.05	0.19	1.77	0.406*	0.190	0.096	1.00			
5. LEV	0.52	3.34	1.52	0.118	-0.009	0.155	0.207	1.00		
6. Cashratio	0.43	0.32	2.24	0.219*	-0.066	0.108	-0.122	-0.014	1.00	
7. ROA	1.83	7.80	1.64	0.238*	-0.01	-0.11	-0.15	0.10	0.07	1.00

***, **, * indicate significance at 0.1% and 1% and 5%, respectively.

Table 3 presents the estimation results of our econometric model with (model 1) and without (model 2) the interaction effect of board gender diversity. Our first hypothesis predicts that digital transformation can improve corporate environmental performance. As column (1) shows, the regression coefficient on the DT variable is positive and statistically significant ($\beta = 2.84$, $p < 0.05$). This would suggest that digital transformation can improve better CSR performance. H1 is thus supported. This result is consistent with previous research such as Chen and Hao (2022) and Wang et al. (2025) which also find a positive association between and digital transformation and environmental performance.

Column (2) shows the estimation results including the moderating variable. Our second hypothesis predicts that the proportion of female directors positively moderates the association between the digitalization and environmental performance. The positive coefficient on the interaction term DT*BGD ($\beta = 0.18$, $p < 0.05$) lends support to this hypothesis as well. It implies that board gender diversity reinforces the positive impact of digitalization on corporate environmental performance.

As regards the control variables at board level, we find that board size has a positive association with CEP, thus supporting the argument that large boards may boost the firm's environmental performance because they are more effective in balancing the interests of diverse stakeholders' groups.

Regarding the other control variables, we find that firm size is positively related to environmental performance, suggesting that the larger the firm size, the more likely the firm is to engage in CSR activities. The coefficient estimates on ROA and leverage are respectively positive and negative.

Table 3. Multiple regression analysis with main and interaction effects

	Environmental performance	
	Model 1	**Model 2**
DT	2.84*	1.94*
	(1.24)	(0.98)
BGD		0.58***
		(0.13)
DT*BGD		0.18*
		(0.09)
Cash	12.21*	10.40**
	(5.41)	(4.75)
Leverage	0.06	-2.88***
	(0.55)	(4.77)
Firm size	3.44**	5.95***
	(55.65)	(41.40)
ROA	0.47***	0.006
	(12.02)	(0.22)
Industry dummies	Yes	Yes
Constant	21.51***	14.01
	(7.17)	(9.37)
N	90	90
R^2	0.27	0.45

***, **, * indicate significance at 0.1% and 1% and 5%. In parentheses are t statistics.

4 Conclusions

This paper sets the stage for further exploration into corporate environmental governance within the framework of Industry 5.0. To the best of our knowledge, empirical studies that investigate how digital transformation influences environmental performance through the lens of board characteristics are relatively limited. This research is an attempt to fil this gap. Specifically, we investigated the potential moderating effect of board gender diversity on the relation between digitalization and corporate environmental performance, using data from Italian publicly listed companies relating to the year 2023.

Our empirical findings reveal that digital transformation significantly enhances corporate environmental performance (CEP), providing a theoretical foundation for harmonizing economic growth with environmental sustainability. Additionally, the empirical findings indicate that gender diversity positively moderate this relationship. In other words, firms with a higher proportion of female directors would be more likely to embrace digital transformation initiatives that improve environmental outcomes. These insights underscore the importance for companies navigating the transition to Industry 5.0 to recognize the evolving composition of their boards and to adjust the gender balance accordingly to mitigate transformation-related risks and advance sustainable development.

Several policy and managerial recommendations may result from these findings.

Companies should increase diversity on corporate boards, particularly by involving more female directors, as a means to reduce the environmental risks associated with digital transformation. Second, companies should develop regular training programs to keep board members and executives informed about the latest industry trends and management innovations, helping to challenge outdated managerial mindsets.

Governments on their behalf should enhance the development of digital infrastructure to support the digital transformation of enterprises. Second, they should establish and refine environmental monitoring systems, along with incentive and penalty mechanisms, to help reduce the environmental management costs for businesses. By leveraging digital technologies, governments can monitor enterprises' environmental performance and offer targeted subsidies to encourage greater engagement in environmental protection (Chen and Hao 2022).

Nonetheless, this study presents several limitations. First, it uses textual analysis to evaluate digital transformation, which may not fully capture the nuances among the digital transformation strategies of firms. It should also be considered that firms may engage in narrative disclosures that may not reflect their actual digitalization efforts. Second, while this study examines the moderating role of board characteristics, it does not consider the underlying mechanisms by which digital transformation may improve corporate environmental performance. Additionally, our focus is limited to board gender diversity, neglecting other potentially influential attributes of corporate boards such as directors' professional backgrounds, cultural diversity and nationalities. Future research could address these limitations possibly by employing longitudinal data, as this study's reliance on cross-sectional data constitutes another limitation.

5 Ethics declaration

This study did not involve procedures requiring ethical clearance, and no ethical approval was necessary for the research conducted.

6 AI declaration

The authors confirm that no artificial intelligence tools were used in the preparation or production of this paper.

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Navigating Sustainable Corporate Governance in the Age of Artificial Intelligence: Primary Evidence from Italy

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Abstract

In the current economic and business context, Artificial Intelligence (AI) becomes a debated topic among academic and practitioners. Although the specific literature has outlined the relationship between top management and digitalization, sustainability topics remain less scrutinized, particularly concerning AI. With these premises, this study intends to investigate whether sustainable corporate governance (SCG) affects disclosure about AI.

To test the research hypothesis, we adopted a mixed approach (i.e., content analysis, structural equation modelling, ordinary least squares and lasso regression) working on a sample of 104 Italian listed companies.

Firms with higher levels of SCG scores display a greater impact on AI disclosure, suggesting that sustainable boards are demonstrating greater integration of AI in their disclosures as well as in their decision-making processes.

Although the literature is becoming increasingly interested in sustainable corporate governance issues, research is still lacking. To the best of the authors' knowledge, no study has previously investigated possible relationships between sustainable governance and the digitization process, especially with regard to the implications of AI.

Our findings provide insightful contributions to SCG- and AI-related literature, enriching the UET framework. In doing this, this study provides important implications for managers – especially at a strategic level – and policymakers.

The research is not free from limitations. First of all, AI disclosure is assumed to be representative of effective AI implementation, leaving room for doubt as a level of AI disclosure does not guarantee the same level of actual integration. Furthermore, it falls into a single-year analysis (2023) and Country (Italy). Therefore, future studies, survey-based, could increase the accuracy of the AI index and expand the analysis over time as well as to other countries.

Keywords: Sustainable corporate governance, Artificial intelligence, Disclosure, SEM, UET

Paper type: Academic Research Paper

1 Introduction

The expansion of the digital economy is fuelled by technologies like the Internet, artificial intelligence (AI) and cloud computing, which significantly influence industrial development and economic growth (Guo et al., 2023). In last years, AI is gaining higher interest from scholars and managers (Bevilacqua et al., 2025). AI can be defined as systems that mimic human cognitive abilities to perform tasks requiring intelligence (Mueller & Massaron, 2021). Hilb (2019) states that "the highest level of intelligence must be synergic, i.e. a state in which human and machine intelligence function and are superior in combination". The debate about AI becomes always more attractive in the business context, where corporate governance must cope with the advent of new technological challenges. AI integration in business processes is transforming industries by enhancing efficiency, innovation and decision-making processes (Kolbjørnsrud et al., 2016) but also raising ethical concerns, regulatory challenges and accountability risks (Duan et al., 2019). In this way, AI takes a central role for the so called sustainable corporate governance (SCG) that pays greater attention on aligning company's and stakeholders' interests (Velte, 2024). Against this backdrop, this paper intends to investigate if SCG affects disclosure about AI, focusing on a sample of 104 Italian listed companies on 2023 data. We applied a mixed method reaching out that companies with higher levels of SCG display a greater AI disclosure. The following of this paper is structured as follows: in Section 2, we review the literature to develop research hypothesis; in Section 3, we detail sampling and methods; in Section 4, we provide results then discussed in the final Section 5.

2 Literature review and hypothesis development

2.1 Theoretical framework

Considering AI, sustainability and corporate governance mechanisms, two theoretical lenses provide the framework for this study: the upper echelons theory (UET) and the innovation theory. Literature conveys that managers lead digital transformation, which plays a crucial role in decision-making processes (Bevilacqua et al., 2025; Guo et al., 2023; Lin et al., 2019). Based on the upper echelons theory, managers' characteristics shape

their behaviours and strategic decisions, ultimately influencing company's objectives, actions, and outcomes (Hambrick & Mason, 1984). Previous research highlights significant correlations between top executives and strategic corporate changes (Hambrick & Mason, 1984; Wiersema & Bantel, 1992). Additionally, several scholars suggest that senior managers influence organizations' innovation efforts (Smith & Tushman, 2005; Wrede & Dauth, 2020). Consequently, corporate leaders play a pivotal role in navigating digital transformation, fostering a digital culture, optimizing resource allocation and managing human capital (Avolio et al., 2000; Gupta et al., 2023). On the other hand, literature use innovation theory to explain how investments in research and development and technology improve governance efficacy and promote sustainable development (Khan et al., 2024).

2.2 Sustainable corporate governance and artificial intelligence

In recent years, a significant shift has occurred in corporate governance practices, moving from a short-term profit-driven orientation towards a long-term and sustainable approach. This transition has been largely influenced also by regulatory initiatives, such as the Corporate Sustainability Reporting Directive and the proposed Directive on Corporate Sustainability Due Diligence (Pizzi et al., 2021). The latter, jointly with the broader Agenda 2030, have intensified the pressure on companies to embed sustainability considerations within their governance frameworks (Velte, 2023), bringing academics and practitioners to emphasize the relevance of SCG. Aligned with the United Nations Sustainable Development Goals, SGC has emerged as a strategic mechanism for guiding companies toward responsible resource management and for addressing both current and emerging environmental and social challenges (European Commission, 2022; Kavadis & Thomsen, 2023). According to the European Commission (2020), sustainable corporate governance refers to a governance model that promotes long-term value creation by aligning corporate interests with those of shareholders, stakeholders and society as a whole. This approach requires firms to integrate sustainability into their strategic and operational decisions, encompassing issues such as social rights, climate change and environmental protection. Basically, SCG can be observed in a board of directors that properly incorporate environmental and social goals into strategy definition, fostering a successful and credible sustainable transformation while also enhancing corporate reputation (Johnstone, 2019; Velte, 2024). From a theoretical standpoint, SCG is often grounded in the triple bottom line framework (Elkington, 1994), which emphasizes the simultaneous pursuit of economic (profit), social (people) and environmental (planet) objectives. Similar to corporate disclosure, which has evolved to reflect sustainability concerns, corporate governance is increasingly embracing this multidimensional perspective aimed at improving the overall effectiveness of sustainability (Lozano, 2012).

Among the several management theories that study the decision-making processes, UET emphasize the relevance of top managers (Hambrick & Mason, 1984). A growing body of research points out that strategic changes within firms are closely associated with the influence exerted by executives (Åberg & Torchia, 2020; Wiersema & Bantel, 1992). In particular, top management teams are increasingly recognized as key drivers of organizational innovation, shaping the direction and intensity of firms' innovation efforts (Smith & Tushman, 2005; Wrede & Dauth, 2020).

Recent advancements in AI have raised fundamental questions about its integration within corporate governance systems. In this context, Hilb (2020) introduces a multidimensional framework that conceptualizes AI's impact on corporate governance across three interrelated domains: desirability (business perspective), feasibility (technological perspective), and responsibility (societal perspective). This framework identifies five potential scenarios of AI integration—from assisted to autopoietic intelligence—highlighting how boards may evolve from being merely supported by AI to co-governing or even being replaced by autonomous decision systems. Such developments call for a rethinking of governance practices, particularly in light of sustainability imperatives. As sustainable corporate governance aims to align corporate strategies with long-term societal and environmental goals (Velte, 2024; European Commission, 2022), it becomes essential to understand how AI can be harnessed not only to improve efficiency but also to enhance transparency, accountability, and ethical oversight in decision-making processes. By embedding AI within the governance structures of firms that demonstrate strong SCG profiles, organizations may foster what Hilb terms "synergic intelligence"—a combination of human and machine intelligence that amplifies corporate effectiveness and legitimacy. In line with this perspective, the present study empirically explores whether companies with more advanced SCG mechanisms are also those more likely to disclose and integrate AI within their strategic narratives, thereby positioning sustainable governance as a key enabler of responsible digital transformation.

2.3 Hypothesis development

Drawing upon UET (Hambrick & Mason, 1984), top management and the broader corporate governance play a crucial role in driving innovation efforts and shaping AI disclosure. Furthermore, according to the innovation theory, which allows us to link innovation with sustainable practices (Khan et al., 2024), we propose the following research hypothesis:

- *H1. Sustainable corporate governance is positively associated with AI disclosure.*

3 Data and methods

3.1 Sample

Our sample includes 104 Italian listed companies, for which both financial and non-financial data over 2023 are available. We retrieved financial data from AIDA Bureau van Dijk and non-financial disclosures from osservatoriodnf.it.

3.2 Variables

The study defines a set of variables to examine the relationship between SCG and AI disclosure.

The dependent variable, Artificial Intelligence disclosure (AI_D), results from a content analysis (Krippendorff, 1980) of the non-financial statements through NVIVO. The analysis evaluates the presence or absence of specific AI-related disclosure items: each item is valued 1 if it appears at least once and 0 otherwise and the arithmetical mean of all these dummies represents the AI_D score.

The main independent variable, Sustainable Corporate Governance (SCG), represents a multidimensional latent construct, starting from the approach of Velte (2022, 2023, 2024). It combines several indicators: the number of non-financial disclosure pages dedicated to environmental, social, and governance issues; the existence of a sustainability committee; the presence of a formal sustainability plan; the inclusion of long-term environmental and social targets; the implementation of a sustainable supply chain; and the disclosure of gender pay gap data. These indicators form the basis for the latent SCG variable, estimated through structural equation modelling (SEM).

We also include control variables to account for firm-level heterogeneity. These are: firm size (measured as the natural logarithm of total revenues) (SIZE), financial leverage (LEV), return on sales (ROS), board age diversity (AGE_D) and industry dummies.

3.3 Econometric models

To test the research hypothesis, we employed an OLS regression. The functional form is the following:

$$AI_D = \beta_0 + \beta_1 SCG + \Sigma contorls + industry + \varepsilon_i$$

4 Results

4.1 Preliminary tests and diagnostics

The following table displays the main descriptive statistics. An initial consideration regards the minimum value of AI_D, which is higher than zero, meaning that each company in the sample provides somehow disclosure about AI.

Table 1**:** Descriptive statistics

Variable	Obs.	Mean	Std. dev.	Min.	Max.
AI_D	104	3.90	0.80	1.95	6.57
SCG	104	0.02	2.27	-4.59	3.15
AGE_D	104	0.28	0.16	0	0.5
ROS	104	3.49	11.80	-33.66	29.22
SIZE	104	19.28	1.77	15.39	24.47
LEV	104	3.39	3.66	1.08	33.11

Moreover, we assessed the Pearson's correlation to detect potential multicollinearity among regressors, that does not occur. As shown in table 2, all coefficients are less then 0.80 (Weisberg, 2005). To be sure, we

performed an additional test – the Variance Inflation Factor (VIF) –, confirming no multicollinearity issues (mean VIF = 2.38 (< 5)).

Table 2: Correlation matrix

	AI_D	SCG	AGE_D	ROS	SIZE	LEV
AI_D	1					
SCG	0.33	1				
AGE_D	-0.09	-0.17	1			
ROS	-0.10	0.02	-0.01	1		
SIZE	0.34	0.28	-0.14	0.32	1	
LEV	-0.01	-0.15	0.03	0.01	0.10	1

4.2 Regression results

Regression results are displayed in Table 3. Given the single-year analysis, we employed an OLS regression; then, we included robust standard errors to avoid heteroskedasticity among data (White, 1980).

able 3: Regression results

y = AI_D	*Coeff.*	*p-value*
SCG	0.09	0.008
AGE_D	-0.11	0.814
ROS	-0.01	0.045
SIZE	0.15	0.000
LEV	-0.01	0.829
industry	Yes	0.000
constant	0.14	0.871
R-sq.	0.28	
Obs.	104	
Prob. > Chi2	11.29***	

The empirical findings reveal a positive and statistically significant association between SCG and AI_D, supporting the research hypothesis and suggesting that companies with more sustainability-oriented governance tend to communicate more about AI-related issues. The overall model exhibits a good explanatory power (R-sq. = 0.28) and the F-statistic further confirms the joint explanatory capacity of the independent variables, strengthening the reliability of the model.

4.3 Robustness checks: Lasso regression

To assess results' robustness, we employed a Lasso (least shrinkage and selection operator), as a machine learning-based technique able to improve the prediction accuracy and interpretability. Figure 1 reports the path-diagram from which the positive coefficient associated with SCG comes out.

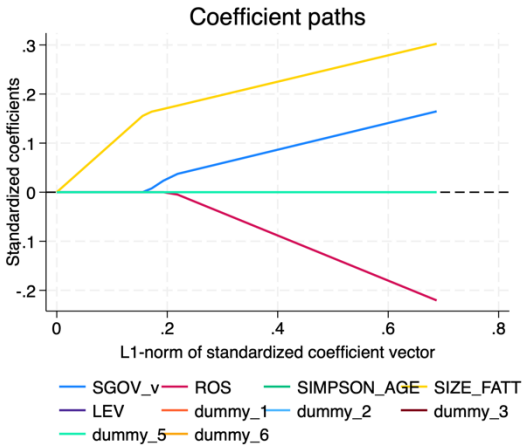


Figure 1: Path-diagram

Finally, we performed the double-selection Lasso linear regression, confirming previous findings (Table 4).

Table 4: Lasso regression results

y = AI_D	***Coeff.***	***p-value***
SCG	0.0920	0.007
N. of obs	104	
N. of controls	10	
Prob. > Chi2	7.26***	
R-sq. (training dataset)	0.60	
R-sq. (validation dataset)	0.67	

5 Discussion and conclusion

The increasing relevance of digital technologies is reshaping industries and managerial processes (Guo et al., 2023; Kolbjørnsrud et al., 2016). Among these technologies, AI stands out for its breakthrough, that simultaneously raises ethical concerns (Duan et al., 2019; Hilb, 2019).

At the same time, the need of long-term value creation has emerged, leading to a corporate governance that combines environmental and social goals within business strategy (European Commission, 2022; Velte, 2024). This integration has given rise to the concept of sustainable corporate governance, which embeds sustainability principles into board structures and strategic oversight mechanisms (Johnstone, 2019; Kavadis & Thomsen, 2023).

Despite the growing academic and institutional interest in both AI and SCG, little is known about how these dimensions interact – particularly in terms of how sustainability-oriented governance influences the disclosure and management of AI within firms. We aim to address this gap by investigating whether SCG acts as a driver of transparency in AI-related disclosure. In doing so, this study points out a positive and statistically significant association between SCG and AI_D. Companies that adopt a more sustainability-oriented governance model tend to be more transparent in disclosing information about AI-related initiatives. These findings support the Upper Echelons Theory (Hambrick & Mason, 1984), suggesting that the values and orientations of top managers, particularly their commitment to sustainability, significantly influence strategic decisions such as technological disclosure (Bevilacqua et al., 2025; Wrede & Dauth, 2020).

From a theoretical standpoint, this study contributes to the integration of UET with the dynamics of digital transformation. As suggested by Hilb (2019), governance in the AI era must be understood as a multidimensional process that balances desirability, feasibility, and responsibility. The concept of “synergic intelligence” – a collaborative interplay between human decision-makers and machine-based systems – emerges as particularly relevant in this context. Firms with advanced SCG practices are not only more inclined to disclose AI usage but may also be more likely to embed AI ethically and strategically within their corporate processes.

These results hold important implications for managers. First, managers should view SCG not only as a compliance requirement but as a strategic asset capable of driving innovation and digital transformation. A strong sustainability culture at the board level can stimulate more effective integration and communication of emerging technologies such as AI.

This research is not without limitations. The analysis is restricted to a single country (Italy) and a single year (2023), which limits the generalizability of the findings. In addition, the binary nature of the AI disclosure variable does not capture the depth, quality or sentiment of AI integration. Future research shall adopt survey-based methodologies to assess managerial attitudes toward AI and the real extent of its implementation. Furthermore, refining both the SCG and AI disclosure indicators could provide a more nuanced understanding of their interplay.

6 Ethics declaration

This research does not involve human participants, animal subjects, or sensitive personal data, and therefore did not require ethical approval. All data used in the study are publicly available from secondary sources, and no ethical clearance was necessary.

7 AI Declaration

No AI tools were used in drafting the paper.

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Digital Transformation and Public-Private Partnerships to Enhance Local Cultural Heritage

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Abstract

The present research aims to explore how digital transformation, when integrated within Public-Private Partnerships (PPPs) and social enterprise models, can foster inclusive, innovative, and sustainable approaches to cultural heritage governance. Anchored in the case study of JustMO', a cultural cooperative operating in Sepino (Molise, Italy), the study investigates how multi-stakeholder collaboration can activate new value creation processes in the cultural sector.

Adopting the SoPHIA evaluation model as a holistic analytical framework, the study examines the cultural, social, educational, and economic impacts of digitally supported heritage initiatives not only to enhance visitor experience and educational outreach but also to reinforce place identity and community ownership.

The analysis emphasizes the strategic role of Special Public-Private Partnerships (PSPPs) in enabling cross-sector collaboration, with social enterprises positioned as key orchestrators of digital ecosystems. These hybrid actors bridge institutional boundaries, channel public and private resources, and promote co-creation through participatory design and open digital infrastructures.

From a theoretical perspective, the paper contributes to current debates on PPPs by proposing an expanded view of social enterprises as drivers of digitally enabled cultural innovation. Ultimately, the study provides insights for cultural managers, policymakers, and scholars seeking to align heritage valorization with sustainability objectives and place-based development strategies.

Keywords: Cultural Heritage, Social Entrepreneurship, Digital Transformation, Public-Private Partnership, New Cultural Ventures

Paper type: Academic Research Paper

1 Introduction

Digitalization has revolutionized access to cultural content, exposing the lack of innovation and limited inclusiveness often associated with traditional top-down management models (Consiglio & Riitano, 2015). The digital transformation of cultural heritage institutions can be considered in relation to their evolution into less authoritarian and more inclusive organizations (Dąbrowska et al., 2022). Implementing new technologies and ways of working requires new knowledge and new collaboration strategies among cultural heritage institutions, which conceive and manage new relationships with external actors and offer innovative forms of participation.

Fostering collaboration among public, private, and community actors is key to reimagining cultural heritage as a shared resource and common good. In this context, bottom-up management approaches, based on collaboration between public and private actors, are emerging as effective models for enhancing cultural heritage and driving local development (European Agenda for Culture). In this context, participatory governance is essential for managing and enhancing cultural heritage, ensuring collaboration between public and private sectors at all decision-making levels.

Public-Private Partnerships (PPPs) exemplify this by integrating diverse actors, models, and tools into a holistic framework that maximizes heritage value, enhances cultural sustainability, drives economic growth, and empowers communities through social innovation, strengthened networks, and active participation in heritage preservation (Allegro & Lupu, 2018). Within this framework, collaboration among the public, non- profit, and private sectors takes the form of hybrid managerial models, such as social enterprises, which strive to achieve economic sustainability while also addressing social and ecological objectives, thereby integrating these aims within their operational frameworks (Murphy et al., 2022).

Despite social enterprises being considered key players in bridging the gap between innovation management and technology-focused stakeholders (Battisti, 2019), research on digital transformation and the implementation of public-private partnership (PPP) projects within social entrepreneurship is still in its early stages.

Recognizing this gap, the current study aims to contribute to the scholarly discourse by exploring the interplay between PPPs, social enterprises, and digital transformation.
On this basis, the authors aim to explore how bottom-up approaches and active multi-stakeholder participation can foster innovation in managing and valorizing local cultural heritage. In detail, focusing on inland areas, which are often marked by neglect and abandonment, the study highlights the potential of place- based approaches to deliver social, economic, and cultural benefits.

2 Literature review

The engagement of individuals and social collectives with the goods, activities, and values intrinsic to culture is paramount for fostering and preserving the collective memory and identity of communities. A comprehensive understanding and appreciation of cultural heritage not only enables local communities to discover the foundational reasons for their cohesion, mutual understanding, and shared purpose but also offers pathways to articulate their identity to external entities. This process stimulates a recognition of self that coexists harmoniously with the diverse identities of other communities, thereby positioning the local identity within a broader European context (Pretelli, 2020).

The public character of cultural heritage, intimately linked to its identity value and the sense of belonging it engenders, necessitates governance models that are inclusive and participatory, promoting efficient management practices (Žuvela et al., 2023; Vitale, 2024). Such models should foster active community engagement in the stewardship of cultural resources. In light of the pressing need to reconceptualize public intervention to address the multifaceted demands of the cultural sector, characterized by challenges such as delays in the protection and valuation of cultural assets, as well as inadequacies in their management, private intervention has increasingly emerged (Consiglio et al., 2020). This has surfaced in diverse legal forms, including private companies, associations, non-profit organizations, foundations, and social enterprises, which together lay the groundwork for co-responsibility between public and private entities and promote a socio-economic vision of cultural valorization (Petraroia, 2018).

Within this framework, scholarly literature recognizes public-private partnership (PPP) collaborations as pivotal in bridging the gap between governance hybridity and organizational logic. Such collaborations serve as crucial conduits for generating both economic and social value, particularly within sectors dedicated to culture and creativity (Quelin et al., 2017). Through the synergistic interplay between the state and private actors (Franch, 2020), PPPs augment the efficacy of public resources by integrating private funding and expertise to facilitate public works and the management of related services.

Public-private partnerships (PPPs) can be categorized based on their specific objectives and purposes. Typically defined as collaborations between public and private entities, PPPs are primarily established by private stakeholders to generate profit. The central goal of such partnerships is to achieve a return on investment for participants. Potential private stakeholders in these arrangements may include a diverse array of entities from the business sector. This category encompasses natural persons, profit-driven legal entities such as private universities, economic operators predominantly utilizing private capital and resources, such as construction firms, and financial institutions, including banks, pension funds, and insurance companies.

In contrast, Public-Private People Partnerships (PPPPs) represent a distinctive form of collaboration that integrates the efforts of public and private entities to support the needs and aspirations of ordinary citizens, the non-profit sector, and end users (Boniotti, 2023). The focus of PPPPs is on civic engagement, social solidarity, and fulfilling societal purposes rather than generating profit. Unlike traditional PPPs, these partnerships do not necessarily prioritize financial returns, and a profound commitment to civic responsibility and a strong inclination towards philanthropic initiatives characterizes the potential private stakeholders involved.

Public partnerships, particularly in the context of Public Special Purpose Partnerships (PSPP), serve distinct objectives aimed at enhancing the utilization and advancement of scientific research. These partnerships are specifically oriented toward the recovery, restoration, planned maintenance, and management of immovable cultural properties, as well as their accessibility to the public and effective exploitation. Such collaborations are vital for the preservation and promotion of cultural heritage, ensuring that these invaluable assets are maintained for future generations while also fostering scholarly inquiry (Sciullo, 2022).

In the context of public-private partnerships, social enterprises emerge as strategic intermediaries, enhancing operational efficiency by connecting disparate sectors and aligning diverse outcomes. The concept of "Social Enterprise" originally emerged in the third sector as a response to community needs through the development of tailored social projects (Iodice & Bifulco, 2024). This notion was catalyzed by the imperative to institutionalize innovations introduced by early "social solidarity cooperatives" (Borzaga et al., 2020). As a result, social enterprises are increasingly recognized for their capacity to generate positive externalities that enhance

community well-being (Jung & Park, 2023), fortify social ties, and create new epicenters for social engagement (Beck & Brooks, 2019).

Specifically, social enterprises contribute to PPP by functioning as strategic connectors that foster efficiency and stimulate social innovation through the following avenues:

- Acting as bridges between governmental bodies, private companies, and non-profit organizations (Battisti, 2019).
- Contributing to territorial impact and social innovation by aligning diversified institutional frameworks and funding models (Catala et al., 2025).
- Supporting capacity building and regional socio-economic development through collaborative efforts involving multiple stakeholders (Kovtun et al., 2022).

The collaboration between public-private partnerships and social enterprises is therefore essential in promoting cultural value and fostering community engagement. These partnerships bridge the gaps between governmental, private, and non-profit sectors, enhancing the management and appreciation of cultural heritage while driving social innovation and improving community well-being.

In this context, it is pertinent to highlight an emerging consideration within the scientific literature regarding public-private partnerships (PPPs) and social enterprises that facilitate digital transformation, specifically for culture-based activities. While less prevalent in existing studies, there are notable indications of the potential role of social enterprises as intermediaries in digital transformation processes. For example, Battisti (2019) underscores the function of social entrepreneurs as vital bridges connecting stakeholders in public-private partnerships, thereby enabling technology-driven social innovation. Additionally, Buyannemekh et al. (2023) identify public libraries as prospective strategic partners in smart city initiatives, positing that community-based organizations can function as significant intermediaries in these contexts.

Upon conducting a thorough analysis of the literature, the authors identified a notable gap concerning the interplay between PPPs, social enterprises, and digital transformation (see Table 1).

Table 1. Partnership models

Model Type	Key Features	Stakeholder Roles	Success factors
Public-Private Partnerships	Alignment of public needs and private competencies; Knowledge sharing; Co-creation of value (Casprini & Palumbo, 2022)	Public sector: Defines needs and provides access; Private sector: Provides technology and expertise	Leadership; Preexisting relationships; Agreement on initial aims
Data-Driven	Leveraging diverse	Public sector: Data	Data integration
Social Partnerships	data sources; Multi-sector collaboration; Focus on societal impact (Susha et al., 2019)	provision and regulation; Private sector: Technology and analytics; Non-Governmental Organizations (NGOs): Community engagement and impact assessment	capabilities; Ethical data use; Clear governance structures
Research and Development Collaborations	Open innovation practices; Focus on operational processes; Building digital ecosystems (Rocha et al., 2021)	Research institutions: Knowledge creation; Businesses: Application and scaling; Public sector: Facilitation and regulation	Engaged workforce; Customer-centric approach; Adaptive mindset
Strategic Partnerships for Platformization	Dynamic collaboration; Focus on digital platform development (Rocha et al., 2021)	Incumbent firms: Resources and market presence; Entrepreneurial partners: Innovation and agility	Flexible collaboration modes; Alignment of strategic goals; Complementary capabilities

Source: author's elaboration

Several studies suggest that digital transformation plays a critical role in the establishment of strategic partnerships that are highly context-dependent, with each model being tailored to specific objectives and environments. As illustrated in the table, the various data-driven modalities do not specifically address the intersection of PPPs, social enterprises, and digital transformation; instead, they adopt a holistic perspective on PPPs and digital transformation across diverse economic sectors, including healthcare, industry, and information technology. In contrast, the dynamics of collaboration and participation and forms of partnership that can

support the exchange of knowledge around these processes have received only limited attention (Li & Ghirardi, 2019).

The wide diffusion of digital technologies presents significant opportunities for both public and private organizations, prompting a growing interest in their impact on strategic, organizational, and collaborative processes (Agostino & Costantini, 2022; Nambisan et al., 2019). Digital transformation, as described by Hinings et al. (2018), refers not merely to the adoption of individual technologies but to the cumulative effect of digital innovations that disrupt traditional practices and reshape entire sectors or ecosystems. Within this conceptual framework, the cultural sector has emerged as a fertile domain for examining how digital tools reconfigure modes of production, distribution, and consumption of cultural content.

Focusing attention on the cultural scenario, recent contributions underscore the transformative capacity of digital technologies in enabling new forms of cultural engagement, participation, and co-creation (Agostino & Costantini, 2022). Cultural institutions, long anchored in hierarchical and custodial models, are increasingly experimenting with technology-enabled strategies that open up their functions to broader audiences and collaborative networks. In particular, digital innovation is proving essential in reshaping organizational dynamics within Public-Private Partnerships (PPPs), where technology acts not only as a tool but also as a catalyst for social innovation and multi-stakeholder collaboration (Battisti, 2019). The literature on digital transformation in the cultural sector has so far focused more on the impact on the public and the emerging possibilities for engagement and empowerment (Clemente et al., 2024; Graham, 2016), while the study of technology-enabled social innovations within PPP frameworks offers critical insights into how inclusive and adaptive governance models can emerge. This research positions itself within the identified gap, aiming to bridge the relationship between PPPs established by social enterprises through the lens of digital transformation.

3 Methodology

Given the explorative purpose of this research, the authors adopted a single case study following the “logic of replication” (Yin, 2009). This qualitative research method (Mariotto et al., 2014) makes it possible to identify the key elements of the individual case and, subsequently, apply them to new situations, thus initiating a process of knowledge dissemination.

In particular, the authors have chosen to conduct the empirical analysis using the SoPHIA framework, which is consistent with the evaluation of cultural heritage interventions due to its holistic approach (Marchiori et al., 2024). The framework's multi-dimensional structure, focusing on domains, people and time, allows for a comprehensive assessment of the expected impact of the project implemented by the selected case study. The authors have chosen to contextualize and implement this model using a longitudinal analysis (Thomson & McLeod, 2015), supported by secondary sources and interviews with key stakeholders, to ensure a robust understanding of the dynamics and outcomes.

The single case study selected is JustMO', a cultural cooperative based in Campobasso (Molise), which represents an exemplary case of adaptive reuse and implementation of the special public-private partnership (PSPP) model. The case was selected for the variety of outcomes it aims to achieve, including the generation of cultural impact, the promotion of community engagement and the exploitation of digital assets to create innovative cultural ventures.

4 Findings

This study explores how bottom-up processes and multi-stakeholder collaboration foster innovation in the management of local cultural heritage. The authors present first insights from the empirical research by applying the SoPHIA framework to the MAT Museum at Palazzo Tiberio in Sepino. Interviews with the cooperative Justmo, which implemented a Special Public-Private Partnership (PSPP) to guide the museum’s development, highlight the strategic value of synergies between public institutions, private actors, and the local community. The analysis reveals strong alignment with the dimensions of place identity, education, and creativity. Therefore the empirical data shows that digital technologies are pivotal not only for heritage preservation but also for enhancing community participation. The MAT Museum serves as a representative case of how digital innovation, through tools such as virtual reality, interactive archives, and touchscreen interfaces, can enrich visitor engagement and reinforce the bond with the territory. A key feature of the project is the co-creation of digital content, which involved local professionals, experts, and citizens, thereby fostering a narrative that is both inclusive and contextually rooted.

The general and specific objectives stated by MAT and the related actions focus on four main themes: Social Capital; Sense of Place; Education and Creativity, Quality of Life.

Regarding Social Capital, the project has prioritized the creation and strengthening of ties with the local community, not only through individual interactions with residents but also through collaborations with local associations such as Officina Creativa, which also acts as an official partner. One of the most relevant initiatives in this sense is the creation of a Community Hub, envisioned as a shared space for gathering and participation, where familiar objects and narratives recognized by the local population are integrated into the museum's environment. Although no formal co-design process was conducted in the early stages, a participatory approach is planned for the future, particularly through post-implementation feedback and collaborative planning of new spaces and initiatives.

In relation to the Sense of Place dimension, the project employed a geo-historical approach to recover local memories and vernacular traditions, placing underrepresented identities at the core of the museum narrative. This approach has not only contributed to redefining the museum as a space of shared memory and territorial identity, but also to strengthening the local community's sense of belonging. In collaboration with the Netherlands Institute in Rome, an aerial video was developed to simulate an archaeologist's perspective from a lightweight flying platform. By using a headset, visitors are able to virtually explore Sepino's territory and archaeological park, thereby deepening their connection to the site.

Focusing on the Education and Creativity dimension, the project leverages digital technologies to enhance local awareness, stimulate visitor creativity, and promote innovative learning models that are both immersive and inclusive. Educational strategies are woven into the museum experience through a blend of multimedia content, interactive storytelling, and experiential learning environments. Key activities, such as multimedia installations, thematic itineraries, and immersive VR experiences, transform the museum into a dynamic space where local history is shared through engaging, multisensory digital tools.

Regarding the dimension of Quality of Life, the project has yielded immediate positive impacts on the local economy, particularly benefiting artisans and creative workers, while also promoting sustainable, experience-based tourism. By enhancing cultural value and generating positive externalities, it effectively contributes to improving community well-being. Moreover, due to the involvement of local professionals and stakeholders, the initiative fosters sustainable territorial growth and paves the way for long-term regional development.

Turning to the stakeholder dimension of the SoPHIA framework, the MAT Museum project reflects a multi-layered collaboration among institutional, academic, professional, and community stakeholders. The University of Naples Federico II led the architectural design while technological support was provided by external consultants specializing in advanced digital systems. In addition, the Dutch Institute in Rome played a pivotal role in producing immersive content, such as the aerial video accessible through virtual reality. At the local level, the Municipality of Sepino provided archival materials and logistical assistance, working closely with the Sepino Archaeological Park and the Soprintendenza. Community engagement was further facilitated by local associations and a territorial coordinator who encouraged the participation of artisans and residents. These diverse stakeholders were classified based on their group affiliation, enabling a systematic evaluation of their respective roles and contributions. Together, these actors form an integrated system that blends academic, institutional, and local expertise, as shown in Table 2.

Table 2. Stakeholder involved in the project

Stakeholder	Role/Contribution
Federico II University – Department of Architecture	Design of exhibition spaces using sustainable materials
Artisan service providers	Crafting installations
Internal and external digital experts	Handling hardware/software, holographic and AR tools
Communication expert	Managing social and multimedia content
Netherlands Institute in Rome	Production of aerial video from archaeologist's perspective
Topography and cartography experts	Creation of a model of the Sepino geographic area
Various experts	Providing insights for different museum sections
Local community	Contributing to archive, ongoing feedback, and participation through associations
Municipal technical office and Mayor of Sepino	Archival material for museum content
Archaeological Park of Sepino	Lending artifacts to enrich museum narrative
Superintendency	Institutional collaboration
Local associations	Creation of the community hub

Source: author's elaboration

This collaborative framework grounds the project in a shared vision of cultural innovation, sustainability, and participatory development. Overall, the MAT Museum exemplifies the effectiveness of special public- private partnerships (PSPPs) in cultural heritage management, demonstrating how the convergence of digital innovation and community engagement can produce enduring territorial impacts.

5 Implications

The empirical analysis provides relevant theoretical and managerial insights for researchers and practitioners in cultural heritage management. Firstly, the study asserts the validity of the SoPHIA framework for evaluating cultural heritage initiatives within a Special Public-Private Partnership (PSPP) context. By addressing the lack of research on the interplay between PPPs, social enterprises, and digital transformation, the study positions social enterprises not merely as intermediaries but as key orchestrators of digital ecosystems. This perspective facilitates understanding of value creation processes in cultural heritage governance, highlighting their role in fostering multi-stakeholder collaboration.

In this vein, from a theoretical perspective, the study extends the application of the SoPHIA framework by testing its validity within a Special Public-Private Partnership (PSPP) context. The findings demonstrate the framework's robustness and adaptability as a multi-dimensional tool for assessing heritage projects, while also highlighting the need for further development. In alignment with Angrisano et al., (2024), according to which some adjustments (and integration) need to be made to make the indicators clearer and unambiguously interpretable, this study argues for the inclusion of a fourth axis of digital innovation to complement the existing triad of time, people and domains. This addition would allow for a more nuanced understanding of digital readiness, integration processes and the long-term sustainability of cultural initiatives, capturing the transformative potential of digitalization in enhancing access, participation, and innovation across the cultural sector.

In a manner akin to the application of the Sophia Framework Test within the context of Officine Culturali, a social enterprise dedicated to the enhancement of the Benedictine Monastery in Catania, Sicily, the utilization of this framework serves as a salient representation of the efficacy of public-private partnership agreements. Such collaborations have demonstrably succeeded in augmenting the cultural experience and rendering knowledge accessible to a broader audience. This transformation not only enriches the cultural fabric but also positions the initiative as a viable instrument for social entrepreneurship. In this direction, this work contributes to extending existing theoretical perspectives on public-private partnerships (PPPs) and hybridity (Hinings et al., 2018; Quélin et al., 2017) by positioning social enterprises as key players of digital ecosystems since they facilitate multi-stakeholder coordination, foster knowledge circulation, and embed technological experimentation in localised cultural strategies.

The conceptualisation of social enterprises as drivers of digitally-enabled social innovation offers a novel lens for understanding value creation in the cultural sector and calls for a broader integration of organisational, technological and social dimensions within PPP theory.

From a managerial perspective, the findings highlight the central role of digital tools in reconfiguring the design and management of cultural heritage projects. The evaluation of the museum through the applied model facilitated a nuanced understanding of the impact that active digital citizenship may have on policy making and intervention strategies. The MAT museum case illustrates how immersive technologies and open digital infrastructures can enhance visitor engagement and foster community co-creation. The findings support the idea that these hybrid models can effectively bridge gaps between innovation management and stakeholder engagement, thus aligning academic discussions with practical applications.

6 Conclusion

This study focuses on the evolving role of digital transformation within hybrid models of cultural heritage governance, highlighting the need to rethink how these elements intersect when mediated by social enterprises operating in local contexts.

However, some limitations of the paper must be acknowledged. The first is the use of a single case study which, although rich in contextual insights, limits the transferability of the results. Furthermore, the specificity of the socio-territorial context and the qualitative approach adopted require further investigation and comparative studies in different cultural and governance environments.

Future research should follow two main directions: first, the empirical verification of the proposed integration of a 'digital innovation' axis into multidimensional evaluation models such as SoPHIA; second, the exploration of how different configurations of public-private-community partnerships adapt to technological change, especially in contexts characterised by institutional fragmentation or infrastructure deficiencies.

Rather than offering definitive conclusions, this work opens up a line of inquiry into how digital transformation can reshape not only cultural practices but also the collaborative logics that underpin heritage enhancement in the contemporary era.

7 Ethics declaration

Ethical clearance was not required for the present research.

8 AI declaration

No AI tools were used in the development of this research

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Measuring Museum Visitor Experience: Fresh Evidence from Bourbon Heritage Sites and potential Collaborations with Startups

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Abstract

This study explores visitor satisfaction at Bourbon cultural heritage sites in Campania, with a focus on the Royal Palace of Naples and the National Archaeological Museum (MANN). Adopting a mixed-methods approach, researchers carried out 97 interviews to assess eight critical dimensions of satisfaction. Through the application of the expectancy-disconfirmation model, the study contrasts perceived quality with the importance attributed by visitors. Findings show strong appreciation for the cultural content offered but point to notable shortcomings in infrastructure, digital accessibility, and post-visit engagement. A clear mismatch between visitor expectations and the actual services provided—especially regarding online communication and complementary offerings—emerges.

The research incorporates a pilot phase conducted by the Siti Reali organization, which represents a foundational step in satisfaction measurement. This phase serves as a valuable input for future collaborations with innovative startups that could enhance and scale similar evaluation processes using digital and data-driven tools.

Demographic and behavioral data indicate a growing interest in thematic experiences and customized itineraries, underscoring the need for more responsive and flexible site management. Overall, the study contributes to the field of cultural tourism by aligning satisfaction analytics with heritage site operations. Strategic proposals aim to strengthen visitor engagement and reposition Bourbon sites within the global tourism landscape, supporting sustainable and visitor-focused growth for Southern Italy's cultural tourism sector.

Keywords: Cultural startups, visitor experience, heritage tourism, entrepreneurial opportunities, digital engagement

Paper type: Practical Paper

1 Introduction

In Southern Italy, Bourbon heritage sites embody a rich but underexploited cultural narrative. Despite their historical significance, these locations are often absent from mainstream tourism circuits, limiting their ability to attract international audiences. Enhancing their visibility depends on prioritizing visitor satisfaction—an essential factor in creating meaningful experiences, encouraging return visits, and ensuring long-term viability.

Improving the cultural tourism offer in Campania requires understanding the quality of interactions visitors have with heritage sites. Research confirms that satisfaction is key to fostering engagement and sustainable behavior (Fyall et al., 2012). However, Bourbon sites have not fully adopted satisfaction-based strategies. This study seeks to bridge that gap, offering insight into how these sites can better align with the expectations of today's cultural tourists. By combining qualitative and quantitative methods—including structured surveys and interviews—the research evaluates satisfaction across eight dimensions, such as accessibility, cultural content, and supporting services.

A key component of this work is a pilot phase conducted in collaboration with the Siti Reali organization, which tested a model for measuring visitor satisfaction at the Royal Palace of Naples and the National Archaeological Museum (MANN). This phase not only validates the methodology but also lays the groundwork for future collaborations with innovative startups that could enhance such assessments using digital tools and smart analytics.

Applying the expectancy-disconfirmation theory (Clemons & Woodruff, 1992), the study identifies mismatches between visitor expectations and service delivery—particularly in digital accessibility, online information, and post-visit engagement. These gaps signal the need for integrated improvements across both physical and digital touchpoints. The analysis supports a shift toward adaptive, visitor-focused management and encourages the development of themed itineraries and immersive experiences to strengthen site appeal.

Ultimately, this research aims to inform sustainable strategies for the revitalization of Bourbon heritage in Campania, helping these sites better connect with modern audiences and reposition themselves within the global cultural tourism landscape. The Research Question is:

- *How can cultural visitor satisfaction be enhanced at Bourbon heritage sites?*

2 Theoretical framework

Bourbon heritage sites in Southern Italy, rich in both tangible and intangible cultural assets, have strong potential to elevate regional cultural tourism. However, realizing this potential depends heavily on visitor satisfaction and the systematic integration of feedback into site management.

Engaging the Cultural Tourist

Effective engagement of cultural tourists requires a clear understanding of their motivations, desire for authenticity, and emotional involvement. Studies emphasize that heritage experiences must go beyond passive observation, fostering personal connections and emotional resonance (Bryce et al., 2015). Technologies like augmented reality (Villamediana-Pedrosa et al., 2018) and inclusive storytelling (Richards, 2018) have been shown to enhance engagement, particularly among diverse and digitally connected audiences.

Strategic tourism planning further supports engagement through integrated itineraries and resource coordination (Teutonico & Palumbo, 2002). Scholars advocate for participatory governance and creative industries as drivers of innovation and sustainability in cultural heritage (Jelinčić & Mansfeld, 2019). Bourbon sites, with their historical depth, are ideal for such strategies but remain largely underutilized. Digital platforms and 3D tools offer untapped opportunities to document, promote, and revitalize these locations (Apollonio et al., 2019).

Visitor Satisfaction and Experience Gaps

Visitor satisfaction is a key metric for sustainable heritage tourism but remains insufficiently explored in Bourbon contexts. The expectancy-disconfirmation theory (Clemons & Woodruff, 1992) is a proven model to evaluate satisfaction by comparing expectations with perceived outcomes. Though widely applied in heritage tourism research (Huh, 2002; Chen & Chen, 2010), it has yet to be fully used in assessing Bourbon sites.

Experiential quality, emotional attachment, and perceived value all influence satisfaction and repeat visitation (Buonincontri et al., 2017). However, studies focused specifically on the Bourbon context are rare. Integrating feedback into management could improve itinerary design and overall experience, aligning more closely with modern cultural tourists' expectations (De Rojas & Camarero, 2007).

Perceived Quality and Attributed Importance

Tourist satisfaction doesn't depend solely on the services offered, but also on how important visitors consider those services. The gap between perceived quality and visitor expectations is critical in shaping satisfaction (Parasuraman et al., 1985; Vajčnerová et al., 2014). Studies confirm that key factors include accessibility, authenticity, emotional resonance, and the perceived safety and comfort of the visit (Zhang et al., 2023; Costea et al., 2017).

Importantly, the role of tour guides and staff interactions also significantly impacts the quality of experience. Tailored, knowledgeable engagement enhances satisfaction and fosters deeper appreciation (Huang et al., 2010; Kara et al., 2023). Future evaluations of Bourbon sites should factor in these elements to refine service design and elevate the overall visitor journey.

3 Methodology

This study adopts a mixed-methods approach, combining qualitative and quantitative tools to assess visitor satisfaction. Using semi-structured interviews and a Likert-scale survey, it evaluates perceived quality versus the importance attributed by visitors across key dimensions of the museum experience, based on the expectancy-disconfirmation model (Parasuraman et al., 1985). The core metric—Satisfaction Index ($X = Q - P$)—captures the gap between expectations and perceived performance.

This methodology was developed and tested as part of a pilot phase through a collaboration between the *Siti Reali* association and the Department of Humanities at the University of Naples Federico II, under a PON research project. Applied to two key sites—the Royal Palace of Naples and the National Archaeological Museum (MANN)—the approach served as an experimental pivot, offering the first evidence of visitor experience trends.

More than a static evaluation, this pilot acts as a strategic starting point: it opens the door to potential future collaborations with innovative startups that could introduce new digital tools, analytics, and service design models. These partners may contribute fresh value propositions aimed at deeper, more dynamic assessments of visitor satisfaction, ultimately enhancing the overall cultural experience and supporting more adaptive, user-centered heritage management.

This qualitative approach enabled a detailed mapping of the visitor experience across key journey touchpoints. By comparing perceived quality with the importance attributed at each stage—from planning to post-visit—the study identifies where improvements are needed to enhance satisfaction. This analysis is

contextualized within the broader "phygital" (physical + digital) framework, increasingly relevant in cultural tourism, as highlighted in recent literature (Florida, 2016; Ballina et al., 2019; Greco, 2022).

Table 1: Phygital Visitors Journey phases

Phase 1: Pre-Visit *(Digital or "Phygital")* **Online Information Accessibility**: ● Visitors explore and access the necessary details for planning their visit through digital platforms such as websites, social media, and booking systems.
Phase 2: Access *(Physical)* **Accessibility of Facilities**: ● The ease of physically reaching the location, including transport options, signage, and infrastructure like ramps or elevators for inclusivity.
Phase 3: Arrival *(Physical)* **On-Site Welcome and First Impressions**: ● Quality of on-site reception, including staff friendliness, signage, and orientation upon arrival at the venue.
Phase 4: Information *(Physical or "Phygital")* **Informative Clarity Before and During the Visit**: ● Availability and clarity of information in physical formats such as brochures, signage, and staff guidance.
Phase 5: Experiential *(Physical or "Phygital")* **Cultural Offering and Immersive Experiences**: ● Interaction with exhibits, artifacts, or artworks and integrating immersive technologies for enriched engagement.
Phase 6: Additional Services *(Physical or "Phygital")* **Complementary Services**: ● Integrating digital and physical services to the core service, such as physical parking and hybrid activities (e.g., app-based audio guides, paper and digital support information materials).
Phase 7: Additional Services *(Physical)* **Accessory Services**: ● Integration services not directly linked to the basic service but can improve its performance, such as Catering, cafeteria, Bookshop
Phase 8: Post-Experience *(Digital or "Phygital")* **Post-Visit Assistance and Engagement**: • Follow-up through digital channels, offering further engagement, support, and personalized recommendations for future visits.

To ensure a comprehensive analysis, the methodological framework integrates both qualitative insights and quantitative metrics, allowing for a nuanced understanding of visitor satisfaction. This approach enables the identification of key strengths and areas for improvement, providing valuable data for enhancing the visitor experience across cultural heritage sites.

4 Results

The results are presented separately for each of the two cultural attractions analyzed: the National Archaeological Museum of Naples (*MANN)* and the Royal Palace of Naples (*Palazzo Reale).* This division allows for a more granular assessment of visitor satisfaction, highlighting site-specific trends and discrepancies between perceived quality and attributed importance. For each site, dedicated calculation tables and bar charts illustrate the satisfaction indices, providing a clear visual representation of visitor responses across different touchpoints in the *Phygital Visitor Journey*.

By structuring the findings in this manner, the analysis ensures that variations in visitor expectations and experiences are accurately captured, facilitating a more targeted approach to improving service quality. The results indicate that while both sites exhibit strong performance in core experiential dimensions, gaps are more pronounced in specific phases such as post-visit engagement and accessory services. The individualized presentation of data enables cultural site managers to develop tailored strategies to enhance visitor satisfaction, leveraging insights from both qualitative feedback and quantitative assessments.

4.1 The National Archaeological Museum of Naples (MANN)

Table 2 Satisfaction Index Archaeological Museum (MANN)

The satisfaction index for each dimension	Satisfaction index calculation formula	Satisfaction Index MANN
X1	Q1-P1	**-0,58**
X2	Q2-P2	**-0,65**
X3	Q3-P3	**-0,58**
X4	Q4-P4	**-0,58**
X5	Q5-P5	**-0,28**
X6	Q6-P6	**-0,53**
X7	Q7-P7	**-0,24**
X8	Q8-P8	**-0,43**

The National Archaeological Museum of Naples (MANN) exhibits both strengths and areas for improvement based on the analysis of visitor satisfaction. The museum's cultural offerings, such as exhibitions and the technologies employed, receive high ratings, indicating that these core aspects are highly valued by visitors. However, significant gaps emerge in areas of post-visit digital engagement and facility accessibility, which have scored lower in perceived quality. Satisfaction indices, negative across all dimensions, suggest that the museum is not fully meeting visitor expectations relative to the importance they place on these aspects. Enhancing support services and accessibility could significantly increase overall visitor satisfaction and encourage repeat visits.

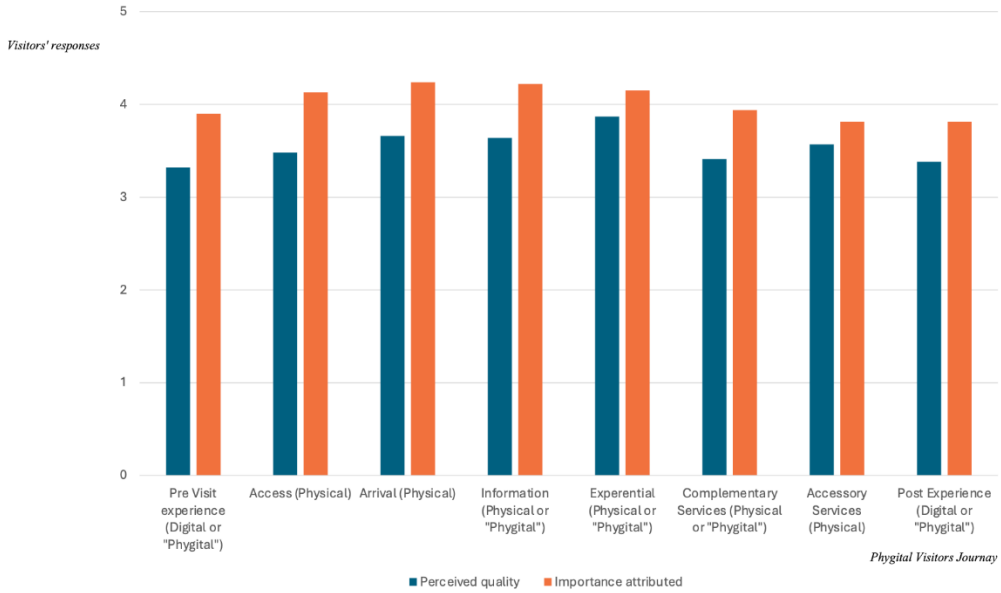


Fig 2: Histogram representation of the relationship between Perceived Quality and Importance attributed - MANN

4.2 The Royal Palace of Naples (Palazzo Reale)

Table 3 Satisfaction Index PALAZZO REALE

The satisfaction index for each dimension	Satisfaction index calculation formula	Satisfaction Index PALAZZO REALE
X1	Q1-P1	**-0,70**
X2	Q2-P2	**-0,31**
X3	Q3-P3	**-0.44**
X4	Q4-P4	**-0,48**
X5	Q5-P5	**-0,14**
X6	Q6-P6	**-0,73**
X7	Q7-P7	**-1,26**
X8	Q8-P8	**-1,12**

The Royal Palace of Naples (Palazzo Reale) exhibits strengths and weaknesses in visitor satisfaction across various dimensions. It performs well in core cultural offerings such as exhibitions, receiving a relatively high

satisfaction rating. However, significant gaps are evident in additional services like dining and digital post-visit engagement, which score notably low in perceived quality and satisfaction indices. These areas represent critical opportunities for improvement to enhance the overall visitor experience. Enhancing these services could lead to more comprehensive visitor satisfaction, contributing to a more positive perception and increased likelihood of repeat visits.

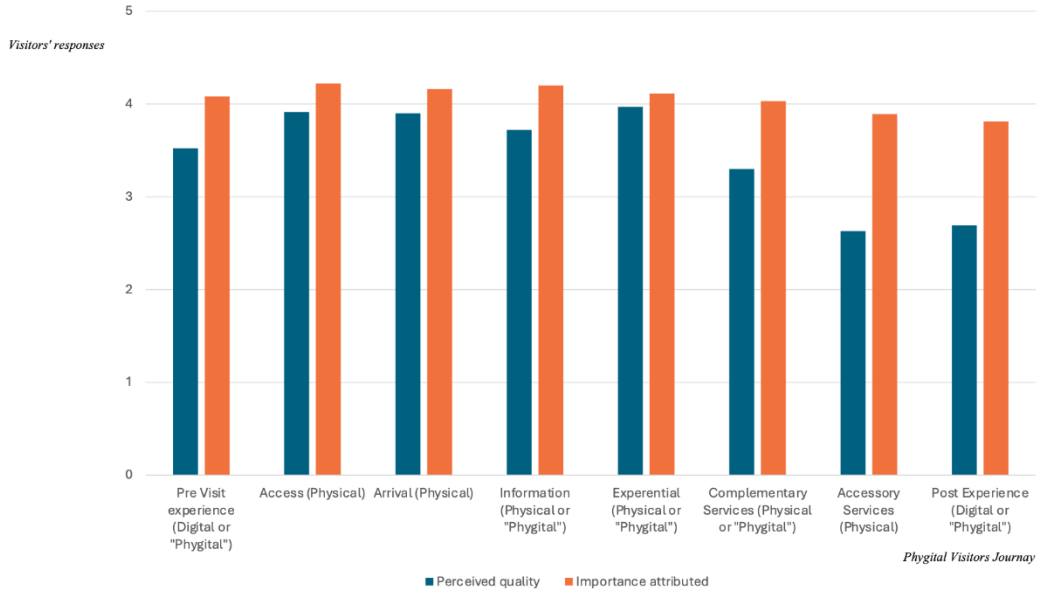


Fig 3: Histogram representation of the relationship between Perceived Quality and Importance attributed - PALAZZO REALE

Overall, the findings emphasize the need for a more balanced alignment between visitor expectations and service performance. While core aspects such as access and experiential engagement perform well, peripheral services and post-visit interactions exhibit notable gaps. Addressing these discrepancies through targeted improvements will be essential in fostering a more seamless and satisfying visitor experience.

5 Implications

5.1 Practical implications

This study provides actionable insights for improving visitor experience management at Bourbon heritage sites in Campania. By analyzing satisfaction indices across key dimensions—such as accessibility, digital communication, and ancillary services—it identifies areas that require strategic intervention. Aligning visitor expectations with the quality of service delivery is essential to enhance engagement and satisfaction. The research also highlights the potential of itinerant tourism models to connect Bourbon sites into cohesive cultural routes, strengthening their visibility and sustainability in a competitive tourism market.

Phase 1: Online Information

Both MANN and the Royal Palace show significant gaps in online information accessibility. Visitors consider this dimension highly important, yet the perceived quality remains low. Enhancing digital platforms is key to improving the pre-visit experience.

Phase 2: Accessibility

Accessibility scores reveal discrepancies, particularly regarding transportation and inclusive infrastructure. Improving access will broaden visitor inclusion and satisfaction.

Phase 3: Reception on Arrival

Visitors report a moderate mismatch between expectations and reception quality). Enhancing staff engagement and signage can improve first impressions.

Phase 4: Clarity of Information

The clarity of information—before and during the visit—needs improvement. Investment in better communication tools is necessary.

Phase 5: Cultural Offerings

This is a strength for both sites. Satisfaction levels are relatively high , confirming the appeal of exhibitions and content quality.

Phase 6: Complementary Services

Online booking and related services remain weak points. Improved systems could boost comfort and reduce friction during the visitor journey.

Phase 7: Ancillary Services

While MANN performs moderately well (−0.24), the Royal Palace shows a significant gap, particularly regarding food services and rest areas.

Phase 8: Post-Visit Digital Engagement

This is a critical shortcoming. Enhancing follow-up communication and digital engagement is essential to extend the visitor experience beyond the physical visit.

In summary, both sites are culturally compelling and attract a wide range of visitors. However, several service aspects—especially digital engagement, accessibility, and complementary offerings—need targeted improvement. Investing in physical-digital integration, thematic experiences, and immersive tools would align the sites with evolving visitor expectations. These findings reinforce the need for a holistic strategy that spans the entire visitor journey, fostering stronger emotional connections and long-term cultural value.

5.2 Theoretical implications

This study contributes to cultural tourism research by applying the expectancy-disconfirmation theory (Clemons & Woodruff, 1992) to Bourbon heritage sites, highlighting how mismatches between expected and perceived service affect satisfaction across various dimensions.

It advances the literature by integrating quantitative satisfaction metrics into heritage tourism analysis (Parasuraman et al., 1985), building on prior work on experiential quality, place attachment, and emotional engagement (Buonincontri et al., 2017; Chen & Chen, 2010).

The findings also emphasize underdeveloped areas such as post-visit digital interaction, echoing calls for research on digital heritage tools (Apollonio et al., 2019; Ford, 2020). In this context, the study advocates for broader application of immersive and interactive technologies to maintain visitor engagement.

Additionally, it supports a networked approach to heritage tourism (Russo & Van der Borg, 2002; Nicolais, 2023), promoting the development of interconnected itineraries that enhance regional tourism flow. This aligns with current discussions on sustainable tourism and participatory governance (Jelinčić & Mansfeld, 2019).

By offering a replicable model for evaluating service quality and expectations, the study provides a valuable tool for heritage managers and policymakers aiming to optimize visitor experiences. Future research should test this model in other historical settings to further refine its application and support the sustainable growth of cultural tourism.

6 Conclusions and future research directions

This study represents a foundational effort in evaluating visitor satisfaction at Bourbon cultural heritage sites through a structured, data-driven methodology. By applying the "Perceived Quality and Attributed Importance" framework across key touchpoints of the visitor journey, the research reveals not only the cultural strength of sites like the Royal Palace of Naples and MANN but also recurring weaknesses in accessibility, online communication, and post-visit engagement. These findings confirm that while the core cultural offerings are appreciated, peripheral services must evolve to meet the expectations of today's culturally active and digitally connected visitors.

Importantly, this study should be viewed as a pilot phase, developed in collaboration with the *Siti Reali* association and the University of Naples Federico II, laying the groundwork for broader applications. It opens strategic possibilities for future partnerships with innovative startups capable of developing digital tools, immersive technologies, and visitor analytics to enhance both measurement and management of visitor experiences. Such collaborations could scale the methodology to additional Bourbon sites—like Caserta, Carditello, and Capodimonte—transforming them into nodes of a wider, interconnected cultural network.

Future research should explore how digital innovation can be systematically integrated into heritage management, not only to assess satisfaction but to co-create new forms of engagement. A regional strategy based on open innovation and public-private cooperation can reposition Bourbon heritage as a dynamic driver of cultural tourism. Ultimately, this pilot demonstrates that heritage experience assessment—if supported by smart, scalable tools—can evolve from a static metric into a catalyst for sustainable and inclusive cultural development in Southern Italy.

7 Ethics declaration

The authors declare that the research was conducted according to standard ethical guidelines and presents no ethical issues.

8 AI Declaration

The authors declare that no generative AI tools were used during the preparation of this manuscript.

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Barriers to Web3 Technologies in Museums: A Qualitative Study in Turin

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Abstract

The museum sector is undergoing a significant digital transformation, accelerated by the COVID-19 pandemic, which exposed vulnerabilities such as revenue losses and reduced visitor engagement. Emerging Web3 technologies, including blockchain and Non-Fungible Tokens (NFTs), offer potential solutions for monetization, visitor engagement, and accessibility. However, adoption in Italian museums remains limited. This study explores the barriers to Web3 technology adoption from an institutional perspective, using qualitative interviews with 23 museum professionals, including directors and curators.

Key findings reveal multifaceted challenges, including skepticism about the added value of NFTs, perceived technological complexity, financial constraints, and regulatory uncertainties related to copyright and data protection. Cultural concerns also emerged, with some stakeholders fearing that digital innovations might compromise museums' traditional roles or lead to excessive commercialization. The study aligns these themes with the Unified Theory of Acceptance and Use of Technology (UTAUT), extending the model to include sector-specific factors.

The research highlights the tension between innovation and tradition in museums, emphasizing the need for compelling use cases, robust regulatory guidelines, and dedicated funding to facilitate adoption. By contextualizing Web3 adoption within UTAUT, this study provides a theoretical foundation for future empirical investigations and practical insights for museums navigating digital transformation. The findings underscore the importance of balancing technological advancement with cultural preservation, ensuring that digital tools enhance rather than overshadow the core mission of museums as custodians of heritage and education. This study contributes to a broader debate on technology adoption in cultural institutions, particularly in contexts with strong historical traditions such as Italy.

Keywords: Cultural Ecosystem, UTAUT, Web3, NFT, Digital Transformation

Paper type: Academic Research Paper

1 Introduction

The museum sector is undergoing a profound transformation, accelerated by the disruptive impact of the COVID-19 pandemic. Museums, as cultural institutions, play a crucial role in preserving and disseminating heritage, fostering education, and contributing to the broader social, economic, and political landscape (Falk, J.H. and Dierking, L.D. 2018). However, the pandemic exposed structural vulnerabilities, including revenue losses, reduced visitor numbers, and budget cuts for exhibitions and educational activities (Ozdil, E. 2023). In response, museums are increasingly exploring digital innovations (Lazzeretti, L. et al. 2022) to ensure sustainability and enhance audience engagement (Pourmoradian, S. et al. 2021).

Among the emerging technologies, Web3 solutions—such as blockchain, Non-Fungible Tokens (NFTs), and Decentralized Autonomous Organizations (DAOs)—have been proposed as tools to revolutionize the museum experience. These technologies offer potential advantages, including authentication and provenance verification of digital artworks, novel monetization models, and enhanced visitor engagement (Valeonti, F. et al 2021). Despite these promising opportunities, the adoption of Web3 technologies in Italian museums remains extremely limited.

While previous research has explored the factors influencing visitors' behavioral intentions toward digital museums (Zheng et al., 2024; Ch'ng et al., 2019), less attention has been paid to the institutional perspective - specifically, the organizational and contextual factors affecting museums' decisions to adopt Web3 technologies. This study addresses this research gap by investigating adoption barriers through qualitative interviews with Italian museum professionals. The research has two primary objectives:

- to identify key adoption themes and evaluate whether existing theoretical frameworks (DOI, TAM, UTAUT);
- to analyze sector-specific factors influencing Web3 adoption, thereby expanding current technology adoption models for cultural institutions.

The paper is structured as follows: Section 2 reviews relevant theoretical foundations; Section 3 details the qualitative methodology; Section 4 presents the emergent themes and theoretical framing; Section 5 discusses

key conclusions; and Section 6 provides practical implications for museum management and digital strategy development.

2 Literature Review

2.1 Web3 Technologies in the Museum Sector

The museum sector faces cultural, economic, and technological challenges that impact its sustainability and relevance. One of the most pressing issues is cultural disengagement, particularly among younger audiences, who require innovative strategies, such as gamification and interactive experiences, to enhance their engagement with museums (Cranmer, E. et al. 2016, Ekinci, Z. 2023). Another significant challenge is the chronic underfunding of the museum sector. Following the COVID-19 pandemic, declining visitor numbers and rising operational costs have further constrained museums' ability to innovate, digital transformation remains uneven, with many institutions struggling due to skill gaps and technological maintenance challenges (Lampis, A. 2018).

In this context, Web3 technologies have emerged as transformative tools, offering innovative solutions for financial sustainability, visitor engagement, and cultural content accessibility. By leveraging decentralized systems such as blockchain and smart contracts, these technologies introduce novel interaction models that reshape audience participation and institutional strategies (Jones, M., 2023).

Among the most widely discussed applications of Web3 in the museum sector are Non-Fungible Tokens (NFTs), which facilitate digital ownership, provenance tracking, and new monetization opportunities. NFTs offer museums alternative revenue streams while enhancing audience engagement through digital collectibles (W. Lab, 2023). Major institutions, including the Museum of Modern Art (MoMA), Musée d'Orsay, and the Los Angeles County Museum of Art (LACMA), have launched NFT-based initiatives, showing a growing interest in these innovations (Musée d'Orsay, 2023; MoMA, 2024). These efforts reflect an increasing recognition of Web3's potential to reshape the cultural landscape and redefine museum engagement strategies.

Web3 technologies facilitate significant transformations in museum business models through three dominant approaches:

- Monetization: Museums generate revenue by tokenizing digital artworks, issuing limited edition NFTs, and leveraging blockchain for authentication and ownership verification.
- Engagement: Visitors interact with NFTs through QR codes, gamified experiences, and exclusive digital content, enhancing audience participation and loyalty.
- Accessibility: Web3 enables virtual exhibitions, immersive experiences, and metadata-enhanced collections, expanding global access to museum content and reducing geographical constraints.

These models illustrate the potential of Web3 in reshaping traditional museum operations (Jung, Y. 2023), yet adoption remains inconsistent, particularly within the Italian museum landscape.

2.2 Background and Theoretical Framing

Understanding Web3 adoption and barriers in museums requires a theoretical framework that explains the factors influencing technology acceptance. While this study adopts a qualitative approach—allowing key themes to emerge from interview transcripts—it also seeks to assess whether existing theoretical models can adequately explain these findings. Several models have been proposed to analyze technology adoption:

The Diffusion of Innovation (DOI) theory (Rogers E. M. et al. 2014) explains how innovations spread within a social system over time. It emphasizes the role of perceived advantages, compatibility, complexity, trialability, and observability in shaping adoption (Dearing, J.W. and Cox, J.G. 2018).

Technology Acceptance Model (TAM (Davis, F. D. 1985) focuses on how perceived usefulness and perceived ease of use influence an individual's intention to adopt new technology. TAM has undergone multiple refinements, culminating in more comprehensive frameworks such as UTAUT.

Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003) integrates elements from multiple adoption models, identifying four primary factors influencing technology acceptance:

- Performance Expectancy: The degree to which using a technology is perceived to improve job performance.
- Effort Expectancy: The perceived ease associated with the use of the technology.
- Social Influence: The extent to which important others (e.g., family, colleagues) influence the decision to use a technology.
- Facilitating Conditions: The extent to which an individual believes that organizational and technical infrastructure supports technology adoption.

Given the specific characteristics of Web3 technologies and the cultural heritage context, this study seeks to determine whether an existing theoretical framework—DOI, TAM, or UTAUT—can adequately explain adoption patterns in museums or whether an extended framework is needed.

3 Methodology

This study adopts an interpretative paradigm, as the primary objective is to understand the subjective experiences and beliefs of participants in the context of early technology adoption in museums. This approach acknowledges that reality is socially constructed, emphasizing participants' perspectives as a fundamental element of the research process. To ensure that participants' perspectives remained central to our analysis, we employed an inductive approach, allowing themes to emerge directly from the interview transcripts (Patton, M.Q. 2014). This methodological choice aligns with the study's goal of identifying both theoretical constructs related to adoption of technology and sector-specific factors influencing Web3 implementation in museums.

3.1. Data Collection

A total of 23 semi-structured interviews were conducted with a diverse group of museum stakeholders, including directors, curators, and employees. Museums were initially contacted via email, and upon agreement, a follow-up video call was scheduled to conduct the interview. The interview questions were designed to explore participants' perceptions of Web3 technologies, potential barriers to adoption, and institutional attitudes toward digital transformation.

Figure 1 provides an overview of the museums included in our study, detailing their size, specialization, and mission.

#	CODE	MUSEUM	MISSION	VISITORS/YEAR
1	MU1	University museum	cultural	40k
2	MU2	University museum	cultural	40k
3	FP1	Private foundation	cultural/corporate	40k-60k
4	MI1	Multimedia museum under corporate dependency	educational	15k
5	MU3	University museum	educational/cultural	15k
6	MC1	Civic museum under direct management	educational	18k
7	FP2	Private foundation	cultural	12k
8	FP3	Private foundation	cultural	26k
9	MI2	Corporate museum	cultural/corporate	300k
10	FP5	Private foundation	cultural	115k
11	MC2	Experimental center for contemporary art	cultural/sustainability	23k
12	MI3	Corporate museum	cultural/corporate	160k
13	MN1	National museum	educational/cultural	135k
14	MI4	Corporate museum	cultural/corporate	5k
15	MI5	Corporate museum	cultural/corporate	60k
16	MI6	Corporate museum	cultural/corporate	1.6k
17	FP6	Exhibition center	cultural	80k
18	FP7	Contemporary art museum	cultural	100k
19	MI7	Corporate museum	cultural/educational/corporate	3.5k
20	FP8	Private entity of origin	cultural/social	5k
21	MC3	Civic museum	cultural	300k
22	MC4	Civic museum	cultural	240k
23	MC5	Civic museum	cultural	90k

Figure 1: list of museums interviewed

3.2. Data Analysis

The interviews were transcribed using Microsoft Word, and to ensure accuracy, a member of the research team manually reviewed and edited all transcripts before proceeding with the coding process.

A flexible coding approach was employed, allowing multiple codes to be assigned to a single unit of data when necessary (Patton, M.Q. 2014). Given our interest in identifying both existing theoretical constructs and novel sector-specific factors, we adopted an inductive coding process: The initial phase of analysis followed an open-coding approach, allowing key themes to emerge organically from the data. This ensured that the findings were grounded in the participants' perspectives rather than predefined theoretical categories. Then, during the coding process, themes were refined, consolidated, and categorized to capture the most significant insights.

4 Results

4.1 Emerged Themes

This section presents the key themes that emerged from the analysis of interview data, highlighting the barriers to Web3 adoption in museums. The findings are structured around these themes and are supported by representative quotes from participants.

4.1.1 Perception of Technology Value

The perceived usefulness of blockchain-related technologies varied among participants. Regarding the potential monetization of digitized museum-owned artworks through NFTs, interest was notably low; almost all participants did not perceive significant value in this model.

Conversely, more than half of the interviewees acknowledged blockchain's potential to enhance visitor engagement. Specifically, museums recognized blockchain's ability to increase visitor interaction, attract a broader audience, and improve accessibility as relevant factors in assessing adoption.

"We are currently investing in gamification and virtual reality projects that will launch in the coming months. We believe both approaches enhance visitor engagement and transform passive observers into active participants in the museum experience."

However, participants did not consider Web3 technologies to be the only, or necessarily the best, solution for increasing visitor engagement. Many interviewees expressed skepticism regarding the added value of NFTs or blockchain-based experiences compared to existing digital tools.

"...So what are the actual benefits? Compared to a photo I take on my phone of the artwork, what added value does it (NFT) bring? Maybe it creates a link with the museum, but often, a museum visit is perceived as a one-time event."

While there is openness to exploring new digital tools, the benefits of Web3 technologies remain unclear to many museum professionals, leading to hesitation in adoption.

4.1.2 Ease of Adoption

A high perceived level of complexity emerged as a significant barrier to Web3 adoption in museums. Many interviewees explicitly cited the technological difficulty of blockchain-based solutions as a primary reason for their reluctance. Participants emphasized that new technologies should integrate seamlessly into existing workflows without requiring drastic operational changes.

" There is a significant entry barrier due to the level of expertise required to develop these solutions—knowing whom to approach, understanding the market, and navigating the technical aspects."

Additionally, several respondents indicated that they would be more inclined to adopt blockchain-related technologies if other museums implemented them first. However, this hesitation was not driven by social pressure but rather by the need for concrete implementation models to follow.

"It would be helpful to have examples to follow—some initial cases that help museums like ours understand the pros and cons, administrative implications, and real impact. If a major national museum acted as an early adopter, it would certainly provide a reference point."

Reducing the complexity of blockchain adoption and providing clear, practical use cases could encourage wider adoption in the museum sector.

4.1.3. Propensity for Innovation

Participants' attitudes toward innovation emerged as a significant barrier to Web3 adoption. Some respondents expressed a strong preference for traditional museum experiences over investments in emerging technologies.

"Right now, I would rather invest in a high-quality exhibition, like a De Chirico retrospective, than spend a substantial amount on emerging technologies."

However, other museums demonstrated a strong belief in the potential of technology as a powerful tool for cultural dissemination. These institutions viewed digital innovation as an opportunity to expand audience engagement and accessibility, rather than as a distraction from traditional curatorial priorities. This divergence underscores the diverse perspectives within the museum sector, with some institutions embracing innovation as a strategic asset while others remain cautious about its implications.

4.1.4. Financial Resources

All museums in the study recognized cost as a major barrier to implementing blockchain-related technologies. Interviewees identified multiple financial constraints, including:

- High implementation costs associated with integrating blockchain technology.
- Limited museum budgets, restricting investment in new digital solutions.
- Competing financial priorities, where other areas require more immediate funding.
- Expenses related to staff training or the need to hire external experts.

"Cost is the fundamental issue. With adequate funding, anything is possible."

"There are two major limitations: first, the lack of a dedicated staff member responsible for digital development, and second, financial constraints. These two factors are clearly linked—the lack of resources prevents us from hiring the necessary expertise."

These financial considerations highlight the importance of funding availability and strategic resource allocation in evaluating blockchain adoption.

4.1.5. Market Perception

In all interviews, stakeholders identified visitor perceptions as a critical factor in Web3 adoption decisions. Concerns about whether visitors would understand or appreciate these technologies influenced museums' willingness to experiment with them. Some interviewees described blockchain-related innovations as *"… polarizing, potentially attracting certain visitors while alienating others".*

Additionally, some stakeholders expressed the belief that their museum's target audience was generally uninterested in such technologies and that Web3 did not align with their visitor demographic.

"Our museum is not suited for these types of technologies. Digitalization, yes, but beyond that, it becomes difficult to justify. Our target audience tends to be older and less familiar with these innovations, making their integration particularly complex."

Research on digital innovation in cultural institutions emphasizes not only the importance of audience attitudes toward novel technological experiences but also the need to educate the public on these topics (Cuseum, 2022 and Trends, 2021). Studies highlight widespread public skepticism toward NFTs, driven by: environmental impact, social perception, and trust (Barua, S. et al. 2025). Many people perceive NFTs as speculative assets rather than tools for social good, making them a divisive and often misunderstood technology. Public skepticism and concerns about financial speculation, can create resistance to their adoption in cultural contexts (Kaczynski, S. 2021).

4.1.6. Regulatory Concerns

Legal and regulatory considerations emerged as significant barriers to adoption. Many museum stakeholders expressed concerns about copyright laws, particularly regarding the digitization of artworks. A major challenge is the presence of rights managed by collecting societies such as SIAE, which limit museums' ability to freely digitize and distribute cultural assets.

"We cannot digitize the artworks for a very simple reason: most of them are protected by SIAE copyright regulations. It would be interesting to explore how this could change once a clear legal framework is established."

The lack of clear regulatory guidelines for blockchain applications in the museum sector was also a frequently mentioned concern. Additional challenges include intellectual property rights, data protection (GDPR compliance), and the legal validity of smart contracts, all of which further complicate adoption. Many interviewees indicated that regulatory clarity would be a determining factor in their institution's willingness to explore blockchain technologies.

The implementation of blockchain in museums introduces complex regulatory and privacy challenges, particularly in relation to data protection and intellectual property rights. As noted in the literature, compliance with legal frameworks such as the General Data Protection Regulation (GDPR), liabilities associated with smart contracts, and uncertainties surrounding digital ownership rights constitute major adoption barriers (Lohmer, J. et al. 2020, Barua, S. et al. 2025).

The largely unregulated nature of the NFT sector exacerbates these concerns, creating an uncertain ecosystem. The absence of standardized criteria for authenticity and value assessment further increases the risk of misinformation and skepticism toward the technology (Gherghelas, S. 2022). Establishing clear regulations and guidelines for NFT transactions, ownership rights, and intellectual property protection would provide museums with a more structured foundation for considering adoption.

4.1.7. Cultural Aspects

A significant number of respondents identified cultural considerations as key factors in adopting and utilizing new technologies. In this context, cultural aspects refer to individual beliefs about the role of museums in society. Many stakeholders expressed concerns that museums should uphold their cultural integrity, which they perceived as a barrier to integrating blockchain-related technologies. This perspective manifested in three distinct ways:

- Preserving the museum space: some respondents believed that museums should remain dedicated to traditional forms of curation and avoid unnecessary technological interventions.
- Risk of losing cultural mission: others were concerned that technology-driven experiences could shift museums toward entertainment rather than cultural enrichment.

"... The idea of enhancing the museum experience with technology seems problematic. If technology is used to create content rather than support existing content, then it feels completely misguided. I strongly oppose the notion of transforming the museum experience into mere entertainment."

"… We must be cautious, as there is a risk of falling into pure spectacle for its own sake. Scientific and cultural foundations must remain a priority, even when integrating new technologies. Otherwise, we risk turning museums into amusement parks, creating superficial entertainment rather than a meaningful cultural experience."

- Museums as spaces for slowing down, not accelerating technological consumption: Some respondents emphasized the role of museums as places for reflection and contemplation rather than environments that promote technological acceleration.

"We strive to create museum experiences that do not rely entirely on digital consumption. We live in a world where image consumption is already so intense and overwhelming that we prefer not to encourage that trend within our museum."

Beyond technical and financial considerations, the philosophical role of museums in an increasingly digital world remains a critical factor in decisions regarding Web3 adoption.

4.2 Theoretical Framing

Through an inductive analysis of museums' stakeholder interviews, several key themes emerged regarding the factors influencing museum adoption of Web3 technologies: Perception of Technology Value, Ease of Adoption, Propensity for Innovation, Financial Resources, Market Perception, Regulatory Concerns, and Cultural Aspects. These themes reflect both institutional and technological barriers, highlighting the complexity of Web3 adoption in the museum sector.

The research findings can be interpreted using the theoretical lens of the Unified Theory of Acceptance and Use of Technology (UTAUT), which has been widely applied in various contexts to assess technology adoption (Zheng, F. et al. 2024). The constructs embedded in UTAUT, performance expectancy, effort expectancy, social influence, and facilitating conditions, serve as a foundation for understanding the key factors influencing Web3 adoption among museums.

Each of the emergent themes aligns with and extends the constructs of UTAUT, as detailed below in Figure 2:

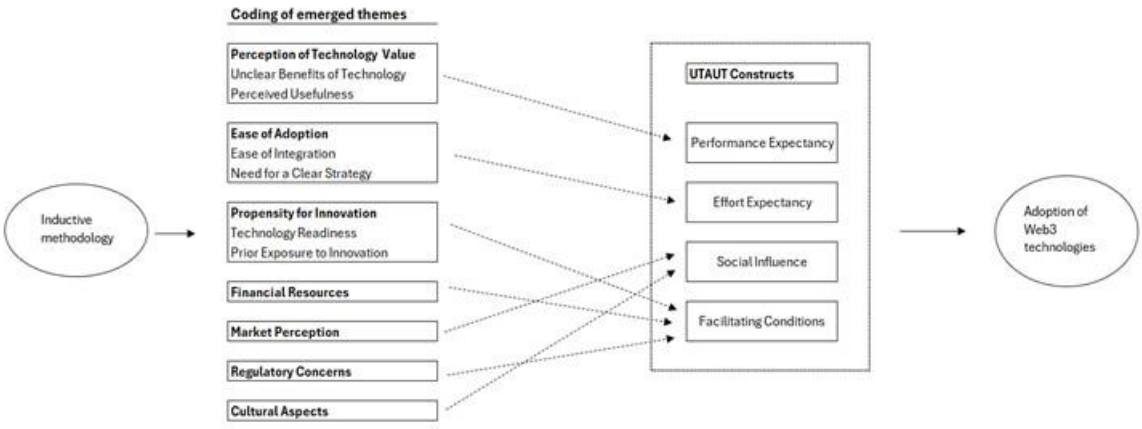


Figure 2: Emerged themes and UTAUT constructs relationship

- Performance Expectancy: This construct is reflected in Perception of Technology Value, as museums struggle to identify clear benefits of Web3 solutions, particularly regarding monetization. While most stakeholders questioned the added value of NFTs, some recognized blockchain's potential in enhancing visitor engagement and accessibility. The lack of compelling use cases and concerns about the long-term sustainability of Web3 initiatives further contributed to skepticism.
- Effort Expectancy: This corresponds to Ease of Adoption, as concerns about technological complexity and integration challenges emerged as major barriers. Participants highlighted the lack of internal expertise and the need for seamless integration into existing workflows. The demand for a clear implementation strategy and adequate training resources was frequently mentioned, emphasizing the necessity of structured support to facilitate adoption within museums.
- Social Influence: This construct aligns with both Cultural Aspects and Market Perception. Interviewees revealed concerns about sector-wide perceptions of museums adopting Web3 technologies, with particular anxiety that emphasizing digital experiences over traditional curation might compromise institutional credibility and lead to negative peer judgment. Additionally, external audience perceptions emerged as equally influential factors, creating pressure that either encourages or discourages adoption decisions.
- Facilitating Conditions: This construct is reflected in Propensity for Innovation, Financial Resources, and Regulatory Concerns. Museums already engaged in digital experimentation (e.g., virtual reality and gamification) showed greater openness to Web3 technologies. However, financial constraints—such as high implementation costs and competing budget priorities—acted as significant barriers to adoption. Furthermore, Regulatory Concerns, particularly regarding intellectual property rights, data protection (e.g., GDPR compliance), and copyright laws, added layers of complexity to decision-making, making institutions hesitant to fully embrace blockchain-based solutions.

By mapping the emerged themes from our qualitative analysis onto the UTAUT constructs, we provide a comprehensive framework for understanding the multi-layered challenges that museums face in adopting Web3 technologies. This alignment allows us to contextualize the findings within established technology adoption theories while emphasizing the unique institutional and cultural constraints of the museum sector.

5 Conclusions

This study advances the understanding of blockchain-related technology adoption in cultural institutions in several key ways.

The findings confirm that the constructs of the UTAUT model are highly relevant for analyzing the adoption of emerging technologies in museums, identifying the most suitable theoretical framework for understanding the behavior of cultural institutions.

Our study extends the classical understanding of social influence by emphasizing key aspects specific to the museum sector and emerging technologies. Two primary dimensions emerge:

- Sector Influence – The integration of Web3 technologies raises concerns about potential commercialization. Many institutions fear that prioritizing digital spectacle over curatorial rigor could undermine their credibility, making them appear more entertainment-driven rather than educational and cultural. As a result, museums are cautious about how their choices will be perceived by peers. This aspect, while not widely addressed in existing literature, is particularly relevant in cultural contexts with a strong historical heritage, such as Italy, where tradition significantly influences decision-making.
- Public Influence – Another emerging concern is the perceived lack of public education on Web3 technologies. Many museum professionals worry that audiences may not fully understand or appreciate blockchain-based initiatives, leading to skepticism or disengagement.

The study also refines the Facilitating Conditions construct by identifying specific dimensions that act as either drivers or barriers to the adoption of emerging technologies in museums. Three key factors are identified:

- Propensity for Innovation
- Financial Resources
- Regulatory Concerns

These dimensions are consistent with existing literature. Previous research has predominantly highlighted economic constraints (Valeonti, F. et al. 2021, Rennie, E. 2022), technical challenges (Cranmer, E. et al. 2016, Hackius, N. Petersen, M. 2017, Helliar, C. V. et al. 2020), and regulatory barriers (Valeonti, F. et al. 2021, Lohmer, J. et al. 2020) as primary obstacles to technological adoption (Venkatesh, V., 2012).

The proposed theory suggests that specific constructs should be integrated into the existing UTAUT framework. Given that this study is based on a qualitative approach, the outcome is a theoretical contribution.

The proposed theory enhances our understanding of the factors that influence behavioral intention in the adoption of blockchain-related technologies within museums. In an era of technological innovation extending into the museum sector, our findings contribute to the broader discourse on technology adoption by identifying constructs specific to blockchain-related adoption in cultural institutions. Our proposed theory has the potential to assist cultural institutions in understanding how to integrate emerging technologies, particularly within contexts deeply rooted in historical heritage. Indeed, the study highlights that one of the most significant barriers to implementation is the tension between digital innovation and the preservation of traditional museum values.

This extended framework will guide future empirical investigations into the adoption of Web3 technologies in Italian museums, bridging theoretical gaps and offering practical insights into digital transformation strategies for cultural institutions.

6 Managerial Implication

This study's findings extend beyond the Italian context, offering valuable insights for cultural institutions in regions with rich historical heritage. Successful Web3 adoption requires a strategic approach that addresses institution-specific barriers while balancing innovation with the preservation of traditional values. Museums must navigate competing expectations, embracing digital transformation while maintaining their role as custodians of cultural authenticity.

The identity paradox underscores how social influence in museums operates differently from conventional UTAUT models, peer perceptions and institutional reputation often outweigh potential technological benefits. To mitigate fears of negative peer judgment, leadership should foster internal alignment on digital strategy and clearly communicate how Web3 initiatives complement rather than compromise core cultural missions.

Adoption decisions are influenced by both horizontal (peer institutions) and vertical (audience) pressures. To effectively manage these influences, museums should actively engage in sector-wide dialogues to establish ethical and curatorial standards for emerging technologies. Rather than following technological trends, Web3 adoption should be assessed through the lens of institutional missions. Leadership teams must develop clear criteria for evaluating how blockchain applications support existing curatorial and educational goals. Additionally, visitor education initiatives, such as explanatory videos and guided NFT demonstrations, can help demystify Web3 technologies for traditional audiences.

Furthermore, museums should advocate for sector-specific regulatory frameworks with cultural policymakers to address challenges related to GDPR compliance and intellectual property rights. For practitioners, these insights highlight the importance of a phased, mission-aligned approach to digital transformation, one that prioritizes institutional readiness while proactively managing reputational risks.

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8 Ethics declaration

Ethical clearance was not required for the research

9 AI declaration

No AI tools were used for the creation of the paper.

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Artificial Intelligence and Value Co-creation in Museums: Promoting Inclusion for People With Disabilities

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Abstract

The present study investigates the potential of Artificial Intelligence (AI) to foster inclusive cultural value in Italian museums, focusing on addressing the physical, sensory and cognitive barriers encountered by visitors with disabilities. The research employed a multiple-case qualitative design, engaging more than twenty museums through a semi-structured online questionnaire administered to accessibility managers. The museums varied in governance, location, and thematic focus, but all were committed to accessibility. The findings demonstrate a robust theoretical understanding of AI's potential to personalise experiences. However, its practical implementation remains predominantly experimental, constrained by infrastructural limitations, organisational rigidity and financial constraints. A significant proportion of institutions engaging with AI, specifically 87.5%, reported incorporating co-design processes with individuals living with disabilities. This finding serves to emphasise the pivotal role that participatory approaches play in ensuring technological solutions are aligned with the needs of the end-users. From a governance perspective, the study posits that truly inclusive innovation necessitates a systemic strategy: museums must invest not only in technological infrastructure but also in interdisciplinary processes that facilitate collaboration among curators, technical specialists and disability-community representatives. Furthermore, the sustainable integration of AI tools necessitates a coordinated commitment across multiple institutional levels, encompassing individual museums, governmental bodies, and disability-rights organisations, to ensure the availability of adequate resources, expertise, and policy support. To strengthen the evidence base, it is recommended that future research should expand the empirical scope by testing the proposed framework on a larger, more diverse sample of cultural institutions and by conducting longitudinal studies to track the long-term impacts of AI-driven accessibility initiatives. The work under discussion here establishes the foundations for human-centred technological innovation that extends beyond the scope of pilot projects and integrates inclusivity as a fundamental element of museum practice.

Keywords: Accessibility, Artificial Intelligence, Value co-creation, Museums, Person with disabilities

Paper type: Academic Research Paper

1 Introduction

Artificial Intelligence (AI) is increasingly transforming the cultural sector, offering innovative opportunities to enhance accessibility and personalize visitor experiences. While recent studies have explored the application of AI in museums, the focus has predominantly been on operational efficiency, marketing, or audience engagement, with limited attention to its potential in addressing accessibility challenges for people with disabilities. At the same time, the literature on value co-creation and inclusive design has emphasized the importance of involving marginalized users in the developing services, yet few empirical investigations have examined how these principles intersect with AI technologies in the museum context.

This study addresses this gap by investigating how AI can be employed to support inclusive value co-creation in Italian museums, with a specific focus on enhancing accessibility for visitors with sensory, motor, and cognitive disabilities. The research aims to map existing practices, identify perceived barriers to adoption, and assess the role of participatory processes in the development of AI-based solutions. By combining a conceptual framework with preliminary qualitative findings from a national sample of museums, the paper contributes to the emerging discourse on human-centered technological innovation in cultural institutions.

2 Theoretical framework

2.1 Value co-creation with people with disabilities

The dynamic economic landscape of the 21st century has precipitated a critical reappraisal of traditional value-creation paradigms, revealing that fostering high-quality interactions, through which individual customers actively co-create distinctive experiences with organizations, is essential for unlocking novel sources of competitive advantage (Prahalad & Ramaswamy, 2004a&b).

Considering this global scenario and the close connection with the ongoing changes in society of which they are a mirror, museums are gradually evolving from their traditional paradigm of value creation towards a model of co-creation of cultural value (Barnes & McPherson, 2019) considered as the best way to focus explicitly on the experiences of all visitors and make them rewarding (Ramaswamy and Gouillart, 2010) despite certain barriers and obstacles that may arise in the co-creation practice (Najda-Janoszka & Sawckuk, 2023b).

Value co-creation is a paradigm that redefines the relationship between museums and visitors, shifting the focus from a unidirectional model of value delivery to a collaborative and interactive approach that promotes collaborative problem solving and stimulates innovation, enabling cultural organisations to adapt dynamically to the expectations and desires of their audiences (Prahalad & Ramaswamy 2004a). Co-creation can benefit the design process (Ali and Liem, 2015), the organization, the entire society (Mazzucato, 2018) and therefore the single visitors. Inclusive co-creation can take the process of designing futures to a level where diverse users' needs can be used as the basis of the design process and consider intersectional and norm critical approaches (Kuuluvainen, 2022). Having a team member representing the end user's identity can enhance understanding of the end-users' needs for all the design team (Hewlett et al. 2013). So, in a co-creation process, the diversity of participants is paramount, because diversity has been proven to increase innovation capabilities in organizations (Nathan and Lee, 2013; Hewlett et al., 2013; Phillips, 2014). This requires cultural institutions to listen to the needs and expectations of their stakeholders, including disadvantaged audiences and people with disabilities (Muscarà & Sani, 2019; Mesquita & Carneiro, 2016).

The principles of co-creation align with the slogan 'Nothing about us without us', popular in the disability rights movements and which has been leading the fight of people with disabilities to see their rights respected since the 1970s. Agree with this view of co-creation, it is no longer just a mere tool for adapting content but becomes a dynamic and interactive process, highly respectful of the rights not only to enjoy but also to participate in the cultural life of people with disabilities, in which visitors themselves take on the role of co-protagonists of the museum experience, contributing with their own perspectives and suggestions to the definition of solutions that best meet their needs (Mulvale et al., 2024). Visitors with disabilities can contribute to the creation of such experiences through their direct involvement, active participation and the ability to personalize their interactions (Minkiewicz & Bridson, 2014). The ability to personalize the experience of enjoyment is configured as a strategic imperative, capable of creating a closer relationship with the end-users (Trischler et al., 2019), ensuring that diversity becomes a point of strength, promoting intercultural dialogue and active and shared participation through which co-creation takes place (Minkiewicz & Bridson, 2014). The personalization of the museum experience, in a context, such as those of people with cognitive, sensorial and physical disabilities, characterized by extremely heterogeneous needs, is the cornerstone for those museums that wish to embody the principles of equality and turn diversity into an asset rather than an obstacle in the context of the cultural offer.

Jung et al. (2017) emphasize the importance of the integrated use of multiple technologies in order to create an environment of value co-creation as part of the experience. The cultural and creative sector, with a particular focus on museums, has recognised the added value of digital tools (Del Vacchio et al., 2020): their diversity and adaptability make it possible to respond to different accessibility needs and broaden how cultural content can be enjoyed. Furthermore, research has applied the new perspective of 'co-creation through interactions' whereby interactions are central and technology is a strategic determinant for co-creating valuable experiences with people, artefacts, processes and interfaces (Ramaswamy, 2020), even if the studies in this regard are still few (Ramaswamy and Ozcan, 2018). This research gap highlights the need for further research that can contribute to a better understanding and implementation of targeted technological solutions that can make museum experiences truly inclusive and accessible for all visitors.

2.2 AI in the cultural sector

The rapid advancements that characterize the current technological era, marked by constant innovation, have significantly contributed to the widespread adoption of Artificial Intelligence (AI). This emerging phenomenon is increasingly recognized for its transformative potential across a wide range of sectors. Within the scholarly discourse, AI is defined as a digital technological application that provides an interactive learning environment and functions in a capacity close to human intelligence. In particular, Vidu et al. (2021) identify it as a form of intelligence that can operate at a cognitive level and has the ability to interpret, adapt to, and shape different environments and circumstances.

Recent studies (Kunz et al., 2024) also suggest that AI, particularly its generative component, is having a more powerful impact on marketing outcomes than previous generations of digital technologies, as its ability to

generate text, images, video and more generally human-like content enables more personalised customer experiences that are difficult to replicate by humans alone.

Artificial Intelligence is emerging as a transformative force also in the museum sector, revolutionizing how these institutions engage audiences, manage operations, and design inclusive cultural experiences.

In the context of cultural heritage, the integration of AI with data analytics can improve exhibition planning and operational efficiency by designing predictive models of crowd flows and visitor preferences, while supporting a shift from passive consumption to active participation, fostering visitor engagement and personalising the museum journey (Rosemary, 2025).

AI's impact extends to educational and curatorial functions: it facilitates the cataloguing of artifacts and supports the digital reconstruction of damaged heritage objects through advanced imaging and computational techniques. Furthermore, AI-driven tools such as natural language processing (NLP) and machine translation enrich the interpretative dimension of exhibitions by enabling multilingual content delivery. These capabilities help overcome linguistic barriers and contribute to creating more inclusive and globally accessible museum environments. Moreover, museums increasingly employ AI to analyze feedback and social interactions, enabling real-time adjustments to content delivery and exhibit design (Li et al., 2024). These advancements position AI not merely as a technological trend, but as a strategic enabler of value co-creation, where museum professionals and audiences, especially those traditionally marginalized, can collaboratively shape inclusive cultural experiences (Carignani et al., 2023; Ramaswamy & Ozcan, 2018).

Recent studies highlight AI's role in making cultural spaces more accessible and inclusive, particularly for individuals with disabilities. Applications range from AI-powered chatbots and virtual guides to automatic transcription tools, sign language avatars, and audio descriptions generated through natural language processing (Islek et al., 2024). Such tools have shown strong potential in reducing sensory, cognitive, and physical barriers to participation, thus aligning with the co-creation paradigm that values diversity and intersectionality (Mele et al., 2022; Kuuluvainen, 2022). Museums leveraging AI for accessibility not only improve visitor autonomy and personalization (Trischler et al., 2019), but also contribute to the broader societal goal of cultural democratization (Candello et al., 2020).

However, despite its promising advantages, the adoption of AI in cultural institutions raises critical questions and concerns regarding ethics and the depersonalisation of the human experience. It is therefore necessary that technological innovation continues to be guided by human-centred design (Wach et al., 2023). The challenge for museum professionals is to strike a balance between technological potential and ethical responsibility, ensuring that AI acts as a facilitator of access, inclusion and the sharing of cultural meaning.

Based on the research conducted by Islek et al. (2024), the authors identified five key areas where AI can assist in creating personalised museum experiences for people with cognitive, sensory and physical disabilities, summarised in Table 1. The table offers a systematic representation of museum accessibility needs broken down by type of disability, comparing traditional facilitators with potential artificial intelligence-based solutions.

In particular:

- Type of disability: five categories are identified that characterise the main challenges (sensory, motor and cognitive) faced by people with disabilities; the last category 'General' refers to all single disabilities and cases of multiple disabilities.
- Facilitators needed: for each category, the analogue or organisational supports usually used (e.g. tactile guides, subtitles, ramps, reduced stimulation environments) to ensure an inclusive and usable museum experience are listed.
- AI-based supports: for each disability domain, advanced technological solutions employing AI are proposed to meet the needs of each visitor; in addition, cross-disciplinary solutions of predictive analytics, visitor satisfaction analysis and advanced search engines are indicated to enhance the experience of all users.

In this way, the table serves as a framework for the design and evaluation of integrated interventions aimed at combining traditional facilitators and AI innovations with a view to universal accessibility.

Table 1: Classification of Artificial Intelligence Tools for Enhancing Museum Accessibility in Relation to Disability Categories

Type of Disability	Facilitator needed	AI support
Visual Impairments: blindness and low vision (VI)	To navigate independently, people with visual impairments need tactile and auditory supports—such as engaging audio guides, acoustic signage, tactile replicas, floor plans, and models—as well as voice-compatible websites and apps.	Automatic audio description of objects in exhibition: to translate the image into sound description
		Optical character recognition: to translate text from image in sound description
		Assist in the creation of tactile graphics, tangible representation of image and objects
		Voice interfaces for those who have difficulty using touchscreen devices or typing
Hearing Impairments: deafness and hard of hearing (HI)	People with hearing impairments require tactile or visual supports—such as captions or subtitles for all audiovisual content, real-time transcription at live events, written guides, sign language interpretation (in-person or virtual), and inductive loop systems for hearing aids.	Automatic textual description of images, videos and works: to translate image into text
		Multimodal chatbot assistants: to guide audiences step-by-step through museum itineraries using Vocal interaction and sign languages
		Sign Language Interpretation: to translate spoken language into sign languages
		Speech-to-text transcription: to translate the audio content in texts
Physical Disability: paralysis, amputations, motor impairments (PD)	People with physical disabilities may struggle to travel to or move around the museum. Remote telepresence systems (e.g., robot-guided virtual visits) address access from afar, while barrier-free design—wide, obstacle-free paths, ramps, lifts, adaptive exhibit equipment—and hands-free interaction systems ensure full on-site accessibility.	Mobile avatars guided by the visitors who cannot physically go to the museum
		Pre-constructed virtual tours to visit the museum from a distance
		Social robot that guides physically impaired visitors who go to the museum in person
Cognitive Disabilities: dementia, intellectual disabilities, learning disorders (CD)	People with cognitive disabilities benefit from simplified language that accurately summarizes captions and texts, along with easy-to-read materials, clear visual aids, structured navigation paths, and low-stimulus environments.	Tool that create texts in Augmentative Alternative Communication in real time
		Tool that create easy-to-read texts in real time
		Gamification to make learning more engaging and enjoyable
General Accessibility (GA)	To improve satisfaction and accessibility for all visitors, including those without disabilities, museums should implement systems that collect and respect users' needs, preferences, and abilities to offer personalised content, navigation, and support tools before and during the visit.	Predictive Analytics to predict visitor needs and preferences and enable museums to proactively address accessibility challenges
		Visitor Satisfaction Analysis to analyse visitor data and identify areas where accessibility could be improved in future exhibitions and programmes
		Advanced Information Retrieval to simplify searching for information on websites

Author's elaboration.

3 Methodology

In line with its exploratory nature, which aims to map the use of AI in Italian museums to increase accessibility and participation of the public with disabilities, this study adopts a qualitative approach (Turner et al., 2021) based on a multiple case research design (Stake, 2013).

The research design involves an initial sampling of Italian cultural institutions, to which a semi-structured questionnaire is sent to collect primary data. The data collection is based on a triangulation strategy (Creswell & Creswell, 2017) aimed at strengthening the reliability and validity of the results, and for this reason the data collected will be cross-referenced with information available on the official websites of the museums.

The selection of institutions was made through a combination of structured sources and independent research by the authors. In order to select the cultural institutions, the authors used ministerial databases and

reports from disability associations to identify those cultural institutions that are considered to be the most accessible for different disabilities.

The selected sample included over twenty Italian museums, chosen to ensure a broad and diverse representation of the national landscape. The selection spans the entire Italian peninsula, from northern regions down to southern regions, thus capturing the geographical diversity of the country. The sample also reflects a variety of governance models, ranging from major national museums to institutions managed by local authorities, private foundations, and non-profit organizations. Furthermore, the museums feature highly heterogeneous collections, encompassing fine arts, archaeology, science, ethnography, and multisensory experiences, allowing the study to investigate both consolidated accessibility practices and innovative, experimental approaches. The only common feature among the selected institutions is their commitment to providing high-quality accessible services for visitors with different types of disabilities.

Primary data have been collected through a semi-structured interview in the form of an online questionnaire. The questions address different areas of AI application, each related to a different type of disability and closely linked to the AI tools identified in Table 1. The questionnaire also explores the actual implementation of these tools in the surveyed museums, the presence or absence of co-design processes with people with disabilities, and the main perceived barriers (technical, economic, cultural) to the adoption of these solutions. The instrument is divided into a series of dichotomous questions, some open-ended and some multiple choice, on a Likert scale from 1 to 5. This multiplicity will allow the study to explore both qualitative and quantitative aspects and to serve as a starting point for more in-depth future studies.

The data will be systematically analysed to identify recurring patterns, good practices and areas for improvement, with the aim of contributing to the development of accessible technologies that are not only functional but also culturally and socially meaningful.

4 Preliminary results

Based on the adopted framework, several preliminary insights emerge. Of the 24 museums contacted, 10 completed the questionnaire (42% response rate). Despite the small sample, the diversity in museum types, governance, and accessibility practices provides valuable insights and helps lay the foundation for broader mapping and development of replicable AI-based accessibility models in Italian museums.

The analysis reveals a substantial openness among cultural institutions toward the potential of AI to enhance accessibility and inclusion. This aligns with the literature, which highlights how AI technologies can foster more autonomous, personalized and emotionally engaging experiences for people with disabilities, while also enriching the cultural experience for the general public (Islek et al., 2024; Trischler et al., 2019; Candello et al., 2020). Tools identified in the literature, such as speech-to-text systems, automatic audio descriptions, and personalized guidance, are consistently cited by respondents as promising solutions for removing physical, cognitive, and sensory barriers. Specifically, respondents rated as particularly useful those AI tools designed to translate or adapt content in real time, including automatic transcription, audio and text simplification, and chatbot interfaces capable of multimodal communication. These tools were especially valued in relation to visual and auditory impairments and in case of cognitive disabilities. The potential of predictive analytics, visitor satisfaction monitoring and advanced search functionality in support of overall accessibility was also recognised, confirming the wider cross-category benefits of such systems.

Despite this strong theoretical consensus, actual implementation remains limited. While 80% of responding institutions report having adopted or planned to adopt at least one AI-based accessibility tool, most applications are still confined to pilot programs or experimental use. Only a few tools, primarily automated subtitling, speech-to-text translation and chatbot guidance, appear to have been integrated more systematically, suggesting that AI adoption in the cultural sector is still in an exploratory phase.

The results also highlight the importance of participatory approaches to AI development. In line with the co-creation paradigm discussed in the literature, 90% of respondents report involving people with disabilities in the design of accessible content, and among those implementing AI, 87.5% say that co-design processes have been or will be part of the development cycle. This involvement is essential not only to ensure technological usability, but also to promote cultural relevance and user empowerment. However, the responses suggest that such participation is not always structured or continuous, raising questions about the depth of user involvement in different museums.

Barriers to AI implementation were frequently mentioned, reinforcing the gap between perceived potential and practical adoption. The most cited obstacles include the lack of internal technical expertise, difficulties integrating new tools with existing systems, and financial constraints. These issues point to a lack of institutional

readiness, and confirm the need for targeted capacity-building and supportive policy frameworks to enable museums to transition from isolated experimentation to sustainable, system-wide innovation.

These results confirm, as already highlighted in the literature, that AI technologies can be key factors in creating inclusive cultural value when combined with participatory design principles. At the same time, they reveal how infrastructural, organisational and economic limitations continue to hinder the spread of AI in the cultural sector.

5 Implications

From a theoretical perspective, this study contributes to advancing the paradigm of value co-creation by empirically demonstrating how Artificial Intelligence can function both as a medium and an agent within participatory processes in the cultural sector (Ramaswamy & Ozcan, 2018; Ramaswamy, 2020). Preliminary findings reinforce the new conception of museums as dynamic ecosystems, where co-creation emerges through continuous negotiation between human actors, technological artefacts and institutional logics.

The study confirms that inclusive AI implementation cannot be conceived outside of human-centered and intersectional design approaches. The high rate of self-reported co-design practices among responding institutions supports the claim that involving people with disabilities as co-creators, rather than passive recipients, increases both the usability and the cultural legitimacy of AI solutions (Mulvale et al., 2024; Minkiewicz & Bridson, 2014). These findings extend the literature on inclusive service design (Trischler et al., 2019; Kuuluvainen, 2022) by demonstrating how diversity and participatory engagement can help mitigate accessibility barriers. The positive perception of AI tools across disability sectors also highlights how personalisation and adaptability serve as strategic drivers of inclusive cultural value.

From a managerial standpoint, the research highlights the fundamental need for a strategic repositioning in the governance of accessibility and innovation. Although most institutions recognise the transformative potential of AI, the data shows that its actual adoption is still limited to specific use cases and early stage applications. This discrepancy suggests that AI-based accessibility needs to move beyond isolated projects towards systematic integration. To enable this shift, cultural organisations should invest in the development of collaborative governance infrastructures and interdisciplinary teams that can ensure that technological innovation is integrated into inclusive decision-making processes.

Furthermore, the institutional heterogeneity captured in the sample reveals significant asymmetries in readiness to adopt AI solutions. This disparity is compounded by recurrent barriers identified in the study, including lack of internal technical expertise, integration challenges with legacy systems, and insufficient financial resources. Acknowledging these barriers constitutes a strategic starting point for addressing them through coordinated institutional responses. Recognizing and systematically mapping these constraints can also inform the design of targeted training programs and support services, helping institutions to build long-term organizational capabilities. In this way, AI can evolve from a promising but underutilized resource into a sustainable driver of accessibility, participatory governance, and digital transformation in the cultural sector.

6 Conclusions and future research directions

The present research has outlined an initial methodological framework for mapping AI-mediated accessibility practices in Italian museums, identifying key areas where technology and participatory design converge to enhance inclusion. Preliminary results confirm the ability of AI to meet the needs of both people with and without disabilities, and highlight a recurring theme in different institutional contexts regarding the selection of AI solutions that have been implemented, those that are currently being implemented, and the obstacles encountered during the implementation process. At an empirical level, future research should include a large-scale dissemination of the questionnaire to a broader and more diverse set of museums. This will allow statistical validation of the patterns observed and facilitate comparative analyses across regions and types of governance. Another line of research involves an in-depth study of the reasons why AI-based solutions that promote the inclusion of all audiences have not yet been implemented, in order to identify the underlying causes of this phenomenon and propose targeted solutions. Furthermore, at a theoretical level, longitudinal studies of selected institutions could reveal the dynamics of organisational change, the cost-benefit trade-offs and the outcomes achieved by visitors over time. This in turn could deepen our understanding of how AI innovations mature from pilot projects to established practices.

7 Ethics declaration

Ethical clearance was not required for the present research.

8 AI declaration

No AI tools were used in the development of the present research.

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Redefining Middle Management: How Generative AI Reshapes Roles and Competencies

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Abstract

This ongoing research investigates how Generative Artificial Intelligence (GAI) technologies are reshaping the roles and competencies of middle managers. While much of the existing literature emphasizes macro-level impacts of AI—such as productivity gains and strategic transformation—this study focuses on micro-level changes, particularly managerial adaptation, decision-making, and skill reconfiguration.

Grounded in activity theory (Engeström, 1987, 2001) and informed by a critical realist epistemology, the study adopts a qualitative, inductive approach. Data is being collected through semi-structured interviews with middle managers from three contrasting organizational contexts: a large enterprise in the energy sector (30 interviews), a medium-sized digital services firm (15 interviews), and a small telecommunications company (15 interviews). This multi-site design enables the analysis of systemic tensions across different governance models and organizational cultures.

Preliminary findings reveal that middle managers are often at the forefront of GAI experimentation, initiating Bottom-Up innovation processes outside official IT channels. These informal practices—frequently associated with Shadow IT—allow for agile problem-solving but also pose significant risks in terms of data security and strategic misalignment. Managers report that GAI tools not only automate routine tasks but also support cognitive structuring, thereby transforming how they plan, communicate, and lead.

The integration of GAI calls for hybrid competencies that go beyond technical know-how. Conceptual skills (e.g., sense-making and system thinking), human skills (e.g., empathy, leadership, conflict mediation), and ethical awareness are increasingly vital. Middle managers thus emerge as key facilitators of digital transformation, mediating between frontline innovation and top-down strategic frameworks.

This paper contributes to the literature by offering a multi-dimensional reading of managerial transformation through the lens of activity theory. It proposes actionable insights for organizations aiming to responsibly integrate GAI, emphasizing the need for adaptive governance, targeted upskilling, and the creation of experimental safe zones. Future work will extend the dataset and explore longitudinal trajectories of GAI adoption and governance.

Keywords: Generative Artificial Intelligence (GAI); middle managers; organizational transformation; Shadow IT; managerial competencies.

Paper type: Academic Research Paper

1 Context and Research Problem

Recent advances in Generative Artificial Intelligence (GAI), such as ChatGPT and large language models, are profoundly transforming organizational environments. These technologies—capable of generating original content, producing ideas, automating complex cognitive tasks, and delivering strategic analyses (Jordan & Mitchell, 2015; Goodfellow et al., 2014; Vaswani et al., 2017)—are emerging as strategic intangible assets (Brynjolfsson & McAfee, 2014; Silic & Back, 2014). Their integration into companies is reshaping not only work practices but also the modalities of cooperation, decision-making, and control, in a context of continuous innovation (LeCun et al., 2015; Senge, 2006).

At the heart of this transformation, middle managers hold a pivotal position. Historically described as facilitators between strategy and operations (Mintzberg, 1973, 1989, 2006; Tengblad, 2006), they are now facing new expectations. On one hand, they are required to integrate GAI into their managerial practices and support their teams in adopting these technologies; on the other, they must navigate an environment where these tools are reconfiguring value chains and redefining professional agency (Sannino & Engeström, 2021; Baird & Maruping, 2021). These “agentic artifacts” shift traditional roles by delegating certain decision-making functions to the machine, thereby challenging the legitimacy and relevance of specific human competencies (Van Doorn et al., 2023).

The emergence of Shadow IT—unauthorized use of technological solutions by employees—illustrates these tensions. The accessibility of GAI fosters bottom-up innovation dynamics, sometimes in conflict with top-down technological governance structures, leading to organizational friction (Silic & Back, 2014; Hillebrand et al., 2025). This phenomenon highlights the need to rethink power structures, risk management, and strategic IT governance (Behrens & Sedera, 2004).

As strategic actors, middle managers must contend with these multiple shifts: new forms of leadership, trade-offs between innovation and compliance, and skill management within unstable technological environments (Tarakci et al., 2023; Wilden et al., 2023). This transformation calls for both conceptual and operational agility, whereby the manager's role extends beyond strategy execution to include the co-construction of technological and cultural innovation (Engeström, 1987; Engeström & Sannino, 2021).

Yet, current research lacks a robust conceptual framework to thoroughly analyze these changes—both in terms of managerial roles (Mintzberg, 1973; Kraut et al., 1989) and competencies (Katz, 1974; Peterson & Van Fleet, 2004). This gap is precisely what the present research aims to address through the following research question: How does the introduction of Generative Artificial Intelligence transform the roles and competencies of middle managers?

2 Research objectives

This research aims to understand how the introduction of Generative Artificial Intelligence (GAI) is reconfiguring the roles and competencies of middle managers in a context of rapid technological transformation and increasing organizational tensions. Using a systemic approach grounded in activity theory (Engeström, 1987, 2001), the study seeks to:

Identify the tensions and contradictions that emerge during GAI adoption;

Develop a robust conceptual framework to analyze the transformation processes of managerial practices;

Map the conceptual, human, and technical competencies required for the effective integration of these technologies (Katz, 1974; Peterson & Van Fleet, 2004);

Propose organizational strategies to support managers during this transition, particularly with regard to Shadow IT and bottom-up innovation dynamics (Behrens & Sedera, 2004; Silic & Back, 2014; Tarakci et al., 2023).

This work thus addresses the need to reconcile technological mastery, ethical awareness, and strategic adaptability in the evolving role of middle managers (Van Doorn et al., 2023; Baird & Maruping, 2021).

3 Theoretical Framework

3.1 Activity Theory

Used as the primary analytical framework, activity theory (Engeström, 1987, 2001) provides a systemic model to understand the organizational transformations triggered by GAI. It consists of six interconnected components: the subject (middle manager), the object (transformation of roles and competencies), the tools (GAI technologies), the rules (IT norms and policies), the community (stakeholders involved), and the division of labor (redistribution of responsibilities). This framework reveals systemic contradictions that may become drivers of expansive learning and organizational change (Sannino & Engeström, 2021).

GAI technologies, as agentic artifacts (Baird & Maruping, 2021), deeply transform the mediation between actors and activities. They create tensions between innovation and compliance (Jordan & Mitchell, 2015; Hillebrand et al., 2025), formal and informal practices (e.g., Shadow IT), and strategic centralization and local agility (Engeström, 2001; Silic & Back, 2014).

The conceptual model used in this study, grounded in activity theory, is presented below. It illustrates the core components of the managerial activity system reconfigured by the introduction of GAI and highlights the systemic tensions likely to emerge.

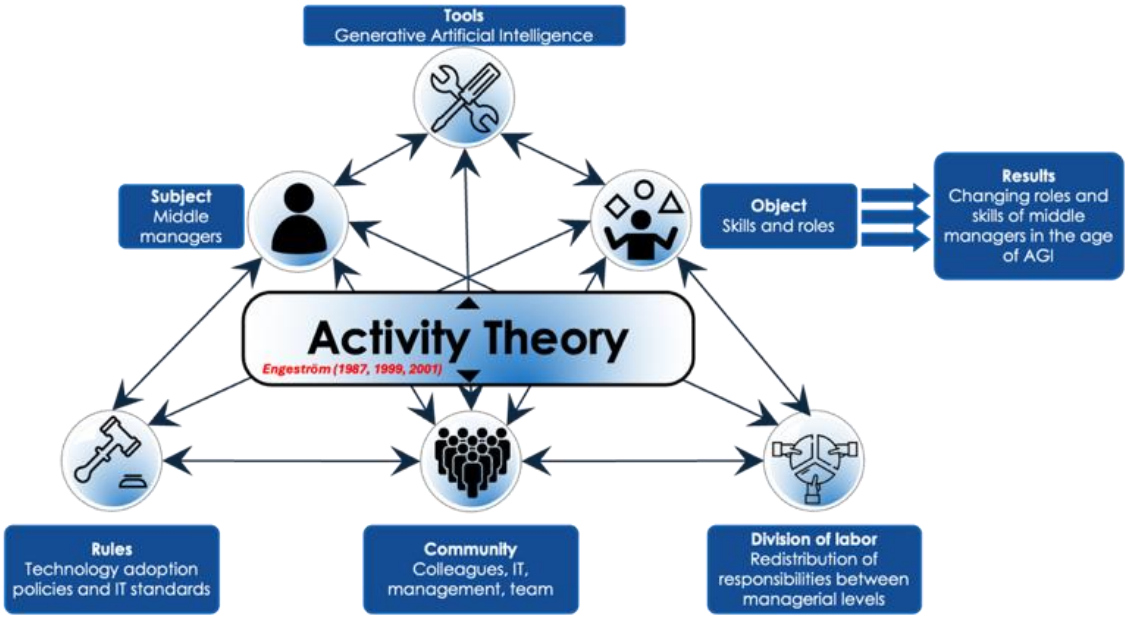


Figure 1: Conceptual model of the activity system applied to middle managers and GAI integration

This model, inspired by Engeström's activity theory, shows the six core elements (Subject, Object, Tools, Rules, Community, Division of Labor) and helps identify contradictions between governance structures and emerging GAI uses.

3.2 Bottom-Up Innovation Dynamics and Shadow IT

In addition, the study draws on bottom-up innovation models, which emphasize the proactive role of middle managers in technological adoption. These informal dynamics highlight both the agility of frontline actors and the risks of strategic and security misalignment (Behrens & Sedera, 2004; Haag & Eckhardt, 2017). Shadow IT—fueled by the accessibility of GAI tools—acts as both a signal of organizational creativity and a source of tension with top-down governance structures.

3.3 Synthesis of the Theoretical Framework

The articulation between activity theory and bottom-up innovation dynamics enables a multidimensional reading of the ongoing transformations. By combining:

- a systemic analysis of structures and tools (Engeström, 1987),
- a competency-based approach to managerial work in digital contexts (Katz, 1974; Wilden et al., 2023),
- and a socio-technical perspective on governance/innovation tensions (Silic & Back, 2014; Hillebrand et al., 2025).

This framework supports a better understanding of the conditions for a successful, ethical, and sustainable adoption of GAI. Positioned at the intersection of these tensions, middle managers emerge as key agents of this organizational transition.

4 Literature Review

4.1 Generative Artificial Intelligence as Strategic Resources

Generative Artificial Intelligence (GAI) technologies represent a major shift in organizational dynamics. Beyond their ability to generate content or automate complex cognitive tasks, they are becoming hybrid strategic resources, combining human and algorithmic intelligence (Brynjolfsson & McAfee, 2014; Jordan & Mitchell, 2015). These tools are actively reshaping decision-making processes, knowledge flows, and governance structures (Baird & Maruping, 2021; Van Doorn et al., 2023).

GAI contributes to the democratization of access to analytical and decision-making tools (Engeström, 2001), fostering greater autonomy among frontline actors. It also reconfigures value chains by enabling local innovations (bottom-up), often outside formal frameworks (Shadow IT)—a phenomenon that simultaneously enhances agility and creates friction with centralized structures (Silic & Back, 2014; Hillebrand et al., 2025).

4.2 Transformations in Managerial Roles and Competencies

The introduction of GAI disrupts the traditional roles of middle managers, who are increasingly expected to act as facilitators of technological transformation (Senge, 2006; Tarakci et al., 2023). Their intermediary position requires them to balance often conflicting demands: strategic vision, operational proximity, and resistance management.

The literature identifies three main categories of skills necessary for this transition (Katz, 1974; Peterson & Van Fleet, 2004):

- Conceptual competencies: systems thinking, the ability to structure and communicate the meaning of change (Engeström, 1987);
- Human competencies: leadership, relational intelligence, and group dynamics facilitation (Silic & Back, 2014);
- Technical competencies: understanding GAI technologies, data-related challenges, and ethical implications (Jordan & Mitchell, 2015; Wilden et al., 2023).

In light of growing automation, managers are also required to reprioritize their responsibilities—leading innovative projects, managing uncertainty, and balancing compliance with experimentation (Baird & Maruping, 2021; Van Doorn et al., 2023).

4.3. Conceptual Ambiguities Around Middle Managers

The literature highlights the lack of consensus on the definition of middle managers. This function is alternately described as frontline manager, operational supervisor, or cross-functional coordinator (Hales, 2005; Benedetto-Meyer et al., 2021), which often blurs the analysis of their strategic impact.

This terminological vagueness becomes particularly problematic in the context of digital transformation, where these actors perform complex and evolving roles that lie between execution and decision-making (Floyd & Wooldridge, 1994; Mahieu, 2007). The integration of GAI technologies further amplifies this complexity, placing middle managers at the center of tensions between technological innovation and organizational governance.

5 Methodology

This research adopts a qualitative approach rooted in a critical realist epistemology (Bhaskar, 1978; Archer et al., 1998; Meissonier, 2022), aimed at exploring the underlying mechanisms behind the transformation of middle managers' roles and competencies in response to Generative Artificial Intelligence (GAI). By combining contextual analysis, situated understanding of practices, and the exploration of systemic tensions, the study seeks to go beyond descriptive approaches and propose a structural and transformational reading of the phenomenon.

5.1. Methodological Framework and Epistemological Stance

Activity theory (Engeström, 1987, 2001; Engeström & Sannino, 2021) serves as the central theoretical lens. It allows the analysis of role and competency reconfigurations within an activity system composed of: the subject (manager), the tool (GAI), the object (managerial transformation), the rules (IT governance), the community (executives, IT, teams), and the division of labor. This systemic view aligns with critical realism, which posits a stratified reality and a continuous tension between structures and agency.

By contrast, other frameworks such as TAM (Davis, 1989), UTAUT (Venkatesh et al., 2003), socio-technical systems (Trist, 1981), or structuration theories (Giddens, 1984; Orlikowski, 2000) were set aside as less suited for capturing the multi-level, informal, bottom-up and often contradictory dynamics observed in the field.

5.2. Data Collection Method

At this stage, data is being collected through semi-structured interviews, primarily with middle managers. Additional perspectives (executives, team members, IT staff) will be integrated in upcoming phases to enrich the analysis. This method allows for an in-depth exploration of the perceptions, experiences, and strategies adopted by actors facing GAI-induced transformations. All interviews are recorded, anonymized, and fully transcribed to ensure rigorous qualitative analysis.

5.2.1 Diversity of Field Sites

Interview participants were selected for their key roles in technological change implementation and proximity to operational teams. Three organizational profiles were included:

Large Enterprise: A mature organization with structured processes and centralized governance, providing a view of planned GAI adoption.

Medium-Sized Enterprise (MSE): A growing company facing tensions between operational flexibility and strategic alignment.

Small and Medium Enterprise (SME): A resource-constrained company often adopting technology opportunistically.

The following figure presents a typology of the organizational settings included in this study, detailing their sector, size, and structure to contextualize the diversity of GAI appropriation.

		Typology	Sector of Activity	Revenue	Nb of Employees
30		**Large French enterprise (LE)**	Production and distribution of electricity	139,7 Md€	179 550
15		**Medium-sized enterprise (MSE)**	IT services and consulting	552 M€	540
15		**Small and medium-sized enterprise (SME)**	Telecommunications	75 M€	175

Figure 2. Typology of the three organizational contexts studied

This table summarizes the characteristics of the three cases: a large enterprise (LE), a medium-sized enterprise (MSE), and a small and medium-sized enterprise (SME), providing a comparative perspective on GAI adoption environments.

5.3. Sampling Strategy

A purposive and theoretical sampling strategy was used, targeting managers positioned between strategy and execution with significant exposure to technological issues. Selection criteria include hierarchical position, involvement in AI-related projects, and sector diversity (telecom, energy, digital services).

Particular attention was given to cross-organizational cultural consistency. Despite varied settings, a shared engineering culture—emphasizing rationality, technical mastery, and problem-solving—shapes how AI is represented and used (Van Maanen & Barley, 1984; Kunda, 1995; Faulkner, 2015).

5.4. Data Analysis

Data is analyzed using an inductive thematic approach (Braun & Clarke, 2006), combined with the dimensions of activity theory. The goal is to identify organizational tensions (technological, normative, human) and understand the mechanisms of managerial adjustment and practice reconfiguration.

Key stages include:

- Initial inductive coding, structured by activity theory components;
- Identification of systemic tensions, such as conflicts between Shadow IT and formal governance policies;
- Analysis of collective learning trajectories, including secondary, tertiary, and expansive contradictions (Engeström);
- Data triangulation through cross-checking with documents and field feedback.

5.5. Validity and Reliability

Methodological rigor is ensured through:

- Source triangulation;
- Validation sessions with interviewees (member-checking);
- A reflexive journal documenting analytical decisions;

- Attention to organizational learning conditions, especially regarding bottom-up innovation and systemic resistance (Sannino & Engeström, 2021; Silic & Back, 2014).

This qualitative method thus enables the identification of internal contradictions within activity systems and the formulation of managerial transformation trajectories adapted to the challenges of GAI

6 Preliminary Findings

The initial semi-structured interviews (32 out of the 60 planned) provide significant, though non-generalizable, insights into the evolving roles and competencies of middle managers in the age of Generative Artificial Intelligence (GAI). These exploratory results help formulate hypotheses about emerging dynamics that will be further investigated in later phases.

6.1. New Roles and Bottom-Up Dynamics

Middle managers appear as key actors in organizational transformation. They translate strategic objectives into concrete actions and facilitate the adoption of GAI within teams (Engeström, 1987; Brynjolfsson & McAfee, 2014). Numerous accounts point to informal and localized use of GAI, sometimes beyond official IT guidelines, illustrating a Bottom-Up innovation dynamic (Silic & Back, 2014). This proactive appropriation is a pragmatic response to operational needs, but it also creates tension with existing IT governance frameworks (Behrens & Sedera, 2004; Senge, 2006).

These grassroots initiatives often arise as adaptive responses to bureaucratic complexity, particularly in large matrix organizations. As one technical manager explains: *"To ask a question to a supplier, I have to send an email to Infrastructure, who contacts Intervention, who then reaches out to the manufacturer. […] That's three emails just to get to the supplier. […] It takes three weeks."*

The reorganization of priorities in constrained environments leads some managers to seek automation tools to compensate for increasing workload: *"We have meetings, but no time to write the minutes. Turning on the transcription tool is a productivity gain."* (Senior manager, B2B distribution)

6.2. Evolving Managerial Competencies

The interviews point to a reconfiguration of required competencies:

- Conceptual: strategic vision, anticipation of organizational impacts, and managing contradictions (Engeström, 2001)
- Human: transformational leadership, strategic communication, change facilitation (Jordan & Mitchell, 2015)
- Technical: familiarity with GAI tools, understanding of ethical and security challenges (Behrens & Sedera, 2004)

Managers must integrate these skills to effectively use GAI while preserving team cohesion and performance (Katz, 1974; Peterson & Van Fleet, 2004). The following figure presents a synthesized framework of managerial competencies required in the GAI era, combining insights from Katz (1974) and Peterson & Van Fleet (2004).

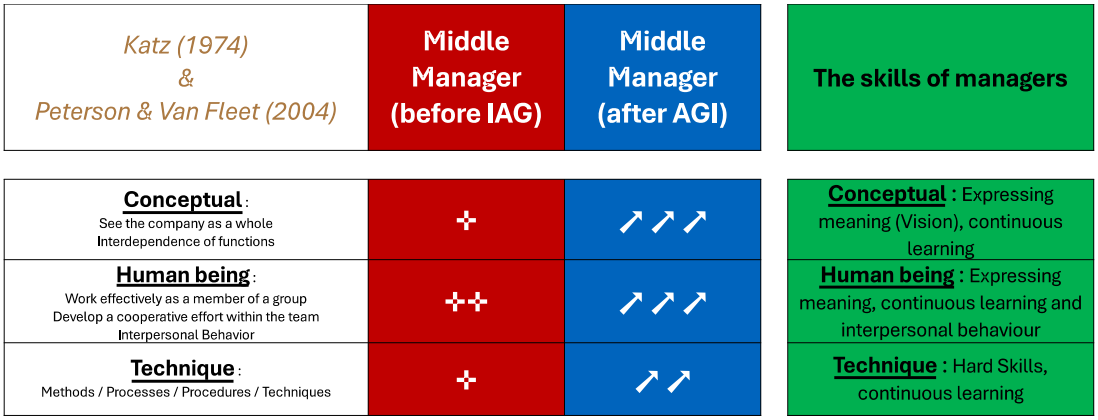


Figure 3. Evolving managerial competencies in the context of GAI

This table illustrates how conceptual, human, and technical skills are redefined in light of GAI integration, based on a cross-reading of foundational models of managerial competencies.

The growing complexity of managerial tasks reinforces the human and organizational dimensions of their role. In critical environments, managers must ensure safety, coordination, and workflow regulation: *"I have to ensure the safety of the site in all situations. […] It's highly precise team management."* (Manager, production site)

GAI is also changing how managers access knowledge, accelerating learning processes: *"I used to waste a lot of time reading forums or PDFs. Now AI gives me context and direction."* (Project manager, digital sector)

6.3. Shadow IT: Innovation or Risk?

Shadow IT is frequently cited as a pathway to GAI adoption. It allows operational agility but introduces risks related to compliance, data security, and strategic alignment (György et al., 2012; Zimmermann, 2014; Berente et al., 2021). Middle managers, acting as mediators, adopt awareness strategies, self-regulation, and even informal coordination with IT departments to mitigate these risks.

GAI usage by middle managers is not limited to technical or productivity-oriented applications—it also supports personal learning and relational development: *"I use AI a bit to help myself—it helps me grow in how I behave and carry myself."* (Technical lead, nuclear engineering)

Meanwhile, some internal training programs are beginning to formalize upskilling: *"We have e-learning training that teaches you how to prompt. […] It's totally autonomous."* (Engineer, engineering department)

In parallel with proactive use, symbolic or emotional forms of resistance are emerging, particularly among experienced staff. These fears, often irrational or shaped by science fiction imaginaries, reflect outright rejection: *"They don't want to use AI. I have a colleague who says it's the devil. […] He's stuck on Terminator. To him, Skynet is going to take over."* (Manager, large company, engineering).

In some cases, AI use is driven by a need for autonomy in the face of organizational inertia: *"I didn't want to wait until next week, so I used ChatGPT. […] I refined the prompt to get pictograms and flags for my slides."* (Product lead, B2B distribution).

6.4. Facilitators of Technological Change

Middle managers are emerging as facilitators of change:

- Managing internal resistance
- Aligning strategic vision with operational execution
- Gradually integrating GAI into work practices

However, this position also exposes them to strong tensions between compliance requirements and innovation pressures.

The integration of AI tools challenges the added value of certain managerial tasks, particularly administrative and reporting functions. One manager puts it bluntly: *"We need to become more efficient. […] I think an AI could handle all time tracking. […] Some managers will be left behind."* (Technical manager, engineering)

Some see AI as a tool for cognitive structuring, helping them with project planning: *"AI helps me structure my thinking—it reminds me of the steps I shouldn't skip when starting a project."* (Technical project manager, tech company)

AI adoption can also create tensions between business units and support teams, especially IT: *"I'm advocating for connecting Copilot Plus in Office 365. But IT says it won't work. […] I'm talking from a business need."* (Cross-functional manager, B2B distribution)

6.5. Summary of Preliminary Findings

The findings suggest that GAI is not merely a technological innovation but a structural and functional transformation of managerial work. The rise of hybrid skills, informal uses, and constant adjustment to internal tensions are key indicators of this ongoing shift.

Some respondents expressed clear awareness of the risk of skill obsolescence and are seeking to reposition themselves as informed technology partners: *"I'd rather be the one telling AI what to do than the one saying 'go away.' […] You need to identify your added value to stay relevant."* (Manager, technical project environment).

Finally, the rapid evolution of tools is creating growing concern over potential internal divides: *"There will be those who have AI—and those who don't."* (Technical lead, tech company).

7 Next Steps

The next phase of this research will focus on completing the qualitative data collection by reaching the target of 60 semi-structured interviews across three contrasting organizational settings (large enterprise, medium-

sized company, and SME). Special attention will be given to the diversity of respondent profiles, incorporating perspectives from senior management, IT teams, and HR departments to triangulate managerial perceptions.

The thematic analysis will be deepened using the Braun and Clarke method (2006), combined with activity theory, to highlight mechanisms of collective learning, sector-specific tensions, and GAI appropriation trajectories.

Furthermore, the conceptual articulation between bottom-up innovation, Shadow IT, and role transformation will be consolidated to develop a general interpretive model applicable to other organizational contexts. Lastly, a strong emphasis will be placed on the dissemination and valorization of the results across scientific and managerial communities (conferences, publications, professional reports).

8 Discussion and Conclusion

The preliminary findings of this study suggest that the introduction of Generative Artificial Intelligence into organizations is not merely a technological development but signals a deeper transformation of the managerial role. Through the lens of activity theory, middle managers are no longer seen as mere executors of strategic directives, but rather as active mediators of the organizational tensions generated by GAI—between autonomy and control, innovation and compliance, individual appropriation and collective governance.

Three key contributions can already be identified:

- Conceptual Contribution: The systemic approach adopted here makes it possible to articulate bottom-up innovation logics and the Shadow IT phenomenon within a robust theoretical framework, positioning contradictions as drivers of transformation.
- Empirical Contribution: The initial interview data reveal emerging managerial practices, often informal, reflecting the development of hybrid skillsets combining relational leadership, technological reflexivity, and ethical sensitivity.
- Managerial Contribution: This research initiates a competency mapping for middle managers who support GAI-related practices—especially in informal or “grey” innovation zones outside formal governance structures.

Beyond its contributions, the study raises several critical questions:

- What is the sustainability of the adaptation burden placed on middle managers?
- How can we prevent the isolation of these facilitators within organizations under pressure?
- Most importantly, how can we design ethical governance models for GAI usage that reconcile local agility with strategic coherence?

9 Ethics declaration

This research did not require formal ethical clearance, in accordance with standard practices in the field of social sciences and humanities. All interviews were conducted following fundamental ethical principles: informed consent, systematic anonymization of data, and respect for participant confidentiality. Participants were informed of the study’s objectives, their right to withdraw at any time, and the strictly academic use of the collected data.

10 AI declaration

Artificial Intelligence tools were used for language support, primarily to enhance the quality of the English translation of this paper, as the author is not a native English speaker. AI assistance was used to rephrase complex sections, harmonize academic style, and ensure terminological consistency across sections. No AI-generated content was included without human oversight, revision, or reformulation.

The author remains solely responsible for the argumentation, analysis, and all interpretations presented in the manuscript.

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A (Fun)Nel Model for Knowledge Management

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Abstract

Think of a funnel. What is its shape? What does it do? It has a large end, larger and larger that allows many elements to pass through, such as grains of sand or kernels of rice; and it has a narrow end, narrowing to block the passage to most of them; funnel has a simple but useful function: it serves to pour a big mass of parts into a container with a small opening. This is, when you think about it, the same principle behind human information processing and knowledge management. This paper proposes a funnel-shaped conceptual framework, that integrates three dimensions of knowledge: complexity; intelligibility; innovability; as the three dimensions of the funnel. Such framework provides a more comprehensive form of understanding complex institutions, both political and economic. It highlights, also, the interaction between information and institutions, and how it can impact human behaviour.

Keywords: Information, Knowledge, Complexity, Relational language, Lateral thinking.

Paper type: Academic Research Paper

1 From cognitive revolution to institutional complexity

We are going through a period of deep and unexpected transformations, in a complex, interconnected world (Harari, 2024). Every day we are flooded with an incredible amount of news and information to which we are not always able to attribute a consistent meaning (Harari, 2019). Millions of years of evolution have given us the tools to decode this world and yet our most common, oldest reaction when faced with the unknown, remains to close in on ourselves. Studies in the fields of Cognitive psychology and Behavioural economics (e.g. Harlé and Sanfey, 2010) demonstrated a natural propensity of humans to withdrawal.

Yuval Noah Harari dates the beginning of the complexity to about 70000 years ago, at the time of the so-called "Cognitive Revolution" (Harari, 2022). In those days, the human species known as "Sapiens" began to develop new modes of thinking and communicating, which soon would make it the dominant species of the entire planet. These abilities, along with the imaginative and cooperative ones (typical of Sapiens), enabled the elaboration of the first collective narratives, such as clans, families, and religions. It is not too difficult to picture those primitive men and women forming their social orders through belief in these narratives; what instead we struggle to understand is that our modern institutions function exactly on the same assumptions. Of course, from a "structural" point of view, institutions nowadays are different: this diversity can be interpreted as a consequence of the degree of complexity achieved by modern societies. A Stone Age hunter-gatherer compared to most of his contemporary descendants had deeper and more varied knowledge whose mastering required years of learning and practice. In modern industrial societies, much of this would be worthless. Humans no longer need to know many things, beyond the field they directly deal with, and for the others they can still rely on experts (whose knowledge determines a circumscribed field as well). The result is that, collectively humans today know more than Sapiens did, but singularly the hunter-gatherers were the most knowledgeable of all times.

Most researchers believe that these achievements, unequaled before or since, were the result of a Revolution occurred in the cognitive abilities of Sapiens. Vera Zamagni (2015) emphasizes this finding, placing the focus on human ability of creating and telling stories: "the real strategic role in determining the degree of progressiveness of various societies is played by philosophical-religious worldviews and the resulting organization of society, its diverse political and economic institutions". The issue is to determine how our institutions can be defined as "complex" and what effects complexity has on knowledge management.

1.1 How to deal with complex institutions

Every idea of knowledge starts with the realization that the same reality can be looked from different points of view. This results in quite varied perceptions, representations, and belief systems, all of which have elements of truth, that need to be considered (Carofiglio, 2023). The Sociologist Ugo Morelli (2024) stated that: "We human beings are a symbolic species; this implies that our capacity for self-regulation and self-organization is based on a process of attributing meaning to what happens in our relationships with others and with the world". Although we have always had great imagination, we cannot deny that the idea of Sapiens for their own village

or tribe was far less elaborate than our modern conception of, for example, the Sovereign State, the European single market, or the global ecosystem.

A simple indicator of increased complexity is the amount of information. Humans are, in contrast to algorithms, not good at organizing large amounts of information, even when operating in small contexts. Perhaps this is why it took *millennia* with backward moments and stagnation to change agricultural pastoral to industrial civilization (Zamagni, 2015). If we want to understand this step we need to focus on the history between the 16th and 18th centuries, along the span of just three centuries that witnessed three revolutions: industrial revolution; scientific revolution; institutional revolution. Common foundation to all three, the exaltation of rationality, as an engine of progress, produced both positive and negative consequences. Whilst innovations in production and organization increased the efficiency of the process, they also fueled vicious mechanisms, accentuated inequalities, fostered the spread of poverty, epidemics, and discontent. Morin (2023) stated that there is a strikingly antinomian association between the wonderful works that resulted of technical rationality, and blindness about the human, social, and cultural consequences of that works. The final effects were, however, brought about by an "Institutional Revolution", which replaced the "old" institutions as the community and the family, with "new" institutions represented by the state and the market. Morin echoes and resumes Marx's main critique of the Capitalist system, and also introduces the dysfunction that he himself terms the "blind intelligence".

"Blind intelligence" is that intelligence that simplifies and tries to dissolve complexity not to make it more accessible, but to adapt it to the needs of new institutions. The market acts, in this sense, as a collector and simplifier of information. It lessens the informational pressure on individual agents and synthesizes the mass of information into values (i.e., the prices) that can be easily understood by anyone; what is lacking is a more in-depth quality of information, about the meaning of those values, and the processes that determined their formation. A similar thing has happened in the public sphere. An increasingly widespread fragmentation or – in extreme cases – polarization of political opinion makes it practically childish to choose who to vote for (the candidate or party that better represents my beliefs on sensitive issues that I do not fully understand). The worst part, even here, is finding out the contents and implications of the politics that will be implemented, by that candidate or party, after the vote. In sum, we need to come to terms with complexity, that increasingly, somehow unpredictable directly influences our decisions and our understanding of reality.

2 The (fun)nel model

2.1 Vertical dimension: complexity

For the direction given to this work, the first dimension of the funnel, the vertical one, is described by complexity. As progress advances, what was difficult to achieve, requiring great physical and mental effort, has become easier and easier to realize: complexity is the hallmark of modernity. It contains within itself all the potentialities that were precluded to our ancestors. There is no reason to avert it although many of us believe it is preferable or even possible to keep away from it. Indeed, the complexities – that have affected so many areas of society – require a more organic, active, and positive approach to their dilemmas.

Being a passive bystander does not help: in fact, this is probably why the immoral and corrupt aspects of modern social systems were able to impose themselves, with practically no resistance. Marcuse nicely illustrated this concept in his 1964 (still very relevant) book *One-Dimensional Man*: the "Welfare State" distributes its many benefits at the cost of the systematic restriction of technically accessible free time, the quantity and quality of goods and services technically available for the individuals vital needs, and most importantly the intelligence (conscious and unconscious) capable of understanding and accomplishing the possibilities of self-determination (Marcuse, 1964). On the other hand, this kind of *modus vivendi* has, in some way, justified and encouraged the status of consumers, making "pure existence" extremely convenient. No reasonable person would give up the achievement of modernity without receiving anything in return and, moreover, true "involution" would be technically impossible. Again, Marcuse warns us against rejecting the Welfare State, for a vague idea of freedom: the loss of the economic and political freedoms, the real conquests of the previous two centuries, may seem like little harm, in a State capable of making safe and comfortable "administered life" (Marcuse, 1964). So, if most individuals are satisfied, to the point of calling themselves happy, with the goods and services that the Government offers them, why would they ever want different institutions? Only in recent time we have started to realize the disaster caused by this trivializing view of complexity and this has at least spurred the urgency to tear away the Maya veil of ignorance and be more self-aware.

2.2 Horizontal dimension: intelligibility

Organizational forms of life have emerged more precisely as responses to complexity: we create and recreate them to process and try to contain uncertainty (Morelli, 2024). It is practically a process of approximation and reduction of differences, characterized by high degrees of undecidability and vulnerability. Strong examples of such distorting effects are advertisements or election programs: even though we know they may not be true, or right, we still listen to them and even agree to be guided by them in our important life decisions.

These behaviours reflect survival strategies, adopted by humans over millions of years with the objective of attributing meaning to reality. A second aspect to be analysed (or the second dimension of the funnel in this case horizontal) concerns the ability to explore this complexity, namely intelligibility. To use Morelli's words again: “complexity is primarily an epistemological and cognitive orientation” (Morelli, 2024); knowledge means trying to identify “windows of comprehensibility” when we are faced with seemingly impenetrable metaphorical walls. Morin (2023) argued that complexity is the challenge of intelligibility and understanding in situations of complexity. So, a greater comprehension of reality also requires a better organization of knowledge, a “socialization” of it, that is, a broadening of its social base. This corresponds in our model to a horizontal widening of the funnel, with new learning and training opportunities in society; the pattern may, however, be opposite.

Intelligibility should not be confused, by the way, with utilitarian intelligence: the last, is but a consequence of our need to overcome the uncertain and ambiguous, with accurate diagnoses lacking equivocation. It responds to a fundamental human function: to separate, to differentiate, and to bring complexity back to the classic true-false scheme. This way of reasoning is also useful (in certain circumstances) but it fails exactly when reality appears in all its ambiguity and contradiction. The price to pay concerns awareness and the risk of manipulation and mystification of reality itself. Morin states that: “simplification becomes closely related to manipulation linked to the idea – or rather the myth – of the conquest of nature and man's dominion over the universe” (Morin, 2023); consider, as an example, the very recent advances in the field of Artificial Intelligence. It can potentially solve endless, practical problems, but, at the same time, greatly reduces the human ability to prevent and correct those same problems in time. In this Morin’s foresight. The algorithm allowed and grew manipulation, hence its countless technical victories, and hence also its ignorance of the perverse effects that could have generated such victories. Perhaps, while technological innovations broaden the horizon of possibilities, they also require greater awareness, to be followed by an ever-increasing civil effort in education, training, and practicing activities.

2.3 Lateral dimension: innovability

The two-dimensional model – we have sketched so far – can be also applied to a three dimensions world. This need has been assimilated, into our case, through the addition of a third variable. The innovability of the model itself, that is, the continuous search for ideas, innovations and “lateral” solutions. Among others, we found most inherent the concept of “lateral thinking” originated by De Bono (2000) as an ideal of overcoming the established order. Lateral thinking consists, precisely, of altering the linear perspective of the problem and seeking a solution, not contemplated by the original situation. Linear logic was suited to reproduce that mechanistic worldview, in vogue until the 19th century and now in deep crisis. A determinist world would not allow any invention and could not have consistency.

Innovation is not only not linear but also not neutral. It depends on factors, such as the motivational structure, of the person applying it, and the use value of freedom it generates (Marcuse, 1991). A perspective, not excluding the economic and technological aspect, but reviving the importance of societal involvement and collective intelligence, in the process of change; stimulating transformative innovation requires an ecosystem that can foster the emergence of communities, based on mutual trust, participated by a plurality of members. It is not enough for innovation to react to societal problems; it must be designed in a more equitable and participatory context keeping in mind also the interest of future generations.

3 Flipping the funnel

So, what to do with the funnel, now that society is about to become more complex and global than ever before? Our proposal is a flip: a flipped funnel looks like a megaphone or an amplifier of ideas and best practices. Following Morin, one more time, we have only to overcome, then, once and for all, the simplification of society; we counterpoint this with a new path which is neither straight nor plotted *a priori* but is outlined as we go along. How the trend triggered now more than three centuries ago, by the three revolutions (scientific, industrial and institutional, or perhaps three separate aspects of one, epochal Revolution?) be reversed, and concreted into a

true mindset? The view from reading Morin's work aims for diversity of viewpoints, and constructive dialogue; it teaches us, not to suppress, but to absorb antinomies and conflicts, turning them into opportunities for growth and evolution.

We must, first, become familiar with relational, reliant language, which uses analogies and metaphors, and structures the world with simple images – hence the inspiration of the funnel. At the same time, it is vital to ensure that such language is not used, by those in an advantageous position, for opportunistic and demagogic purposes: it can be hazardous if it means approximation and confusion. For the same reason, experts need to be persuaded to make their knowledge available to the community, not as an exercise in erudition, but as a civic duty to share culture and translate complexity; culture requires the proper incentives.

However, the "flow" could also be inverted and, like going through the flipped funnel, bring new knowledge from below to the higher planes. This is – in the intend of this work – both a challenge and a lesson of complexity, which only collectively we can understand.

4 Ethics declaration

This work is, in all its parts, an original product of the Author. All quotes are provided with an indication of the reference. No violation of the professional conduct, and ethics of a research community, has taken place, in the opinion of the writer, in the writing process.

5 AI declaration

No part of this work is generated by artificial intelligence; however, some AI tools are used to check the accuracy of the translation from Italian. The final check is still personal.

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AI-Driven Data Integration in Real Estate Development Processes

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Abstract

The fragmentation of data on the existing built environment is a critical obstacle to the governance of urban spaces. Although a wide range of data sources is available, from satellite imagery and environmental sensors to socio-demographic and cadastral datasets, these resources often lack interoperability and integration.
This deficiency limits the ability of governments and stakeholders to conduct accurate monitoring, implement informed real estate development strategies, and promote sustainable urban regeneration practices.
The research aims to explore how the integration of advanced Artificial Intelligence (AI) models, particularly Generative Adversarial Networks (GAN) based technologies, can contribute to the development of innovative approaches for urban management and the enhancement of disused building stock. In particular, the analysis aims to investigate the role of AI in Due Diligence (DD) processes, through a literature review in the areas of Smart Cities (SC) and Urban Management (UM), to define a theoretical-methodological framework to support data-driven urban regeneration strategies.
These technologies enable the generation of predictive urban models by combining heterogeneous inputs, such as geospatial frameworks, land-use data, environmental performance, and socioeconomic indicators. The research adopts a multidimensional approach based on a systematic literature review, which identified more than 1,200 academic contributions. Through a multi-stage filtering process, the most relevant analyses were classified into two main areas: *"Artificial Intelligence and Smart Cities"* and *"Artificial Intelligence and Urban Management",* with a focus on *"Due Diligence"* and models for *"Architectural Heritage Enhancement."* Integrating AI capabilities into the development of urban regeneration strategies has the potential to create resilient and smart cities. This can optimise resources while minimising land consumption and enhance inclusive and collaborative governance. Despite growing scholarly interest, analysis has revealed significant gaps in the development of these technologies.
The proposed approach is in line with emerging urban agendas and promotes a transition to resilient, circular, and smart cities. This study advocates for digital innovation that is not only technologically advanced but also ethically grounded and socially inclusive.

Keywords: Artificial Intelligence, Urban Management, Architectural Heritage Reuse, GAN models, Due Diligence

Paper type: Academic Research Paper.

1 Introduction

Contemporary cities are complex and constantly evolving systems, where social changes and internal dynamics continuously redefine the urban fabric. In the next three decades, it is estimated that nearly two-thirds of the world's population will live in urban settings, highlighting the acceleration of global urbanisation (Acioly et al. 2020). This scenario poses significant challenges for urban planners and real estate developers, who must design innovative strategies to efficiently manage urban land and infrastructure.

A key element in supporting such strategies is reliable, updated, and meaningful data availability. The integration of advanced technologies and large-scale data management processes offers significant potential to enhance urban functionality, quality of life, and the development of Smart City (SC) ecosystems (Singh et al. 2024). Since urban development processes often lead to an unequal distribution of opportunities, the inclusion of social equity objectives in enhancement strategies is becoming essential (Barberis et al. 2020). In this regard, SC technologies can support efforts toward greater inclusion and sustainability (Al-Rimawi and Nadler 2023; (Ahmad Afaneh and Isam Shahrour 2017).

Sustainability can be pursued through the conscious management of the existing building stock. Buildings that have lost their original functions risk abandonment and underuse. Transforming this heritage into a resource requires adaptations in governance structures, institutional frameworks, and financial mechanisms (Baud et al. 2021).

To address these challenges, the future of cities depends on the integration of SC, Smart Real Estate (SRE) solutions, and other innovative technologies. Collaborative public-private partnerships will play a crucial role in promoting sustainable and innovative development (Deakin and Al Waer 2011). Within this integrated vision, cultural heritage becomes a strategic asset for the transition to more resilient and sustainable urban models.

The research aims to explore how the integration of advanced AI models, particularly GAN-based technologies, can contribute to the development of innovative approaches for urban management and the enhancement of disused building stock. The analysis aims to investigate the role of AI in Due Diligence (DD) processes, through a literature review in the areas of Smart Cities (SC) and Urban Management (UM, to outline a theoretical-methodological framework to support data-driven urban regeneration strategies.

The paper is structured into three main sections: the first introduces the theoretical framework and methodology; the second offers a critical review of the literature on AI, SC, and UM, focusing on DD; and the third discusses the results and proposes final reflections on possible operational developments.

2 Materials and methods

This literature review is based on a filtering methodological approach divided into 3 phases. The analysis is oriented toward the systematic and integrative analysis of the scientific literature with the objective of outlining the state of play about AI applications in urban contexts (Figure 1).

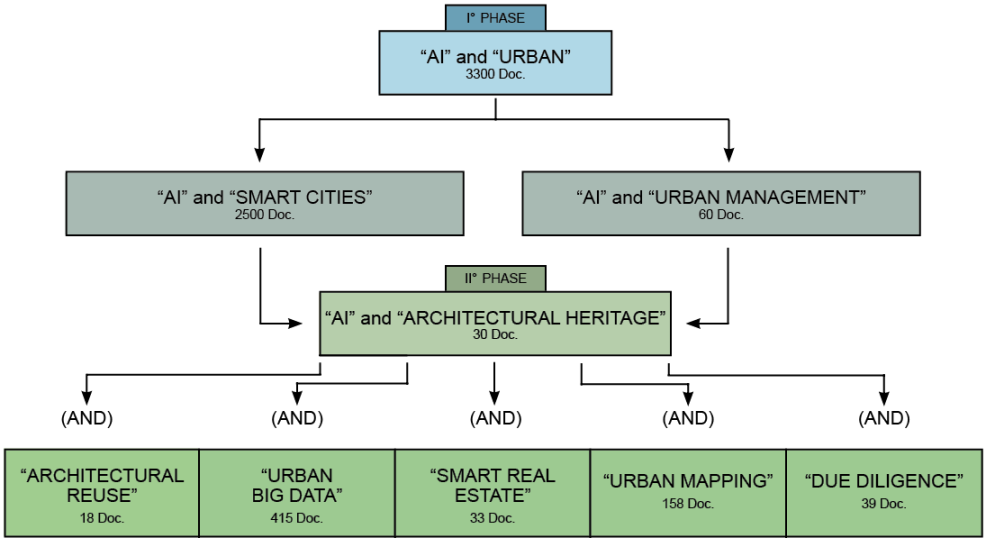


Figure 1: Methodological outline of research (Authors' elaboration)

The papers collection started in Phase 1 with the research of literature related to artificial intelligence and urban environment to define a general framework of reference for the application of AI in urban monitoring, development or transformation processes. In this research, the first extensive collection is composed of 3,300 scientific contributions. Papers were selected mainly through a targeted query on SCOPUS, focusing on its implications in urban ecosystems' governance, planning, and management, to trace emerging theoretical trajectories and identify the main areas of application of AI in the contemporary urban domain. The link between Generative AI and a more efficient and responsive management of cities is underlined in literature, as affirmed by Beroche, who stated that it can contribute significantly to urban management thanks to its ability to dramatically reduce the processing time and costs associated with analysing unstructured data. AI enables real-time scenario development and improves the decision-making capacity of public administrations (Beroche, 2023).

In the second phase of the data collection process, divide the research into two branches, and focus on the relationship between AI and smart cities or AI and urban management. In this research, the second step of the process collected 2,500 scholarly contributions regarding the relation between AI and smart cities and 60 papers relating to the link between AI and urban management. Both of these are sub-samples of the previous step.

Next, the bibliographic analysis focused on the exploration of AI applications in architectural heritage enhancement processes. This phase (Phase 2), by filtering papers collected in the steps 1 and 1b, led to the identification of 30 scholarly contributions deemed particularly significant for understanding the role of AI in the regeneration of the built environment and in defining strategies geared toward adaptive reuse. This phase investigated how AI-based theoretical models and technological tools support strategies for recovery, adaptive reuse, and regeneration of the built environment.

Finally, the last refined queries for the research are related to five subtopics (Phase 2b): architectural reuse, urban big data, smart real estate, urban mapping and due diligence. The selection of contributions favoured

those studies that present a data-driven and interdisciplinary perspective, integrating the knowledge of architecture, urban planning and data science. The thematic articulation that emerged from this phase confirms the centrality of an integrated and multidimensional approach, in which AI is configured not only as a technical support tool, but as a real catalyst for transformative processes oriented toward urban resilience, operational efficiency and long-term sustainability.

By filtering the final five subsamples on the basis of criteria such as consistency, completeness, innovation and the use of data, the final sample of analysis is composed by 23 papers, belonging to 1.200 different nationalities and 23 different authors (Table 1).

Table 1: Final paper sample (Authors' elaboration)

N	AUTHORS	Arch. He. reuse	Urban Data	Real estate	Urban mapping	Due Diligence	Topics
1	Ahmad Afaneh and Isam Shahrour, 2017				X		1
2	Allam and Dhunny, 2019		X		X		2
3	Al-Rimawi and Nadler, 2023			X		X	2
4	Al-Rimawi and Nadler, 2025		X	X			2
5	Barberis et al., 2020	X	X	X		X	4
6	Batty, 2016		X				1
7	Beroche et al., 2023				X		1
8	Bosone et al., 2019	X					1
9	Bosone et al., 2021	X				X	2
10	Cellucci, 2021	X		X			2
11	Cesario, 2023		X	X	X		3
12	Chioma et al., 2020			X			1
13	Cinquepalmi et al., 2023	X	X	X	X	X	5
14	Cugurullo et al., 2024		X		X		2
15	Djokić et al., 2025				X		1
16	Girard and Gravagnuolo, 2025	X	X	X			3
17	Gravagnuolo et al., 2021	X					1
18	Gravagnuolo et al., 2024	X		X		X	3
19	Kandt and Batty, 2021		X		X		2
20	Maha Shree J et al., 2024	X					1
21	Oral, 2024					X	1
22	Seagraves, 2024				X	X	2
23	United Nations, 2017		X		X		2

Just one of the 23 papers analysed covers all five topics underlined in the research, and just one analyses 4 to 5 topics, excluding urban mapping. Three contributions focus on different combinations of three topics, while most of the papers analysed face just one or two topics.

3 Results

The results outline the advancement of research in the respective fields analysed, but also highlight theoretical and operational gaps that need further exploration. Indeed, recent reflections on *"Urban Artificial Intelligence"* confirm the emergence of a hybrid field, in which AI is configured as an invisible but crucial infrastructure in the transformation of cities. Urban AI acts as a catalyst for complex processes, enhancing predictive analytics, data interoperability and future scenario building. As highlighted in the report *"The Future of Urban AI"* (Batty et al. 2023), the adoption of AI in cities still faces challenges related to data reliability and institutional fragmentation.

It has thus emerged how the adoption of AI tools allows for the expansion of the capacity for evaluative analysis of the built heritage, thanks to the possibility of cross-referencing heterogeneous data (morphological, structural, historical, energy, environmental, economic-social) and generating predictive outputs useful for the definition of sustainable regenerative scenarios. The most recent applications show the evolution of these tools from simple computer aids to intelligent analytical environments, which can integrate qualitative and quantitative assessments to identify the most promising use cases, minimising risks and maximising positive socio-economic impacts.

In general, the SC concept acquires an evolution from a purely technological paradigm toward an adaptive system capable of receiving and responding to citizens' needs in real time. This transition implies an increasing integration between innovative technologies, digital infrastructure, and civic participation, outlining scenarios

in which AI can become an enabling tool to improve operational efficiency and the equity and resilience of urban systems.

The emerging vision is to consider cities as *"smart ecosystems"* in which the digital infrastructure is intertwined with the physical and social components of the territory (Cugurullo and Acheampong, 2024). Addressing the scope of UM extends a second front of consideration, as the analysed papers tend to evaluate AI as a tool for supporting strategic planning, built asset management, and urban governance. From this perspective, AI is explored as a technology that can expand the analytical capacity of public and private actors, facilitating predictive asset valuation practices and environmental monitoring (Al-Rimawi and Nadler 2025). As highlighted in the report "*Generative AI for Urban Governance"*, generative AI technologies do not just support technical processes but also take on an inherently political nature.

Moreover, according to the Urban AI Guide, "Urban Artificial Intelligence" is a synthesis of co-production between cities and innovative technologies. AI transforms cities, but the cities themselves - with their data, infrastructure, and communities - shape the development of smart solutions (Popelka et al. 2023).

The first, related to AI and Architectural Reuse, comprised 18 scholarly contributions investigating the potential of AI in supporting adaptive reuse strategies of existing architecture. The analysed contributions highlight the growing role of smart technologies in assessing the conservation state of buildings, simulating sustainable transformation scenarios, and defining operational strategies aimed at rehabilitating the built environment. As a result of the last filtering process, some recurrent themes emerged that were used as keywords for the research. Five distinct sub-samples contributed to the final sample definition, each focusing on a different aspect. The first, related to AI and Architectural Reuse, was composed of 18 scholarly contributions investigating the potential of AI in supporting adaptive reuse strategies of existing architecture. The contributions analysed extol the growing role of smart technologies in assessing the conservative state of buildings, simulating sustainable transformation scenarios, and defining operational strategies aimed at rehabilitating the built environment. (Gravagnuolo et al. 2024) affirmed that effective decision-making processes in the context of cultural heritage require appropriate tools. In this sense, evaluation is central in constructing choices, recognising values, interests and needs, and exploring the different factors that may influence decisions.

From this perspective, the adoption of AI emerges as an enabling tool to address the multidimensional complexity characterising adaptive reuse processes (Gravagnuolo et al. 2024). Indeed, the literature highlights how the proper use of AI can contribute significantly to economic growth, social welfare and environmental regeneration, promoting more sustainable and circular urban development.

In parallel, the extensive literature on urban Big Data, numbering 415 scientific papers, has offered a solid methodological framework, highlighting the potential of AI in data management. his component has reinforced the paradigm of data-driven urban governance, where predictive analytics and advanced modelling are essential tools for adaptive and informed planning. In particular, Big data provides a lens through which the complexities of urban form can be analysed, understood, modelled, and even imagined and tested in different scenarios (Djokić et al. 2025).

Further reflections emerged from the comparison with the area of Smart Real Estate, represented by 33 studies, in which how AI can contribute to real estate valuation and the definition of sustainability-oriented investment strategies are analysed. In this area, it emerges how the integration of digital technologies, such as Internet of Things (IoT), BD, AI and digital twin (DT), enables more efficient real estate asset management and data-driven decision support, improving quality of life and promoting sustainable urban development (Al-Rimawi and Nadler 2023). In addition, recent studies show that the deployment of smart buildings and interconnection with urban infrastructure contribute significantly to reducing energy consumption and emissions, enabling new real estate valuation and investment models based on sustainability and operational efficiency (Al-Rimawi and Nadler 2023).

Also of considerable relevance is the area of Urban Mapping, which is explored in depth through 158 contributions highlighting the use of AI to create high-resolution urban representations capable of dynamically rendering the city's morphology. Geospatial Deep Learning (DL) technologies, applied to the analysis of satellite and aerial imagery, enable the precise identification of urban morphology and the development of three-dimensional models of built fabric and street networks. In particular, the adoption of advanced convolutional models, integrated into a GIS environment, enables the extraction of complex features such as building footprints and street networks from orthorectified imagery, improving the accuracy of urban analyses and supporting the definition of more informed and responsive spatial policies. (Orusa et al., 2024).

Finally, the theme of Due Diligence, investigated through 39 papers, highlighted how AI can optimise the preliminary stages of decision-making through a more efficient and transparent analysis of technical, legal, economic, and environmental information related to real estate assets. However, critical literature analysis

highlights a significant gap: the lack of structured theoretical frameworks and shared metrics to systematically assess the “urban reusability” of disused buildings.

3.1 “Artificial Intelligence” AND “Smart Cities”

From the analysis of the co-occurrences related to the combination of the keywords *“Artificial Intelligence”* and *“Smart Cities”*, elaborated through VOSviewer, by applying a co-occurrence analysis of terms, authors, or publications, using a distance-based visualisation approach where the proximity between nodes reflects the strength of their relationship, based on techniques such as the VOS (Visualization of Similarities) mapping method.

The relationships between the main key terms in the examined literature are illustrated in Figure 2. The network graph shows five large clusters that emerge, distinguished by the colours red, green, blue, yellow, and purple, with a total of 422 occurrences.

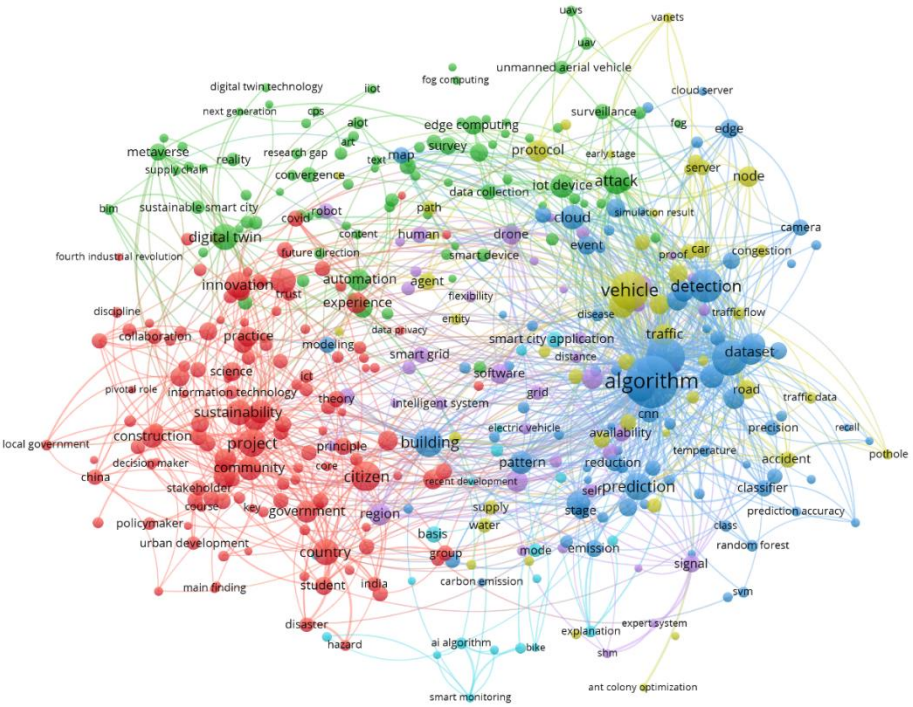


Figure 2: Map of co-occurrences emerging from the research. "Artificial Intelligence" AND "Smart cities"
Authors’ elaboration

The red cluster includes public policies, urban planning, and sustainability concepts. Keywords such as *“CO2 emissions”*, *“project”* and *“community”*, closely related to terms such as *“country”*, *“citizen”*, *“urban development”*, and *“government”*, highlight the centrality of regulatory and social aspects.

In the blue cluster, a focus on the relevance of IT, algorithmic and predictive is observed. The concentration of keywords such as *“prediction”*, *“probability”,* and *“machine learning”* underlines the importance of the data-driven approach. It is interesting to note how *“building”* and *“map”* occupy an intermediate position between the clusters belonging to the urban sphere and those belonging to the IT/technological sphere.

In the green cluster, on the other hand, concepts that recall the use of advanced technologies such as *“sensors”, “digital twin”*, and *“automation”* prevail. The presence of terms related to automation and robotics, combined with references to smart tracking, suggests potential solutions to transform the analysis and intervention processes.

The purple cluster can be interpreted as representing the “smart network” theme, encompassing both the physical and digital infrastructures, with particular emphasis on flexibility and the interaction between human and cyber interfaces.

The yellow cluster highlights the widespread application of AI in the mobility sector, which is traditionally one of the earliest fields to integrate artificial intelligence technologies. In this representation, network governance and innovation are in a form of dialogue and the relationships between the concepts analysed highlight an evolving panorama in which interdisciplinarity and the ability to integrate different skills appear crucial to promoting new urban policies (Figure 3).

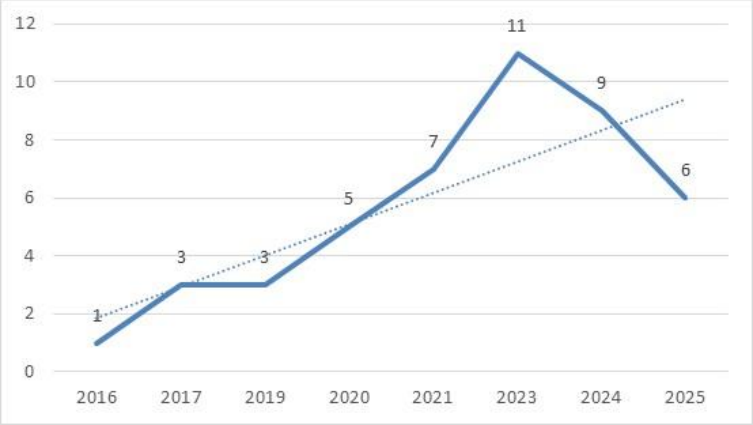


Figure 3. Trend of analyzed publications over the years (Authors' elaboration on Genuary 2025)

The emergence of a data-driven urban paradigm, currently in a phase of progressive consolidation, is characterised by an increasing integration of analytical methodologies, decision-making frameworks, and sustainability imperatives. However, this integration remains fragmented and inconsistent, underscoring the imperative for further theoretical elaboration and operational innovation to ensure that intelligent urban solutions enhance system optimisation and foster the development of more equitable, inclusive, and resilient urban environments.

3.2 "Artificial Intelligence" AND "Urban management"

The co-occurrences from the scientific literature relating to the binomial "Artificial Intelligence" and "Urban Management" are represented by the semantic map in Figure 4. The map is divided into two main sets, which reflect a polarisation between a conceptual and a technical-functional approach.

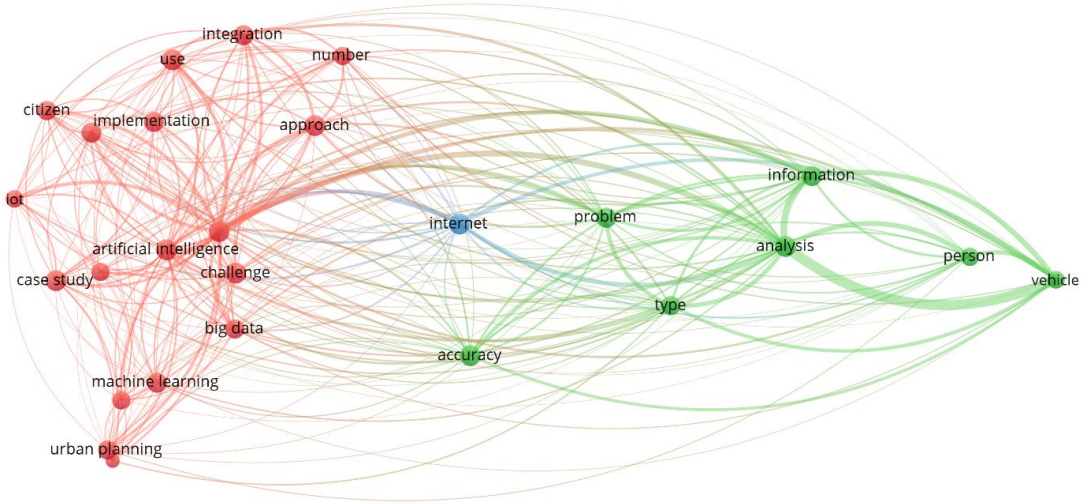


Figure 4: Map of co-occurrences emerging from the research. "Artificial Intelligence" AND "Urban Management"

The red cluster focuses on concepts such as "Artificial intelligence", "Urban planning", "Implementation", "Integration", "IoT" and "Big Data". This area signals a theoretical and methodological interest in the strategic role of AI in urban planning and management processes. The recurrence of terms such as "Use", "Challenge" and "Citizen" suggests a reflection on the potential, but also the critical issues, connected to the social, cultural and organisational dimensions of the introduction of AI in cities. The green cluster, on the other hand, focuses on more operational concepts such as "Analysis", "Information" and "Accuracy". This section outlines a literature focused on AI as a tool for optimisation and automation, particularly in traffic management, big data analysis, and the construction of predictive models. The focus is on analytical precision, data classification and the efficiency of intelligent systems in urban contexts.

Interestingly, the intermediate position occupied by the term internet seems to act as a conceptual node between the two clusters, reflecting the role of digital infrastructures in the connection between decision-

making processes and emerging technologies. A still fragile connection between the different conceptual structures emerges as an element of final critical reflection. The map confirms how AI is now recognised as an incentive for the evolution of urban management, but at the same time highlights how the scientific approach to the topic is still fragmented, with an evident separation between theoretical visions and practical applications.

3.3 "Artificial Intelligence" AND "Due Diligence"

The scarce presence of scientific contributions dedicated to AI and Due Diligence or the valorisation of unused Architectural Heritage underlines a gap in the current literature. These areas represent a promising research field, in which AI could evolve as a technical tool and cognitive decision-making infrastructure, capable of supporting more sustainable, inclusive and built-regeneration-oriented urban policies.

Although still marginal in the scientific debate, the topic of DD represents a strategic area for the application of AI, operating on two distinct levels: urban and architectural.

AI can enhance DD practices at the urban scale by supporting predictive assessments on brownfield sites, territorial risks and regenerative potential. The studies by (Al-Rimawi and Nadler 2023 - 2025) show how the integration of innovative technologies and data-driven tools strengthens the preliminary phases of decision-making processes in the real estate and urban planning fields, transforming DD into a strategic lever for sustainable planning.

At the architectural scale, several contributions explore the application of AI in the technical and performance assessment of the built environment, with a particular focus on adaptive reuse processes (Cinquepalmi et al. 2023; Gravagnuolo et al. 2021; Barberis et al. 2020). In these studies, AI enables the automated analysis of morphological, energy, and structural data, integrating multi-criteria approaches to support more informed and sustainable decision-making. Despite its potential, the literature points to a fragmented landscape, characterised by the absence of consolidated models and scalable applications. This highlights the pressing need to develop robust methodological frameworks that can establish AI as a reliable decision-making tool within urban and real estate regeneration processes.

4 Conclusions

The literature review reveals significant gaps, particularly the absence of tools specifically designed to support urban regeneration through the rehabilitation of disused spaces and buildings using AI technologies. While advanced technologies offer promising solutions, the risk of disproportionate and top-down applications remains, potentially neglecting social and cultural dynamics. Hence, it is crucial to integrate community engagement tools and participatory governance strategies to balance technological innovation with urban resilience (Allam and Dhunny 2019). The effectiveness of AI tools lies in their ability to process large volumes of data, refining analyses and automating resource optimisation. Various subcategories of AI — including GAN models, Generative Pre-Trained Transformers (GPT), Machine Learning (ML), Information and Communication Technology (ICT), Internet of Things (IoT), Cloud Computing, and Software as a Service (SaaS) — form the technological infrastructure for data-driven urban development (Talari et al. 2017). Successful SC and SRE solutions implementation requires high-tech information systems and sharing platforms to analyse collected data (Al-Rimawi and Nadler 2025). Moreover, the literature identifies the fragmentation of local policies and the difficulty in implementing data-driven strategies as significant barriers to efficient and sustainable urban development (Acioly et al. 2020). Although Urban Big Data (BD) represents a highly innovative sector, critical issues such as data source fragmentation and lack of interoperability persist. One notable weakness is the limited connection between real estate (RE) research and urban regeneration and sustainability efforts. While many studies apply AI to asset valuation and market trend prediction, few address the relationship between real estate markets and adaptive reuse strategies. This suggests that the real estate sector remains largely anchored to traditional development models focused on new constructions, rather than enhancing existing assets. The convergence of AI, BD, and property management models may offer a pathway to overcome these challenges, fostering more rational and effective urban resource management and promoting smart but also sustainable, inclusive, and adaptable cities to future challenges. The level of integration of AI into urban governance is still limited by theoretical and operational limits, even if the European Union tends to propose new operational applications oriented towards sustainability, circularity and territorial equity.

The research has highlighted how AI today represents a stimulus to rethink the contemporary city, especially in urban regeneration and valorisation of abandoned buildings. The adoption of generative models and predictive tools based on data opens up concrete operational scenarios to overcome the critical issues related to information fragmentation, lack of interoperability and the absence of systemic approaches.

SC technologies have reached sufficient maturity to be integrated into operational processes, but highlight also the lack of a structured model to guarantee interoperability between data and digital platforms (Al-Rimawi and Nadler 2025). A structural barrier that limits the real potential of AI in urban contexts, making it urgent to build open, integrated and scalable information ecosystems.

In this scenario, the issue of the reuse of abandoned buildings remains marginal in the scientific debate. The introduction of the Reusability Index (RI) by the European Commission represents a first step towards the definition of shared metrics (Barberis et al. 2020).

Future research developments will have to focus on the creation of interoperable frameworks capable of connecting predictive models and urban decision-making processes. Only a convergence between technological intelligence and social vision will transform cities into intelligent organisms capable of learning, evolving and generating social value. The challenge for the cities of the future is not only technological but profoundly cultural; integrating AI is not an end but a means to build safer, more resilient, and inclusive urban environments.

5 Ethics declaration

The authors declare that they have respected all ethical standards during the research process. All sources and references have been properly cited, and any potential conflicts of interest have been disclosed. The research was conducted independently and without external influences.

6 AI declaration

The authors confirm that Artificial Intelligence tools were used to assist only in language refinement and summarization. No AI system was employed for the generation of original scientific content, analysis, or critical evaluations included in this paper. The authors retain full responsibility for the originality, accuracy, and integrity of the research findings.

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Let Me Entertain You: Managing Socially Sustainable Experience Economy Ecosystems

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Abstract

This research aims at exploring and understanding the complex contemporary phenomena of socially sustainable Experience economy. It contributes to the academic discussion around Experience economy research, strategy and policy by developing understanding about managing social sustainability within Experience economy ecosystems in Finland. The core question of this doctoral thesis is *how to ensure everyone equal access to Experience Economy Ecosystems?*

The context of this research is the new *Experience Economy research program* conducted at Tampere University. This article is part of a doctoral thesis, focused in specifically on industry phenomenas *Accessibility of Experience* and *Paths and Communities of Experience.* The Experience economy research program generates a rich empirical context and metadatabase highlighting the ongoing transformation and market development within the uprising Experience Economy ecosystems in Finland.

In this article experience economy is studied through social sustainability and in specifically inclusivity, to identify and analyse the mechanisms for managing social development goal SDG implementation within the experience economy ecosystems. Empirical data is drawn from OAF Outsider Art Festival. OAF is a new multidiscipline art festival, organized in conjunction with the largest Nordic art festival Helsinki Festival. OAF promotes diversity, equity and inclusion (DEI) and contributes to Social Development Goal implementation (SDG) by managing innovative collaborations between industry outsiders and insiders. OAF provides an interesting case - an industry specific critical “node” -within the EE ecosystem, providing new knowledge from the perspective of industry outsiders.

In result, by identifying, analysing and mapping the critical nodes, access points and stages where social transformation and inclusivity actualise and create socially sustainable, experience driven business models, this research creates new knowledge of managing social sustainability within Experience economy ecosystems and networks, in research and practice. This research contributes to Sustainable Development Goals (SDG): *Sustainable cities and communities (11), reduced inequalities (10), partnerships for the goals (17), industry, innovation and infrastructure (9), decent work and economic growth (8).*

Keywords: Experience economy ecosystems, social sustainability, inclusion, co creation, festival management

Paper type: Academic Research

1 Introduction

This research aims at exploring and understanding the complex contemporary phenomena of socially sustainable experience economy. It contributes to the experience economy research, strategy and policy makers by developing understanding about managing social sustainability within Experience economy ecosystems in Finland. This research contributes to Sustainable Development Goals (SDG): *Sustainable cities and communities (11), reduced inequalities (10), partnerships for the goals (17), industry, innovation and infrastructure (9), decent work and economic growth (8).*

The core phenomena, social sustainability, is studied from the perspective of social transformation and inclusivity in the context of Experience economy ecosystems and networks. The core question of this research is *how to ensure everyone equal access to Experience Economy Ecosystems?*

The context of this research is the new *Experience Economy research program* conducted at Tampere University from 2024 to 2027, specifically on industry phenomenons "Accessibility of Experience”, "Events & Fairs", "Paths and Communities of Experience". The Experience Economy research project provides a rich empirical setting featuring private and public organizations such as the City of Tampere in Finland, National Hockey League (the largest professional sports organization in Finland), Nordic Hospitality restaurant group, Tampere Fairs, Live Nation Finland, Nokia Arena and many smaller actors and organizations from art festivals to film makers.

In this doctoral thesis experience economy is studied through social sustainability and in specifically inclusivity, to identify and analyse the mechanisms for managing social development goal SDG implementation within the experience economy ecosystems. By taking an industry mediator perspective, this research studies transformative experiences as a way to drive sustainable business innovation and inclusive management practices enabling open access to co-creation and co-innovation.

This article presents a case of Outsider Art Festival. OAF is produced by a social enterprise Pertti's Choice Outsider Art Agency, founded by four disabled musicians of the punk band Pertti Kurikan Nimipäivät (Pertti Kurikka's Nameday PKN). The band represented Finland in the Eurovision song contest in 2015. After touring around the world for two years, the band decided to start a business to drive societal change and disability employment. For the past five years, Pertin Valinta (Pertti's Choice) has been running *Outsider Art Festival OAF* to empower marginalised groups and for giving power to outsiders in taking over mainstream stages.

With the combination of relevant literature around Experience economy and empirical data collected from the field, this research aims at studying the social dimensions of experience economy and the accessibility of experiences by exploring (1) what are the assumptions behind the creation of experiences and moreover, what are the needs, expectations and lived experiences of people who deviate from these norms, and second (2), what are the mechanisms of managing accessible experiences and events and determining shared value for sustainable ecosystems to service that journey and third (3) what are the typologies of organizations staging and creating experiences and how to develop shared assets such as common language, forums, policies and support programs for these organizations?

2 Socially Sustainable Experience Economy

The political origins of social sustainability is grounded in the UN 2030 Agenda (UN report 2022). The Commission for Social Development (2022) stated that strengthening social sustainability is an essential in the current global situation marred by numerous crises. The implementation guidelines show the path to addressing societal challenges, growing inequalities within and between nations. Opportunities for the most vulnerable people to access education and finding decent work is stated as a human rights and security issue that must be actively improved. There is a need to develop multi-level cooperation and targeted programmes to guarantee security and opportunities for everyone.

According to the UN evaluation reports (2019, 2023) the development of SDG implementation has stopped and will not reach the goals in 2030. As a positive exception to this negative development, the Nordic countries, and in specifically Finland has taken a lead position in SDG implementation. The UN report points out future development goals towards sharing best practices and creating new knowledge for other countries to follow. The report shows, that it is important to promote inclusion and engagement in all levels, from the international through the national and the regional to the local and in the level of intersectoral policies and governance (Fancourt & Finn 2019).

WHO's implementation package (2019) highlights the importance of facilitating intersectoral collaborations through transformative and whole-of-system approaches. Thus, in this thesis, SDG implementation is examined as a whole of system complexity to fully grasp relevant managerial and entrepreneurial assets and the core values and future of the socially sustainable experience economy.

Socially sustainable experience economy offers a current research topic that challenges with its ambiguous and multidisciplinary nature. Experience economy is considered one of the fastest growing global markets and experiences are increasing in popularity as sustainability, urbanization and the evolution of competition have accelerated the impact. The power of experiences has reached acknowledgment for socially transformative capacity and the creative industry is seen as essential for the further development of European economies and societies by generating social cohesion (OMC Report, 2019). According to the World Economic Forum (2019) *"the experience economy is booming, but it must be for everyone"* (2019).

The interest towards experience economy has grown also among scholars during the last decade (Pine & Gilmore, 1998, 2011 Chevchouk & al. 2021). However, as a concept, experience economy is still unstructured and lacking scientific research and discussion among scholars and practitioners (Chevtchouk & al. 2021.) Experience economy is often conceptualized either through the perspective of specific industries or as an extension of the value chain for products and services. Moreover, experientiality constitutes as one of the most rapidly expanding phenomena of our time, driving profound transformations in consumer behavior and business models.

Currently, in the experience business, creative industries and corporate reality, social responsibility is increasing significance as part of employee, audience and customer experiences and corporate responsibility. Scholars of knowledge management have addressed the growing interest towards sustainability presenting many interesting viewpoints to sustainability and the organization's need to adapt their business models and values to prioritize social and environmental responsibility alongside economic success (Lerro, A. & al 2023). However, compared with ecological sustainability, social sustainability still lacks understanding on promoting SDG's within creative economies and ecosystems.

3 New Stages for Shared Value Creation

As economies have evolved from services and products towards the primacy of experiences it is interesting to explore experiences as the key phenomenon for creating social and economical transformation. In their Big idea (2011) Porter & Kramer introduced a new way to achieve shared value by three key ways that companies can create shared value opportunities: 1) By reconceiving products and markets, 2) by redefining productivity in the value chain and 3) by enabling local cluster development. However, they also pointed out that realizing shared value requires leaders and managers to develop new skills and knowledge, such as a deeper appreciation of societal needs, a greater understanding of the true bases of company productivity, and the ability to collaborate across profit-nonprofit boundaries.

The original idea of Pine & Gilmore, founders of Experience economy, presented "work as theatre and every business as a stage" (2011) leading to interesting multi-disciplinary developments showing positive results of integrating creative knowledge to other fields through intersectoral collaborations (WHO 2018; Anttonen & al. 2016; Berthoin & Strauss, 2013, Sorsa & al 2017) highlighting the value of collective and creative experiences in supporting organisational transformation, social cohesion and community building as effective, participatory, collective activities (Berthoin & Strauss, 2013, Schiuma 2018; Sorsa & al 2017).

From the perspective of social value, it's important to critically observe, *who has access to the ecosystem and who gets to get up on that stage, who has the power to decide*? By raising up these questions this research exhibits new actors to the stage and explores the deeper significance and transformative impact of experiences. Open strategy scholars (Vaara & al, 2019) highlight *participation* as a core concept in defining open strategy in terms of strategy agency and power dynamics and inclusion. However, questions remain on *who is included and who excluded* from participating (Samra-Fredericks, 2005; Mantere & Vaara, 2008, Whittington et al 2019). Although the term open strategy implies widespread transparency and inclusion in strategy-making, real-life examples and practices mostly tell a story of more limited participation and role of organizational members outside the core establishment such as lower-level employees or external actors is underrepresented over top- or middle management (Vaara & al, 2019, Seidl et al 2019). Increased inclusion and engagement results in wider range of ideas and efficiency in strategy implementation (Splitter, 2024). The way different people understand and communicate strategies varies, as well as the quality of discourses.

Socially sustainable experience economy offers a current research topic that challenges managers with its ambiguous and multidisciplinary nature. Shifting focus from single organisations to networks and ecosystem level strategy work, and from top-management to the marginal actors, it is possible to explore new stages, (Pine & Gilmore, 2011; Schiuma 2018; Berthoin & Strauss 2015; Sorsa & al. 2017), where participants experience new transformative ways of seeing, thinking, and doing things that add value for them personally (Ravasi & Rindova, 2017; Hautz et al., 2017). However, integration of different level actors engaged in the strategy process, demands high level discursive competence and open access to strategic knowledge (Splitter, 2024). Ford and Ford (2008) present the idea of critical focal points, 'nodes', featuring specific places and moments where different stakeholders of the network intertwine, share and create something truly meaningful. By identifying and studying these critical "nodes", events as focal points of the industry ecosystem, this research points out direction for inclusive open strategy work and shared value creation within the Experience Economy ecosystems (Ford & Ford, 2008; Porter & Kramer, 2011).

4 Inclusive festival management, case study of Outsider Art Festival OAF

Drawing from empirical data, Outsider Art Festival OAF provides an interesting case - an industry specific critical "node" -within the EE ecosystem. OAF is a new multidiscipline art festival, organized in conjunction with the largest Nordic art festival Helsinki Festival. OAF promotes diversity, equity and inclusion (DEI) and contributes to Social Development Goal implementation (SDG) by managing innovative collaborations between industry outsiders and insiders. OAF presents an interesting case example by engaging "outsiders" to induce viewpoints, discourses, and solutions outside the established paradigms and industry conventions (Hautz et al., 2017).

OAF serves as a connecting point, a stage and a platform for Finnish Outsider Arts, featuring multidiscipline network working in the fields of music, visual arts, film, performance arts and literature. Besides the artistic productions, OAF showcases new visions and abilities of the industry outsiders to promote a larger societal impact and agenda. In 2020, after the covid pandemia, OAF initiated an employment program to ensure everyone open access to the creative industries. Through the program, OAF facilitates collaborations between sustainable business partners, engaged in creating new employment paths to the industry outsiders. In five

years, the program has initiated various collaborations- co-creation, co-production and co-curating- of the industry outsiders and insiders to challenge discriminatory and exclusive industry practices and drive social transformation by introducing new, inclusive practices as a joint agenda.

OAF offers an interesting research environment to study social development goal SDG implementation within the experience economy ecosystems. In this research, OAF provides a collection of empirical data, policy documents, strategy documents, interviews and videos of the experiences of both outsiders and insiders of the experience ecosystem: artists, producers, curators and managers as well as sponsors, venue partners and the audience. Guided by the internationally recognised statement of the disability advocates *"nothing about us, without us"* (Charlton, 1998) creates the foundation for all OAF operations and the demand for developing inclusivity as a collective effort. OAF offers support in employment and advocacy for people marginalized for various reasons, such as disability, mental health, social issues and ethnicity. By *"giving power to the outsiders"* and helping them in *"taking over the stage"* OAF creates a new platform for radically open strategy making for marginalized populations to engage and present their lived experiences and life stories through creative encounters. Beside the creative content and capabilities, OAF showcases new, accessible and socially sustainable value chains and inclusive production models, promoting a wider recognition of disability employment and inclusion in the labour market.

5 Contribution and relevance

This research contributes to social development goals by identifying mechanisms for managing inclusive practices both in management and research within the Experience economy ecosystems. Drawing from current literature around experience economy, transformational experiences and the empiria from Outsider Art Festival OAF, this research introduces the 1) experiences and expectations of industry outsiders and insiders, 2) mechanisms for managing accessible experiences and 3) offering new insights on the discussion how accessibility and inclusivity is experienced and facilitated as shared value, communication and space.

With the combination of literature around Experience economy and the empirical data drawn from Outsider Art Festival OAF's networks, this research creates new knowledge to the complex and multifaceted issue of managing social sustainability within the experience economy ecosystems from the perspective of industry outsiders and insiders. In this case, outsider's position is used to refer to the way marginalised populations are represented and taken into account as equal actors in ecosystems of the industry ecosystem, engaged in decision-making and operations, as leaders, managers, curators and creators of events and creative content.

Based on the preliminary findings collected from the OAF strategy documentation and stakeholder interviews, the main reasons for being left outside the industry conventions are *the unaccessibility of qualifying education and supportive services.* Furthermore, outsider statements point out that *creative industries are not generally recognised as possible working opportunities for outsiders by their supporting networks.* From the perspective of the advocate organisations working with outsiders, *open strategy can offer new direction to supporting outsiders engagement in co-creation with the insiders*. Opening access can also lead the way for insiders to many ways perceived and even closed worlds of the outsiders. *Accessibility is discussed also as a communicative issue* besides the industry structures. As the open strategy scholars have argued, the demand for *professional discourse can create an obstacle* for open access, when people are using very distinct and industry specific language. As a part of communications, technology can also create an issue. Using technological systems for example in collecting experiences and data can also turn out to be challenging and even discriminating for people who don't have digital access due to guardianship or the lack of technical skills.

From the insider perspective, industry conventions appear to also cause challenges, but for different reasons. The *difficulties in finding a shared space, language and ways of co-working* become critical issues that require special knowledge and competence. Although industry insiders are seeking ways to drive societal impact by new, collaborative ways, they *lack the competence in managing or facilitating collaborations* with industry outsiders. To succeed in shared value creation, it appears critical to have support on a managerial level to fully engage in promoting open access and power shift on industry level. When succeeded, both insider and outsider experiences *state joy for giving and having a voice, space and power to decide*, make a difference and create experiences that are "*truly meaningful and transformational*".

In conclusion, open strategy and shared value creation are introduced as an inclusive practice and a way to look beyond the conventional practices and viewpoints and expand the scope beyond the organisation to ecosystem level and the society. Taking the mediator perspective, this research highlights how inclusivity challenges meditative actors and managers in facilitating the various stakeholder perspectives within the ecosystem in flux. Moreover, this research sheds light to the impact ecosystem level collaborations can have on driving industry conventions and societal transformation. Creating a shared space and agenda around shared

values and strategic goals, enables a more profound impact to the ecosystem level over single organisations and industries.

Looking beyond the Experience economy ecosystems, this research has relevance to social sustainability endeavors also on other industries. By identifying and mapping the critical nodes, access points where SDG implementation actualise, this research provides new knowledge on creating business models, managerial and entrepreneurial strategies on promoting social sustainability within Experience economy ecosystems and networks, in research and practice. Furthermore, this research points direction to inclusive research and engaging outsiders in creating scientific knowledge as a collective effort and calls for attention to engaging outsiders in the knowledge creation according to the fundamental statement of the disability agenda: Nothing about us without us.

6 Ethics declaration

I commit to conducting my research in accordance with ethical guidelines as stated in the Code of Conduct for Research Integrity in Finland and Europe. As a researcher, I prioritize participant consent, confidentiality, and the integrity of the data.

7 AI declaration

AI has been used in conducting this research for reviewing grammar, spelling (Finnish to English) and references.

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Global or Local Player? – Cultural Diversity and Barriers in STEM Studies

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Abstract
The aim of the current study is to examine the perception of cultural diversity among German STEM students. Previous research has mainly focused on the attitudes towards gender in the STEM field. This study undertakes an innovative approach and explores the opinions of German STEM students with and without a migration background on cultural diversity and educational barriers. To test this, we conducted semi-structured interviews with 90 STEM students from two German cities. The data was analysed with a qualitative content analysis. The results show that both students with and without a migration background are to a large extent unfamiliar with the topic of cultural diversity. Most STEM students think that cultural diversity has a positive impact on work performance. Some of the barriers which students with a migration background face are unfair university structures, lack of support in the educational system, challenges of cultural adaptation, and insensitivity or hostility from host-culture members. This study shows the need for a more inclusive university culture in the STEM field. It also emphasizes that diversity trainings can successfully prepare students for intercultural experiences.

Keywords: Cultural Diversity; STEM; Discrimination; Students

Paper type: Academic Research Paper

1 Introduction

Difficulties in integrating and utilizing diversity in the field of education in science, technology, engineering and mathematics (STEM) have existed for a long time. This issue has, however, not been fully addressed so far (Atadero et al., 2018; Best et al., 2013; Chédru & Delhoume, 2023; Maji et al., 2023). The current discussion refers to the lack of diversity in the STEM degree programs and professions which has become a major concern. The participation of underrepresented groups in STEM should be increased. This is considered critical for preserving the future vitality of the field, as demographic shifts and the complexity of modern problems have demonstrated a need for diverse perspectives and approaches (Atadero et al., 2018). Furthermore, a more diverse STEM workforce is seen as essential for meeting the ethical obligations and serving the needs of all populations (Atadero et al., 2018; Best et al., 2013; Chédru & Delhoume, 2023; Maji et al., 2023). Related to this discussion, an extensive body of scientific literature and policy papers emphasizes the importance of not only attracting future female scientist, engineers and mathematicians but of developing the professional culture, sensitivity related to gender issues, and professional stereotypes related to gender (Anger et al., 2018; Best et al., 2013; BMBF, 2020; Froehlich et al., 2022; Schäfer, 2006). At the same time, there is a noticeable gap in the discussion on diversity of cultural background and interculturality in this sector.

In the current German educational system, students with a migration background show a lower study success rate despite similar or higher study motivation, especially in STEM subjects (Miyamoto, 2018; Educational Report Germany 2018). A large body of research has identified several reasons for this discrepancy: unfair structures and lack of support in the educational system (Koehler & Schneider 2019), challenges of cultural adaptation (Deardorff & Arasaratnam-Smith 2017), as well as host-culture members' lack of sensitivity or hostility (Uslucan 2020). For the purposes of this study, persons who immigrated to Germany in the first or second generation are considered immigrants. This means that at least one parent or the participants themselves immigrated to Germany (Kemper 2010). Those categories are clearly unable to display the complexity of interpersonal variety in this group of participants (Atadero et al., 2018). However, people with a migration background might differ in the way they experience cultural differences and disadvantages. Furthermore, the topics of sensitivity or abilities related to cultural diversity are not widely addressed in German STEM curricula (Auferkorte-Michaelis & Linde, 2022).

The concept of diversity of the cultural background in German STEM education is related to the issue of reducing phenomena of discrimination (discrimination and fairness perspective; Auferkorte-Michaelis & Linde, 2018; Ely & Thomas, 2001) as well as to questions of abilities and skills necessary to deal effectively with different cultural orientation systems (integration-and-learning perspective). The discrimination and fairness perspective is related to the process of inclusion and refers to providing equity of conditions to access and participate in STEM education (Villanueva Alarcón et al., 2021). The integration and learning perspective focuses on the

utilization of diversity. One of the main aims of this perspective is not simply to avoid discrimination but to prepare students to interact effectively and appropriately in an international and complex context (Genkova & Schreiber, 2022).

As the STEM sector is the most internationalized sector in Germany, STEM-education just recently set a focus on addressing cultural / ethnic discrimination and on providing skills to succeed in this working environment (Anger et al., 2021). Previous research on organizational diversity could show that understanding the perception and connotation of cultural heterogeneity is a crucial precondition to effectively develop individuals' attitudes and skills to deal with it (Bergman et al., 2023; Genkova & Schreiber, 2022; Genkova et al., 2021). While the perceptions and attitudes related to gender have been thoroughly discussed in the literature and in the practice, hardly any studies have been conducted on the perception of cultural diversity in German STEM subjects. Given the urgency of including and utilizing cultural diversity in the STEM-education, the main aim of the current paper is to contribute to the understanding of the perception of diversity in the German STEM education. Our approach is to explore the perspectives of German STEM students with a migration background, as well as their non-immigrant fellow students on diversity and related barriers by means of a comparative, qualitative study.

2 Theory

Diversity management revolves around the composition of individuals within an organization, encompassing both their similarities and differences (Krell, 2013). Previous research shows that diversity at universities is reflected in demographic characteristics (e.g. migration background, age), cognitive aspects (knowledge structures, values), subject differences, functionality (skills, organizational cultures, communication) and institutional affiliation (Higher Education Awareness for Diversity, HEAD model, Gaisch & Aichinger, 2016). While all these characteristics hold varying degrees of significance, certain dimensions of diversity are particularly meaningful due to their impact on individual identity and the associated challenges and opportunities (Van Dick & Stegmann, 2016).

Research on the integration and learning perspective focuses on the pros and cons of heterogeneity in organizations and institutions referring to the information-processing perspective and the social identity approach (Schneid et al., 2016). The information-processing perspective posits that diversity is linked to the application and the thorough processing of relevant information, leading to enhanced performance within diverse teams. On the other hand, the social-identity approach suggests that the formation of subgroups in workgroups based on shared attributes, such as age or cultural background, can result in conflicts and hostile behavior (van Dick & Stegmann, 2016).

Culture and age are both significant components of an individual's social identity, serving as categorization tools for oneself and others, with particular emphasis on subjective differences between groups (social identity approach; Tajfel & Turner, 1979). Culture, in this context, refers to a psychological framework that shapes identity through norms governing perception, cognition, and behavior (Thomas, 2003). When the sense of belonging to a specific cultural or age group becomes more salient or subjectively relevant, individuals tend to view themselves and others less as unique individuals and more as representative members of a particular group (van Dick & Stegmann, 2016).

The categorization elaboration model (CEM, van Knippenberg et al., 2004) aligns with the social identity approach and provides an explanation for the performance disparities observed among diverse teams in a replicable manner (van Dick & Stegmann, 2016). The core premise of the CEM is that groups with diverse members possess a greater potential for diverse perspectives, knowledge, and general information, leading to more comprehensive information processing and, consequently, more innovative solutions. However, the formation of subgroups (based on subjectively relevant group characteristics and salience) can trigger negative emotional consequences, ultimately resulting in poorer performance if the subgroups develop a hostile relationship. This occurs when the subgroups fail to recognize each other or acknowledge their respective contributions, thereby threatening their identities (van Dick & Stegmann, 2016).

Beyond the direct negative impact on utilizing diversity-potentials, research indicates that subgroup formation based on cultural background has profound implications for fair opportunities and appropriate intergroup behaviour (Kunze, 2013). Certain professions exhibit a historical lack of diversity compared to others. This discourages minorities from considering them as viable career options. In the context of STEM education in Germany, individuals who deviate from the stereotypical image of a STEM graduate (e.g., male, white; Leicht-Scholten et al., 2009) in terms of their ethnic/cultural background and gender often encounter both direct and indirect forms of discrimination, making them vulnerable groups. Alongside the already existing obstacles faced by members of vulnerable groups, they also tend to have fewer resources to navigate through changes or crises, such as the ongoing COVID-19 pandemic (Lörz et al., 2016; Zimmer et al., 2021). As a consequence, people from

non-academic backgrounds (which are overrepresented among students with immigration background) have exhibited increased intentions to drop out during the pandemic (Becker & Lörz, 2020), and individuals with a migration background face higher dropout rates in STEM (aspiration-performance paradox, Miyamoto, 2018). These challenges are further compounded by intersectionality, which occurs when individuals face disadvantages due to multiple intersecting characteristics.

Following the CEM, the utilization of diversity in STEM-education and the workplace requires a positive and appreciating approach towards diversity from all institutional members. Considering the internationalized working environment as well as existing discrimination, STEM-graduates are thus expected to appreciate diversity, to understand existing power-asymmetries, and to develop the skills necessary to interact appropriately and effectively with individuals with other cultural orientation systems. One of the aims of STEM-education should thus be, to provide such attitudes, skills and knowledge to STEM-students (Atadero et al., 2018). Previous research shows that individuals in Western Europe evaluate, seek, or reject relationships with members of social outgroups based on the perception as beneficial (Stürmer & Benbow, 2017; Paolini, Harwood, & Rubin, 2010; van Dick et al., 2008). International studies on STEM-students' perception of cultural otherness highlight the need to prepare students appropriately for intercultural experiences (Bergman et al., 2023; Chédru & Delhoume, 2023) and record the naivety of unprepared STEM-students towards diversity (Atadero et al., 2018; Bergman et al., 2023; Maloshonok et al., 2022; Villanueva Alarcón et al., 2021). Students facing cultural otherness might also experience stress or threat related to their cultural orientation system not working or related to the social pressure to act politically correct (Chédru & Delhoume, 2023). At the same time, students with a migration background are facing open and hidden disadvantages (Koehler & Schneider, 2019; Miyamoto, 2018). However, little is known about how German students with a migration background and WIHTOUT-M perceive the issues of diversity and discrimination and how the STEM-education might address inclusion and utilization of diversity. To elaborate on diversity potentials for the education in STEM-subjects, the current study thus investigates the research question of how students with a migration background and WIHTOUT-M perceive educational barriers and diversity in the German STEM-education. This includes the following sub-questions:

- Are students aware of the cultural diversity in their social environment?
- What attitudes towards cultural diversity do students have?
- Are there barriers for students with a migration background?

3 Method

To answer the research question, we conducted a qualitative study by means of semi-structured interviews. The interviews were designed to provide a holistic picture of the subjective theories (Hilmer 1969) of students with students with a migration background and without a migration background students without a migration background towards cultural diversity and discrimination in the STEM-education context. The interview guideline contained a total of 47 both open questions and semantic differentials, plus questions for a possible specification of the answers. To ensure conceptual equivalence and comparability (Genkova 2019) across the subgroups, the final interview guideline was discussed by several experts on diversity with and without a migration background. The interviews took place from May to December 2019. Participants were approached on the premises of two colleges and universities. They were directly interviewed if they had been studying a STEM subject for more than one year. It was assumed that students must have spent some time at a university to be able to answer all relevant questions in a meaningful way. In the beginning, the participants were informed that the interviews would be recorded. In accordance with the applicable data protection guidelines, written consent was obtained that the anonymous recordings may be used for scientific purposes. The interviews were held in German language (all participants had a sufficient level of German) and took 20 to 60 minutes. Interviews were recorded and transcribed afterwards. The translated Interview-Guideline is attached to this submission.

We analyzed the transcribed interviews inductively using qualitative content analysis according to Mayring (2010). This method offers the advantage of remaining very close to the original statements and enabling a great depth of interpretation (Krippendorf 2004). Qualitative content analysis contains three steps, paraphrasing, generalizing, and categorizing. Paraphrasing involves restating the information or ideas from a source text in your own words while maintaining the original meaning. The goal is to express the content using different sentence structures and vocabulary. Generalizing involves identifying broader patterns or themes within the data or source text. It entails extracting the core concepts or ideas that are common across different instances or examples. Categorizing involves grouping similar ideas, concepts, or themes together based on their shared characteristics. It entails creating categories or codes that represent different aspects of the content being analyzed. Table 1 provides an example of the evaluation. The content analysis was conducted by the researcher

who also conducted the interviews. Subsequently, the formation of categories was discussed with three experts on diversity at universities to ensure better objectivity as a basis for interpretation (Bengtsson 2016).

Table 1. Example for paraphrasing, generalizing and categorizing an answer in the interview *(interviews have been conducted in German, this is a translation for exemplary purposes only and does not claim equivalence to the original content)*

Step	Interview content
Question	What do you personally understand by diversity?
Answer	And this refers to people, not Smarties? (laughs) Yes, so different character traits, different worldviews.
Paraphrasing	Different character traits and worldviews
Generalizing	Heterogeneity of Character traits, world views
Categorizing	Character, Perspectives

90 students in Osnabrück and Munich participated in the interviews. 16 of them belonged to the University [blinded for peer review] and 15 to the University [blinded for peer review]. Two belonged to the [blinded for peer-review] and 57 to the [blinded for peer-review]. The participants are on average 24 years old. 50 of the participants are male whereas 40 are female. 59 bachelor and 31 master students who studied a STEM subject from the third semester onwards were surveyed. 42 students had a migration background and 48 did not. In addition, 18 of the participants are first-generation migrants, the others are second-generation migrants.

4 Results

We tested the research question how students with a migration background and students without a migration background perceive diversity. More specifically, we focused on the ways cultural heterogeneity was utilized and included. To enable a thorough comprehension of the latent subjective theories of cultural diversity we analyzed two different sources of information: the interview transcripts and the derived categories.

4.1 Are students aware of the cultural diversity in their social environment?

To answer the first research question, are students aware of the cultural diversity in their environment, we examined several different aspects related to diversity. We addressed the general concept of diversity, its impact, and possible ways to approach it. The results showed that diversity was a topic of minor importance for the surveyed students. Even though most participant statements created the general impression that diversity is of huge relevance, many respondents expressed hesitation, and three explicitly stated that they did not have even a vague idea. Overall, multiple categories were enumerated, but mostly by individual respondents who listed a large number of terms. It was a common practice to mention only one term, such as biodiversity or diversity of character traits. This points to the vast unfamiliarity with the topic prior to that.

To identify the relative significance of specific diversity characteristics, we posed the following closed-ended question: "Which of the following characteristics do you consider important for diversity? Rate their importance on a scale of 1 (not important) to 7 (very important)." We observed that assigning a particular connotation to attributes such as age, gender, disability, religion/worldview, and 'race'/ethnic origin dismayed some students. Only the category 'race'/ethnic origin was evaluated differently by students with a migration background in comparison to students without a migration background. It received a higher rating overall. Subsequent parts of the interview covered the topic of the biased treatment of women in STEM fields. Nevertheless, this unfavorable practice was not evident in the assessment of the gender category: no difference was found between male and female participants.

students with a migration background and students without a migration background responded differently to the first question. There was no differentiation between first-and second-generation immigrants though. With the exception of one student, all students with a migration background mentioned terms like origin, cultures, or 'race', but felt clueless and could not provide further clarifications. students with a migration background and students without a migration background gave conceptually different answers about the elaboration on diversity in society. The opinion of almost all students without a migration background was that substantial efforts to a satisfactory degree were made for the topic of diversity in society (an example was the special access to the cafeteria building for people with disabilities). In sum, students without a migration backgrounds' answers created the impression of an oversimplified view on diversity in their environment. Participants who had a bare notion only avoided the topic more often and made more jokes and excuses during the interviews. Thereby, some interviewees were more conscious of the political relevance of the topic than of

the topic itself ("...But there are simple rules here, to which you have to stick!"). students without a migration background were convinced of the importance of diversity for society. The main reason for this was that participants felt insecure rather than interested or engaged.

Among students with a migration background, only 14 % believed that people paid enough attention to diversity, while 55 % explicitly expressed the view that cultural diversity in particular, was not given due consideration in society. Participants, however, were unable to provide clear reasons for the lack of sufficient concern for diversity. Just as students without a migration background displayed unawareness and insecurity, students with a migration background's awareness was limited by vague ideas rather than concrete knowledge about political or social issues. Furthermore, we observed that students with a migration background noticed differences between social classes, while for students without a migration background this was not a relevant criterion.

4.2 What attitudes towards cultural diversity do students have?

The answer to research question two, about attitudes towards cultural diversity, comprised the following interview questions : How is the impact of extensive diversity perceived in society? And how is it perceived in a university or within a workgroup? Additionally, the study investigated the students' perspectives on the appropriate approaches to of diversity and what they would recommend to a friend when dealing with diversity.

When asked "Do you perceive the impact of extensive diversity in society as positive or negative?" 25 % of the students responded that it is limited to negative. In contrast, 10% of the students with a migration background and 30% students without a migration background state that one should hide or ignore one's distinct cultural characteristics. The students with a migration background justify this attitude by disregarding cultural differences or trivializing them at the expense of their individual competence. For the question "In your opinion, does extensive diversity within a work or study group have a positive or negative impact on the group's outcomes?", it was expected that students would provide competent answers, as they regularly have practical experience in this context. It was found that the majority of responses were positive or tended to be positive. One-third of the participants, however, believed that a condition has to be met for diversity to be beneficial for group outcomes: there must be good communication.

This view was predominant among those who initially had only vague notions of the concept of diversity. One students with a migration background explicitly stated that he considered cultural differences to be nonsense but acknowledged that "there are a few values that one must adhere to here...". Some of the participants seemed to agree with this view and implicitly or explicitly challenged the value of diversity, despite initially being only partially aware of this issue.

students with a migration background demonstrated a more open-minded view and reported more positive attitudes towards cultural diversity. At the same time, they also enumerated various problematic issues such as language barriers, acculturation issues, and the difficulties of unfamiliar environments. Appreciation of diversity was positively related to mindfulness towards cultural differences and the resulting predicaments and opportunities. The participants displayed throughout the interview much doubt as to how to pertain to cultural diversity. Participants' insecurity was manifested in stress or evading reactions on the request of details about cultural diversity like e. g. the instrumental benefit of diversity. Participants who were only remotely familiar with the concept of diversity, felt more insecure and tended to perceive diversity as problematic. This was even more the case if participants reported that they have a lot of knowledge of political correctness but a low understanding for diversity. None of the participants received any previous diversity training.

4.3 Are there barriers for students with a migration background?

To identify potential barriers for students with a migration background, we first probed social integration as to how they appraise themselves in comparison to their peers. . Subsequently, we assessed to what extent and how they differ from the surrounding environment with 14 brief questions. The categories encompassed various aspects such as behavior, language, leisure activities, living conditions, religion/worldview, caregiving responsibilities, place of residence, ethnic affiliation or nationality, migration experience/background, educational background, appearance, age, mental and physical abilities, as well as any other characteristics they found relevant. Analysis revealed that the most prominent categories were language and communication style, leisure activities, educational background, ethnic background, and migration background/experience. Language differences were characteristic specifically for first-generation migrants. Concerning leisure activities, nine participants highlighted their experience of migrating to Germany as a turning point and reported that leisure opportunities they encountered were divergent in comparison to their home countries. This resulted in a sense of disorientation on campus and there was a need for time to adapt to these new leisure activities.

Furthermore, participants were queried about the size of their social circles and their characteristic features. WITHOUTH-M reported more frequently having large friend circles, compared to students with a migration background. Additionally, students with a migration background emphasized that they shared cultural heritage with their friends, whereas students without a migration background primarily highlighted that they had common academic pursuits and leisure activities. Second-generation migrants consistently expressed that individuals with a migration background went through similar hurdles and perspectives in their social circles. In particular, this included dealing with the complexities between their parents' cultures and Germany. One participant summarized the reasons as follows: “more common topics and views of the world. Less insensitivity or discussions.”.

The following question to participants assessed whether they perceived that all students received equal treatment by instructors. Surprisingly, twenty individuals responded negatively. Among them, three female participants expressed experiencing differential treatment or preferential treatment because of their gender. However, no supporting evidence of racist or sexist discrimination by instructors was provided. Regarding the question of whether their own cultural characteristics are perceived more as an advantage or disadvantage, 35% students with a migration background answered that they rather reckon their migration background a weakness. The main causes of this opinion were the physical appearance or the foreign name, four of them simply mentioned the migration background in general as a cause . Returning to the question of whether participants supported the display of their own cultural peculiarities, some individuals declared that their migration background gave rise to relatively low self-confidence. However, migrant participants who have stated that one should follow an assimilation strategy and renounce their own cultural characteristics showed bigger peer groups, mostly comprised of students without a migration background.

Regarding experiences of discrimination, there were differences in the answers between the cities. Students in Osnabrück do not report a single instance of discriminatory behavior on the part of lecturers or the university management. In Munich, twenty percent of students with a migration background reported that foreign students are generally discriminated against and that they have been subject to discriminatory behavior themselves (being ignored and receiving worse grades than others). Usually it was lecturers (white, male, older) who were convicted of discriminatory tendencies. Students though also committed this behavior.

Structural aspects of disadvantages did not seem to greatly affect in participants’ life. Most participants who migrated stated that they had problems with orientation. However, nearly all of them were aware that re-orientation is a natural process after moving to another culture and did not report extensive stress due to acculturation. Despite having sporadically strenuous interpersonal issues, most participants appreciated university organizations in Germany. They stated that they had access to all valid information and bureaucratic processes mostly do not last too long. In contrast, none of the participants received organized support for integration apart from German language courses. Furthermore, no knowledge about opportunities at the university or in general was, provided.

5 Discussion

In summary, the majority of participants demonstrated a limited or a simplified understanding of the concept of diversity. students with a migration background showed a greater awareness of the importance of their own cultural background. While the level of identification with their heritage culture varied, students with a migration background generally perceived themselves as distinct from others. Some students with a migration background had experienced discrimination before and many were aware of their vulnerability compared to others. However, most of them struggled to identify concrete options for promoting fairness in society or the university context. On the other hand, students without a migration background did not perceive their social environment as particularly diverse. They recognized the importance of cultural diversity for the future, but did not perceive any problems as long as they don’t get confronted with otherness personally. Nevertheless, their lack of understanding became evident when discussing specific dimensions of diversity, causing stress and a tendency to overlook the topic's importance and practical implications.

Students with a migration background appeared to be less socially integrated on average. Some attributed this to feeling different from the majority. The perception of discrimination was prevalent among a portion of the interviewees, as described by Blasco and Paunova (2018). Awareness of belonging to a stereotyped group, according to Massey and Fischer (2005), can lead to a decrease in individual performance and a heightened susceptibility to stereotype threat. This aligns with the finding that students who were more aware of their differences, perceived their migration background as a disadvantage.

Two coping strategies were observed among students with a migration background. While the majority tended to embrace their cultural characteristics, some believed that hiding their cultural attributes would

facilitate success in the host culture, similar to Berry's (1980) concept of assimilation. The perception that diversity had no or a negative impact on their performance played a central role in this strategy. As a result, they adopted a skeptical or avoiding attitude towards cultural diversity, in general, which supports previous studies on diversity management suggesting that negative beliefs about the effectiveness of diversity increase identification with one's own subgroup (van Knippenberg et al., 2004; Wang et al., 2019). In contrast, other participants had grown accustomed to feeling less included and tried to make the best of their situation through integration. While sensitive to discrimination in their social environment, none of the participants had a scientific understanding of diversity. Consequently, they showed little or no reflection on their situation at the university or possible ways to address it. Problems or challenges related to diversity were perceived as "off-topic" issues that might hinder their studies. This could be attributed to the lack of inclusion of cultural diversity topics in the STEM curriculum (Koller & Rudolph, 2017). Structural disadvantages described by Auferkorte-Michaelis and Linde (2018) or Koehler and Schneider (2019) did not seem relevant to the experiences of the participants in the current study. While students acknowledged the challenges of cultural adaptation and reorientation, most were able to cope individually, challenging the arguments put forth by Jungbauer-Gans and Gottburgsen (2021). However, the participants' perception of few disadvantages does not negate the need for systematic support, as low sensitivity and intercultural interaction competence in the social environment could indirectly impact academic performance by limiting access to social resources.

The current study has some limitations. Due to the small sample, representativeness cannot be assumed. By applying a structured interview guideline, the range of possible answers of the respondents was limited. Moreover, it is questionable whether results can be transferred to other subject areas, as relevant training is much more widespread there. While no differences between men and women appeared in the interview, their specific points of view have not been considered in the current study.

6 Conclusion

The current results contribute to the discussion about implementing diversity in STEM-education (comprehensively described by Atadero et al., 2018) by providing insights in the existing lack of sensitivity and knowledge about diversity among German STEM-students. We could show the tendency to neglect diversity among students with a migration background and students without a migration background that is connected to this unawareness. Simultaneously, the study reveals the challenges faced by students with a migration background, such as difficulties in cultural adaptation and a hesitant or even hostile attitude towards heterogeneity in their social environment. Given students without a migration background appear largely insensitive to diversity, it is essential to establish a positive and inclusive diversity culture among university lecturers and students as a key objective in STEM education. Moreover, there is a need for systematic diversity education within the STEM field. Although STEM is highly culturally diverse and internationalized, only a minority of students receive structured education to develop intercultural attitudes and competencies. This lack of adequate education poses a risk of problematizing and avoiding diversity. The results show that its vitally important to provide at least some orientation on the nature and effects of culture, interculturality and discrimination.. International studies could already demonstrate the effectiveness of interventions or trainings on diversity sensitivity or competences in STEM-education (Bergman et al., 2023; Chédru & Delhoume, 2023; Schäfer, 2006). Future studies should investigate the effectiveness of different forms of diversity education in fostering inclusive attitudes and reducing othering among STEM students, ideally through comparisons with other academic disciplines.

7 Ethics declaration

Ethical clearance for this study was waived in line with regulations of the conducting organization. Data was collected anonymously. Participants gave informed consent prior to participation in this study.

8 AI declaration

No generative AI technology was used in conduction the study or writing the manuscript.

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A Country's Innovativeness as a Determinant of Income Convergence

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Abstract
Disproportion in the level of economic development is more of a historical fact than a recent phenomenon. The empirical analysis in this study, based on ten selected countries, six of which are the high-income and innovation leaders and four middle-income countries (of which one is the regional innovation leader), shows that in the last decades, the income gap has increased in absolute terms while decreasing slightly in relative terms. The income gap (absolute) increased less for middle-income countries ranked as more innovative. This study investigates whether the difference in knowledge becomes a more relevant determinant of income convergence than capital growth. This study's empirical analysis is based on two samples. To evaluate the impact of innovations on economic growth and income convergence, we used a sample of ten economies, which were grouped into two categories (high-income and middle-income), and compared their average income over time. It spans the period from 2004 to 2023. The income gap between the two groups of countries has increased from 41,330 (constant 2015 US$) in 2004 to 49,989 (constant 2015 US$) in 2023. If we compare individual middle-income countries with a group of high-income countries, we see that the gap has increased less in those more innovative. The analysis also shows a strong positive relationship between the average value of four Global Innovation Index components (Human capital and research, Business sophistication, Knowledge and technology outputs, and Creative outputs) and GERD per capita. Based on an evidenced positive relationship between innovativeness and expenditures for R&D, we estimated aggregate production function on a sample of 35 European economies from 2000 to 2023 (annual data). Estimation shows that gross fixed capital formation growth of 1% leads to output growth of 0.32%. Employment growth leads to output growth of 0.214% and R&D investment growth of 0.157%. Growth in other exogenous factors (TFP) contributes to output growth by 0.02%. The estimation results show a highly positive impact of expenditures on R&D on economic growth. The country's educational outcomes strongly determine research and innovative activities, especially regarding science education. Observing the strong relevance of the expenditures for R&D and the innovative potentials for economic growth, what are the options if a country cannot provide innovative growth internally? Technology transfer is one possibility, therefore, less innovative countries should encourage and support technology transfers through FDI or other forms to narrow the knowledge and income gap if they cannot increase R&D investments.

Keywords: Income convergence, Innovativeness, GERD, Technology transfer

Paper type: Academic Research Paper

1 Introduction

Disproportion in the level of economic development is a more historical fact than a recent phenomenon. Historically, most countries still have a development gap compared to developed economies. Although the gap diminished in some parts of the world in the second half of the 20th century, such as Southeast Asia and China, European middle-income countries, despite higher rates of economic growth at the beginning of the 21st century, have an income that is, on average, 4.6 times lower than that in developed European countries (Popov & Jomo, 2018).

Solow's model implies that the rate of return on capital is lower in countries with more capital per worker; thus, there is an incentive for capital to flow from rich to poor countries, which will also tend to cause convergence. In addition, if there are lags in the diffusion of knowledge, income differences can arise because some countries do not yet employ the best available technologies (Romer, 2001). This study investigates whether the difference in knowledge becomes a more relevant determinant of income convergence than capital growth. Knowledge accumulation (expansion of scientific and technical expertise) has been widely seen as an essential factor of economic development through its impact on labor productivity and other production inputs. According to Powell and Snellman (2004), the key component of a knowledge economy is a greater reliance on intellectual capabilities than on physical inputs or natural resources.

Alcidi et al. (2018) show that in the EU, overall income convergence has taken place over the last 15 years at both regional and country levels in terms of higher growth of the poorest (beta-convergence) as well as reducing differences in GDP per capita (sigma-convergence). Central and Eastern countries lead the convergence process, while Southern regions have systematically underperformed relatively to the EU average, further deteriorating their relative position and diverging to the bottom. On the other hand, country aggregates hide different

patterns at the regional level. This is the case in Central and Eastern European countries, where capitals accelerate the convergence process while the rest of the country lags behind.

The empirical analysis in this study, based on ten selected countries, of which six are the high-income and innovation leaders and four middle-income countries (of which one is the regional innovations leader), shows that in the last decades, the income gap has increased in absolute terms (income is measured as GDP per capita in constant US$) while decreasing slightly in relative terms (share of middle-income countries in GDP of high-income countries).[1] The income gap increased less for middle-income countries ranked as more innovative, while less innovative countries struggle to reduce the income gap despite significant investments in fixed assets.

Why do middle-income countries progress slowly in terms of their innovativeness? Moreover, how can they catch up with more innovative countries?

Innovations are essential to economic growth through their impact on labor productivity and other production inputs. Empirical evidence shows the value of intellectual property in creating economic growth, enhancing productivity and profitability, and increasing enterprise value.

R&D investments were seen as the most crucial determinant of the country's innovativeness and are significantly higher in developed countries than in most middle-income countries (China is an example of an exception to this rule, with high investment in R&D and the value of innovation index). However, R&D investments are not determined only by financial resources. The human capital of the country is also significant. The share of STEM graduates is positively associated with R&D expenditures, meaning that to increase R&D activities and innovativeness, the country also needs adequate human capital (Baćović et al., 2022).

What are the options if a country cannot provide innovative growth internally? Technology transfer is one possibility. UNCTAD (2004) reported that many developed countries have adopted measures that directly or indirectly facilitate technology transfer. These measures include financing support, training, matching services, partnerships and alliances, and equipment purchase or licensing support. Technology transfer through FDI is also commonly seen as a good path to increase innovativeness. Phi et al. (2024) analysed the effects of FDI in Vietnam in transferring technology. They showed that FDI positively contributed to technology development, stimulating innovation in science and technology applications while improving competitiveness for domestic enterprises. They also emphasize that, due to the need for R&D activities and management capabilities, there are numerous difficulties in applying and transferring technology to the country. Najabat et al. (2023) show that FDI has positively impacted technological innovations in BRICS countries.

This study aims to investigate possible causes of income divergence between high and medium-income economies and suggest potential solutions to reverse the trend. Therefore, we will examine trends in income and innovativeness in selected countries. Also, to estimate the impact of investment in R&D on income growth, we will calculate production function on a sample of 35 European economies and the period from 2000 to 2023 (panel data). To investigate variations between innovativeness and income, we will examine the relationship between selected components of the Global innovation index produced by WIPO and GDP per capita.

The study has four sections. After the introduction, the most relevant findings from the literature are presented in the second section. In the third section, we offer empirical analysis, followed by a discussion and a conclusion in the fourth section.

2 Literature review

Literature on the relevance of research and innovation is vast, providing much evidence of the positive impact of knowledge growth on economic prosperity. Kaur and Singh (2016) studied the effect of knowledge on an economic level and economic growth across 42 selected developing economies. They found a positive correlation between the knowledge economy index and economic level, but there is a very weak marginal effect of the knowledge economy on economic growth. Barkhordari, Fattahi, and Azimi (2019) studied the empirical relationship between the knowledge-based economy and economic growth in MENA countries and found that institutions, human capital, research, infrastructure, and business sophistication are the pillars of the knowledge-based economy that influence a significant and positive economic growth. Pece et al. (2015) analysed if the long-term economic growth is influenced by the innovation potential of an economy for Poland, the Czech Republic, and Hungary and provided evidence of a positive relationship between economic growth and innovation. Maradana et al. (2017) examined the long-run relationship between innovation and per capita

[1] *The terminology of* convergence *— understood to mean declining dispersion in per capita incomes across countries — and catch-up — understood to mean increases in average incomes relative to the developed countries — can be helpful in distinguishing between these two concepts, particularly when ostensibly similar measures move in opposite directions. (The World Bank blogs: Convergence or Catch-Up? Aart Kraay, February 28, 2023)*

economic growth in 19 European countries over the period 1989–2014. Using the cointegration technique, the study finds evidence of a long-run relationship between innovation and per capita economic growth.

3 The empirical analysis

2.1 Data and sample

This study's empirical analysis is based on two samples. To estimate aggregate production function, we used a sample of 35 European economies from 2000 to 2023 (annual data)1. To evaluate the impact of innovations on economic growth and income convergence, we used a sample of ten economies, three of which are leading European economies in innovativeness (Switzerland, Sweden, and the United Kingdom), three leading Asian economies (Singapore, South Korea, and China), the United States of America, and middle-income European economies (Bulgaria, Montenegro, and Serbia). It spans the period from 2004 to 2023.

Data used in this study are presented in Table 1.

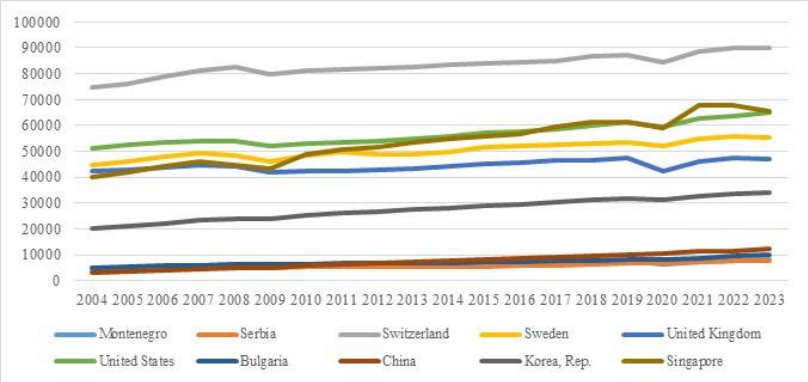
Table 1. List of variables

Indicator	Source	Data extracted
GERD per person, €	Eurostat, GERD by sector of performance [rd_e_gerdtot]	02/12/24
GERD, % GDP	Eurostat, GERD by sector of performance [rd_e_gerdtot]	02/12/24
GDP per capita, €	Eurostat, Main GDP aggregates per capita [nama_10_pc__custom_14327640]	06/12/24
GDP per capita, constant 2015 US$	WDI (World Bank national accounts data and OECD National Accounts data files)	10/12/24
Gross domestic product at market prices, Current prices, million euro	Eurostat, GDP and main components (output, expenditure and income) [nama_10_gdp__custom_14378735]	11/12/24
Gross fixed capital formation, Current prices, million euro	Eurostat, GDP and main components (output, expenditure and income) [nama_10_gdp__custom_14378775]	11/12/24
Total employment (resident population concept - LFS), Thousand persons	Eurostat, Employment and activity by sex and age - annual data [lfsi_emp_a__custom_14379674]	11/12/24
Employment to population ratio, 15+, total (%) (national estimate)	WDI, International Labour Organization	11/12/24
Global Innovation Index 2023	WIPO	10/12/24

Source: Author's compilation

3.1 Income divergence

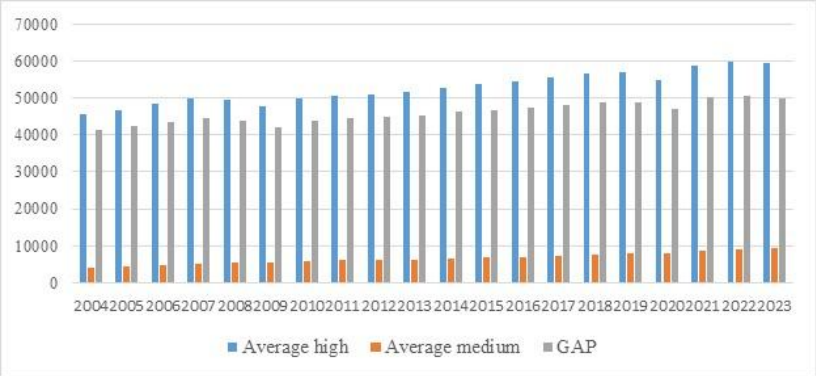
We grouped ten countries from the sample into two categories (high-income and middle-income) and compared their average income over time. Switzerland, Sweden, the United Kingdom, the United States, Singapore, and South Korea are high-income countries that are also highly innovative. China, Bulgaria, Montenegro, and Serbia are middle-income countries, and China's innovation index is significantly higher than the other three countries. The income level of individual countries is presented in Graph 1.



Graph 1. GDP per capita (constant 2015 US$), ten economies, 2004-2023
Source: WDI database

[1] *Dataset is available on request*

The income gap between the two groups of countries has increased from 41,330 (constant 2015 US$) in 2004 to 49,989 (constant 2015 US$) in 2023 (Graph 2). If we compare individual middle-income countries with a group of high-income countries, we see that the gap has increased less in those more innovative. In China, the gap has increased by 11%, in Bulgaria by 22%, but in Montenegro and Serbia by 25%.



Graph 2. The average income of groups of high-income and middle-income countries and the income gap
Source: Author's computation based on the WDI database

3.2 Country's innovativeness and investment in R&D

We analyze the relationship between the country's innovativeness and economic development measured with GDP per capita, using data on investment in R&D measured with GERD per capita and components of the Global Innovation Index 2023 produced by WIPO (Human capital and research, Business sophistication, Knowledge and technology outputs, Creative outputs). Table 2. presents the average values of four components of the GII (2023), investment in R&D measured with GERD and economic development level measured with GDP per capita for ten selected economies.

Statistics show that the innovative capacities of high-income economies are significantly higher than those of middle-income economies in all areas (except in China, which is considerably more innovative than other middle-income economies in the group). Montenegro has the lowest score in knowledge and technology outputs, while Serbia has the lowest value of the creative outputs indicator.

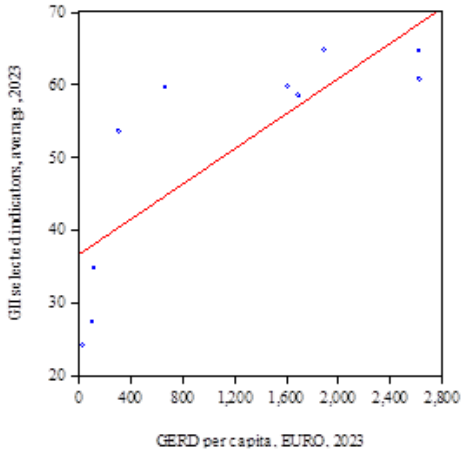
Table 2. Components of the GII, GERD, and GDP per capita, Selected Economies, 2023.

	Human capital and	Business sophisticati	Knowledge and	Creative outputs	Average	GERD per capita 2023*	GERD, % GDP,	GDP per capita, 2023 (constant	GDP per capita, 2023 (€ market
Switzerland	59.8	65.5	65.3	68.2	64.7	2622.0	2.26	89,942	92,760
Sweden	62.7	75.8	63.4	57.3	64.8	1891.0	3.57	55,521	51,020
United Kingdom	58.9	58.4	61.4	60.0	59.7	665.0	2.90	47,005	45,191
Singapore	63.2	69.4	55.3	46.0	58.5	1692.6	2.16	65,422	78,362
Republic of Korea	66.9	60.9	53.3	58.2	59.8	1606.0	4.85	34,121	30,630
China	49.8	54.1	61.5	48.9	53.6	308.0	2.56	12,174	11,652
United States	56.5	69.9	63.7	53.0	60.8	2628.0	3.59	65,020	75,551
Bulgaria	31.1	36.0	33.9	38.2	34.8	116.3	0.79	9,779	14,690
Montenegro	32.4	28.1	18.8	17.2	24.1	28.9	0.36	8,375	11,000
Serbia	34.7	27.8	31.4	15.6	27.4	99.4	0.88	7,736	11,350

Notes:
**or the latest available data (Switzerland - 2021; UK, Montenegro - 2019, South Korea, China, USA - 2022, Singapore - estimate)*
*** or the latest available data (Singapore - 2020, Switzerland - 2021, UK - 2021-Unesco, South Korea, China, USA - 2022, Montenegro - 2019)*
**** data for UK, USA, Singapore, South Korea, China were converted from USD (USD=0.9248 EURO exchange rate)*

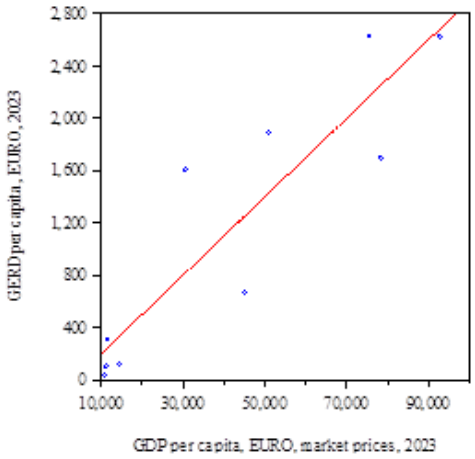
Source of data: GERD per capita, GERD, % of GDP - Eurostat (GERD by sector of performance [rd_e_gerdtot]); GDP per capita - Eurostat (Main GDP aggregates per capita [nama_10_pc__custom_14299138]); Global Innovation Index 2023

The empirical analysis shows a strong positive relationship between the average value of four GII indicators and GERD per capita (Graph 3).



Graph 3. The relationship between GII and GERD per capita components, ten countries, 2023.

The empirical analysis shows a strong positive relationship between economic development level measured with GDP per capita and GERD per capita (Graph 4).



Graph 4. The relationship between GDP per capita and GERD per capita, ten countries, 2023.
Source of data: Eurostat

3.3 Production function

In this study, the aggregate production of an economy is a function of gross fixed capital formation, labor, gross domestic expenditures on R&D (GERD), and total factor productivity (TFP):

$$Y_t = A_t K_t^{\alpha} L_t^{\beta} R_t^{\gamma}, 0 < \alpha + \beta + \gamma < 1\,, \qquad (1)$$

Yt represents the economy's output at time *t*, A_t is TFP, and K_t, Lt and $R_t$represent capital stock, labor, and gross domestic expenditures on R&D (GERD), respectively. The constants *α, β*, and γ represent the capital, labor, and R&D share in income, respectively.

After taking natural logs, the following equation is obtained:

$$LY_t = c + \alpha LK_t + \beta LL_t + \gamma LR_t + \varepsilon_t, \qquad (2)$$

Where *c* is the intercept, *α*, *β*, and γ are constant elasticities, and ε_t is the error term.

The aggregate production function was estimated in 35 European countries from 2000 to 2023 (the panel OLS (fixed effects) model). The estimated results are presented in Table 3.

Table 3. Panel Least Square (fixed effects), equation (2)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Gross fixed capital formation growth	0.325525	0.015682	20.75843	0.0000
Employment growth	0.214727	0.064592	3.324366	0.0009
Gross domestic expenditures on R&D growth	0.157642	0.018040	8.738536	0.0000
C	0.021959	0.001904	11.53101	0.0000
R-squared	0.618805	Durbin-Watson stat		1.909748

Source: Authors' calculation

All exogenous variables defined in Equation (2) positively impact output growth. A growth in gross fixed capital formation of 1% leads to output growth of 0.32%. Employment growth leads to output growth of 0.214% and R&D investment growth of 0.157%. Growth in other exogenous factors (TFP) contributes to output growth by 0.02%.

4 Discussion and conclusion

Disproportion in the level of economic development is a more historical fact than a recent phenomenon. Historically, most countries still have a development gap compared to developed economies. The empirical analysis in this study shows that in the last decades, the income gap between the most innovative high-income countries and middle-income countries has increased in absolute terms (income is measured as GDP per capita in constant US$) while decreasing slightly in relative terms (share of middle-income countries in GDP of high-income countries). The income gap increased less for middle-income countries ranked as more innovative, while less innovative countries struggle to reduce the income gap despite significant investments in fixed assets. This study investigated whether the difference in knowledge becomes a more relevant determinant of income convergence than capital growth.

Knowledge accumulation (expansion of scientific and technical knowledge) has been widely seen as an essential factor of economic growth through its impact on labor productivity and other production inputs. According to Powell and Snellman (2004), the key component of a knowledge economy is a greater reliance on intellectual capabilities than on physical inputs or natural resources. The country's educational outcomes strongly determine research and innovative activities, especially regarding science education. The study by Baćović and Milović (2024) investigated possible causes of declining innovativeness in Europe. Their analysis shows that expenditures for R&D and education in STEM programs are essential determinants of the country's innovativeness.

This study's empirical analysis shows that the innovative capacities of high-income economies are significantly higher than those of middle-income economies in all areas (except in China, which is considerably more innovative than other middle-income economies in the group). The analysis also shows a strong positive relationship between the average value of four GII (The Global Innovation Index) indicators and GERD per capita. The estimated production function on the sample of 35 economies (panel data) shows a highly positive impact of expenditures on R&D on economic growth.

The European Commission – Joint Research Centre's EU Industrial R&D Investment scoreboard for 2024 shows that leading investors (top ten) originate from the USA, China, Japan, Switzerland, South Korea, the UK, Taiwan, India, Canada, and Israel. Those are also highly innovative countries. The less innovative countries do not catch up in investment in R&D or innovations, widening the income gap compared to high-income countries.

Observing the strong relevance of the expenditures for R&D and the innovative potentials for economic growth, what are the options if a country cannot provide innovative growth internally? Technology transfer is one possibility. UNCTAD (2004) reported that many developed countries have adopted measures that directly or indirectly facilitate technology transfer. These measures include financing support, training, matching services, partnerships and alliances, and equipment purchase or licensing support. Technology transfer through FDI is also commonly seen as a good path to increase innovativeness. Karagiannis (2007) shows that R&D expenditure originating from abroad affects GDP growth rates significantly and positively, as do human capital, educational characteristics, and investments in Information and Communication Technology (ICT). Therefore, less innovative countries should encourage and support technology transfers through FDI or other forms to narrow the knowledge and income gap if they cannot increase R&D investments.

Ethics declaration

The ethical clearance for the research in this paper was not needed.

AI declaration

AI tools were not used in the development of this paper.

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Towards a Unified Framework for Knowledge Worker Roles: A Systematic Literature Review

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Abstract

This study tackles the absence of a unified framework for categorizing knowledge workers, a gap that constrains effective management and strategic alignment in knowledge-driven organizations. While these workers are central to innovation and value creation, existing definitions and taxonomies remain inconsistent and fragmented.

A systematic literature review of 26 peer-reviewed articles from Scopus and Web of Science was conducted. The study applied structured keyword searches and inclusion criteria to identify thematic patterns, classification criteria, and conceptual models relevant to knowledge workers and their roles.

The analysis uncovers a broad set of classification dimensions, including task complexity, educational background, organizational roles, and engagement with knowledge processes. It introduces a typology of eleven functional roles—knowledge Handlers—anchored in how individuals create, apply, and transfer knowledge. The study also delineates ten core processes and thirteen activities integral to knowledge work. These findings reflect a shift from static categorizations toward dynamic, context-sensitive interpretations of knowledge workers' roles.

The scope is limited to published literature, which may omit practitioner insights and sector-specific nuances. The absence of empirical validation also constrains immediate practical application.

The synthesized framework offers a structured basis for human resource management, knowledge management, and leadership strategies, enabling more precise role alignment, task design, and integration with digital tools in diverse organizational settings.

By consolidating dispersed research into an integrative taxonomy, this study advances theory and practice in knowledge management. It provides a foundation for future empirical studies and supports the development of adaptive classification systems for managing knowledge-intensive roles.

Keywords: Knowledge workers, Categorization, Systematic literature review.

Paper type: Academic Research Paper

1 Introduction

Knowledge work involves converting information into actionable insights applicable across contexts, yielding tangible and intangible outcomes. These tasks are complex, non-repetitive, and lack predefined structures. Knowledge workers (KWs) use tools and frameworks to generate, share, or apply knowledge vital to problem-solving, innovation, and organizational success (Bosch-Sijtsema, et al., 2011);(Eugenia, 2024).

KWs are highly qualified professionals across fields like IT, law, education, and science, who transform specialized information to achieve organizational goals (Garcia, 2007). They combine deep expertise and broad knowledge to drive innovation, requiring strategic alignment with evolving goals and adaptive leadership (Mannucci & Yong, 2017); (Kaur, et al., 2019); (de Weerd, et al., 2024). As organizational growth increasingly depends on their contributions, KWs are key to sustaining innovation and managing change in dynamic environments (Carleton, 2011); (Regan, 2023).

The shift to a knowledge-based economy requires strategic adaptation, yet categorizing and aligning knowledge work with organizational needs remains difficult (Pricopoaia, et al., 2024). Inefficiencies like poor integration and manual processes hinder innovation, while vague definitions weaken HR strategies and task management (Robberts, et al., 2015); (Hannola, et al., 2018). Robust frameworks are essential for streamlining processes, enhancing agility, and enabling sustainable growth (Wang, et al., 2011); (Mortimore, et al., 2023).

The lack of a systematic categorization of KWs poses challenges for strategic workforce management, limiting the alignment of unique competencies with evolving demands. Despite extensive studies, the absence of a comprehensive framework restricts the adaptation of diverse skills to organizational goals (de Weerd, et al., 2024); (Molina, et al., 2024). Effective management requires tailored strategies that address autonomy, motivation, and lifelong learning, rather than uniform approaches (Eugenia, 2024). Leadership must recognize

diverse motivations to harness team strengths fully (Talajić, et al., 2024). Clarifying the categorization of intellectual capital is crucial for effective workforce strategies that support growth and innovation.

Developing a unified framework for categorizing knowledge work and workers requires understanding the principles that shape this domain. Without this, fragmented definitions overlook role complexity. Identifying core competencies, context, and collaboration supports an integrative model for managing KWs in dynamic settings. This study systematically reviews classifications, revealing themes, criteria, and gaps. It maps patterns to organizational needs and promotes incremental discovery over fixed schemes. It contributes to KM by advancing evidence-based categorization and offers insights to guide strategic decisions and future research.

2 Background

In the knowledge-based economy, KWs are vital for innovation and value creation, reflecting growing global demand for their expertise(Che, et al., 2021); (Han, et al., 2023). Despite their importance, classifications remain fragmented and contested across disciplines (Yau, 2003); (Wang, et al., 2011); (Heidary Dahooie & Ghezel Arsalan, 2012); (Surawski, 2019). Traditionally based on work nature and occupational role, these classifications now reflect diverse approaches and methodologies(Wang & Yan, 2010).

Knowledge work has been categorized based on task content, processes, and complexity (Wang, et al., 2011). Perrow's distinction between complex and routine tasks clarifies its cognitive demands (Cool & Belkin, 2002);(Corso, et al., 2006).

KWs are commonly classified by educational background, the breadth of expertise, and traits like creativity, independence, and problem-solving (Pyöriä, 2005); (Kelly, et al., 2011); (Prataksita, et al., 2023). A classification system identifies three primary criteria for KWs: knowledge stock, skills, and personal qualities, with specific attributes like academic background, innovation ability, and psychological traits(Wang & Yan, 2010). Another categorizes them by work content, personal traits, work style, and the centrality of knowledge in their roles (Han, et al., 2023).

Knowledge work is complex and multidimensional, yet existing definitions lack a unified perspective (Yau, 2003);(Wang, et al., 2011). The fragmented studies and the absence of an overarching framework hinder alignment with organizational goals across sectors (Franek & Grublova, 2011); (Wymbs, 2012). Static classifications further limit understanding of its dynamic and evolving roles (Pyöriä, 2005).

Despite extensive research, KWs remain inconsistently classified due to varying definitions, leading to unclear data on their prevalence and growth (El-Farr, 2009);(Surawski, 2019);(Nisula & Olander, 2023). A unified categorization is lacking, and a limited understanding of their roles, workflows, and skill development hinders effective classification and contribution enhancement (Garcia, 2007).

The fragmented definitions of knowledge work highlight the need for a unified framework (Cool & Belkin, 2002); (Wymbs, 2012). Studying its core properties and evolving complexities is essential to reflect its true nature (Wang, et al., 2011). Such a model would help organizations adapt and optimize processes through technology-driven solutions (Syed, 1998).

As knowledge-intensive roles grow more complex, a clear framework is needed to distinguish KWs and address their specific needs. Tailored categorizations improve workforce management, role alignment, and utilization (Wang & Yan, 2010);(Han, et al., 2023). Without it, inconsistent definitions will persist, fragmenting research and limiting cross-field application (El-Farr, 2009).

Research on knowledge work remains fragmented, lacking a unified, adaptable framework. Prior studies explored cognitive demands, skills, and motivations but failed to address role complexity. Synthesizing existing categorizations and core elements is crucial. This study sets the foundation for developing an integrated framework suited to varied contexts and organizational needs.

3 Methodology

This study analyzes 26 articles to examine how knowledge work and workers are categorized, identifying key themes and patterns. Using a systematic literature review (SLR), it applies defined research questions and keyword-based searches with consistent selection criteria. The SLR outlines initial categorizations and supports future research and practice. For this research, the following questions are explored:

- What frameworks and criteria define and classify knowledge work and workers?
- What are KWs' roles and responsibilities in managing organizational knowledge assets?

Keywords were selected to capture concepts related to KWs, knowledge work, and their classification, ensuring relevant studies were included. The selected keywords include: "knowledge work*" OR" knowledge job*"OR" knowledge worker*"OR" intellectual work*" OR" intellectual job*"OR" cognitive work*" OR" cognitive

job*"OR "knowledge-based work*" OR" knowledge-based job*" OR" knowledge-intensive work*" OR" knowledge-intensive job*"OR "knowledge occupation*" OR" knowledge-based occupation*"OR "knowledge employee*" OR" creative worker*" OR "expert worker "OR "knowledge professional "OR" knowledge duti*"OR" knowledge task". Additional keywords were included to refine the search and ensure a targeted focus on categorizing knowledge work and KWs. These terms include "categor*" OR "class*" OR "typolog*" OR "taxonom*" OR "segment*" OR "framework" OR "model*". This approach ensured a thorough search for pertinent articles.

A thorough search was conducted using Scopus and Web of Science, chosen for their relevance and access to quality scholarly sources. Figure 1 shows the exclusion criteria: peer-reviewed, English-language studies focused on knowledge work and KWs. The search had no date limits and concluded in late October 2024.

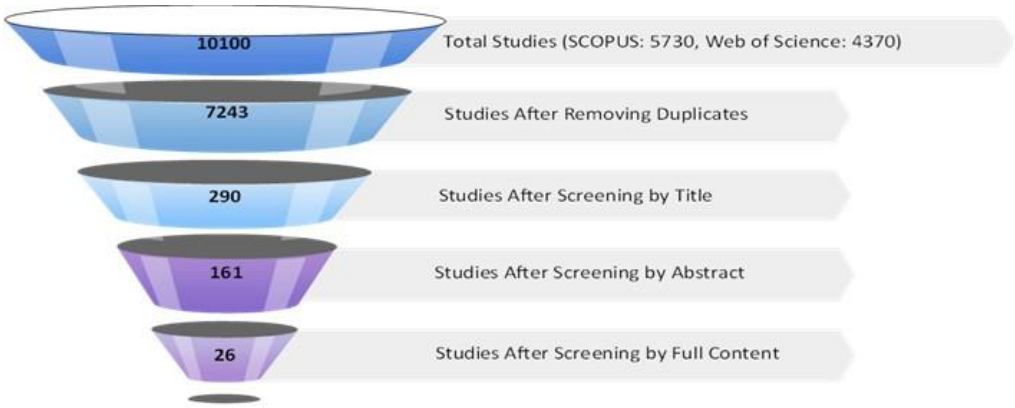


Figure 1. Article Screening Flow Overview

4 Results and Discussion

4.1. Overview of Selected Studies

4.1.1. The Progression of Publications Over the Years

The publication trend on the categorization of KWs and knowledge work, as shown in Figure 2, demonstrates a relatively stable trajectory over time.

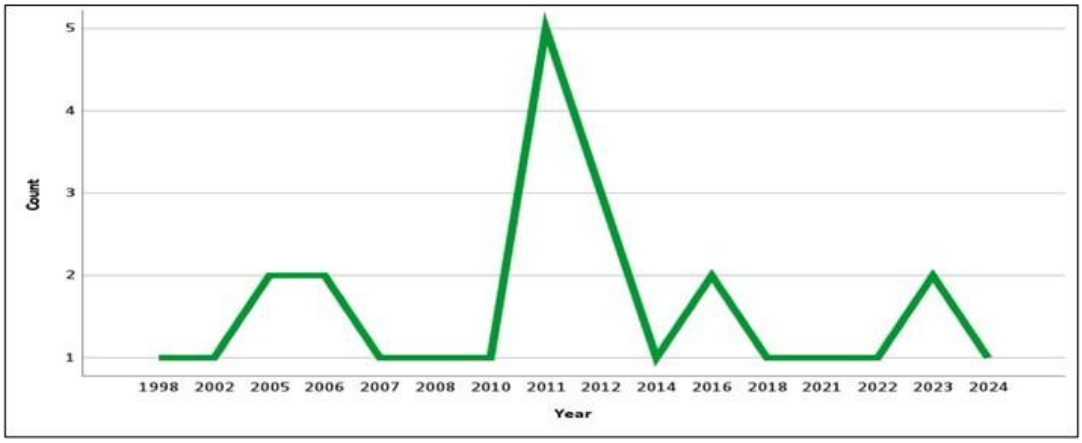


Figure 2. Trends in Research on the Categorization of KWs and their Work.

A significant peak in 2011 highlights a period of intensified academic interest, potentially linked to notable developments or challenges in the field. Research activity has remained steady but moderate, characterized by sporadic surges rather than continuous growth. This pattern suggests that, although the topic remains relevant, it has not consistently been a primary focus of scholarly attention outside of specific periods of heightened interest.

4.1.2. Analysis of Research in the Reviewed Papers: Types and Approaches Explored

As shown in Figure 3, the reviewed articles present a balanced methodological mix. Empirical studies (46.15%) dominate, followed by theoretical (30.77%), with mixed methods (15.38%) and reviews (7.69%) less common. Qualitative methods lead at 50%, while quantitative (30.77%) and mixed approaches (11.54%) are less used. This reflects a focus on real-world contexts but signals a need for more theoretical and integrative work.

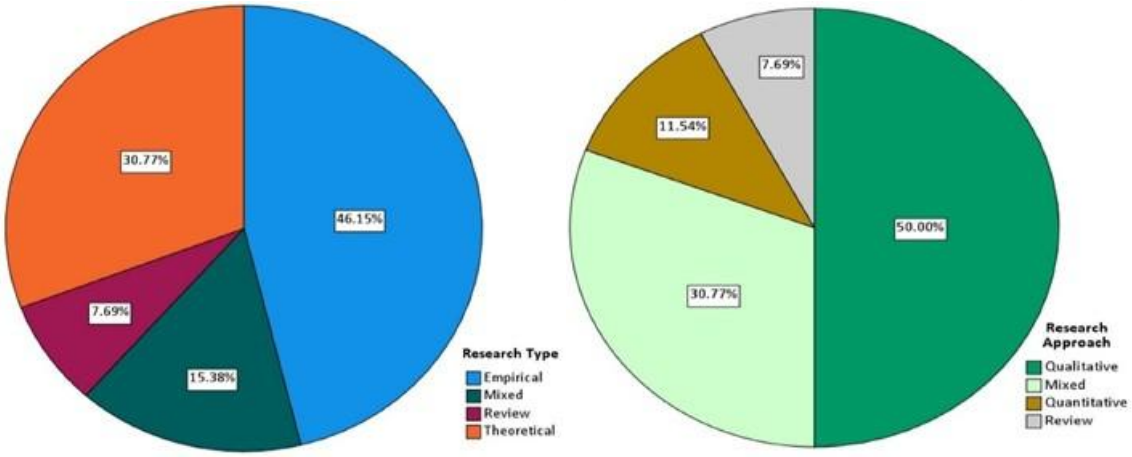


Figure 3. Types and Approaches of Reviewed Studies.

4.1.3. Assessment of Articles by Research Methodologies

As shown in Figure 4, the SLR reveals diverse methodological approaches. Mixed methods are most common (38.46%), followed by literature analysis and case studies (15.38% each). Surveys, reviews, and content analysis represent 7.69%, while ethnography and conceptual synthesis are the least used (3.85%). This indicates a preference for integrated approaches and highlights underused methods for future exploration.

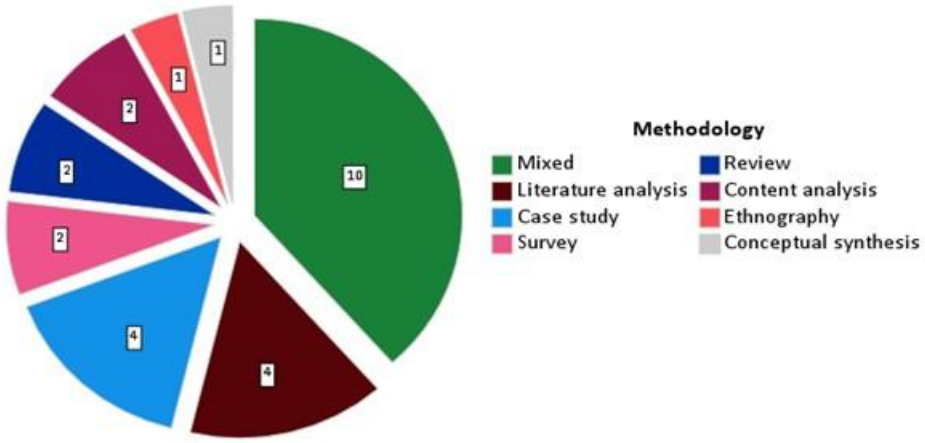


Figure 4. Methods of Research.

4.2. Exploring the Definitions and Categories of KWs, Their Work, and Associated Concepts

4.2.1. Criteria and Categories of Knowledge Work

Table 1 summarizes the dimensions of knowledge work, highlights the criteria used in the reviewed studies, and identifies categories.

Table 1. The Analyzed Research on Knowledge Work: Classification and Criteria.

Criterion	Description	Citations
Workflow Structure	Fully to weakly structured systems reflecting task management.	(Schwarz, 2005); (Scherp, et al., 2012).
KM Processes & Activities	Core processes: acquisition, transfer, sharing, transformation, and application.	(Reinhardt, et al., 2011); (Hannola, et al., 2018).
Base of Activities	Knowledge-based (analysis, creation) vs. communication-based (collaboration, coordination).	(Heidary Dahooie, et al., 2011).

Criterion	Description	Citations
Sequence of Activities	Ordered steps taken to meet goals or solve problems.	(Pan, et al., 2007).
Tasks	Defined by procedural clarity (analyzability) and variability.	(Corso, et al., 2006); (Robberts, et al., 2015).
Interaction with Information	Mode (recognition/specification), method (scanning/searching), goal (learning/selecting), and resource type.	(Cool & Belkin, 2002).
Information load	Variability (similar/diverse) and amount (small/large).	(Hashemian Bojnord & Afrazeh, 2006).
Types of Knowledge	Factual, conceptual, procedural, metacognitive, contextual, and operational knowledge dimensions.	(Salisbury, 2008); (Muhammed, et al., 2010).
Mediating Tools	Boundary and epistemic objects supporting localized, embedded, and invested knowledge for collaboration.	(Dionne & Carlile, 2024).
Collaborative Knowledge Systems	Communities emphasize tacit knowledge and shared understanding; Collectivities focus on goals and processes.	(Lindkvist, 2005).
Functionality	Purpose-driven: collection, connection, communication, criticism, and consumption.	(Iliescu, 2021).

4.2.2. Processes Involved in Knowledge Work

This study identifies six core, interconnected processes—acquisition, sharing, transfer, organization, application, and learning—central to the knowledge lifecycle. A *process* is a structured series of activities aimed at a specific goal, forming a consistent workflow. The following sections detail these processes, offering a framework for how knowledge is generated, disseminated, and applied in organizations:

- Knowledge Acquisition: Learning new knowledge from within or outside the organization (Watanabe & Benton, 2013).
- Knowledge Creation: Generating new ideas or solutions (Schwarz, 2005); (Salisbury, 2008).
- Knowledge Discovery: Uncovering new, previously unknown patterns, insights, or relationships within data using analytics or data mining techniques (Hannola, et al., 2018).
- Knowledge Retrieval: Accessing and locating relevant information through activities such as searching and reading documents (Schwarz, 2005).
- Knowledge Organization: Systematically structuring and storing knowledge into accessible and formalized structures to classify, archive, and preserve information (Schwarz, 2005); (Salisbury, 2008); (Watanabe & Benton, 2013).
- Knowledge Sharing: A bidirectional and collaborative process of distributing and communicating knowledge to enhance learning, problem-solving, and its broader application (Schwarz, 2005); (Salisbury, 2008); (Watanabe & Benton, 2013); (Hannola, et al., 2018).
- Knowledge Transfer: A unidirectional and purposeful process of moving knowledge between individuals, teams, or organizations to ensure understanding, usability, and practical application (Hannola, et al., 2018).
- Knowledge Application: Practical use of knowledge to perform tasks, solve problems, or improve workflows (Schwarz, 2005); (Salisbury, 2008).
- Knowledge Reuse: Leveraging previously created knowledge across different contexts.
- Knowledge Repurposing: Modifying or adapting knowledge assets to meet new requirements or address objectives in varying contexts (Salisbury, 2008).

4.2.3. Activities Associated with Knowledge Work

An *activity* is a specific action within a process that produces an output. Dissemination, networking, and sense-making are vital for creating, refining, and spreading knowledge. The following sections explain these activities, offering a systematic understanding of their role in knowledge work:

- Dissemination: Spreading information through tailored communication, product integration, and refined knowledge transfer to stakeholders(Syed, 1998);(Reinhardt, et al., 2011);(Widmann, et al., 2012);(Iliescu, 2021).
- Sense-Making: Cognitive Interpreting of information by recognizing patterns and implications to convert data into actionable insights(Syed, 1998);(Widmann, et al., 2012).
- Networking: Establishing relationships and interacting with people or organizations to leverage expertise, bridge knowledge gaps, and exchange information.

- Feedback: Critically assessing information, propositions, or objects to evaluate risks, identify inconsistencies, and provide constructive evaluations(Reinhardt, et al., 2011);(Iliescu, 2021).
- Refining: Adapting, filtering, improving, and experimenting with methods or approaches to align with contextual needs, tool limitations, and collaborative environments(Syed, 1998);(Dionne & Carlile, 2024).
- Modeling: Questioning existing methods, articulating their value, and aligning benefits across various approaches to sustain collaboration.
- Mapping: Identifying connections between knowledge elements, questioning feasibility across domains, and organizing combinations for later negotiation(Dionne & Carlile, 2024).
- Selection: Filtering and identifying relevant knowledge within internal resources by valuing and prioritizing key elements(Widmann, et al., 2012).
- Search: Retrieving specific resources, such as experts or specialized web services offering functions like translation or problem-solving.
- Authoring: Creating textual and media content, either individually or collaboratively, using software systems such as word processors or presentation tools.
- Analyzing: Examining and thinking about information carefully to understand and evaluate it thoroughly.
- Learning: Acquiring new knowledge, skills, or understanding during work execution or through formalized learning material.
- Monitoring: Keeping oneself or the organization updated about selected topics to ensure relevance and awareness(Reinhardt, et al., 2011).

4.2.4. Tasks Related to Knowledge Work

Knowledge work is classified into four types based on task analyzability and variability: routine (standardized), non-routine (creative), semi-routine (tacit knowledge-based), and complex routine (variable but analyzable) (Corso, et al., 2006). *Tasks* are the smallest goal-oriented units requiring critical thinking and specialized skills. Embedded in activities, they support KM by addressing specific objectives through methods that enhance clarity, organization, or problem-solving. Below is a breakdown of key tasks within knowledge-intensive environments:

- Information Discovery: Finding a (partially) known information object.
- Information Recognition: Recognizing useful information objects by scanning through an information resource.
- Information Evaluation: Evaluating the usefulness of information objects.
- Information Organization: Determining the content/structure of a set of information objects(Cool & Belkin, 2002).
- Collaboration: Collaborating with peers to share ideas, information, and feedback to achieve work goals.
- Communication: Communicating with employers, peers, clients, and suppliers to exchange updates and maintain alignment.
- Problem-solving: Solving problems by interacting and researching available online material.
- Time Management: Organizing and scheduling meetings to ensure efficient workflow(Robberts, et al., 2015).
- Resource Interaction: Accessing and interacting with company resources.
- Document Management: Creating and updating documents and reports.
- Work Management: Managing workflows efficiently through planning, resource allocation, and coordinating with others to ensure productivity(Heidary Dahooie, et al., 2011).

4.2.5. Criteria and Categories of KWs

KWs are categorized across multiple dimensions based on specific criteria highlighting their organizational roles, skills, and contributions. Table 2 provides an overview of these dimensions, detailing the requirements from the reviewed studies and the corresponding categories used to classify KWs.

Table 2. Criteria and Categories of KWs.

Criterion	Description	Citations
Education, Skills, and Abilities	Advanced education, diverse skills, and traits like creativity and autonomy.	(Kelly, et al., 2011);(Prataksita, et al., 2023).
Client Interaction and Revenue	Client relationship management and revenue generation.	(Wymbs, 2012).

Hierarchical Roles	Organizational roles from decision-makers to entry-level positions.	(Kelly, et al., 2011); (Wymbs, 2012).
Knowledge Engagement	Interacting with knowledge and participating in KM.	(Franek & Grublova, 2011); (Watanabe & Benton, 2013).
Task and Workflow Alignment	Creative versus operational tasks and alignment with workflows.	(Scherp, et al., 2012); (Mortimore, et al., 2023).
Connectivity and Interaction	Communication, mobility, and interaction patterns within and outside organizations.	(Greene & Myerson, 2011); (Geiger, et al., 2016); (Dionne & Carlile, 2024).
Organizational Integration	Integration of human expertise and algorithmic enhancements.	(Mortimore, et al., 2023)

KWs are distinguished by education—often advanced degrees or multidisciplinary qualification—and by skills, which may be specialist (domain-specific) or generalist (cross-disciplinary and managerial). Abilities like creativity, autonomy, and initiative enable innovation and task independence(Kelly, et al., 2011); (Prataksita, et al., 2023). KWs also differ by client interaction and revenue roles: finders drive new business, minders manage clients, and grinders offer task-based support (Wymbs, 2012). Organizational roles span decision-makers (finders), managers (minders), and entry-level staff (grinders), as well as functional types like bench scientists and expert generalists (Kelly, et al., 2011); (Wymbs, 2012). Engagement with explicit/tacit knowledge and time spent on KM further distinguish advocates, skeptics, busy people, and hopefuls (Franek & Grublova, 2011);(Watanabe & Benton, 2013). Task type and workflow alignment also matter: HKWs perform creative, cognitively demanding tasks; NHKWs execute predefined or computationally intensive ones (Scherp, et al., 2012); (Mortimore, et al., 2023). Workflows may be organizational (structured), individual (dynamic), or integrated (cross-functional). Connectivity and interaction behaviors define types such as Pragmatists, Bricoleurs, Passengers, and Maniacs, and mobility patterns further distinguish Anchors, Connectors, Gatherers, and Navigators (Greene & Myerson, 2011);(Geiger, et al., 2016);(Dionne & Carlile, 2024). Organizational integration balances human expertise and algorithmic support: HKWs contribute innovative solutions, while non-HKWs enhance efficiency through predefined tasks, from idea generation to applied knowledge (Mortimore, et al., 2023).

4.2.6. Knowledge Handlers' Roles

In organizations, a role refers to the responsibilities, behaviors, and expectations that guide task execution. This study identifies Knowledge Handlers (KHs) as individuals who manage knowledge through eleven key roles—detailed in Table 3—that support knowledge flow, decision-making, and workflow efficiency while addressing KM gaps and optimizing asset use.

Table 3. Knowledge Handlers' Roles.

KH Role	Role description	Citation
Knowledge Applier	Utilizes knowledge, resources, and expertise to achieve practical objectives.	(Schwarz, 2005); (Salisbury, 2008); (Franek & Grublova, 2011); (Heidary Dahooie, et al., 2011); (Watanabe & Benton, 2013).
Knowledge Creator	Develops innovative ideas, solutions, and systems.	(Schwarz, 2005); (Salisbury, 2008); (Franek & Grublova, 2011); (Heidary Dahooie, et al., 2011); (Widmann, et al., 2012); (Iliescu, 2021); (Mathieu, 2022); (Prataksita, et al., 2023).
Knowledge Evaluator	Evaluates knowledge quality based on accuracy, relevance, risk, and value.	(Cool & Belkin, 2002); (Iliescu, 2021).
Knowledge Facilitator	Maintains functional, accessible knowledge systems to support effective sharing.	(Lindkvist, 2005); (Greene & Myerson, 2011); (Widmann, et al., 2012); (Watanabe & Benton, 2013); (Mortimore, et al., 2023).
Knowledge Learner	Learns by applying knowledge to build skills and proficiency.	(Reinhardt, et al., 2011).
Knowledge Arranger	Structures and classifies data for efficient retrieval and use.	(Syed, 1998);; (Schwarz, 2005); (Salisbury, 2008); (Mathieu, 2022); (Mortimore, et al., 2023); (Dionne & Carlile, 2024).
Knowledge Protector	Safeguards knowledge through secure, durable storage and maintenance.	(Mathieu, 2022).
Knowledge Refiner	Refines information to suit specific needs and evolving demands.	(Salisbury, 2008); (Robberts, et al., 2015).

Knowledge Retriever	Retrieves relevant data from internal and external sources.	(Syed, 1998); (Cool & Belkin, 2002); (Schwarz, 2005); (Reinhardt, et al., 2011); (Widmann, et al., 2012); (Watanabe & Benton, 2013); (Robberts, et al., 2015); (Hannola, et al., 2018); (Iliescu, 2021).
Knowledge Sharer	Shares knowledge via platforms like repositories, email, and communities.	(Syed, 1998); (Salisbury, 2008); (Reinhardt, et al., 2011); (Hannola, et al., 2018); (Iliescu, 2021).
Knowledge Transferer	Transfers knowledge to ensure clarity and shared understanding.	(Syed, 1998); (Reinhardt, et al., 2011); (Widmann, et al., 2012); (Hannola, et al., 2018).

5 Conclusion

This study systematically examines the classifications and roles of KWs, addressing gaps and inconsistencies in the existing literature. By analyzing 26 key studies, it identifies recurring themes, emerging dimensions, and criteria that define knowledge work and its processes. The findings lay the groundwork for developing a comprehensive framework for categorizing KWs, emphasizing their diverse roles, skill sets, and organizational contributions. Critical dimensions such as task complexity, educational background, organizational integration, and evolving cognitive demands highlight the importance of KWs in driving innovation and competitiveness in knowledge-intensive settings. The next step can be to combine these different dimensions of analysis to detect and determine specific practical use situations in businesses and organizations.

While this research offers valuable contributions, it has certain limitations. Its reliance on existing literature introduces the potential for biases inherent in prior studies, and the limited dataset may not fully capture the spectrum of knowledge worker roles across different sectors. Furthermore, the absence of empirical validation restricts the practical application of the proposed framework.

Future research should synthesize the identified dimensions into a coherent framework for categorizing KWs. This framework can be validated through case studies, longitudinal research, and large-scale surveys. Integrating cross-disciplinary perspectives, technological advances, and cultural contexts will enhance its relevance. Emerging technologies such as artificial intelligence and machine learning offer opportunities to automate tasks, streamline workflows, and redefine knowledge work. Sector-specific adaptations could address the distinct needs of industries like healthcare, education, and IT. By addressing the identified limitations and further developing the framework, future research can provide transformative insights for academia and practice in an increasingly knowledge-intensive global economy.

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7 Ethics declaration

This research involved content analysis and theoretical development based on existing literature. As it did not involve human participants, personal data, or sensitive materials, ethical approval was not required.

8 AI declaration

AI tools (ChatGPT4.0 and Grammarly) were used only for improving grammar, sentence structure, and abstract clarity. All ideas and analyses are solely the authors' own.

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Do Mentors Influence the Effects of the Entrepreneurial Programs of Early-Stage Start-Ups Pivot Decisions? An RCT Experiment

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Abstract

Do mentors influence the effects of the entrepreneurial programs of the early-stage start-ups pivot decisions? We address our research question investigating the role of mentors supporting entrepreneurs' decisions in an early-stage training program, receiving the scientific method or the effectuation approach. In order to achieve our goal, we based our research on Kram's Mentor Role theory (Kram, 1985) and we applied it to the scientific method, according to the theory-and-evidence-based approach (Agarwal et al., 2024), and to Saras Sarasvathy's theory of Effectuation (Sarasvathy, 2008), related to the evidence-based approach. Previous research, in fact, has considered mentors as experienced people who can support mentees' decisions, career-development and activities within organizations, by coaching, challenging, and directing (Kram, 1985; Wilson and Elman, 1990). Moreover, mentorship is an important building block of educational programs within entrepreneurial support programs (Yitshaki, 2025). Nevertheless, little is known about the role of mentors in start-ups that have received an Entrepreneurial training (ET) program specifically based on the scientific and effectuation approach to decision-making. In this vein, we discuss how mentors' support can change decision-making processes, in terms of radical and incremental pivot decisions, of entrepreneurs adopting the scientific approach and the effectuation approach. To investigate our question, we collected evidence via a randomized control trial (RCT) in which 308 early-stage start-ups from Italy of a pre-acceleration program were randomly assigned to "treatment" (scientific, effectuation) and "control" group. Each start-up in treatment and control groups had from 0 to 7 mentors, from the beginning of the program. We observed firms throughout and post-training and we compared differences concerning radical and incremental pivot decisions between firms with mentors and without mentors in the treatment and control group, focusing on mentors' support. We find that start-ups with mentors are not more likely to pivot radically, on the other hand they make more incremental pivots than firms with no mentors. In particular, firms with mentors trained by scientific method are more likely to pivot incrementally than firms in the effectuation and control group. We suggest that it is due to mentoring that reinforces the scientific approach and realigns what entrepreneurs have learnt during the training program. These findings highlight important insights for mentorship research, showing how mentors can shape decision-making processes in ET programs, for the literature on entrepreneurial decision-making and for stakeholders involved in designing training programs that support entrepreneurs.

Keywords: decision-making, scientific approach, startup mentors, randomized control trial, pivot

Paper type: Academic Research Paper

1 Introduction

Early-stage start-ups typically have to face several critical decisions characterized by extreme uncertainty (Shepherd and Gruber, 2020). To address this uncertainty, recent research has proposed various interventions to help entrepreneurs' decisions, typically provided in the form of entrepreneurial training (ET) programs (Alexandria et al., 2014; Bacigalupo et al., 2016; Morris et al., 2023). ET programs aim to enhance entrepreneurs' decision-making processes by helping them gather relevant information to refine their value proposition and better understand whether to pivot radically their business idea or to implement other solutions, such as incremental pivot. Moreover, there is an existing research stream showing that entrepreneurs who learn specific decision-making approaches through ET programs perform differently from those who do not (Camuffo et al., 2024). In particular, researchers indicate that entrepreneurs trained in a scientific approach to decision-making are more likely to make fewer pivots. These outcomes occur because these entrepreneurs, by leveraging specific decision-making frameworks, collect different types of information that ultimately shape their decisions and performance. Prior research also indicates that entrepreneurs may rely on additional sources of information not strictly related to their decision-making approach, which can influence the evolution of their business ideas, thus affecting the impact of the ET programs in which they are included (Shepherd and Gruber, 2020). Indeed, prior work highlights that entrepreneurs' decision-making approaches can be influenced by external factors, particularly during the early stages of a start-up. For instance, previous literature has considered mentors as external factors that can support mentees' decisions, career-development and activities within organizations, by coaching, challenging, and directing, fostering Mentor Role Theory (Kram, 1985; Wilson and Elman, 1990). As well, there is evidence that mentoring has a relevant effect on entrepreneurs because it helps to develop

successfully their career (Hetty van Emmerick, 2004; St-Jean and Mathieu 2015). Furthermore, there is evidence that the role of mentoring in assisting people who start their own business requires to be transferred to new start-ups through entrepreneurial programs (Waters et al., 2002). Despite these elements, we lack evidence on how external mentor support might affect the impact of ET programs focused on specific decision-making approaches, such as the scientific approach (Camuffo et al., 2020) and the effectuation approach (Sarasvathy, 2008). This gap is particularly relevant for both scholars and practitioners, as different training programs can prompt entrepreneurs to seek different types of information when assessing the viability of their ventures, thus affecting their performance. Given these premises, this research aims to investigate how being supported by an external mentor may affect the impact of entrepreneurial training programs that teach specific decision-making approaches during the early stages of developing an entrepreneurial idea. Building on this, we address the following research question: *"Do mentors influence the effects of the entrepreneurial programs of early-stage start-ups pivot decisions?"*. To address our question, we based our research on Kram's Mentor Role theory (Kram, 1985) and we applied it to the scientific method, according to the theory-and-evidence-based approach (Agarwal et al., 2024), and to Saras Sarasvathy's theory of Effectuation (Sarasvathy, 2008), related to the evidence-based approach. In order to achieve our goal, we leveraged data collected through a randomized control trial (RCT) embedded in a pre-acceleration program. We randomly assigned 308 Italian entrepreneurs to three different groups, each exposed to a distinct entrepreneurial training. One group received training in a scientific decision-making approach (Camuffo et al., 2020), another group in effectuation (Sarasvathy, 2008), and the last group in a heuristic approach emphasizing trial and error. We then assessed the presence of an external mentor and its interaction with an early-stage start-up through a survey conducted before the intervention. Our econometric results show that the presence of an external mentor influences the effect of learning a specific decision-making approach on the number of incremental pivot made. Specifically, the scientific approach is reinforced by mentors, who help start-ups to make efficient strategic shifts, thus their entrepreneurs understand mentor's recommendations properly, since they are exposed to the scientific approach to entrepreneurial decision-making.

2 Theoretical background and hypothesis development

Previous literature has focused on entrepreneurial training programs (ET) for early-stage startups due ETs play a vital role in supporting their development (Camuffo et al., 2020; Kotha et al., 2023; Leatherbee and Katila, 2020; Novelli and Spina, 2024). These programs seek to provide entrepreneurs with competencies that enable them to mitigate the uncertainty inherent of shaping a new business model. In particular, ETs affect how entrepreneurs collect information, enhancing their decision-making ability, such as making pivotal decisions about their business idea. More precisely entrepreneurs, who learn specific decision-making approach through ETs have a better understanding of the value of their project, thus the number of pivots made (Camuffo et al., 2020). For instance, research on programs based on teaching a scientific approach to decision-making has shown that entrepreneurs who learn this approach are more likely to make fewer changes to their value propositions or customer segments (Camuffo et al., 2024). Despite previous research on the impact of teaching specific decision-making approaches, relatively little is known about external factors that may influence their effects (Battaglia et al., 2024). Indeed, studies on early-stage start-ups have suggested that external factors can influence both the type of information entrepreneurs collect and their decision-making strategies (Shepherd and Gruber, 2020). Among these external factors, prior literature highlights the significant role that external mentors can play in shaping entrepreneurs' decisions (Hetty van Emmerick, 2004; St-Jean and Mathieu 2015). In particular, researchers consider mentors as experienced people who can support mentees' decisions, career-development and activities within organizations, by coaching, challenging, and directing (Kram, 1985; Wilson and Elman, 1990). Mentors' role is relevant, since they can share success stories of local startups and entrepreneurs that may not be procured in other forms (like books, publications, or news). They also help entrepreneurs crossing the Valley of death phase successfully, that otherwise would occur without their support (Al-Shaikh et al., 2021). Moreover, mentors can act as facilitators, encouraging entrepreneurs to test their ideas (St-Jeanne and Tremblay; 2020) and adjusting their entire business model (Cohen et al., 2019). Building on this, the relationship between external mentors and early-stage startups leads to different outcomes compared to those of unsupported entrepreneurs. Indeed, previous studies indicate that entrepreneurs supported by an external mentor are more likely to persist with their ventures (Chatterji et al., 2019). In addition, research has observed that external mentors can prompt entrepreneurs to make incremental adjustments to their business ideas (Welbourne Eleazar et al., 2022). Furthermore, previous research has shown that mentorship is an important building block of educational programs within entrepreneurial support programs (Yitshaki 2025). As a result, public organisations have implemented programmes to support entrepreneurs during the first years of

their business start-up and mentoring is part of such programmes (St.-Jean and Tremblay, 2020). Building on these considerations, we found out that little is known about the role of mentors in start-ups that have specifically received an entrepreneurial training (ET) program based on the scientific and effectuation approach to decision-making. Indeed, we argue that external mentor support will influence the impact of learning a specific entrepreneurial decision-making approach on pivoting decisions associated with the scientific and effectuation approaches (Camuffo et al., 2024; Battaglia et al., 2024). For this reason, we propose the following hypotheses:

- *H1: Entrepreneurs who learn a scientific or an effectuation approach to decision-making and are supported by an external mentor will make more incremental than radical pivot.*
- *H2: Entrepreneurs who learn a scientific approach to decision-making and are supported by an external mentor will make more incremental pivot than other entrepreneurs.*

3 Methodology and data

3.1 Methodology

We collected evidence via a randomized control trial (RCT) in which 308 early-stage start-ups from Italy were randomly assigned to "treatment" (scientific, effectuation) and "control" group. Similarly to previous studies (Battaglia et al. 2024; Camuffo et al., 2024), we embedded a field experiment in a pre-incubation program targeting early-stage start-ups. During the experiment, we randomly assigned entrepreneurs to two treatment groups (being taught how to develop a business model using the scientific approach; and being taught how to develop a business model using the effectuation approach). We also assigned entrepreneurs to a third control group where they have been taught how to develop an entrepreneurial idea using heuristics, like trial-and-error.

The pre-incubation program was delivered online (due to Covid-19 lockdowns) and it provided training to early-stage start-ups for a short period of time. After the call for application, our initial samples include 308 early-stage start-ups. Using randomization, we divided the 308 start-ups between the two treatment groups and the control group. We checked that each treatment group (102 start-ups for the scientific approach and 105 start-ups for the effectuation approach) and the control group (101 start-ups) were balanced on several key covariates that might affect the absorption of the treatments and subsequent outcomes, including if an early-stage start-up was supported by an external mentor. Differences between the treatment groups and control are small in magnitude, and there are no significant differences between the three groups. The pre-incubation program lasted from October 2020 to February 2021. The program was focused on market validation. The contents and length of each session was the same for each group, but with different logics in the decision-making approaches taught to each group. The first treatment group learnt to develop an idea using a scientific approach; entrepreneurs assigned to the second treatment group learnt to develop an entrepreneurial idea using an effectuation approach. The control group learnt how to develop an entrepreneurial idea using the same tools of the two treatment groups, but without learning how to use these tools following a scientific approach or an effectuation approach. We avoided possible contaminations among the three groups following previous best practices used in field experiments regarding decision-making approaches (Camuffo et al. 2024). Each firm in treatment and control groups had from 0 to 7 mentors, from the beginning of the program. We observed firms throughout and post-training and we compared differences concerning radical and incremental pivot decisions between firms with mentors and without mentors in the treatment and control group, focusing on mentors' support.

3.2 Data collection

We collected data following a two-step approach. The first stage of data collection was performed before the beginning of the pre-acceleration program, during the enrolment phase. Before enrolling in the pre-acceleration program, we asked entrepreneurs to fill out a survey regarding the characteristics of their entrepreneurial idea and about the demography characteristics and human capital of the founding team. Moreover, we asked to the entrepreneurs if they were supported by an external mentor in developing their entrepreneurial idea. If a startup was followed by one or more mentor, we asked to entrepreneurs to specific the relation with each mentor and the human capital characteristics of each mentor. These data collection was used to randomize the entrepreneurs between the three treatments and to create part of the independent variables. During the second stage of the data collection, we collected data for 10 points of observation over XXX months since the program started using interviews. Each interview was led following a semi-structured approach to collect information about the entrepreneur decision-making, whether they pivoted or not.

Moreover, after the training (3rd point of observation) and at the end of the observation period (10th point of observation) we updated information on whether a startup was supported by an external mentor.

3.3 Dependent Variables and Independent Variables

3.3.1 Dependent Variables

We used two dependent binary variables to capture pivoting. First, we employed a binary variable, *Radical Pivot*, taking the value 1 whenever an entrepreneur made a radical pivot and 0 otherwise. Second, we employed a binary variable, *Incremental Pivot*, taking the value 1 whenever an entrepreneur made an incremental pivot and 0 otherwise. To collect this information, in each interview, we asked entrepreneurs to explain whether they had made radical or incremental changes of their business model.

3.3.2 Independent Variables

To assess whether the presence of mentors affects the outcomes of the ET, we used an independent binary variable *Has Mentor* taking the value 1 whenever an entrepreneur had almost one mentor and 0 otherwise. We collected this information through the baseline survey to assess the mentor's support. Thus, we employed two categorical variables, *Intervention* taking the value 1 whenever an entrepreneur was in the control group, 2 whenever an entrepreneur was in the scientific group, 3 whenever an entrepreneur was in the effectuation group, and *Number of interview* taking the value from 0 to 10. Following previous studies on the effectiveness of entrepreneurial training programs (ETs), we collected this mentor-related information before the treatment, at the end of the treatment, and at the conclusion of our data collection. Table 1 presents the descriptive statistics for both the independent and dependent variables.

Table 1**:** Descriptive statistics

Variable	**Observations**	**Mean**	**Standard deviation**	**Min**	**Max**	**Description**
Dependent						
Radical pivot	3,388	0.13	0.41	0	3	Binary variable. 1 whenever an entrepreneur makes a radical pivot; 0 otherwise.
Incremental pivot	3,388	0.94	1.14	0	7	Binary variable. 1 whenever an entrepreneur makes an incremental pivot; 0 otherwise.
Independent						
Has Mentor	308	0.29	0.45	0	1	Binary variable. 1 if a mentor has almost one mentor, 0 otherwise.
Intervention	308	2.01	0.82	1	3	Binary variable. 1 if an entrepreneur belongs to Control group, 2 to Scientific group, 3 to Effectuation group.
Number of interview	3,388	5	3.16	0	10	Categorical variable from 0 to 10.

3.4 Statistical approach

We tested our hypotheses using econometrics analysis, leveraging on data collected along the 10 points of observation. Given the nature of our dependent variables, we adopted negative binomial model for testing the cumulate amount of radical and incremental pivot of early-stage start-ups. As far as our independent variables are concerned, similar to previous studies on testing the boundary conditions of teaching decision-making approach (Battaglia et al. 2024), we created a set of exclusive dummy variables mapping the presence of having learnt a decision-making approach or not and having an external mentor or not (Wooldridge, 2015). Finally, we include a vector of control variables to capture potential differences in the instructors' teaching styles, and we cluster standard errors at both the instructor and intervention levels.

4 Results

Models (1) and (2) present the empirical analysis of the number of radical and incremental pivot. We find that start-ups trained by the scientific approach or the effectuation approach and have external mentors are not more likely to pivot radically, on the other hand they make more incremental pivot than firms with no mentors. These results confirm H1. Specifically, firms with mentors trained by scientific method are more likely to pivot incrementally than firms in the effectuation and control group. We suggest that it is due to mentoring that

reinforces the scientific approach and realigns what entrepreneurs have learnt during the training program. Conversely, entrepreneurs in the control group do not understand mentor's recommendations properly, since they are not exposed to the scientific approach to entrepreneurial decision-making. On the effectuation group, the mentor's effect is even less because entrepreneurs are more practical and less driven by a structured method, like the scientific approach. Furthermore, mentors are experienced people, who strengthen entrepreneurs' knowledge absorbed through the scientific training and develop the start-up's network. Specifically, they help entrepreneurs to make efficient strategic shifts, shown by incremental pivot decisions that are more accurate and precise improvements than radical pivot decisions. This effect is evident not only during the scientific training but also in the long-term period, because mentors help entrepreneurs to take decisions, making them recall what they learnt during the program. Collectively, these results confirm H2.

Table 2: Regressions with *Radical pivot* and *Incremental pivot* as dependent variables.

Variables	**(1)** **DV: Cumulative** **Radical Pivot** **Negative Binomial Cross Sections**	**(2)** **DV: Cumulative** **Incremental Pivot** **Negative Binomial Cross Sections**
Control X Has Mentor	0.324 (0.180)	0.160 (0.246)
Scientific X No Mentor	-0.176 (0.513)	0.007 (0.951)
Scientific X Has Mentor	-0.039 (0.941)	0.600*** (0.000)
Effectuation X No Mentor	0.224 (0.374)	0.243** (0.027)
Effectuation X Has Mentor	-0.562 (0.337)	0.320** (0.024)
Constant	-1.650*** (0.000)	-0.002 (0.984)
Observations	308	308
Dummies for Instructor	Yes	Yes
Clustered errors	Intervention Instructor	Intervention Instructor

Standard errors in parentheses. DV stands for "dependent variable".
***$p < .01$, **$p < .05$, *$p < .10$.

5 Conclusions

This work makes three contributions. First, it contributes to the literature on ET (Alexandria *et al*., 2014, McKenzie and Woodruff, 2014) and the role of mentors, by offering evidence that mentors influence the effects of the entrepreneurial programs of the early-stage start-ups' pivot decisions. Second, given the focus of this work on a scientific approach to decision-making, it offers a contribution to the research stream regarding the use of methods applied to entrepreneurial decision-making (Camuffo et al., 2020; Novelli and Spina, 2024). The scientific approach, in fact, is consistent and recommended to be adopted but, as element of novelty, we suggest that the role of mentors is required to strengthen the scientific approach and to realign it after the entrepreneurial training's period. Third, by showing mentors' effects on entrepreneurs participating in training programs, we offer useful insights for policymakers, universities and other institutions involved in the creation and supply of ETs to support entrepreneurs.

Ethics declaration

This research was approved by Bocconi Research Ethics Committee with protocol references SA000105.

AI declaration

AI tools were used for proofreading.

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Navigating Uncertainty through Knowledge Sharing: Lessons from Tourism in Times of Pandemic. Case Study from Poland

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Abstract

Crises in tourism have become increasingly common. Yet, COVID-19 stands out as the most disruptive event, causing significant damages to the global economy, severely impacting the tourism sectors across the regions. Even though it has been five years since the crisis started, the pandemic's influence on global tourism can still be noticeable. This study focuses on Polish tourism organisations with the purpose to explore in-depth the role of knowledge sharing processes and their usefulness in mitigating the effects of crisis in tourism.

Analysis of the case suggests that the organisation's key role during a crisis was to serve as a knowledge broker. The analysed case indicates that different types of information and knowledge were significant during that period. For the industry, key knowledge concerned the information related to legislation and the proposed changes. For municipal and governmental level, quantitative data from tourist traffic was important. For tourists, a focus was put on navigating the restrictions. Given the numerous constraints imposed by the pandemics, the organisation adapted to the new reality by increasing its dependence on ICT systems. This includes the creation of a dedicated subpage, ongoing e-mail and newsletters communication, video chats with training, regular online team meetings and employees' conversations via online chats.

This study is based on qualitative in-depth analysis and the semi-structured interviews with representatives of a local tourism organisation in Poland. This research employs a single case study design, focusing on the organisation as the unit of analysis. This study contributes to the body of literature by expanding the understanding of the role of knowledge sharing processes within the context of the tourism crisis. It offers valuable insights for researchers exploring the application of knowledge management to crisis management.

Findings of this study deliver food for thought for both the academic community and tourism organisations eager to facilitate their operational activity during hazardous events. The results offer practical guidance for managers regarding the knowledge sharing practices on how to enhance the resilience and performance of their organisations during crisis, while simultaneously supporting the tourism industry.

Research output is limited to the analysis of a single organisation (illustrated through a case study example) and thus, the analysis presented may not fully capture the complexity of the entire sector. The organisation is operating in Poland, and this can additionally limit the usefulness of analysis to one country specifics.

Keywords: KM, Knowledge sharing, Crisis management, Tourism, COVID-19

Paper type: Academic Research Paper

1 Introduction

Due to the escalating impacts of climate changes and dynamic geopolitical context, crises in tourism have become increasingly common. Yet, COVID-19 stands out as the most disruptive event so far (Higgins-Desbiolles, 2020), causing significant damages to the global economy, also severely impacting the tourism and travel sectors across the regions and destinations. Even though it has been five years since the crisis started, the pandemic's influence on the global tourism industry can still be noticeable. Regardless of the negative consequences, for some companies COVID-19 served as a catalyst for internal changes, highlighting new organisational roles and strengthening existing mechanisms and processes. Tourism organisations, as key players integrating companies within the tourism sector, exemplify this type of organisation.

This study focuses on Polish tourism organisations, concentrating on their internal knowledge sharing practices and operational roles during crisis situations. Based on review of the existing literature, recognizing the potential contribution of knowledge management to enhance crisis management effectiveness (Mistilis and Sheldon, 2006; Racherla and Hu, 2009; Orchiston and Higham, 2016; Barišić et al, 2020; Ng et al, 2022; Kir Kuščer et al, 2021), the purpose of this study is to explore in-depth the role of knowledge sharing processes and their usefulness in mitigating the effects of crisis in tourism. This preliminary study is based on a single case-study, presenting the results of qualitative research conducted via the semi-structured interviews from a local tourism organisation in Poland.

This paper is structured in the following way. In the next section, a theoretical background is presented, describing the contribution of KM to crisis management and knowledge sharing practices during a crisis. In the third section, the methodology of the study is presented and in the fourth - results and discussion.

2 Theoretical background

2.1 Contribution of KM to crisis management

Knowledge management and its applications in tourism and hospitality organisations has not been intensively examined so far. One of the papers discussing this topic is provided by Racherla & Hu (2009), where the authors propose a framework for knowledge-based crisis management in the hospitality and tourism industry. According to the authors, the application of KM in hospitality and tourism organisations can significantly improve their crisis management capabilities through the improved acquisition and dissemination of critical information. Knowledge management practices not only support decision-makers in performing their roles more effectively but also facilitate the efficient sharing and reuse of organisational resources (Racherla & Hu, 2009). Also Orchiston & Higham (2016) highlight that crisis knowledge management in tourism can significantly improve destination recovery, increase resilience to future disruptive events, and improve communication with all relevant stakeholders during a crisis. By systematically capturing and sharing knowledge gained from past crises, organisations can better predict challenges, offer better crisis responses, and speed up the recovery phase (Orchiston & Higham, 2016). Knowledge management plays a critical role in supporting the effectiveness of Destination Management Organisations (DMOs) during a crisis, becoming a key tool for their management strategies. Furthermore, effective knowledge management supports the evolving role of DMOs, namely going beyond marketing functions and including responsibilities such as stakeholder coordination, strategic communication, and crisis response (Blackman et al., 2011). To sum up, while approaches to crisis management may be different, they all highlight anticipation, preparedness, quick dissemination of accurate and up-to-date information, response from the authorities and sustainable long-term solutions. Effective knowledge management, defined as the timely provision of relevant information to stakeholders, combined with suitable knowledge management practices for gathering, organising, and applying knowledge, can significantly support tourism crisis management (Jia et al., 2012). On the basis of the above, it can be stated that knowledge management is useful for better crisis management in various types of entities and this topic should be further examined in practice among tourism organisations.

2.2 Knowledge sharing practices during crisis

Among the processes of knowledge management, one of the key ones is knowledge sharing. Effective knowledge sharing is a crucial element of crisis management for tourism destinations, helping stakeholders to respond timely and in a coordinated manner. According to Mistilis and Sheldon (2006), effective knowledge sharing requires destinations to explicitly identify and encode their critical knowledge within structured information systems, facilitating efficient dissemination to all relevant parties. Furthermore, the authors highlight that collaboration and reliable communication of information among stakeholders and response organisations are fundamental during crises, contributing to quick knowledge exchange, so crucial during a crisis (Mistilis & Sheldon, 2006). Therefore, knowledge sharing not only helps in coordination among stakeholders, but also significantly improves the resilience and capacity of destination organisations for crisis recovery.

Effective knowledge sharing in crisis management requires proper channels and interactive mechanisms. According to Racherla and Hu (2009), the optimal way to disseminate and use crisis-related knowledge is by establishing networks and communities, within which stakeholders can engage, exchange knowledge, and learn from their mutual experiences. Such interactions create a dynamic feedback loop, supporting organisational capabilities in knowledge acquisition, storage, and preparedness for future crises (Racherla & Hu, 2009). Therefore, creation of collaborative networks not only helps in real-time crisis responses but also significantly contributes to building sustainable, knowledge-based resilience for future events of this type.

Apart from knowledge transfer, it is also important to prevent the loss of valuable organisational experiences and lessons learned. According to Toubes at al. (2021), destinations that want to recover successfully from a disaster, should implement knowledge transfer processes together with deliberate strategies for minimizing organisational forgetting. Those processes and strategies are necessary to make sure that the knowledge gained from the previous crises is retained, disseminated, and successfully applied in future situations (Toubes et al., 2021).

What is important is that this knowledge sharing should not be limited only to selected actors within a sector. According to Ghaderi et al. (2014), tourism organisations that shared knowledge with other sectors demonstrated greater preparedness in addressing future crises. Therefore, it can be assumed that cross-sectoral knowledge exchange contributes to organisational resilience and improved responsiveness in future crises (Ghaderi et al., 2014) and this kind of knowledge sharing (cross-sectoral) should be encouraged and supported.

However, according to the study by Ghaderi et al. (2014), knowledge sharing practices were often limited - almost 60% of managers declared that they shared information only within their own professional groups. In contrast, only 40% indicated a willingness to disseminate new information across the broader tourism industry. Managers who limited their sharing practices during a crisis to their professional group indicated that all parties must take joint responsibility for problem-solving and exchanging experiences (Ghaderi et al., 2014).

As far as various actors engaged in knowledge sharing are concerned, their role is crucial both during and after a crisis. Boundary spanners and knowledge brokers—such as DMOs at national, regional, and local levels, as well as industry associations and government agencies—are particularly important to support the flow of information between diverse stakeholders (Blackman, Kennedy, & Ritchie, 2011). In particular, DMOs possess better capacity than individual small and medium-sized enterprises (SMEs) to keep knowledge from past crises and promote its transfer. It is due to the fact that SMEs often lack the resources or willingness to engage in organisational learning processes (Toubes, Araújo-Vila, & Fraiz-Brea, 2021). For better crisis knowledge management, DMOs should undertake actions to facilitate communication and knowledge exchange across the sector, including the selection and empowerment of boundary spanners to eliminate organisational and sectoral divisions (Blackman, Kennedy, & Ritchie, 2011).

To sum up, knowledge sharing and knowledge transfer are important elements of successful crisis management in the tourism sector both during its occurrence and afterwards. It is important to create proper channels and interactive mechanisms, as well as to engage various actors and stakeholders.

3 Methodology

This study aims to explore in-depth the role of knowledge sharing processes in mitigating the effects of crisis in tourism. In order to address this purpose, the following research questions have been stated:

- RQ1: What activities did the organisation perform for knowledge sharing during the COVID-19 pandemic?
- RQ1: What knowledge was important during the pandemic for tourism organisation?
- RQ2: What knowledge sharing tools were used by tourism organisation in the period of crisis?

This research employs a single case study design, focusing on the organisation as the unit of analysis (Yin, 2003). According to Mariotto et al. (2014), employing a single case study strategy might prove advantageous for academic investigation, as it facilitates a profound understanding of the phenomenon in focus. This study is based on qualitative in-depth analysis and the semi-structured interviews with representatives of a local tourism organisation in Poland, which served as the primary data collection method. The study informants were two employees representing managerial and specialist positions. Data collection process took place in December 2023 and January 2024. Interviews were recorded and transcribed *verbatim* (Poland, 1995) to be translated afterwards to English. For data coding MAXQDA software was used.

Tourism organisations act within the framework of Destination Management Organisations. They bear responsibility for the management and marketing of tourism destinations, including attractions, amenities, cities or whole regions. Tourism organisations function as key sectoral bodies, having a pivotal role in the coordination of a multi-faceted network of stakeholders across the entire tourism industry (UNWTO, 2007). This intermediary role enables these organisations to have a constant access to external knowledge and to connect various sources of such knowledge.

4 Results and discussion

Analysis of the case study suggests that the organisation's key role during a crisis was to serve as a knowledge broker, which goes in line with the understanding of such organisations as institutions acting in the role of "information brokers" provided by UNWTO (2007). The organisation acted as a central hub of knowledge, integrating various stakeholders (including members, business partners, employees, governmental and municipal entities, tourists) and facilitating the constant knowledge exchange during the pandemic crisis. The transfer of knowledge was from various levels and sources, as indicated by the CEO of the organization:

"They (i.e. access and management of knowledge) were key and fundamental. We basically became an information broker in the first months, if I may say so. That is, we had the opportunity to obtain information

firsthand from the government level, from the municipal level, and pass it on to the industry and vice versa." - CEO of the organisation

The analysed case also indicates that different types of information and knowledge were significant during that period. These can be categorised according to the main stakeholder groups that were the recipients. For the industry, key knowledge concerned the information related to legislation and the proposed changes. For municipal and governmental level, quantitative data from tourist traffic, as well as data regarding occupancy and average prices in hotels/restaurants were very important. For tourists, on the other hand, a focus was put on navigating the restrictions, i.e. the availability of services, such as museums, cultural centres, etc. All these types of knowledge were needed for the sector and its various stakeholders. The role of the examined organisation was to receive, verify and disseminate this knowledge.

"It depends a bit. [...] we played such a gatekeeper role, where data came from both sides, and we had to authenticate them, but these data were different depending on who expected from us." - CEO of the organisation

An important aspect of the analysed case is the use of knowledge sharing tools during this crisis. Given the numerous constraints imposed by the pandemics, the organisation adapted to the new reality by increasing its dependence on ICT systems for their day-to-day activity, and this technology adoption goes in line with the observed trend in tourism and travel industry (Yepez & Leimgruber, 2024). This includes the creation of a dedicated subpage on the organisational website with all the pandemic-related information (dedicated to all members of organisations), ongoing e-mail and newsletters communication, video chats with training, regular online team meetings and employees' conversations via online chats. Both the knowledge and ways of presenting it was useful and suitable for various stakeholders in times of the crisis. These activities were supposed to help the partners surviving and navigating through the crisis.

"The subpage of our tourism portal, where we gathered information [...] - it was about collecting knowledge that, from our perspective, was useful for our partners, for entities that cooperated with us." - Specialist representing the organisation

"We did a video chat once a week for our members, but we invited essentially the whole industry. These were general, there were also ones specifically for hotels and specifically for guides, there were meetings with lawyers who explained how to even prepare a company for restructuring, what it entails, how to properly submit an application, how to appeal if necessary. " - CEO of the organisation

Additionally, the preliminary results indicate that close cooperation and networking with external organisations and partners was of a great significance in knowledge sharing processes in a time of crisis, which has been already indicated in the literature (Ghaderi et al., 2014).

"We try to cooperate with everyone willing to work with us, starting from guides, managers of attractions, the gastronomy sector, hoteliers, various governmental and non-governmental institutions, of course, the Polish Tourism Organisation, and so on - I could list them for a long time. Being somewhat in the middle, I feel that we often know more and know it faster. - Specialist representing the organisation

To sum up, the presented case study shows that during the crisis the key role of a tourism organisation in Poland was to become a knowledge broker. Due to its position and network of partners, the organisation was able to collect, verify and disseminate knowledge crucial from the perspective of various stakeholders. The role of collaboration and various types of knowledge needed during a crisis were highlighted.

5 Conclusion

This study contributes to the body of literature by expanding the understanding of the role of knowledge sharing processes within the context of the tourism crisis. It offers valuable insights for researchers exploring the application of knowledge management to crisis management. On the basis of the literature analysis, several key points can be noted. First of all, effective crisis management in tourism relies on sharing various types of knowledge for different stakeholders and organisational learning. Tourism organisations should explicitly capture and encode critical knowledge to enable quick communication among stakeholders and support coordinated responses within the sector (Mistilis & Sheldon, 2006; Racherla & Hu, 2009). Second, keeping knowledge through transfer processes and eliminating organisational forgetting are essential for the creation of resilience and sustainable recovery after the crisis (Toubes et al., 2021). Unfortunately, despite its importance, knowledge sharing often remains limited within professional groups, showing the need for better and broader collaboration across the tourism sector (Ghaderi et al., 2014). Finally, Destination Management Organisations, industry associations and government agencies act as important boundary spanners, keeping crisis experiences and supporting knowledge flow between stakeholders to better prepare for future crises (Blackman, Kennedy, & Ritchie, 2011; Toubes et al., 2021).

As far as case study is concerned, it shows that during the crisis, the key role of this Polish tourism organisation was to act as a knowledge broker, using its position and partner network to collect, verify, and disseminate critical knowledge to various stakeholders. The findings also highlight the importance of collaboration, and the diverse types of knowledge required for effective crisis management of different stakeholders (not all types of crisis knowledge were equally important to each partner/stakeholder).

All in all, findings of this study deliver food for thought for both the academic community and tourism organisations eager to facilitate their operational activity during hazardous events. The results offer practical guidance for managers regarding the knowledge sharing practices on how to enhance the resilience and performance of their organisations during crisis, while simultaneously supporting the tourism industry with relevant knowledge and assistance.

Research output is limited to the analysis of a single organisation (illustrated through a case study example) and thus, the analysis presented may not fully capture the complexity of the entire sector. The organisation is operating in Poland, and this can additionally limit the usefulness of analysis to one country specifics. Those limitations will be overcome in the future by additional cases and analysis at international level.

6 Acknowledgements

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7 Ethics declaration

The authors report there are no competing interests to declare, and ethical clearance was not required for the research.

8 AI declaration

The authors report that AI tools assisted in the development of this paper with respect to linguistic matters, i.e. translation.

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Open Innovation for Virtual Worlds: A Design-Driven Theoretical Framework for the Creation of User-Generated Experiences

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Abstract

This paper investigates the evolving role of users in Virtual Worlds (VWs), emphasizing their transition from passive consumers to active creators of immersive experiences. In the context of platforms like Roblox, Decentraland, and Fortnite, the study explores the dynamics of User-Generated Content (UGC) and User-Generated Experiences (UGEs), drawing on principles from Open Innovation and User-Centered Design, the research develops a design-driven framework that integrates co-creation, co-design, and co-production processes within the Double Diamond model and expands the theory with tailored design phases. Through a comparative analysis of three leading VWs, the study identifies key challenges and proposes a structured framework to enhance creativity, inclusivity, and business opportunities. The framework is validated against academic literature and case study insights, offering an approach to participatory innovation in digital environments. The paper concludes by outlining future directions for ethical integration and hybrid physical-virtual applications.

Keywords: Virtual Worlds, User-Generated Content, Open Innovation, Virtual economy

Paper type: Research paper

1 Introduction

1.1 Landscape: Virtual Worlds and UGC

As defined by the European Commission (2023), Virtual Worlds (VWs) are immersive, persistent digital environments that simulate real and imaginary settings through various technologies—spanning from 3D graphics, Blockchain Technologies, Virtual Reality (VR), Mixed Reality (MR), Extended Reality (XR). These environments are characterized by user-driven innovation, customizable avatars, and real-time interaction within spatially and socially coherent digital ecosystems, as pioneered long ago by Bartle (2003). Over the years, these platforms have evolved from entertainment spaces into complex socio-technical systems that host collaborative, economic, and educational activities (Dionisio, Burns and Gilbert, 2013). Over time, VWs have evolved from being primarily entertainment-oriented spaces into sophisticated socio-technical systems that support collaborative, economic, and educational interactions (Dionisio, Burns and Gilbert, 2013). These environments enhance users' sense of immersion and presence (Schultze, 2010), enabling a wide spectrum of activities—from simulation and design to learning, socializing, and conducting transactions (European Commission, 2023). More recently, their integration with emerging technologies such as generative AI (Wang, Wang and Siau, 2024) has further accelerated their development by lowering participation barriers and expanding creative and co-creative possibilities.

The shift toward users as active creators (Goanta, 2020) lies at the core of User-Generated Content (UGC), which Naab and Sehl (Naab and Sehl, 2016) define as digital content produced outside professional routines and made publicly or socially accessible. UGC includes a wide range of outputs—texts, data, and user actions—such as virtual objects, avatar customizations, interactive narratives, and immersive spaces, all shared through independent channels with communicative or expressive intent (Santos, 2021). Contemporary VWs like Roblox, Decentraland, and Fortnite actively support large-scale UGC creation by embedding developer tools that empower users to easily build content (Lee and Law, 2023; Zhang, Gui and Kou, 2024). This evolution reflects the democratization of content creation, now embedded in participatory digital cultures that previously marginalized non-professional contributors (Główczyński, 2022).

A prominent and growing typology of UGC is User-Generated Experiences (UGEs)—immersive, interactive activities and environments authored by users within virtual worlds (de Freitas *et al.*, 2009; Blascovich and Bailenson, 2011; Acharya and Wardrip-Fruin, 2019). UGEs enable users to engage with rich and immersive spaces where to design, often collaboratively, using tailored tools like Fortnite Unreal Editor and Roblox studio (Epic Games, 2024b; Roblox Corporation, 2025). They span applications in education, entertainment, and social collaboration, supporting UGE creation through modular development, and feedback mechanisms (Maloney and Freeman, 2020).

Currently, VWs are recognized as mainstream digital spaces, engaging millions of users daily in active content creation (Decentraland, 2017; Epic Games, 2024a; Roblox Corporation, 2024). This participatory nature positions them as relevant arenas for community-driven innovation (Moritzen, 2022), enabling a broad spectrum of innovation—from products and services to processes and entire systems. These contexts provide strategic opportunities for research on how open innovation (Chesbrough, 2003, 2019) can support the development of inclusive, user-driven, and co-creative virtual ecosystems (Kohler *et al.*, 2011). Specifically, when it comes to exploring the design of UGC within VWs, the scientific literature remains notably scarce, opening up a relevant space for exploration.

2 Theoretical Background

2.1 VWs Sectors of Application

As enabling infrastructures, VWs span diverse professional domains, extending beyond their entertainment origins. In education, they support immersive, simulation-based pedagogy, experiential and collaborative learning (Johnson and Levine, 2008; de Freitas *et al.*, 2009). In healthcare, they simulate medical procedures, enhance patient-practitioner interaction, and enable safe, controllable settings for health interventions (Castronova *et al.*, 2009). In urban planning and architecture, they are leveraged for virtual prototyping and collaborative design (Kashiripoor, 2023), while cultural institutions utilize them for cultural heritage and interactive exhibitions (Hutson, Weber and Russo, 2023). In corporate contexts—particularly post-pandemic—VWs are employed for remote work, onboarding, and training, offering spatialized alternatives to conventional video conferencing (Hew and Cheung, 2010).

When for entertainment—and especially gaming—VWs host complex, hybrid economies that largely depend on users adopting and engaging with user-developed content. These economies center on the exchange of digital assets—avatars, environments, interactive objects—often mediated by platform-specific currencies and linked to real-world financial systems (Castronova, 2005; Dionisio, Burns and Gilbert, 2013). The integration of decentralized technologies has introduced new monetization models such as play-to-earn, creator royalties, and blockchain-based ownership (Ramadhan, Suryodiningrat and Mahendra, 2023). Platforms like Roblox and Decentraland allow users to earn income through virtual goods, events, and mini-games, supported by marketplaces and smart contracts that empower creator agency (Główczyński, 2022). Despite their potential, these systems also raise concerns about labor exploitation, digital inequality, and platform governance (Zhang, Gui and Kou, 2024).

2.2 Open Innovation: From Co-creation to Co-Production

As discussed, the creation of UGEs signals a shift from traditional top-down content production toward a bottom-up model, where users act not only as consumers but as active creators. This evolution redefines the participatory paradigm, involving users in the ideation, design, and delivery of digital products and services. Such an approach closely aligns with the principles of Open Innovation, which emphasizes distributed knowledge and collaborative value creation across organizational boundaries (Chesbrough, 2003). Open innovation can manifest through early-stage co-creation, where users contribute ideas and contextual insights (Prahalad and Ramaswamy, 2004); co-design, which engages users in shaping the design of products, services, and beyond (Burkett, 2012); and co-production, where users participate in the implementation, becoming autonomous agents in the production system (Brudney and England, 1983).

2.3 Emerging Gaps and Research Question

While UGC in VWs is gaining scholarly and practical traction for its potential to foster creativity and participatory innovation, several challenges persist. First, the lack of unified design frameworks that integrate VWs possibilities with creative practices (Friedman and Hendry, 2019). Second, difficulties in sustaining long-term user engagement, often resulting in content homogenization and limiting the democratization of content creation (Kohler & Fueller, 2011; Maloney & Freeman, 2020), especially considering cross-platform possibilities. Third, support for opening new business opportunities within virtual economies, which demands a rethinking of UGE ecosystem design and governance to ensure participatory equity and inclusive innovation (Maloney and Freeman, 2020; Zhang, Gui and Kou, 2024). Ultimately, although the literature offers insights within each domain—and at the intersection of any two—a key gap lies at the convergence of all three: UGC, VWs, and open innovation, particularly when viewed through a design lens.

To address these gaps, this study poses the following research question: *How can creative processes for UGE creation be designed to enable cross-platform collaboration, foster creativity, sustain user engagement, and support the generation of desirable content—ultimately supporting business opportunities in VWs?*

In light of this, Design Thinking (Brown, 2008) and structured models like the Double Diamond process (Figure 1) (Design Council, 2005; Nessler, 2016) provide relevant design approaches for developing UGEs, adopting an iterative (Zhu and Lin, 2023) and user-centered perspective (Mattelmäki and Visser, 2011). Complementing them is participatory design (Namioka and Schuler, 1993), which bridges co-creation, co-design, and creative exploration.

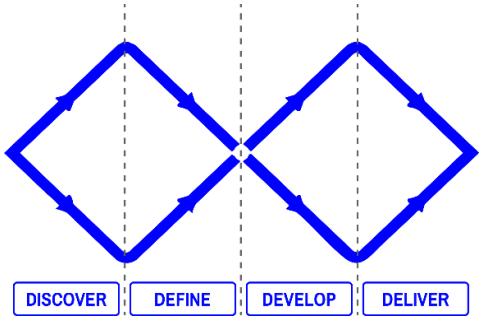


Figure 1: The Double Diamond process (Design Council, 2005)

3. Methodology

The methodology consists of six sequential steps that guide the process from analyzing current discourse in the literature to conducting a case study, ultimately supporting the development and validation of a comprehensive framework.

Phase 1: Literature review. Covering from 1970 to 2024, and spanning the domains of VWs, UGC, and open innovation, a total of 203 sources were analyzed (Ventura, 2025), both academic (Google Scholar, Scopus, Web of Science, JSTOR) and grey (EU reports, industry documents). The review identified theoretical gaps and emerging challenges, informing the research question and the case studies analysis. The review was limited to accessible resources in English and Italian.

Phase 2: Case study analysis. An initial set of 15 VWs, based on Barrett (2024), was shortlisted using eight criteria derived from the literature: Presence of monetization systems (Gupta, S. *et al.*, 2022), Persistence (Dionisio, Burns and Gilbert, 2013), Real-time collaboration (Dionisio, Burns and Gilbert, 2013), Brand collaborations (Joy *et al.*, 2022), UGC Creation (Naab and Sehl, 2016), Commerce opportunities (Dibbell, 2006), Usage of advanced technologies (Brunet, Mattavelli and Chiariglione, 2023), and Broad audience outreach (Dionisio, Burns and Gilbert, 2013). Three VWs are selected as case studies: Roblox, Decentraland, Fortnite are selected representing diverse approaches to UGE, monetization, and community engagement. Analytical dimensions and sub-dimensions for analysing cases were also literature-informed: Open Innovation (Co-creation, Co-design, Co-production)(Chesbrough 2003, 2019; Prahalad & Ramaswamy, 2004; Burkett, 2012; Brudney & England, 1983), Role of a VW Environment (Immersive Experiences, Brand Collaborations) (Bartle, 2004; Joy et alt. 2022; Acharya & Wardrip-Fruin, 2019), Community engagement (User to User Interaction, Community Collaboration) (Bartle, 2003; Kohler et alt, 2011), UGC Creation (UGC Design and Monetization Opportunities) (Naab and Sehl, 2016; Gupta, 2022) and Intellectual Property Rights (Safitra *et al.*, 2023).

List of cases

15 Virtual Worlds analyzed in literature review, from Barrett (2024)

Selection Criteria to Shortlist Barrett

- Persistence of the platform
- Presence of real-time collaboration
- Presence of brand collaborations
- Includes creation of UGC
- Commerce opportunities
- Usage of advanced technologies
- Presence of monetization systems
- Broad audience outreach

Literature-Inspired Dimensions & Sub-dimensions of Analysis

Dimensions	Sub-dimensions	Reference
Open Innovation	Co-Creation, Co-Design, Co-Production	(Chesbrough, 2006; Voorberg, Bekkers, & Tummers, 2015; Prahalad & Ramaswamy, 2004; Graham et al., 2013)
Role of a Virtual World Environment	Immersive Experiences	(Bartle, 2003; Schroeder, 2016; Girvan, 2017; Juul, 2005)
	Platform for Brands	(European Commission, 2023; Castronova, 2005; Graham et al., 2013; Bartle, 2003)
Community Engagement	User to User Interaction	(Schroeder, 2016; Parkkila, 2017; Nevelsteen, 2017; Lastowka, 2008; Juul, 2005)
	Community Collaboration	(Schroeder, 2016; Juul, 2005; Lastowka, 2008; Graham et al., 2013)
Generation of Content	Monetization Opportunities	(Lastowka, 2008; Zhang, Cui, & Kou, 2023; Główczyński, 2022; Bartle, 2003; Friedman & Hendry, 2019)
	UGC Design	(Bartle, 2003; Castronova, 2005; Mayer-Schönberger, 2006; Nevelsteen, 2017)
Intellectual Property Rights		(Lastowka, 2008; European Commission, 2023; Bartle, 2003; Mayer-Schönberger, 2006)

Figure 2: Phase 2 of Methodology summarized

Phase 3. Theoretical framework. Integration of the Open Innovation approach with the co-creation, co-design and co-production processes, the Double Diamond design model (Design Council, 2005) and the phases identified in the literature.

Phase 4. Validation against literature. The framework is validated through cross-referencing with existing literature. A comparison matrix, developed for this purpose, is integrated into the theoretical framework presented in the result paragraph.

4 Case Studies Analysis

The three selected VWs—Roblox, Decentraland, and Fortnite—serve as representative cases for examining the interplay between UGC, design, and open innovation. Figure 3 displays a comparative analysis that describes each case across key dimensions for a structured identification of similarities, differences, and emerging patterns aimed at informing critical insights for the theoretical framework development.

	Case 1	Case 2	Case 3
	ROBLOX. Free to play online game platform and game creation system for users to program and play games created by themselves or other users. In-game purchases are available through a virtual currency called Robux.	**DECENTRALAND.** 3D VW browser-based platform where users can buy in-platform plots of land as NFTs via the MANA cryptocurrency (Ethereum blockchain). Designers can create and sell clothes and accessories for avatars in WWs.	**FORTNITE.** A multiplayer online video game evolved into a multifaceted VW and creative platform serving as an ecosystem that integrates UGC, branded collaborations and live virtual events.
		Open Innovation	
Co-Creation, Co-Design, Co-Production	Users ideate, build, and refine content collaboratively using Roblox Studio, blurring lines between developers and players, with monetization through DevEx.	Users ideate through the DAO and events, co-design with tools like the Builder, and refine content via feedback before publishing as NFTs or interactive experiences.	Creators brainstorm ideas, build with UEFN, and refine content through collaboration and playtesting. The Creator Economy 2.0 shares 40% of revenue, promoting global, user-driven innovation.
		Role of a VW Environment	
Immersive Experiences	Roblox offers low-barrier tools, global feedback, and fast iteration, enabling creators of all skill levels to build and distribute innovative content.	Decentraland offers diverse virtual worlds, from art galleries to concerts and educational games, providing boundless creative expression without physical limits.	Fortnite blends gaming, music, and storytelling through iconic virtual events like concerts by Travis Scott and Ariana Grande, transforming entertainment into interactive, shared experiences.
Brands Collaborations	Luxury brands like Gucci and Givenchy use Roblox to create interactive virtual spaces, engaging younger audiences and expanding digital brand presence.	Brands like Adidas and Gucci create branded spaces and events in Decentraland, merging marketing with immersive virtual experiences to engage digital audiences.	Brands like Nike, Balenciaga, and Marvel collaborate with Fortnite to launch virtual goods and events, merging fashion, pop culture, and gaming to engage younger audiences.
		Community engagement	
User to User Interaction	Chat, multiplayer gameplay, and events foster community and real-time social engagement among users across experiences.	Social tools, multiplayer games, and community events foster user interaction and collaboration, enhancing the social fabric of the platform.	Collaborative gameplay, live events, and social sharing on platforms like TikTok and YouTube enhance community engagement and feedback among users.
Community Collaboration	Forums, groups, Discord, and social platforms support teamwork, feedback, mentorship, and co-creation, strengthening the creator community.	DAO proposals, forums, Discord, and hackathons enable idea sharing, feedback, and co-creation, empowering creators through open, community-led collaboration.	UEFN, forums, and Discord support teamwork and mentorship. Hackathons and challenges drive innovation, while social media helps creators connect, learn, and co-create.
		Generation of Content	
UGC Design	User-generated content drives Roblox's diversity, with AI tools streamlining creation and lowering entry barriers for 3D assets and environments.	Creators design wearables, land, and games using the Builder, with blockchain ensuring ownership. Content reflects global diversity and innovation.	Tools like Fortnite Creative and UEFN enable users to design diverse, AI-enhanced content. Continuous community contributions keep the platform fresh and engaging.
Monetization opportunities	Creators earn Robux by selling items and experiences, with conversion to real currency via DevEx and exclusive programs enhancing earning potential.	Creators earn through NFT sales, event tickets, rentals, and MANA transactions, supported by an open economy that incentivizes innovation and income.	Creators earn through V-Bucks sales, subscriptions, and Creator Economy 2.0 payouts based on engagement. Transparent systems convert virtual income into real-world revenue.
		Intellectual property rights	
	Creators retain content ownership under IP laws; Roblox enforces DMCA compliance and protects rights through reporting and takedown systems.	Assets are owned as NFTs with blockchain-based governance, ensuring creator rights, transparency, and fair revenue sharing while resolving disputes effectively.	Creators own their work but grant Epic usage rights. DMCA enforcement and reporting tools ensure IP compliance and protect original content.

Figure 3: Case study analysis

4.1 Insights from Case Study Analysis

The comparative analysis of three virtual worlds Roblox, Fortnite, and Decentraland enabled the identification of critical insights into the dynamics of UGE creation within digital environments. The analysis highlighted key factors such as the fragmentation of tools and processes across platforms, which revealed the need for a unified and structured framework. Second, the importance and the diffusion of real-time collaboration and community-led practices underscored the need for sustained support mechanisms that facilitate collective creativity and engagement. Third, the analysis identified limitations in current systems for onboarding novice creators, particularly in non-professional contexts, thus pointing to the need for accessible, inclusive design methods that accommodate diverse levels of technical and creative expertise. Fourth, issues regarding intellectual property rights and value distribution models highlighted the need for equitable governance, protecting and empowering creators within virtual economies. These emergent needs directly informed the construction of the proposed design-driven open innovation framework, which integrates co-creation, co-design, and co-production processes across the Double Diamond model, thus responding to both systemic and experiential challenges, providing methodological support for designing user-generated experiences in ways that are participatory, technologically enabled, and economically sustainable.

5. Theoretical Framework

This study conceptualized a framework integrating (i) the three core dimensions of Open Innovation—co-creation, co-design, and co-production— and (ii) the four stages of the Double Diamond model (Design Council, 2005)—Discover, Define, Develop, and Deliver, alongside a set of tailored sub-phases specific to UGE development. Specifically, this study builds on Nessler's (2016) version of the Double Diamond, extracting from its 15 phases a seven-phase model (Figure 4) for UGE creation in virtual worlds, spanning from need identification to iterative testing.



Figure 4: Seven Design phases for UGE creation in VWs.

The proposed framework (Figures 5 and 6) is designed to enhance UGE creation within VWs, focusing on the design of immersive experiences while addressing the existing gaps. Each open innovation mode is mapped onto corresponding stages of the design process to highlight the evolving role of user participation, and tailoring the Double Diamond model to the specific needs of immersive experience design thus deriving adapted phases for UGE Development.

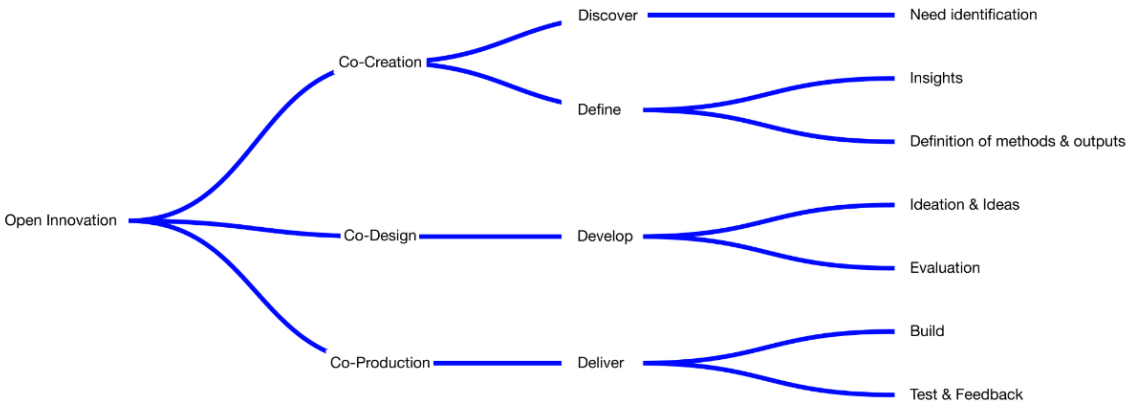


Figure 5: Theoretical Framework: Structure

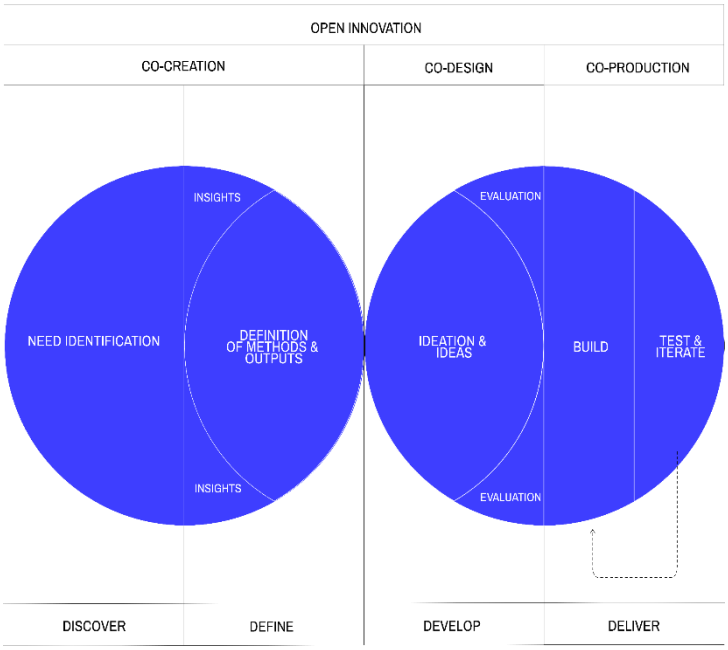


Figure 6: Theoretical Framework: Interaction of the instances

Co-creation is mapped onto the *Discover* and *Define* phases, which form the foundation for contextual understanding and strategic framing. In *Discover*, the **Need Identification** focuses on uncovering and articulating the core needs and challenges faced by users and stakeholders. It involves analyzing the user context, mapping user journeys, understanding their environments, behaviors, and motivations, identifying barriers and opportunities, as well as environmental and social factors that shape user experiences in virtual worlds. As a consequence, it fosters reflective thinking and helps surface what matters most, thereby ensuring that user-centered solutions are grounded in real-world concerns. In *Define*, the **Insights** phase involves translating raw data into meaningful narratives that explain why users behave the way they do, what matters most to them, and where existing systems fail to meet their expectations. It synthesizes data and observations into meaningful, actionable takeaways, revealing patterns in user behavior, reframing challenges, and serving as a springboard for innovation by shifting perspectives and anchoring the process in deep user empathy—they provide the interpretive lens through which design challenges are reframed. The **Definition of Methods & Outputs** phase shifts toward structuring the design problem in a clear and actionable way. It involves crafting a well-framed design challenge, by translating user insights into clear, strategic design questions. It helps structure the design challenge, define outcomes, and guide teams toward targeted ideation, thus supporting a reflective activity that ensures alignment across stakeholders and creates a coherent brief for the next phase.

Co-design takes place during the *Develop* phase, where users actively contribute to generating and refining solutions. The **Ideation & Ideas** phase encourages creative exploration, where diverse concepts are brainstormed and articulated in response to the defined challenge. Emphasis is placed on encouraging divergent thinking and avoiding premature convergence. Ideas are shaped to address specific user needs while considering feasibility, impact, and implementation strategies. In the **Evaluation** phase, concepts are systematically assessed to identify those with the highest potential. It involves assessing and prioritizing these ideas based on criteria such as user value, technical viability, and innovation potential, through a structured decision-making process aimed at identifying the most promising concepts to be selected for further development. Evaluation methods may include comparative matrices, user voting, expert panels, feasibility analyses, and so on. Importantly, users remain engaged during this phase through co-evaluation techniques, ensuring that their voices continue to shape the selection and refinement of ideas. The outcome is a shortlist of well-founded, high-impact concepts that are ready for prototyping and implementation.

Co-production is embedded in the *Deliver* phase, where users become key collaborators in shaping and implementing the final experience. The **Build** phase involves developing and refining prototypes that translate conceptual ideas into tangible prototypes. Prototypes can range from low-fidelity mockups (e.g., paper sketches, wireframes) to high-fidelity interactive prototypes or immersive digital models, allowing creators to test core features and interactions. It also considers technical feasibility and usability, laying the groundwork for implementation in virtual environments. Technical teams collaborate with user-creators to experiment with different formats and functionalities. This stage also involves planning for production and implementation,

addressing project management dimensions such as timeline, resources, and stakeholder responsibilities. Finally, the **Test & Feedback** phase focuses on structured testing of prototypes with end users through usability sessions, live trials, playtests, and feedback loops. The aim is to assess how well the prototype performs in real or simulated conditions and to identify areas for improvement. Testing protocols are designed to capture qualitative and quantitative feedback, validate key assumptions, and ensure alignment with user expectations. This phase often includes rapid iteration cycles—implementing changes, re-testing, and refining until a stable and user-approved version emerges. The outcome is a validated solution with a clear pathway for full deployment in the VW.

The theoretical framework presented was validated across all its phases through a systematic comparison with the analyzed literature. This validation process, summarized below, highlights the conceptual alignment between Open Innovation, the Double Diamond model, and the extensive scientific discourse on VWs. It identifies supporting literature for each phase, thus demonstrating the relevance and coherence of the framework in addressing the complexities of UGE creation within VWs.

	Instance	Description	References
Approach	Open Innovation	In the context of VWs, Open Innovation emphasizes participation, shared governance, and community-driven insights, enabling a wide range of contributors—users, developers, and stakeholders—to engage in the creation of User generated content. By lowering barriers to entry and leveraging collective intelligence, this approach enhances both creative diversity and technological adaptability. The framework also ensures that collaboration aligns with the platform's ecosystem and evolving user needs, fostering an environment where content generation is continuous, user-driven, and capable of scaling efficiently. This enables virtual worlds to remain engaging, sustainable, and responsive to emerging trends, reinforcing their role as interactive and evolving digital spaces.	Chesbrough (2003, 2019); Wielinga & Robijn (2023); Friedman & Hendry (2019); Nolte et al. (2022); Kou & Gui (2023)
Process	Co-creation	Co-Creation is the collaborative process where users, designers, and platform stakeholders actively contribute to shaping interactive content, virtual environments, or digital assets. This phase emphasizes participatory ideation, where users are not just consumers but also co-developers of experiences within a platform. It involves investigating the creative and technical possibilities, aligning user motivations with platform affordances, and fostering an open innovation environment.	Prahalad & Ramaswamy (2004); Chesbrough (2003);
	Co-design	Co-Design is a collaborative approach where ideas transition from concept to prototype, enabling creators to actively develop and refine User-Generated Content ideas for immersive experiences. This phase focuses on transforming conceptual insights into tangible ideas, ensuring that solutions are feasible, original, and user-centered.	Brown (2008); IDEO (2013); Mattelmäki & Visser (2011)
	Co-production	Co-Production is the implementation phase where prototypes are developed, integrated, and tested within the platform's ecosystem. This stage emphasizes turning designs into functional content, ensuring that UGC meets both user expectations and platform standards. Through modeling, publishing, playtesting, and iteration, creators refine their work, leveraging user feedback to enhance engagement, usability, and overall quality.	Rzeszewski & Evans (2020); Maloney & Freeman (2020)
DD Phases	Discover	The Discover Phase serves as the foundation for understanding how users interact with UGC in virtual worlds. This phase investigates the motivations, barriers, and behavioral patterns that shape user participation in creating, engaging with, and living UGC-driven experiences. Through qualitative research, it seeks to uncover insights that inform the design and development of more engaging and accessible platforms.	Design Council (2005), Nessler (2021)
	Define	The Define Phase synthesizes insights gathered during the Discover Phase to establish clear, actionable goals. This phase serves as a bridge between research and implementation, ensuring that identified challenges, opportunities, and user needs translate into strategic, well-defined objectives that guide the next steps in the process.	Design Council (2005), Nessler (2021)

	Develop	The Develop Phase is dedicated to the ideation, and refinement of ideas and workflows that facilitate collaborative User-Generated Experiences creation. This phase builds upon the insights generated during Co-creation, focusing on enhancing efficiency, usability, and co-creation dynamics within immersive platforms.	Design Council (2005), Nessler (2021)
	Deliver	The Deliver Phase is the stage where the UGE framework is implemented through prototyping, testing, and iterative refinement. This phase ensures that User-Generated Experiences are functional, engaging, and aligned with user expectations before full deployment. By gathering feedback, addressing technical issues, and enhancing usability, teams refine their solutions to deliver high-quality, immersive outputs.	Design Council (2005), Nessler (2021)
Phases	Need identification	The Need Identification Phase is focused on understanding and defining the core needs of users and stakeholders. Through tools like Problem Framing, Sense-Making Wall, User Map, and User Value Map, this phase analyzes the problem, maps users, and identifies the values and motivations driving their needs. It sets the foundation for user-centered solutions by clarifying what matters most to those involved.	Mattelmäki & Visser (2011); Friedman & Hendry (2019)
	Insights	The Insights Phase is dedicated to highlight deeper understandings from gathered data and observations, ensuring that user needs, behaviors, and motivations are synthesized into meaningful, actionable insights. These insights serve as the foundation for reframing challenges and driving innovative solutions.	Schuler & Namioka (1993); Voorberg et al. (2015); Maloney & Freeman (2020)
	Definition of Methods and Outputs	The Definition of Methods and Outputs Phase focuses on reframing the problem and structuring it into actionable questions that drive creative and strategic ideation. By utilizing tools like Problem Reframing and How Might We (HMW) statements, this phase ensures that teams consolidate their understanding of the challenge while articulating it.	IDEO (2013); Design Council (2005); Zhu et al. (2019); Nessler (2016)
	Ideation and Ideas	The Ideation and Ideas Phase is centered on generating, exploring, and naming concepts that address key challenges. This phase encourages unconstrained creativity, allowing teams to brainstorm diverse solutions that can later be refined and evaluated.	Prahalad & Ramaswamy (2004); Füller et al. (2011); Kou & Gui (2023)
	Evaluation	The Evaluation Phase is a structured process designed to assess, compare, and prioritize ideas using the Evaluation Matrix. This phase ensures that the most feasible and original ideas are selected for further development. By systematically rating concepts against predefined criteria, this tool ensures that the chosen solution aligns with project objectives and user needs.	Rzeszewski & Evans (2020); Friedman & Hendry (2019); Maloney & Freeman (2020)
	Build	The Build Phase is dedicated to creating, testing, and refining prototypes to advance the development of solutions. This phase transitions ideas into tangible forms, allowing teams to explore feasibility, usability, and functionality in a structured and iterative manner. By leveraging tools like the Experimentation Card, Lo-Fi Prototypes, and Advanced Prototypes, this phase ensures that solutions evolve based on user feedback and technical validation.	Brown (2008); Hollensen et al. (2022)
	Test & Feedback	The Test & Feedback Phase is a crucial step in refining solutions, ensuring that both the prototype and its supporting operational processes function effectively. By continuously testing, refining, and optimizing, teams validate assumptions, enhance user experience, and streamline operational efficiency before full deployment	Flanagan & Nissenbaum (2014); Füller et al. (2011); Schuler & Namioka (1993); Friedman & Hendry (2019)

Figure 7: Framework validation against literature

6 Discussion & Conclusions

6.1 Addressing Key Gaps

The design-driven framework presented directly addresses the key gaps identified in the literature. (i) It responds to the lack of unified frameworks by offering a structured, collaborative process that guides creators through all stages of UGE development, drawing on both theoretical foundations and insights from real-world platforms. (ii) It mitigates the limited support for inclusive, broad, and sustained creative participation by integrating methodologies such as UCD, enabling contributions from both novice and expert users, and thus

empowering various users to actively engage in the creation process. This accessibility-oriented approach lowers technical entry barriers, fosters creative inclusiveness, and encourages diverse content creation. (iii) At the same time, it addresses the challenge of balancing creativity with desirability by embedding engagement-focused methods and phases that prioritize user relevance and meaning. In doing so, it enhances creator agency while ensuring alignment with the values and expectations of target communities. (iv) It responds to the need for tailored support to sustain new business opportunities emerging from the evolving economies of VWs. Drawing from Maloney and Freeman (2020), the framework incorporates methods and principles that enable creators not only to contribute creatively but also to engage meaningfully in the economic structures of the platforms, by embedding mechanisms and could possibly implement technologies that emphasize transparency, intellectual property awareness, and value co-creation. Furthermore, the framework fosters the emergence of participatory business models that are both scalable and inclusive, positioning creators as key stakeholders within VW economies, allowing them to co-define outputs and to benefit from more equitable innovation dynamics.

6.2 Study limitations and future research directions

While the proposed framework offers a robust and theoretically grounded contribution to the design and governance of UGE creation in VWs, several limitations must be acknowledged. (1) The framework was developed through a limited number of case studies—specifically Roblox, Fortnite, and Decentraland. Although these platforms represent leading models in the current VW landscape, the focus on three cases may limit the generalizability of the findings across other emerging platforms with different configurations. (2) The framework emphasizes qualitative and design-based methods, which, although appropriate for exploring user-centered innovation processes, do not include quantitative assessments or longitudinal impact evaluations, thus restricting the capacity to measure long-term effects of the framework on user engagement, content quality, or economic returns.

Building upon this, promising directions emerge for future research concern expanding the framework's validation across a broader sample of VWs including smaller platforms, educational environments, and open-source services would enhance the generalizability of findings. Furthermore, including comparative studies to test the adaptability in diverse contexts, and longitudinal studies to evaluate the sustained impact on creator engagement, content diversity, and business outcomes over time.

7 Ethics Declaration

No ethical clearance was required for the research presented in this paper.

8 AI Declaration

No artificial intelligence tools were used in the design, execution, or analysis of this study.

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Managing Prices in the Age of AI: A Taxonomy of AI Applications to Support Pricing Decisions

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Abstract

In an increasingly digitized and hypercompetitive market landscape, pricing is evolving from a static, cost-based process into a dynamic, strategic function powered by Artificial Intelligence (AI). Organizations are moving beyond traditional pricing models by leveraging real-time analytics, predictive modelling, and behavioural insights to enhance pricing decisions. AI enables large-scale automation and personalization of prices, allowing firms to adapt continuously to changes in demand, consumer behavior, and competitive signals. However, this shift also raises critical concerns regarding transparency, fairness, and algorithmic accountability—especially in consumer-facing markets, where price sensitivity and perceptions of justice directly influence trust and loyalty. This study shows how AI reshapes pricing across four impact areas—predictive modelling, real-time optimisation, behavioural adaptation, explainability and fairness—and, through a systematic literature review, distils a two-level taxonomy of AI applications in pricing. The findings demonstrate that AI-powered pricing enhances forecasting accuracy, enables granular and dynamic price optimization, and improves behavioural targeting through the integration of cognitive heuristics such as anchoring and loss aversion. These benefits, however, must be balanced against the heightened risks of opacity, unfair discrimination, and regulatory non-compliance, which can erode consumer trust. The study emphasises that AI is not merely a technological tool, but a transformative agent that reshapes market dynamics and redefines consumer expectations. As such, the adoption of transparent, explainable, and ethically aligned AI models is essential—not only to ensure compliance with emerging regulatory frameworks, but also to foster long-term consumer confidence and sustainable competitive advantage. The paper concludes by calling for interdisciplinary research to explore the longitudinal effects of AI-based pricing, ethical governance mechanisms, and the integration of social responsibility into algorithmic pricing strategies.

Keywords: Price Management; Behavioural Economics; Artificial Intelligence; Systematic Literature Review; Marketing

Paper type: Academic Research Paper

1 Introduction

The increasing digitalization of global markets has profoundly transformed pricing, elevating it from a rule-based administrative function to a strategic, data-driven lever. Once grounded in cost-plus logic or fixed price lists, pricing is now shaped by real-time analytics, algorithmic models, and, increasingly, behavioural insights. More recently, Artificial Intelligence (AI) has become a prominent driver of this transformation. AI empowers organizations to automate pricing determinations while simultaneously enhancing these processes through predictive capabilities, contextual responsiveness, and psychological attunement (Prithi & Tamizharasi, 2025; Li et al., 2022).

In recent years, the literature has highlighted growing interest in the strategic potential of AI applied to pricing. Erdmann et al. (2024) propose a framework for evaluating AI-based pricing systems through the lenses of sustainability, regulatory alignment, and economic efficiency, underlining the importance of predictive accuracy and customer value creation. Gerlick and Liozu (2020) delve into the ethical and legal implications of algorithmic personalised pricing, emphasizing that perceptions of fairness and transparency are critical for consumer acceptance. This transition—from manual segmentation to algorithmically optimised targeting—reflects a broader shift toward AI-driven value extraction and reinforces the need for transparency and explainability in automated systems.

Agarwal et al. (2024) stress that algorithmic opacity may hinder not only regulatory compliance but also managerial capacity to interpret and govern pricing logic. In response, tools from the field of Explainable Artificial Intelligence (XAI)—such as SHapley Additive exPlanations (SHAP) and Local Interpretable Model-agnostic Explanations (LIME)—help reconstruct pricing rationale, thereby enhancing interpretability and trust (Peng et al., 2023). Concurrently, the integration of behavioural economics into AI models is gaining momentum. Shan and Li (2025) demonstrate that cognitive biases such as anchoring and loss aversion significantly affect price perception and can be embedded in intelligent systems to reinforce personalisation. In the tourism sector, for

example, Nguyen and Nguyen (2025) show how reinforcement learning-based dynamic pricing algorithms can adjust in real time to consumer preferences, improving financial performance.

This study contributes to this interdisciplinary dialogue by synthesising insights from machine learning, behavioural economics, and algorithmic governance to explore how AI is reshaping pricing architectures. Through a systematic literature review, four thematic dimensions are identified through which AI impacts pricing decisions: predictive modelling, real-time optimisation, behavioural adaptation, explainability and fairness.

The remainder of the paper is structured as follows: Section 2 outlines the theoretical background, with particular attention to AI methodologies and behavioural pricing theories. Section 3 describes the research methodology, including the literature review strategy and the development of the taxonomy. Section 4 presents the key findings, organised around the four thematic dimensions. Finally, Section 5 offers theoretical, managerial, and policy-related implications and suggests avenues for future research.

2 Theoretical Background

This section outlines the interdisciplinary theoretical foundations that inform the integration of Artificial Intelligence (AI) in pricing systems. The focus is placed on the convergence of computational methods, behavioural economics, and governance frameworks. Special attention is given to the mechanisms through which AI technologies shape, and are shaped by, consumer psychology and regulatory imperatives. The section is structured in two interrelated subsections: AI methodologies in pricing, and behavioural pricing theories.

2.1 AI Methodologies in Pricing

Artificial Intelligence (AI) has introduced new paradigms in pricing by enabling firms to shift from reactive, rule-based strategies to proactive, data-driven optimisation (Duan et al., 2019; Davenport et al., 2020). Among the most widely adopted methodologies are supervised learning, unsupervised learning, and reinforcement learning. Supervised learning techniques—such as eXtreme Gradient Boosting (XGBoost) and Long Short-Term Memory (LSTM) networks—are commonly used to forecast demand, estimate price elasticity, and analyse market dynamics based on historical, behavioural, and contextual data (Ma & Sun, 2020; Kumar et al., 2019). These models support a wide array of pricing applications, including dynamic price adjustment, personalised promotions, and contextual targeting. In AI-powered environments like e-commerce, these capabilities allow companies to adapt offers in real time, increasing pricing precision and relevance (Huang & Rust, 2021; Corbo et al., 2022). Unsupervised learning, typically implemented through clustering algorithms, enables the identification of latent customer segments without the need for predefined labels. These clusters serve as a foundation for differentiated pricing strategies based on behavioural profiles and contextual relevance (Erevelles et al., 2016; Sestino & De Mauro, 2021). In practice, this enables more accurate segmentation and microtargeting, especially in environments where consumer preferences are dynamic and unstructured. Reinforcement learning offers a more autonomous and adaptive approach, where pricing algorithms learn over time by interacting with consumers and market signals. These models adjust prices dynamically, responding to real-time feedback such as user behaviour, conversion rates, and competitive movements (Guda & Subramanian, 2019; Campbell et al., 2020). Applications of reinforcement learning are particularly effective in scenarios such as surge pricing, auction-based platforms, and real-time bidding. As these AI-driven methodologies advance, they bring growing concerns about algorithmic opacity and the need for explainability. Tools from the field of Explainable Artificial Intelligence (XAI)—including SHapley Additive exPlanations (SHAP) and Local Interpretable Model-agnostic Explanations (LIME)—enable stakeholders to interpret, audit, and validate automated pricing decisions (Peng et al., 2023; Davenport et al., 2020). These tools play a crucial role in maintaining transparency, regulatory compliance, and consumer trust in complex algorithmic environments.

2.2 Behavioural Pricing Theories

Behavioural pricing theories are grounded in the notion that consumers do not respond to prices in fully rational ways, but are influenced by heuristics, cognitive biases, and emotional factors. Integrating these principles into AI-supported pricing systems enables the development of more persuasive, adaptive, and personalised strategies (Shan & Li, 2025; Huang & Rust, 2021). Among the most relevant biases are the anchoring effect, whereby consumers evaluate prices relative to an initial reference point, and loss aversion, which amplifies the perceived impact of a price increase compared to an equivalent discount. These psychological mechanisms are increasingly embedded into machine learning models, allowing prices to be tailored to individual thresholds of acceptability (Ma & Sun, 2020; Kumar et al., 2019). In digital environments, such approaches manifest through techniques like charm pricing (e.g., €9.99 instead of €10), urgency framing, and

perceptual customisation of offers. The literature also highlights that the application of AI in personalised pricing must balance persuasive effectiveness with ethical and reputational considerations. Corbo et al. (2022) emphasise the importance of transparent models capable of explaining the rationale behind price recommendations. Excessive opacity can generate perceptions of manipulation or discrimination, undermining consumer trust and diminishing purchase intent (Davenport et al., 2020; Erevelles et al., 2016). Moreover, AI technologies allow real-time monitoring of consumer behavioural responses, enabling dynamic adaptation of pricing strategies. In particular, reinforcement learning models can learn which psychological patterns are most effective for each customer segment, thus enhancing the precision of personalisation (Campbell et al., 2020; Guda & Subramanian, 2019). Finally, the adoption of Explainable AI (XAI) approaches is equally crucial in behavioural pricing: explaining not just what is proposed, but why, can significantly increase consumer acceptance of AI-driven recommendations and reduce psychological resistance (Sestino & De Mauro, 2021; Duan et al., 2019). In this sense, algorithmic governance should not be viewed solely as a regulatory constraint, but as a strategic lever for building long-term relationships with increasingly fairness-sensitive customers.

3 Methodology

This research adopts a Systematic Literature Review (SLR) methodology as a structured, transparent, and replicable approach to synthesising existing knowledge, consistent with best practices in management and artificial intelligence adoption research (De Mauro et al., 2019; Duan et al., 2019). Unlike narrative reviews, often characterised by a higher degree of subjective interpretation, SLRs minimise bias through the application of rigorous protocols and standardised procedures. To ensure methodological transparency, the review process was aligned with the PRISMA framework (Moher et al., 2009), which provides a structured guideline for article identification, screening, eligibility assessment, and inclusion. The PRISMA method is widely recognised for enhancing the transparency, replicability, and methodological rigour of systematic reviews across management, information systems, and data analytics research (De Mauro et al., 2019). The methodological approach was articulated into three main phases: (i) selection of the article corpus; (ii) extraction and categorisation of article content; (iii) analysis of AI-related pricing dimensions through structured content analysis. This multi-layered process ensured both analytical depth and procedural replicability, enabling the development of a dual-level taxonomy that illustrates how artificial intelligence technologies are reshaping pricing decision-making across predictive, behavioural, and ethical dimensions.

3.1 Review Scope and Selection Criteria

The scope of this review was defined at the intersection between AI-driven pricing models, behavioural pricing mechanisms, and the ethical and regulatory challenges associated with algorithmic governance. The literature search was conducted exclusively using the Scopus academic database by employing a structured query:

((TITLE (price) OR TITLE (pricing)) AND (TITLE ("artificial intelligence") OR TITLE (ai) OR TITLE ("analytics"))) AND PUBYEAR > 2009 AND PUBYEAR < 2026 AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "cp")) AND (LIMIT-TO (LANGUAGE , "English"))

Because this string already limits results to English-language journal articles (“ar”) and conference papers (“cp”) published between 2010 and 2025, several inclusion criteria were operationalised at the search stage. To ensure relevance and quality, four inclusion criteria were applied: (i) peer-reviewed journal articles or conference papers written in English; (ii) publication years 2010-2025; (iii) explicit focus on AI applications to pricing with managerial, behavioural, strategic, ethical, or regulatory implications; and (iv) availability of the full text. Studies were excluded when they (a) addressed purely technical AI issues without a pricing or managerial dimension, (b) reported single, non-generalisable case studies, or (c) lacked retrievable full texts.

In the first phase, a preliminary screening was conducted based solely on the titles and abstracts of the identified documents. As a result of the initial bibliographic search conducted through Scopus using a structured query string, a total of 337 contributions were identified. A first screening phase was carried out to filter out articles that were not relevant to the scope of the research, leading to the exclusion of 237 contributions that did not align with the intended research domain. A refined set of 100 articles was then subjected to a deeper review, with a focus on the presence of specific keywords, thematic alignment with the field of AI in pricing, and overall methodological robustness. This qualitative assessment led to the final selection of 52 contributions, which represented the most relevant and insightful works for the purposes of the structured content analysis and taxonomy elaborated in the study. Figure 1 summarizes the resulting article selection process.

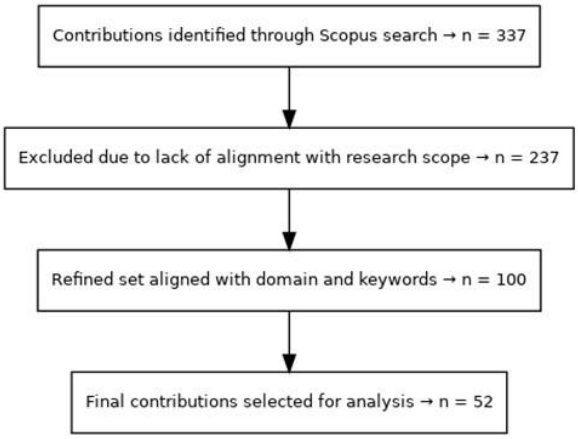


Figure 1: Funnel diagram of the article selection process.

3.2 Structured content analysis

Following the article selection phase, a Structured Content Analysis was conducted to classify the main pricing mechanisms and themes identified across the reviewed articles. Inspired by the methodological approach proposed by Kohlegger, Maier, and Thalmann (2009), a human-coding procedure was used. Key concepts were grouped into recurring thematic patterns through an iterative categorization process, which resulted in the four dimensions shown in Table 1. In the taxonomy, each dimension represents a high-level impact area; within every impact area, we further identified recurrent use-case scenarios that specify how AI supports pricing practice. This method enabled the development of a coherent and replicable taxonomy, systematically capturing the strategic, behavioural, operational, and ethical dimensions underpinning AI applications in pricing systems.

Table 1: Summarized output of the structured content analysis: impact-area clusters, document count, corpus share, and representative keywords.

Impact area	Papers (n)	Share of corpus	Representative keywords
Predictive Modelling	20	39%	demand forecast, price elasticity, time-series
Real-Time Optimisation	11	21%	dynamic pricing, surge, RL
Behavioural Adaptation	8	15%	anchoring, loss aversion, personalisation
Explainability and Fairness	13	25%	SHAP, LIME, transparency

4 Findings and Discussion

This section discusses the key findings, organised around the four impact areas and their associated use-case scenarios, as identified in this study. Each branch of the taxonomy, shown in Figure 2, reflects a distinct pathway through which Artificial Intelligence (AI) is reshaping pricing mechanisms across industries.

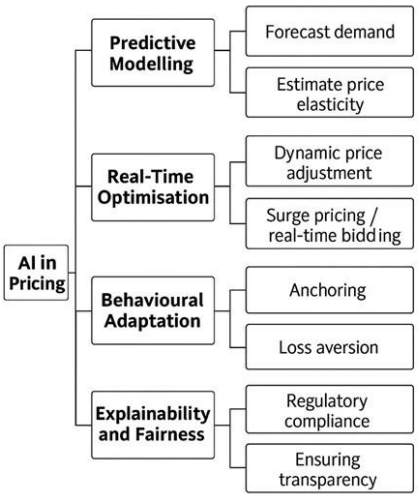


Figure 2: Two-level taxonomy of AI in pricing: impact areas (Level 1) and illustrative use-case scenarios (Level 2).

4.1 Predictive Modelling

Predictive modelling refers to the use of supervised learning algorithms to anticipate demand trends, forecast price elasticity, and optimise pricing strategies based on historical and contextual data. Techniques such as Extreme Gradient Boosting (XGBoost) and Long Short-Term Memory networks (LSTM) have proven highly effective in this area (Ma & Sun, 2020; Kumar et al., 2019). Applications in industries like e-commerce and transportation demonstrate the strategic advantage of leveraging demand forecasting to drive dynamic price adjustments (Li et al., 2022; Nguyen & Nguyen, 2025). Moreover, research indicates that predictive models increasingly incorporate external variables—such as competitor behaviour and macroeconomic indicators—to refine their accuracy and business relevance (Duan et al., 2019).

4.2 Real-Time Optimisation

Real-time optimisation focuses on deploying reinforcement-learning (RL) algorithms that enable dynamic price adjustments and surge-pricing or real-time bidding schemes in response to market signals. This approach is particularly critical in sectors where supply and demand conditions fluctuate rapidly, such as tourism and ride-sharing (Guda & Subramanian, 2019; Nguyen & Nguyen, 2025). For instance, dynamic pricing algorithms allow companies to optimise occupancy rates and revenue by adapting to real-time consumer behaviour and booking patterns (Sidlauskiene, Joye, & Auruskeviciene, 2023). Recent advances in RL not only improve financial performance but also enhance customer satisfaction by offering contextually appropriate prices (Peng, Peng, & Xu, 2024).

4.3 Behavioural Adaptation

Behavioural adaptation highlights how AI models integrate cognitive biases into pricing strategies, aligning offers with consumer decision-making heuristics. Anchoring effects, loss aversion, and charm pricing are increasingly embedded within algorithmic designs (Huang & Rust, 2021; Erevelles, Fukawa, & Swayne, 2016). For example, charm pricing techniques—such as setting a price at €4.99 instead of €5.00—have been shown to significantly affect purchase intention (Jeong, Choo, & Yoon, 2021). Moreover, recent studies emphasise the role of behavioural targeting enhanced by AI in personalising price offers to individual cognitive profiles, thereby optimising perceived value and conversion rates (Prithi & Tamizharasi, 2025; Shan & Li, 2025).

4.4 Explainability and Fairness

The final dimension addresses the growing need for transparency and ethical safeguards in AI-based pricing systems. Explainable Artificial Intelligence (XAI) frameworks, such as SHapley Additive exPlanations (SHAP) and Local Interpretable Model-agnostic Explanations (LIME), are increasingly adopted to provide understandable rationales for algorithmic pricing decisions (Sestino & De Mauro, 2021; Davenport et al., 2020). This concern is particularly critical in pricing contexts where customers may perceive algorithmic adjustments as unfair or opaque (Peng, Peng, & Xu, 2023). Furthermore, regulatory frameworks like the General Data Protection Regulation (GDPR) are compelling firms to design pricing algorithms that are transparent, accountable, and free from discriminatory practices (Gerlick & Liozu, 2020; Elyakim, 2025). Research suggests that explainability not only supports legal compliance but also enhances consumer trust and loyalty, ultimately contributing to a more sustainable competitive advantage (Raphael et al., 2024; Zhou et al., 2025).

5 Conclusions and Implications

The present study contributes to the growing body of literature at the intersection of AI, behavioural economics, and pricing strategy by proposing an integrated framework that describes the four impact areas of AI in pricing and how they are linked to concrete use-case scenarios. It enriches existing theory by demonstrating how AI not only automates pricing decisions but actively co-shapes market dynamics and consumer behaviour. In line with Erdmann et al. (2024), the analysis highlights that ethical and sustainability dimensions must now be considered core criteria in evaluating AI-enhanced pricing models.

From a managerial perspective, the paper underscores that AI-powered pricing systems represent both a technological opportunity and an organisational challenge. Managers must not only select appropriate AI techniques—such as Extreme Gradient Boosting (XGBoost) for demand forecasting or Reinforcement Learning (RL) for real-time price adjustments—but also ensure their alignment with strategic objectives and ethical principles. As demonstrated by Harley-Davidson's experience with AI-driven campaign optimisation (Power, 2017), pricing engines achieve superior results when designed to iteratively learn from behavioural and

contextual data. Furthermore, for small and medium-sized enterprises (SMEs), a focused approach is critical: prioritising specific high-impact pricing applications over generic AI adoption optimises resource utilisation and strategic fit.

From a regulatory standpoint, the study reinforces the urgent need to develop coherent legal frameworks capable of addressing the opacity, discrimination risks, and asymmetries of power generated by algorithmic pricing systems. Gerlick and Liozu (2020) caution that unchecked personalised pricing can erode consumer trust and exacerbate social inequalities. In this regard, the integration of Explainable Artificial Intelligence (XAI) tools — such as SHapley Additive exPlanations (SHAP) and Local Interpretable Model-agnostic Explanations (LIME) — should be mandated for consumer-facing algorithms, particularly when price discrimination practices are involved. While initiatives like the European Union's AI Act and the General Data Protection Regulation (GDPR) lay critical foundations, issues related to enforcement and practical interpretability remain significant challenges.

The evolution of AI-driven pricing systems presents several promising avenues for future research. Empirical studies are needed to assess how different AI techniques — such as Reinforcement Learning (RL) and Explainable Artificial Intelligence (XAI) — influence consumer trust and long-term loyalty in dynamic pricing contexts (Sestino & De Mauro, 2021; Davenport et al., 2020). As new tools for algorithmic transparency are developed, it becomes increasingly important to evaluate not only their technical performance but also their perceptual impact on consumers. A relevant direction concerns the interaction between AI-based pricing and sustainability objectives. As highlighted by Raphael et al. (2024), the integration of AI in price management must increasingly incorporate environmental and social governance (ESG) criteria to ensure responsible innovation. Investigating how pricing algorithms can be optimised not only for profit maximisation but also for sustainable consumption behaviours represents a key opportunity for future studies. Interdisciplinary research is also essential to understand the broader socio-economic consequences of AI-powered price personalisation. Insights from behavioural economics, digital ethics, and consumer protection law can contribute to designing algorithms that balance personalisation with fairness and inclusivity (Gerlick & Liozu, 2020; Elyakim, 2025). Finally, long-term empirical investigations are necessary to explore the organisational capabilities and cultural transformations required for the successful implementation of AI-based pricing. We corroborate recent contributions (De Mauro & Pacifico, 2024) stressing that technological adoption alone is insufficient without corresponding changes in data governance, leadership strategies, and continuous learning practices. By addressing these areas, future research can enhance the effectiveness of AI-based pricing systems while contributing to the development of a more transparent, ethical, and sustainable digital economy.

6 Ethics Declaration

This study did not involve human participants, personal data, or ethically sensitive content requiring formal clearance. No ethical approval was necessary.

7 AI Declaration

This paper was developed with the support of an AI-based assistant for drafting and language refinement. All content has been reviewed and validated by the authors to ensure academic accuracy, integrity, and originality.

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Knowledge Management in Diverse Organizations: A Meta-Data Analysis

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Abstract

The concept of Diversity in the Workplace (DiW) and the Knowledge Management (KM) concept have been the subject of extensive analysis from a wide range of perspectives, typically at the micro, meso or macro level. However, there remains a paucity of research addressing the interrelation between these two concepts. The present study adopts an exploratory approach, utilising a bibliometric co-citation and coupling technique in conjunction with a comprehensive literature review. This approach offers novel insights into the past and present dynamics of the intellectual structure. The co-citation study reveals three predominant clusters within the intellectual structure, two of which are associated with the primary variables, i.e. KM and DiW, while a third serves as a theoretical framework for the interrelation between KM and DiW. In contrast, contemporary research trends are oriented towards the role of the TMT (or upper echelons in general) in KM, the significance of inter-organizational collaboration, and the management of "distance" due to heterogeneity. This study aims to explore the interrelation between DiW and KM. The findings reveal that the intellectual evolution of research commences with the concept of DiW, progressing to KM, and culminating in the theoretical nexus between them.

Keywords: Knowledge management, Surface diversity, Deep-end diversity, Bibliometric approach, Literature review

Paper type: Academic Research

1 Introduction

According to the latest report published by Eurostat (2024), the foreign-born represent 13% of the total EU population. Things get even more interesting when considering the age range between 15 and 64 years old as very close to the age of the active European workforce. The data indicates that 15.6% of the European workforce is composed of foreign-born employees. In other words, considering a team of 10 members, very probably, that there will be two almost two foreign-born members. The situation seems to be even more intense when considering the United States of America. In fact, according to the data published by the Federal Reserve Bank, in January 2025, 19,5% of the total American workforce is foreign-born. In 2007, only 15,58% of the workforce was foreign-born, confirming an exponential increase of almost 27%.

The increasing international interdependence among organizations, partly driven by globalization, has introduced significant challenges that must be addressed Fischer (2003). Among these challenges, the effective management of DiW—both within and beyond organizational boundaries—stands out as particularly critical (Nishii & Özbilgin, 2007; Singh, 2018). This necessity is even more pronounced in today's VUCA (volatile, uncertain, complex, and ambiguous) environment, where rapid and appropriate strategic adjustments are essential (Rathore et al., 2021). In this regard, scholars such as Urbancová et al. (2020) and Erburu et al. (2005) argue that if managed effectively, DiW can lead to a sustainable competitive advantage, as theorized by Barney (1991).

Conversely, KM has emerged as one of the most critical capabilities for contemporary organizations, as it serves as a key driver of sustainable competitive advantage (Mahdi et al., 2019). In this context, Torres et al. (2018) analyzed the relationship between knowledge-related factors, such as human capital while Johannessen and Olsen (2003) emphasized the importance of dynamic, context-specific training.

Nevertheless, there has been a paucity of attention paid to the interrelation between DiW and KM. By "interrelation," we refer to the bidirectional interactions among these variables. In essence, this entails the inquiry into whether DiW exerts a driving influence on KM practices, or if effective KM practices engender DiW.

To shed light on this "black box", the authors adopted a mixed methodology, combining the bibliometric approach, based on co-citation, and bibliometric coupling techniques, as well as a selective literature review. The bibliometric study was conducted following the PRISMA protocol (Moher et al., 2015) and adhered to the guidelines proposed by Donthu et al. (2021) and Zupic and Čater (2015).

Based on this framework, the following research questions were established:

- *RQ1: What are the general dynamics surrounding the interaction KM-DW*
- *RQ2: What is the intellectual structure of the research*
- *RQ3: What are the current research trends*

2 Theoretical frameworks

2.1 Knowledge Management

To manage knowledge as an asset in an effective manner, it is first necessary to develop a comprehensive understanding of the concept since there is not a general and universally accepted definition. Among the most salient definitions of knowledge is that proposed by (Davenport and Prusak 1998: 5) which define it as *a fluid mix of framed experience, values, contextual information, and expert insight that provides a framework for evaluating and incorporating new experiences and information.* In contrast, I. Nonaka (1994) defines knowledge as being *"justified truth".* However, to properly exploit this valuable asset it is extremely important to properly manage it (Alavi and Leidner 2001; Omotayo 2015). In this regard, generally, scholars refer to KM as the process of capturing, organizing, storing, and sharing knowledge within an organization to enhance its overall performance and competitive advantage.

Grant (1996a), posits that, under the knowledge-based theory of the firm, the most salient characteristics for effective knowledge utilization are transferability, capacity for aggregation, appropriability, specialization in knowledge acquisition, and the knowledge requirements for production. The whole KM process is comprised of various phases, which are categorized into two fundamental categories: knowledge creation and knowledge application. The former encompasses activities such as knowledge creation and acquisition, with consideration for the knowledge's origin, whether internal or external. Conversely, the second category is more focused on activities such as integration, transferability, storage, measurement, and protection.

In the field, special relevance has the SECI model proposed by L. Nonaka et al. (1996). The model distinguishes between tacit and explicit knowledge and based on their interaction explains how knowledge is created and converted. Other authors have highlighted the relevance of knowledge as a strategic resource that can further improve the competitiveness of an organization (Boisot 1998; Donate and Canales 2012; Tallman et al. 2004) or lead to a sustained competitive advantage (DeNisi et al. 2003)

2.2 Diversity in the workplace. Dimensions, benefits, and challenges

Despite the absence of a universally accepted definition of the concept of diversity, it is generally understood within organizational contexts to denote the presence of individuals from diverse backgrounds, encompassing, but not limited to, factors such as race, ethnicity, gender, age, religion, sexual orientation, disabilities, and cultural backgrounds. This concept encompasses a range of dimensions that contribute to the richness and variety of perspectives within an organization (Cox & Blake, 1991).

Different authors have enhanced the benefits that DiW can generate in an organization (Smith & Schonfeld, 2000). Among them, DiW enhances innovation and creativity as it fosters the generation of new ideas and solutions by bringing together individuals with different perspectives and knowledge being in some specific situations a source of conflict as well (Bassett-Jones 2005). Diverse teams are more likely to challenge conventional thinking, encouraging creativity and innovation (Hoever et al. 2012; Paulus 2000). In addition, Cummings (2004) has pointed out the significant improvement in problem-solving and decision-making. Diverse teams consider a wider range of viewpoints and approaches when addressing complex problems. They bring different insights and experiences, leading to more comprehensive and effective decision-making processes. Also, DiW might generate increased adaptability and flexibility capabilities. Organizations with diverse workforces are better equipped to adapt to changes in the business environment. Different backgrounds and perspectives facilitate flexibility and agility in responding to market shifts and customer demands (Boone & Hendriks, 2009).

Proper management of the DiW can lead to other benefits such as enhanced employee engagement and satisfaction. Inclusive environments that value diversity create a sense of belonging and psychological safety for employees(Downey et al. 2015). When individuals feel respected and valued for their unique contributions, it leads to higher levels of engagement, job satisfaction, and retention (Rich et al. 2010). Also, there are many challenges related to the concept of diversity such as discrimination, communication and language barriers, resistance to change, Inclusion and lack of representation, group dynamics, and internal conflict.

3 A mixed methodology

The present research proposes a mixed methodology, combining a systematic literature review with a bibliometric approach. Specifically, the literature review identified the top 10 most relevant articles in the field, based on the received citations (Liang et al. 2011) which are considered to be one of the most relevant and used indicators of scientific production (Abramo et al. 2015). This combination of strategies has been implemented in various research studies, as these techniques are considered to be complementary (Zupic and Čater 2015). For instance, Feng et al. (2017) employed the same methodology to investigate the relevance of corporate social responsibility for the supply chain. Conversely, Bawack et al. (2022) utilized the same methodology to analyze the utilization of Artificial Intelligence in E-Commerce. In addition, Rashmi and Kataria (2022) utilized the same methodology in the context of work-life balance.

In general, the complementarity between the systematic literature review and the bibliometric techniques has been approached in two different ways. Firstly, according to Linnenluecke et al. (2020), the proper bibliometric visualization of the findings and discussion generated from the literature review renders the entire process replicable and more scientific. Consequently, the authors propose a guideline to be followed to properly enlarge the literature review section by using bibliometrics as a tool to visualize the data. Additionally, Marzi et al. (2025) have proposed a mixed methodology, termed the Bibliometric Systematic Literature Review (B-SLR), which combines the strengths of both approaches while mitigating their respective limitations. In this research, the literature review was conducted considering articles as research unit rather than at a cluster level, since one of the objectives was to properly identify the dynamics surrounding the research topic.

3.1. A bibliometric approach

Bibliometric studies generally retrieve the data from the Web of Science (WoS) or Scopus database. In cases where the data set is limited, both databases can be used, or other databases such as Google Scholar, PubMed, or JSTOR can be added. In this instance, the decision was taken to utilize the WoS platform, primarily due to its historical academic relevance and the current trends observed in metadata studies. Despite the increasing relevance of Scopus, WoS continues to lead the field, with 50.1% of published articles relating to meta-data analysis (Zhu and Liu 2020).

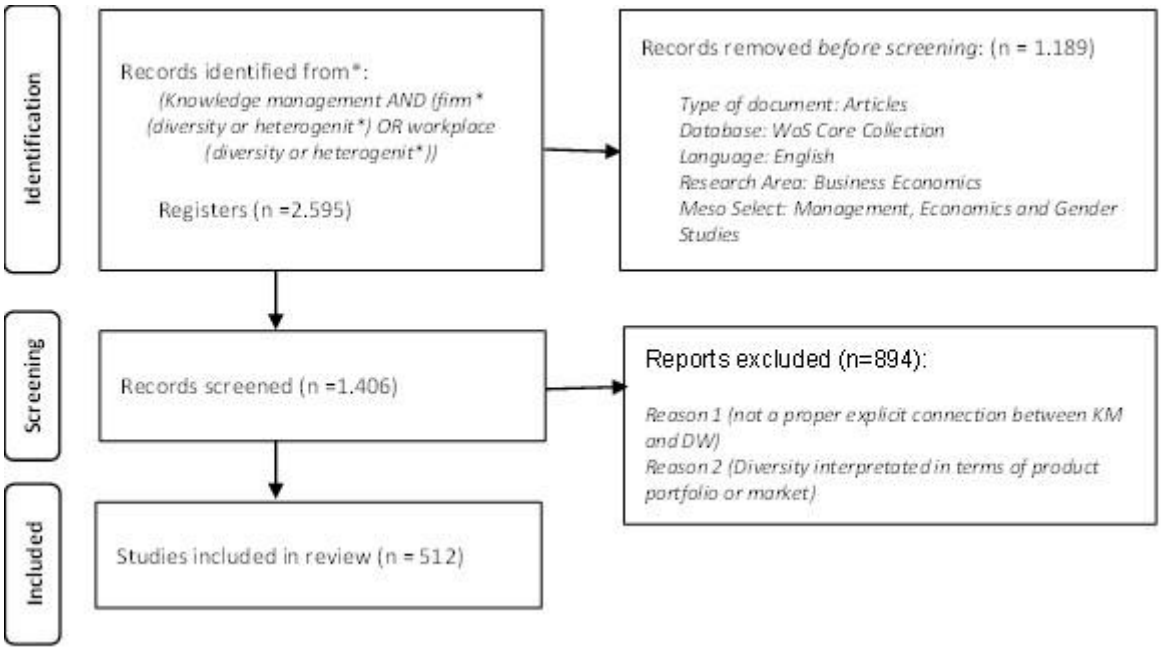


Figure 1: PRISMA Flow-Chart

Following the guidelines proposed by Donthu et al. (2021), Zupic and Čater (2015), and PRISMA Flow-Chart after launching the query *(Knowledge management AND (firm* (diversity or heterogenit*) OR workplace (diversity or heterogenit*))* a total of 2.595 articles were obtained. To further increase the coherence of the research during the before-screening process a total of 1.189 articles were removed mainly because not part of the WoS Core Collection, Social Sciences Citation Index (SSCI); Research Area (Business Economics), and Meso Criteria.

Based on previous bibliometric studies, the initial 50 articles were revised by all the authors part of the research. Then, in a second moment, all the results were shared among them to analyze the coherence of the selective criteria implemented. After a second round of reviews the total selective criteria coherence was reached based on the previously established selective criteria: a) there must be a proper and explicit link between KM and DW, b) Diversity should be interpreted in terms of workplace, either permanent or ad hoc teams. Therefore, out of the initial dataset of 2.595 articles just 512 of them meet the selection criteria.

3.1.1 Descriptive statistics

As a response to the RQ1, according to the "*analyse results"* section that the WoS Platform offers, 428 articles have been classified under the management Wos category hence very close to 81%. The second most relevant category is Business with 278 articles or 54% of the total of the articles. The rest of the categories are economics (n=40: 7.8%), engineering industrial (n=38: 7.4%), and psychology applied (n=34: 6.7%). Also, considering the number of articles published per year, the trend has always been positive till 2021, where certain maturity can be noticed but with a strong recovery trend. In fact, from 2014 to 2024 there has been an increase of 84.2% in scientific production. Also, interesting insights emerge while analyzing the micro topics related to the research. The data indicates that knowledge management is the core micro topic (n= 259: 50.5%) followed by job satisfaction (n=78:15.2), corporate governance (n=43: 8.3%), and internationalization (n=36: /%). On the other hand, considering the country of origin, the USA is the leading country almost 33% of the total scientific production has been generated there. The second place is held by the People's Republic of China (PRC) with almost 14% of the production. The rest of the top 10 country contribution follows the following trends England 13%, Italy 8.7%, Spain 8%, Netherlands 7%, Taiwan 7%, Germany 6.6%, Australia 6.3% and finally France 5.4%.

3.1.2 Top ten articles literature review

The below table illustrates the top ten most relevant articles according to the citation received in WoS out of the original dataset of 512 articles. We decided to use the citation instead of other filters such as pertinence as it is the selected indicator generally and traditionally has been linked to the quality of the research. It is important to mention that not all the articles have as their main objective to analyze the interrelation between KM and DiW, however, it is secondarily mentioned as part of the model or the theoretical framework.

Table 1: Literature Review: Top 10 most-cited articles.

Year	Tot Cit.	Author	Knowledge stage	Diversity type/locus	Output	Underlying theory	Main findings
2000	2027	(Dyer and Nobeoka 2000)	Sharing Creation	Deep-end/Meso: Macro /Inter-Organizational	Knowledge Network	Knowledge-Based Theory of Firms	A well-managed and structured knowledge sharing-network fosters the knowledge sharing and creation
2004	998	(Cummings 2004)	Sharing	Deep-end/Meso Inter-Organizational	External Knowledge Sharing	Social Capital	Structural diversity enhances knowledge-sharing
2010	832	(Volberda et al. 2010)	Acquisition Integration	Deep-end/Macro	Homogenize the concept of Absorptive Capacity	Absorptive Capacity Dynamic Capabilities	A model highlighting the antecedents, processes, and outcomes of absorptive capacity
2004	785	(Rodan and Galunic 2004)	Sharing Integration	Deep-end/Micro	Managerial performance and innovativeness	Knowledge-Based Theory of Firms	To foster managerial performance and innovativeness It is essential to have a heterogeneous network.
2007	746	(Sampson 2007)	Acquisition Integration	Deep-end/ Inter-Organizational	Innovation	Absorptive Capacity Organizational Learning	An inverted U shape relationship between partner's knowledge heterogeneity and innovation
2005	613	(Hinds and Mortensen 2005)	Sharing	Not Specified (Geographical)/Meso	Conflict Management	Social Identity	How geographical dispersion affects team conflict and the roles that shared identity, shared context, and spontaneous communication play in moderating this relationship

Year	Tot Cit.	Author	Knowledge stage	Diversity type/locus	Output	Underlying theory	Main findings
2011	597	(Bell et al. 2011)	Creation Sharing	Surface: Deep-end/ Meso	Team performance	Value in diversity	Diversity in functional background, education, and organizational tenure is closely tied to knowledge variety. Traits like age, gender, and race/ethnicity are less directly connected to knowledge content, but they can still influence knowledge exchange via
2004	568	(Almeida and Phene 2004)	Creation Integration	Deep-end/ Inter-Organizational	Knowledge creation	Knowledge-Based Theory of Firms	By leveraging the technological strengths of the MNC and fostering robust relationships with local firms, subsidiaries can enhance their knowledge creation and innovative performance.
1992	531	(Michel and Hambrick 1992)	Integration Creation	Deep-end/Meso	Need for managerial characteristics	Upper Echelons Resource Based View	The greater the need for interdependence posed by a firm's diversification strategy, the greater its top team's firm-wide operating knowledge base.
2011	523	(Østergaard et al. 2011)	Creation	Surface:Deep-end/ Meso	Innovation	Knowledge-Based Theory of Firms Value in diversity	A positive correlation exists between diversity in employees' educational backgrounds and the introduction of innovations

In constructing the literature review matrix, the authors elected to incorporate fields associated with each of the primary variables encompassed by the research, including the knowledge stage in relation to KM as outlined by Grant (1996b). Furthermore, diversity type and locus, referring to the superficial and deep-end diversity and the micro, meso, and macro level, were included as directly linked to the DiW variable. To comprehensively identify the mechanisms underlying the interrelationships, the underlying theory, outcomes, and primary findings were incorporated.

The findings indicate that the interrelation KM-DiW follows specific dynamics. Firstly, regarding the dimension of diversity, the results indicate that deep-end diversity is of particular relevance in the proposed interrelation. Indeed, of the ten most cited publications, Østergaard et al. (2011) highlight aspects of surface diversity, including gender, age and ethnicity. However, only gender and education (deep-end diversity dimension) were found to be relevant to innovation. About the locus of diversity, the meso level is worthy of particular attention, given that most of the research has been focused on the effect on team performance. In certain instances, the TMT should be considered, while in others, a more generalist team perspective should be adopted. It is also noteworthy to observe that this interrelation is, in certain instances, associated with the emergence of a novel diversity locus, such as inter-organization, consequent to the firm's diversification, thus giving rise to novel diversity dynamics.

Furthermore, the interaction between DiW and KM has been approached under different theoretical frameworks according to the literature review conducted. For instance, the resource-based view (RBV) provides a theoretical framework to understand how firms can leverage unique resources such as knowledge and DiW or capabilities such as KM to gain a competitive advantage. The framework suggests that DiW can enhance the knowledge available within the organization, leading to increased innovation, problem-solving ability, and adaptability especially relevant in VUCA environments.

In addition, the knowledge-based theory (KBT) initially proposed by Grant (1996a) as an extension of the RBV framework provides valuable insights, highlighting the mechanisms through which KM practices can facilitate and enhance diversity within organizations. The core idea behind the KBT theoretical framework is diverse teams hold varied tacit and explicit knowledge based on their personal characteristics and functional backgrounds. Therefore, the diversity of the explicit and implicit outputs con further increases the organizational knowledge base. This theory shares important aspects with the organizational learning theory as well since further highlights the process through which an organization creates, retains, and transforms knowledge.

Furthermore, the social capital theory seems to carry special relevance while considering the proposed interrelation since it enhances the relevance of the formal and informal networks within our abroad organization. In the proposed interrelation the theory closely interacts with the cognitive diversity theory sharing the idea that different cognitive frameworks lead to new knowledge. This is due to the fact, as previously mentioned that DiW in the proposed interrelation has been generally analyzed under the deep-end dimension. Men et al. (2019) demonstrated that cognitive team diversity has a moderating role in two relationships such as knowledge sharing - absorptive capacity and knowledge sharing - knowledge integration.

The Dynamic Capabilities Theory as proposed by (Teece et al. 1997) very often closely interacting with the absorptive capacity theory has also been implemented. The main idea is that DiW by interaction with KM leads toward new capabilities very relevant to the current VUCA environment. For instance, Roberson et al. (2017) analyzed the relevance of diversity management while considering knowledge management under the dynamic capabilities prospect, indicating a direct impact on the market, operations, and stockholders.

Finally, the value in diversity and the upper echelons diversity are more related to the relevance of the DiW concept. The main idea is that DiW should be considered a strategic asset since it can generate unique resources and capabilities for the organization. Generally, scholars have highlighted in the process of value creation the characteristics of the top management teams (TMT) since directly involved in the decision-making process.

3.1.3 Co-citation

In response to RQ1, which pertains to the identification of the intellectual structure, or, as defined by Donthu et al. (2021) the *"past"* of the research, the authors implemented a bibliometric co-citation technique. It indicates the number of times two articles are co-cited in other works; therefore, it provides some useful insights to properly identify the intellectual ground of the proposed research topic. The resulting scientific network map is indicated in the figure below:

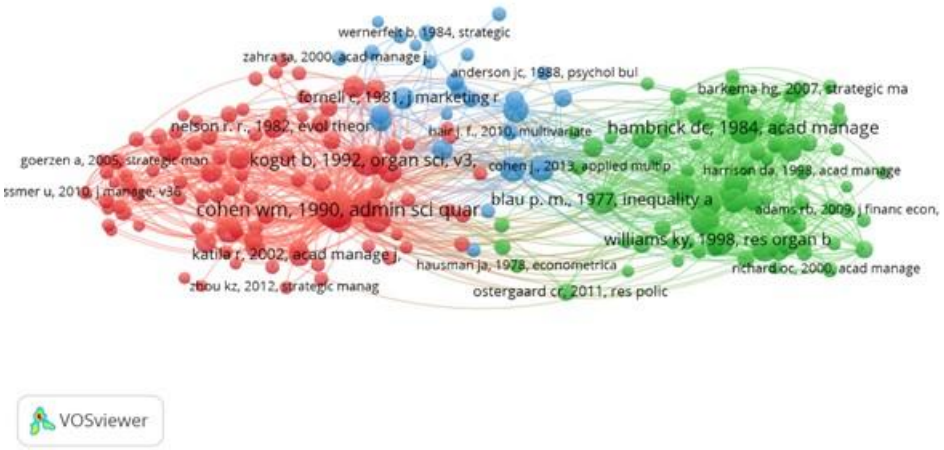


Figure 2: Co-Citation Network

The results obtained indicate a scientific network map composed of three clusters, indicated with red, blue, and green colors. In order to further understand the dynamics of the clusters, table number one indicates the most relevant co-cited articles according to the total link strength. This is interpreted as the general relevance of the articles among all the links.

Table 2: Top 10 most co-cited articles

Year	Autor	Title	Cluster	Links	Total link strength
1990	Cohen et al	Absorptive capacity: A new perspective on learning and innovation	1	194	1918
1984	Hambrick et al	Upper Echelons: The Organization as a Reflection of Its Top Managers	2	176	1278
1992	Kogut et al	Knowledge of the Firm, Combinative Capabilities, and the Replication of Technology	1	190	1206
1998	Williams et al	Demography and Diversity in Organizations: A review of 40 years of research	2	176	1183
1977	Blau P.	Inequality and Heterogeneity	2	191	1140

Year	Autor	Title	Cluster	Links	Total link strength
2007	Harrison et al	What's the difference? diversity constructs as separation, variety, or disparity in organizations	2	180	1093
1999	Pelled et al	Exploring the Black Box: An Analysis of Work Group Diversity, Conflict and Performance	2	183	1091
1991	March JG.	Exploration and Exploitation in Organizational Learning	1	192	1029
2006	Laursen at al	Open for innovation: the role of openness in explaining innovation performance among U.K. manufacturing firms	1	180	1013
1989	Bantel et al	Top management and innovations in banking: Does the composition of the top team make a difference?	2	169	972

As is can be noticed, clusters one and two are of particular significance. Forty per cent of the ten most cited articles are in cluster one, while the remaining articles are in cluster two. There is an absence of cluster three. The first cluster appears to be more closely associated with KM, with an approach encompassing diverse perspectives, including absorptive capacity Cohen and Levinthal (1990), firm knowledge (Kogut and Zander 1992), and the significance of exploration and exploitation in organizational learning (March 1991) considering the possible effects of KM over firms innovation capabilities. Consequently, the designation of the cluster as "Knowledge Management" appears to be a rational proposition. However, a general tendence of the cluster is that DiW has been paying special attention to the surface level of the diversity under a meso level, very often for the upper echelons perspective.

Conversely, cluster number two appears to be more oriented towards the DiW concept, approaching it from different perspectives and locus. Hambrick and Mason (1984) analyzed the DiW through the lens of the Upper Echelons theory, thus focusing on senior management roles. A similar trend was followed by Bantel and Jackson (1989), but with a focus on the banking sector. Conversely, alternative authors have approached the DiW concept from a macro perspective (Blau 1977; Harrison and Klein 2007; Williams and O'Reilly III 1998).

Finally, although the three articles under the third cluster do not appear in the top ten, they are of particular significance as they elucidate the methodology of the interaction between KM and DiW. Among the most salient theories, as previously indicated, some are more closely associated with the theoretical component, while others are more closely associated with the theoretical arguments. For instance. Aiken (1991) proposed the guidelines to be followed while considering multiple regressions while Podsakoff et al. (2003) paid special attention to the common method biases in behavioral research and to use of self-report measures in organizational research (Podsakoff and Organ 1986). Additionally, Fornell and Larcker (1981) proposed the use of structural equation models considering unobservable variables. Besides, the relationship KM-DiW lies on theories such as RBV as proposed by Barney (1991). In addition. Teece et al. (1997) proposed the dynamic capability theory to integrate, build, and reconfigure resources as a response to the always-changing network. Furthermore, I. Nonaka (1994) proposed the Knowledge-Based Theory of Firms. Also, Cyert and March (2015) established the ground for the Behavioral theory of the firm. In addition, Grant (1996b) highlighted the relevance of a firm's ability to integrate knowledge based on RBV, Dynamic Theories, and the Knowledge-Based Theory of Firm highlighted the relevance of a firm’s ability to integrate knowledge. Finally, Hitt et al. (1997) based on BRV and the Knowledge-Based Theory of Firms proposed an international perspective establishing a positive relationship between international diversification and R&D activity.

Considering the average publication year for top five articles of each cluster, the research flow seems to start with the DiW concept (1992) by then switching to Knowledge Management (1994) and finally on the theoretical connection between the two previously mentioned concepts.

3.1.4 Bibliometric coupling

In Donthu et al. (2021) words, the bibliometric coupling corresponds to the “current” dynamics of the chosen research topic. Following Rojas-Lamorena et al. (2022) in the bibliometric coupling we only considered the last five years of the research activity, in other words, 2024, 2023, 2022, 2021, and 2020. The technique refers to bibliometric coupling when two documents cite a common third one, therefore it very relevant in order to undercover the current research dynamics.

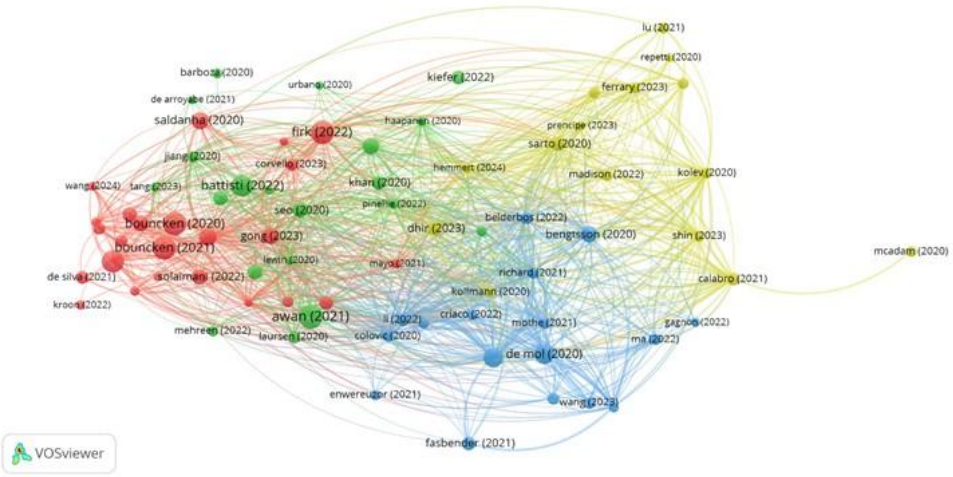


Figure 3: Bibliometric coupling

The data indicate a scientific map composed of four clusters, each one of them indicated with a different color. More specifically, cluster one is indicated with red color, cluster two with green color, cluster three with blue color, and finally cluster four with golden color. To properly analyze the dynamics surrounding the current research, below are indicated the top 10 most relevant articles in bibliometric coupling according to the total link strength considered as the total number of the shared articles between the specific articles, following therefore the same methodological as in the case of co-citation study.

Table 3: Top 10 biometric coupling articles

Year	Authors	Title	Cluster	Links	Total Link Strength
2021	Richard et al	The Effects of Racial Diversity Congruence between Upper Management and Lower Management on Firm Productivity	3	60	257
2021	Li et al	Leveraging age diversity for organizational performance: An intellectual capital perspective	3	62	242
2022	Li et al	From inclusive climate to organizational innovation: Examining internal and external enablers for knowledge management capacity.	3	59	236
2020	Kolev et al	Board demography and divestitures: The impact of gender and racial diversity on divestiture rate and divestiture returns	4	42	226
2022	Belderbos et al	Top management team international diversity and the performance of international R&D	3	53	200
2021	Calabro et al	Entrepreneurial Orientation and Family Firm Performance: The Moderating Role of TMT Identity-Based and Knowledge-Based Faultlines	4	48	193
2023	Shin et al	Faults and Faultlines: The Effects of Board Faultlines on CEO Dismissal	4	40	193
2020	Sarto et al	Human capital and innovation: mixing apples and oranges on the board of high-tech firms	4	47	191
2024	Hemmert et al	Enhancing innovation through gender diversity: a two-country study of top management teams	4	56	183
2020	Colovic et al	Group culture, gender diversity, and organizational innovativeness: Evidence from Serbia	3	56	179

Some interesting insights emerge from the bibliometric coupling. First, according to the total link strength the current research is dominated mainly by the green and golden cluster, since the red and blue are blue one seems to be not primarily relevant as not part of the top 10 articles. Considering the main research topics of every cluster the cluster have been have named:

The blue cluster (3) “Approaching the surface diversity” as the articles part of it pays special attention to this dimension even though in some cases international work experience (Belderbos et al. 2022) or external contingency (Li et al. 2022) is mentioned. The authors generally agree on the fact that surface diversity leads to a wider knowledge base that can serve as a mediator or directly impact firms’ innovations and, therefore, their general performance.

On the other hand, the golden cluster (4) was denominated as “TMT activity” analyzing the effects of the TMT characteristic’s composition on outcomes such as divestiture rate, CEO dismissal, and innovation generally under a deep-end diversity since it leads to new knowledge base or sharing.

Regarding the rest of the clusters, the red one (cluster 1) seems to be more related to the KM paying special attention to the distance due to the heterogeneity that might exist at a meso, macro, or inter-organization level and to its repercussion over the innovation (Wen et al. 2021) in some cases, either digital (Firk et al. 2022) or radical (Gong et al. 2023).

Finally, the green clusters (number 2) seem more related to the inter-organization partnership considering the effects of the partnership heterogeneity either over firms' strategies such as internationalization (Haapanen et al. 2020; Lewin et al. 2020), HRM politics related to the cross-border collaboration (Seo et al. 2020) or new Venture (Yu and Wang 2021).

4 Conclusions

A paucity of research has been identified while explicitly linking DiW with KM. This has prompted our exploratory research, the findings of which generate interesting practical and theoretical implications. The performed literature review reveals that the interrelation pays special attention to the deep-end dimension of the diversity, frequently under a meso level that quite often corresponds to the TMT level. In certain instances, a novel dimension of heterogeneity, such as inter-organizational, is incorporated. The proposed interrelation gives rise to a variety of outcomes, including the creation and consolidation of knowledge networks, the generation of new knowledge, knowledge sharing, enhanced innovation, improved problem-solving capabilities, and enhanced firm performance whether under a financial or non-financial perspective.

In addition, in response to the RQ1, the results indicate that the proposed interrelation has been analyzed under a management focus primarily highlighting therefore the relevance of proper management. Also, data indicate that the two most relevant countries in terms of research are the USA and China. As for the intellectual structure composition, it is composed of three main clusters. Two of them correspond to the main research variables such as DiW and KM and the third one corresponds to the theoretical framework linking them such as the Organizational Learning, Knowledge-based view of firms, the Resource-based view, and dynamic capabilities. The findings are quite reasonable since to properly understand the proposed interrelation and the correspondent dynamics it is extremely important to better understand each one of the variables. Finally, regarding the bibliometric coupling, the data confirms that the current research topic is generally concentrated on KM, the role of the TMT characteristics generally under a surface.

The proposed research suffers some limitations such as the researcher’s subjectivity during the bibliometric implementation. Also, the fact that in some papers there was not a direct and explicit relation between DiW and KM but an indirect mention of it generally considering the role that KM covers in the interaction between. Therefore, for future research lines, would be interesting to uncover the new trends, perhaps with the use of a bibliometric study based on keywords.

5 Ethic declaration

During the elaboration of the present paper there was no need for ethical clearance since the secondary information was provided from official scientific databases such as Web of Science (WoS).

6 AI declaration

During the elaboration of the present paper, DeepL has been used from time to time to properly traduce and format the text.

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Bibliometric Ensemble-Based Community Detection Analysis of AI, Knowledge Management, and Emerging Technologies Convergence in Business Paradigms

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Abstract

This work has investigated the convergence of the business paradigms of artificial intelligence, knowledge management, and emerging technologies. This work uses a relevant new database that considers the scientific literature on the field. The bibliometric methods used were related to the multiple correspondence analysis, which helped construct a conceptual map, and ensemble community detection clustering, which helped identify the relevant "cores" of the literature. As a relevant result, we found the key role of data-driven strategies but also the necessity of rethinking education and training. In fact, the rise of AI as a very relevant technology in knowledge management can impact how firms create and store knowledge. Of course, these changes necessitate adequate organizational changes to facilitate the integration with the systems, process, and, most, people.

Keywords: Artificial Intelligence, Technology, Knowledge Management, Bibliometric Analysis, community Detection

Paper type: Academic Research Paper

1 Introduction

Artificial intelligence (AI)1 Other new technologies are increasingly finding their way into knowledge management (KM) (see Krüger, 2023; Nurlia, 2023). Knowledge management is concerned with increasing the value of intangible assets in organizations (Liebowitz, 1999). It is related to organizations' strategy to gain a competitive advantage in various areas, such as human resources, technology systems, and artificial intelligence (Liebowitz, 2001).

Artificial intelligence enables companies to manage large amounts of data, recognize patterns in the data, and gain insights to act on them. These capabilities enhance important aspects of traditional knowledge management, particularly digitizing knowledge creation, retrieval, and sharing (Gao et al., 2018).

Integrating new technologies such as blockchain, the Internet of Things (IoT), and cloud computing into direct knowledge-sharing platforms enables secure, scalable, and efficient knowledge dissemination. At the same time, blockchain ensures data integrity and trust, while IoT enables real-time data integration, and cloud computing provides the necessary computing power and scalability (Christidis & Devetsikiotis, 2016). Consequently, integrating these technologies has proven to be a key element in developing novel business accelerators that enable scalable, innovative, and sustainable solutions (Stiegler, 2021).

Emerging technologies combined with knowledge management form a revolutionary approach encompassing organizations' three main pillars: People, Processes, and Technologies (Obermayer & Tóth, 2021). Jarray et al. (2023) highlight the beneficial support that AI provides in the fundamental areas of knowledge management: creation—in the sense of reorganizing existing or acquired knowledge—storage and retrieval—for classifying and storing business information and practices—sharing—in the sense of improving communication between colleagues and employees—through AI platforms.

First, a growing body of literature on AI emphasizes its potential to improve knowledge-based processes (Fowler, 2000). In this context, for example, machine learning is increasingly used to automatically classify, store, and quickly retrieve knowledge assets (Zhou et al., 2020).

In this regard, the proposed analysis would show how new technologies can contribute to disseminating and collaborating knowledge and information.

Another future perspective from an initial literature review before the bibliometric analysis is the significant new subfields beginning to be explored more deeply. These include the increasing focus on ethics in AI and its impact on knowledge management work, particularly on eliminating bias and the transparency of decisions (see

[1] We thank an anonymous referee for their constructive suggestions.

Feldman et al. 2022). Linking sustainability and AI is another emerging area of research that testifies to the global demand for sustainability and ethically rewarding business behavior (see, e.g., Yiğitcanlar, T. 2021).

The present bibliometric approach can provide a framework for interdisciplinary research. This analysis is important for gaining insights into evolving research topics, themes, and opportunities. It is a solid approach to capturing the existing scientific literature in the field (Donthu et al., 2021; Aria & Cuccurullo, 2017; Drago et al., 2021; Gatto et al., 2023; Drago & Aliberti, 2019). The advantage of bibliometric analysis concerning a narrative or systematic literature review is that quantitative methods can be used to identify some "hidden patterns" that can be discovered. In this way, the bibliometric analysis is best suited to explore the literature to identify some relevant patterns like "cores" of the literature as groups of keywords considered together in scientific words and clusters of keywords indicating new research areas.

2 Data and Methodology

Bibliometric analysis, a systematic study of the scientific literature, allows researchers to track the evolution of this interdisciplinary field over time (Donthu et al., 2021; Aria & Cuccurullo, 2017). Based on citation networks, co-authorship patterns, and keyword co-occurrence, the most cited publications, prolific authors, and relevant research clusters with matching keywords can be extracted. Using an ensemble community detection approach, we can discover the literature's relevant and stable "core" (Drago, 2018; Drago et al., 2021).

The following analysis can provide a general picture of how AI and new technologies are integrated into KM and how this impacts organizational practice.

A bibliometric study can uncover some key emerging trends. In this way, starting from the initial query on Scopus using a relevant source for bibliometric studies, we obtained the bibliometric valuable database in the analysis of the literature (see Baas et al. 2020). The query considered was:

("artificial intelligence" OR "AI") AND "knowledge management" AND ("emerging technolog " OR "new technolog*" OR "digital technolog*").*

The query was performed on the day 25/12/2024. Then, it was possible to proceed to the exploratory analysis of the literature and identify the most relevant data structures using MCA multiple correspondence analysis and network analysis. Then, considering the publications' co-occurrence network, the authors identified the different communities using several community detection approaches (Fortunato 2010). Finally, it was considered an ensemble community detection MCA-based approach to synthesize the results obtained by the different community detection algorithms. In this way, the final results are reliable because they come from a hierarchical clustering validation process in which we identified the final number of clusters (Brock et al., 2008).

In this topic, a bibliometric analysis ensemble community-based approach (Drago, 2018) can obtain more robust results than a single algorithm. This approach has the potential to explore the foundations of the intellectual debate driving this change.

3 Results

The bibliometric analysis is performed using different methodological tools, as seen in the previous section. In particular, the starting point is to consider multiple correspondence analysis to identify a specific concept structure map with the literature's most relevant topics and themes. According to this premise, in Figure 1, which was obtained by performing the initial bibliometric dataset, the multiple correspondence analysis, we can identify three clusters of themes that can be considered mostly together. In this respect, when some themes are particularly close to others, these terms are considered together in the scientific articles, so they are the basis of a debate. In this respect, mapping the existing literature and identifying relevant themes is possible. Dimension 1 is related to the educational paradigms (on the left) versus the technological and methodological ones. Dimension 2 is related to human concerns (on the upper half) and technological concerns (on the lower half). It is possible to consider various themes in the literature, like education-related computing, e-learning, engineering education, and curricula. This last statement is relevant because education is a significant concern in this literature. This concern is also relevant on the second axis (dimension 2), where it is possible to consider various technologies and approaches. Considering the three clusters identified (the red, the blue, and the green), it is possible to identify the first relevant cluster on education (curricula, education concern, e-learning, engineering education). The fact that these technologies and approaches are so close means intense conceptual proximity of the different topics considered in the publications. In this first cluster, the proximity is not as high as in the second case, the blue cluster. Here is a stronger proximity of the concepts considered together in the scientific publications (for instance, knowledge transfer, emerging technologies, and information systems). Three focuses here are implementing artificial intelligence, knowledge management in practice in organizations,

and strategic aspects. Finally, the green cluster can be considered centered on the ethical aspects of the new technologies.

Then, it is possible to analyze the co-occurrence network of the keywords in the different studies to identify stable communities, which can be obtained from the consensus process described in Drago (2018). In particular, the multiple correspondence analysis achieved from the different memberships of the different community detection approaches used allows us to identify robust clusters.

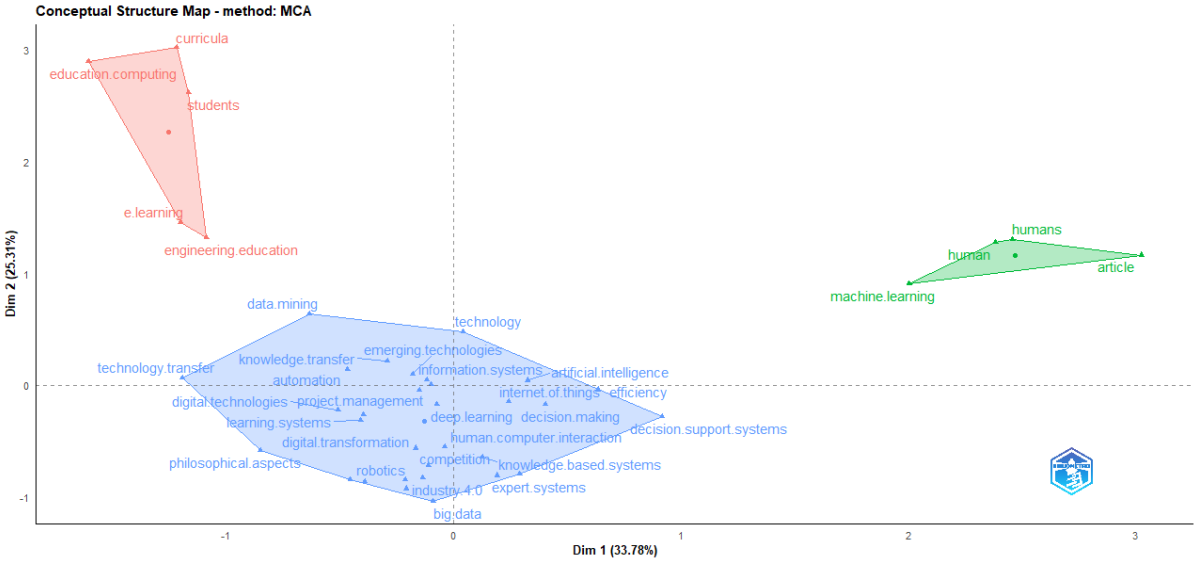


Figure 1. The Conceptual Structure Map using the MCA

The interpretation, from Figure 2, of the different clusters identified as relevant groups of concepts simultaneously considered together in the literature is the following:

- AI-driven knowledge management as standard practice: AI-supported knowledge platforms will become standard in companies, promoting automated and extended knowledge processes.
- Rise of knowledge analytics and predictive insights: Data-driven decision-making enabled by AI and machine learning will become a pivotal element of business strategies.
- Emerging paradigms such as e-health and digital health and their positive effects on the social ecosystems
- Emerging technologies transforming KM ecosystems and the associated effects: Blockchain, and new technologies impacting the workforce (and relative problems of training of the actual workers)
- Human-AI collaboration and cognitive augmentation in knowledge processing: AI can increase the workers' human capital
- Ethical AI in knowledge management: A new research direction is emerging that emphasizes ethical AI and sustainable knowledge management.

These can be identified as significant and economically relevant.

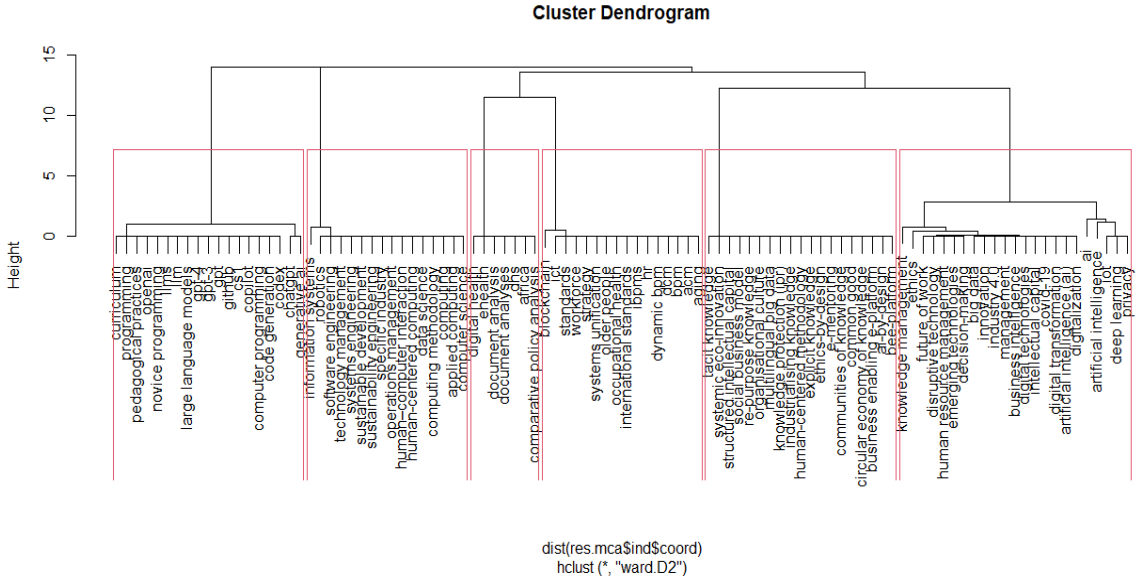


Figure 2. Hierarchical Clustering to identifying the relevant "cores" of the literature

4 Conclusions

This work has analyzed a new bibliometric dataset on the convergence of AI, Knowledge Management, and Emerging Technologies in Business Paradigms. The analysis was conducted using a bibliometric analysis focused on concept mapping and ensemble community detection, which is useful for identifying relevant groups of keywords maximally related to each other in the scientific literature.

The final result is that all agents' relevant aim is to maximize the benefits of these technological breakthroughs for growth and sustainable competitive advantage. Companies that effectively integrate AI and new technologies into their knowledge management strategies will gain a sustainable competitive advantage, improve decision-making, and drive innovation.

The introduction and development of AI in the KM strategy could be complete when organizations adopt generative AI and Narrow or Machine learning AI. The use of different kinds of AI can empower companies' performances and create a ground where capabilities are continuously enhanced.

To stay ahead, companies should take a data-driven, AI-powered approach to knowledge management while considering ethical, regulatory, and sustainability concerns. For this reason, education in this context is very relevant for companies and could be an important asset at every level.

5 Ethics declaration

The authors declare that ethical clearance was not required for the research due to the nature of the data used in the scientific study.

6 AI declaration

AI was used only to improve the readability and language of the work. This technology was used with control, and the results were carefully reviewed. We are ultimately responsible and accountable for the contents of the work.

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Employee Withdrawal and Knowledge Management Processes

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Abstract

This conceptual paper aims to identify and present the potential impacts of employee withdrawal on knowledge management processes in organizations i.e.: knowledge sharing & transfer, knowledge creation & development, knowledge application, and storage. Employee withdrawal is a subtype of counterproductive work behaviour and a critical issue for organisations. Specifically, it refers to a set of attitudes and behaviours used by employees when they stay at the job but for some reason decide to be less participative in duty engagement. Employee withdrawal may take either a physical or a psychological form and may begin with small and irrelevant actions like being late, or daydreaming, but they might culminate in more serious and significant behaviours like absenteeism, missing meetings, cyberloafing, or quitting that can be detrimental to the organization. Most research frames employee withdrawal behaviours as negative behaviours from the organizational point of view, mostly due to cost. However, a large proportion of organizational knowledge is personalized and resides in individuals' heads, therefore researching employee withdrawal behaviours is particularly critical in the context of knowledge management. To the best of the authors' knowledge, there are no publications that comprehensively describe the potential impact of employee withdrawal on different knowledge management processes. In the face of the above, there is a clear need to investigate how employee withdrawal behaviours may potentially harm knowledge sharing & transfer,, knowledge creation & development, knowledge application, and storage in organisations.
To do so, the authors of this paper related the found literature and described the potential impact of employee withdrawal behaviours on different knowledge management processes. Furthermore, the selected sources have been analysed in relation to each other, identifying conceptual overlaps which help in understanding how employee withdrawal behaviours may impact various knowledge processes.
Originality/value – The paper contributes to the understanding of the relationship between employee withdrawal behaviours and knowledge management processes.
Practical implications – The study provides food for thought for managers and owners on how the withdrawal behaviours of their employees might potentially hinder knowledge sharing, transfer, creation, development, application and knowledge storage in their organizations.

Keywords: Employee withdrawal, knowledge management, knowledge management processes

Paper type: Academic Research Paper

1 Introduction

Although employees are expected to exhibit positive attitudes and behaviours in the workplace, unfavourable behaviours may also be observed. Job satisfaction and motivation of employees fluctuate throughout their careers for various reasons. Withdrawal behaviours may result from occupational stress, unsatisfactory working, decreased job satisfaction (Beehr and Gupta, 1978) and may manifest themselves in many different forms in organizations. The researchers most often group the behaviours into two forms, namely physical and psychological withdrawal behaviours (Colquitt, Lepine and Wesson, 2013). Psychological withdrawal consists of actions that provide a mental escape from the work, and actions that allow the employee to physically escape from the work environment are referred to as physical withdrawal behaviours (Lehman & Simpson, 1992). Specifically, employee withdrawal refers to a set of attitudes and behaviours used by employees when they stay at the job, but for some reason decide to be less participative in their duty engagement (Kaplan *et al.*, 2009).

Globalisation and decentralisation in workplaces make it harder for supervisors to oversee their employees' performance, particularly in desirable but hard-to-achieve areas such as proactivity and creativity (Eldor and Harpaz, 2016). Similarly, not all managers or leaders are capable of readily recognizing signs of employee withdrawal in order to react promptly. Withdrawing employees, whose morale and motivation to work decrease can also demotivate others, which in turn can cause serious damage to the organisation and hinder its long-term development (Zhang *et al.*, 2023). Considering the high importance of employee commitment for the success of effective knowledge management in organisations (Stankiewicz and Moczulska, 2015), it may be expected that withdrawing employees may threaten it. Moreover, research by Deloitte has shown that technology alone is not enough to harvest the value of knowledge management, and argues that managers need to move beyond the narrow techno-centric knowledge paradigm because "traditional views of how to deal with knowledge no longer apply" (Weiss, Becker and Behme, 2021). In the context of generating, sharing, and managing knowledge,

organisations cannot underestimate the human factor (Weiss et al., 2021). Despite the growing importance of human factors in knowledge creating, sharing, preserving, and other knowledge processes, little is known about how employee withdrawal might influence them. To fill this knowledge gap, this paper aims to identify and present the potential impacts of employee withdrawal on knowledge management processes in organizations i.e.: knowledge sharing & transfer, knowledge creation & development, knowledge application and storage.

The paper develops in the following way. The second part presents the methodology, and the third section the concept of employee withdrawal. In the fourth section, potential impacts of employee withdrawal on knowledge processes are described. The last section concludes the paper.

2 Methodology

This present study contributes to the academic literature on employee withdrawal, knowledge management, and human resources management in general. This study is based on the analysis of the literature related to employee withdrawal and knowledge management processes. The authors related the found literature and assessed the potential impact of psychological and physical withdrawal behaviours on different knowledge management processes. To ensure methodological rigor and transparency, this paper adopts a structured approach to analysing and categorizing the literature on employee withdrawal and knowledge management processes. The research process involves a review of relevant academic literature. Furthermore, the selected sources are analysed in relation to each other, identifying conceptual overlaps, and divergences in understanding how employee withdrawal behaviours impact various knowledge processes. To provide valuable input, the authors assessed the relevance, empirical grounding, and applicability of each source. This systematic approach ensures that the paper moves beyond a simple synthesis, offering a structured and valuable contribution to knowledge management in the context of employee withdrawal.

3 Employee withdrawal

The theory on behavioural responses to adverse work events, declining organizational performance, and job dissatisfaction suggests that employees might react in one of four general ways - Exit, Voice, Loyalty, and Neglect (Kolarska and Aldrich, 1980). Two of them have been classified as withdrawal behaviours - Psychological withdrawal (neglect) and physical withdrawal (exit) (Colquitt, Lepine and Wesson, 2013). The withdrawal behaviour of the employee is defined by Spendolini (1985) as some form of volitional response to the perceived deterrent conditions designed to increase the psychological and physical distance between the employee and the organization. Since some withdrawal behaviours may share common antecedents, such as occupational stress or dissatisfaction with working conditions, they may be positively related (Beehr and Gupta, 1978). In Table 1, there are presented some forms of withdrawal behaviours identified in the literature, together with their definitions.

Table 1. Definitions of selected forms of employee withdrawal behaviours.

Physical withdrawal behaviours	
Long breaks	"Involve longer-than-normal lunches, soda breaks, coffee breaks, and so forth that provide a physical escape from work." (Colquitt, Lepine and Wesson, 2013)
Absenteeism	"Occurs when employees miss an entire day of work." (Muchinsky, 1977)
Missing meetings	"When employees neglect important work functions" (Colquitt, Lepine and Wesson, 2013)
Psychological withdrawal behaviours	
Daydreaming	"When employees appear to be working but are distracted by random thoughts or concerns." (Colquitt, Lepine and Wesson, 2013)
Cyberloafing	"Any voluntary act of employees' using their companies' internet access during office hours to surf non-job related Web sites for personal purposes and to check (including receiving and sending) personal e-mail." (Lim, 2002)
Employee silence	"Deliberate intention to withhold ideas, information, opinions, or questions about the job or organizational possible issues and improvements." (Van Dyne, Ang and Botero, 2003)
Turnover intention	"Voluntary, conscious, and intentional wilfulness to leave the present employer" (Tett and Meyer, 1993).
Looking busy	"An intentional desire on the part of employees to look like they're working, even when not performing work tasks."(Feizi *et al.*, 2012)

Importantly, employee withdrawal behaviour is difficult to detect because it can happen either physically or psychologically without others noticing, highlighting the significance of the problem for example during remote work (Syrek et al., 2022). Employee withdrawal may begin with small and irrelevant actions like longer breaks or daydreaming, but they might culminate in more serious and significant behaviours like absenteeism, missing meetings, employee silence, or even turnover intention, which can threaten knowledge management in organisations. In the following section, the potential impacts of these behaviours on knowledge processes will be discussed.

4 Potential impacts of employee withdrawal on knowledge processes.

Any knowledge activities require the involvement of employees, their focus on work, organization, and environment, and the effectiveness of knowledge processes depends on employees' behaviours and their skills (Stankiewicz and Moczulska, 2015). Taking this into account, employee withdrawal may adversely impact various processes related to knowledge management in organizations. The authors of this paper analysed the found literature and described the potential impact of psychological and physical withdrawal behaviours on different knowledge management processes. Furthermore, the selected sources are analysed in relation to each other, identifying conceptual overlaps, which helps in understanding how employee withdrawal behaviours may impact various knowledge processes.

4.1 Knowledge sharing & transfer

The first, most intuitive and researched impact of employee withdrawal relates to knowledge sharing, because its effectiveness largely depends on the willingness of knowledge workers to share their intellectual resources with others (Hajric, 2018). Employee withdrawal refers to a range of negative behaviours that distance the employee from the organisation and weaken ties (Liao *et al.*, 2022). Since knowledge sharing is an act of voluntary exchange of information, skills, or insights (Davenport, 1997), one can also expect a high negative impact of withdrawal on knowledge sharing. According to Jacobs and Roodt (2007), those employees who intend to leave in the future avoid sharing knowledge with their coworkers, and according to Tian *et al.* (2021), employee withdrawal behaviours negatively impact employee willingness to share tacit knowledge. A sign of employee withdrawal is exhibiting less effort and work motivation than usual, therefore knowledge sharing might be completely neglected. If employees withdraw physically, meaning they are absent for the entire day, miss meetings, or make long breaks to avoid work, it is apparent that their knowledge cannot be shared when someone needs it. Frequent or prolonged absenteeism, and missing meetings, mean less opportunity for knowledge transfer, which in consequence can create delays in projects where knowledge transfer is crucial. For new hires, the absenteeism or quitting of experienced employees can lead to incomplete knowledge transfer during onboarding. In contrast, psychological withdrawal can be particularly dangerous in terms of its impact on knowledge sharing. When an employee is engaging in psychological withdrawal, “the lights are on, but nobody’s home.” (Feizi *et al.*, 2012). All activities like cyberloafing, daydreaming, and looking busy, provide mental escape from work. Therefore, even if individuals may seem to be physically present at work, they may be psychologically dispatched and do not engage in sharing their knowledge with others. Formalised training may be an employee's responsibility and a task delegated by a superior. Nevertheless, the quality of the training may be worse, causing fragmentation and potential loss of critical organizational knowledge. Knowledge sharing is perhaps the single most important aspect of the knowledge processes since the vast majority of knowledge initiatives depend upon it (Hajric, 2018), and may potentially be the most exposed to the negative impact of employee withdrawal.

4.2 Knowledge creation & development

Employee withdrawal undermines an organizational capability to effectively create and develop knowledge. Creating new knowledge is an important goal for most organizations, but it is difficult to achieve. According to Nonaka and Takeuchi (1995), effective knowledge creation depends on a high degree of personal commitment. Therefore, one can expect that both forms of employee withdrawal may severely hinder the creation of new knowledge. Knowledge creation involves tapping into the tacit and often highly subjective insights, of individual employees (Nonaka and Takeuchi, 1995). Those who withdraw from organizations might not take part in any form of discussion, reflection, or brainstorming sessions and may abandon sharing their insights to not make them available for testing and use by the company as a whole. Developing new ideas, improving processes, and finding creative solutions to challenges require a lot of commitment, which the withdrawing employee is certainly lacking. Similarly, the withdrawal of an employee will have a negative impact on the development of

knowledge. One of the factors on which the process of individual knowledge development relies is creativity (Probst and Rohmhardt, 1997). Collective knowledge development involves the learning dynamics of teams, and it is necessary to have an atmosphere of openness and trust to allow the intensity of communication so that the results of collective learning are superior to individual learning (Probst and Rohmhardt, 1997). Creativity means the production of new and useful ideas and fuels innovation in organizations (Amabile, 1996; Zhou & Shalley, 2008). Employee creativity is necessary to spark the types of innovations that enable organizations to stay ahead of their competition (Colquitt, Lepine, and Wesson, 2013). The disengaged employees who withdraw both physically and psychologically become emotionally disconnected from co-workers in ways that disguise their "thoughts, feelings, creativity, beliefs, and values" (Kahn, 1990, p.702). Therefore, if withdrawing employees are distancing themselves from the team, become silent, and are no longer creative, this can have a potential negative impact on the knowledge development process, as creativity and collective learning are crucial for the process to be successful.

4.3. Knowledge application

As knowledge application is closely related to knowledge sharing (Chang and Lin, 2015), and inadequate application encompasses weak dissemination of knowledge (Coleman and Casselman, 2016), it is reasonable to assume that employee withdrawal may also negatively impact this knowledge process. According to Saifi (2015), three factors seem important for knowledge application, they are creativity, problem-solving, and working with others. The process of knowledge application involves retrieving and using knowledge in support of making decisions, and solving problems (Saifi, 2015). Knowledge application in research is among others measured by the extent to which employees apply their ideas in their job (Parayitam *et al.*, 2021). Employee withdrawal often manifests through employee silence - "deliberate intention to withhold ideas, information, opinions, or questions about the job or organizational possible issues and improvements"(Van Dyne, Ang and Botero, 2003). Moreover, absenteeism can delay the application of knowledge in ongoing tasks, delay some projects, or result in temporary knowledge gaps. If employees are quitting- voluntarily leaving the organizations, they may not make the effort to apply stored and shared knowledge, ideas, and new information to enhance work, make decisions, solve problems, and innovate. Therefore, employee withdrawal can have a potential negative impact on knowledge application, particularly in time-sensitive or knowledge-intensive activities.

4.4 Knowledge storage

People have been and will always remain natural repositories of knowledge (Cong, Li-Hua and Stonehouse, 2007). If knowledge is buried inside the heads of individuals, the organization becomes very vulnerable if those individuals start to engage in withdrawal behaviours. Knowledge storage refers to the process of recording knowledge and storing it in repositories such as archives, databases, and filling systems (Gao, Chai and Liu, 2018). Effective transferring of an individual's memory into an information system so that everyone can continue to access that person's knowledge even after the person has left the organization is crucial. This requires a lot of effort to ensure that employees are willing and able to analyse their own knowledge and make it available to others. Although the process of storing knowledge seems to be more technical, the human factor is also of great importance here. Therefore the knowledge documenting or storing process is in most of the organization's continuous, meaning a regular, but not daily activity. Short term physical withdrawal of an employee should not harm this process (unless some crucial and valuable knowledge is not documented), similarity the absenteeism does not lead to the loss of the already stored knowledge. Probably what brings more noticeable consequences on the process of knowledge storage is the psychological withdrawal of employees. Employees who have been withdrawing psychologically for a long time may be demotivated to document their newly acquired knowledge and may neglect their duty to update the knowledge that is already written down. Because of this, the knowledge stored in the organization may be incomplete, outdated or inadequately organized, making it less useful to others.

To sum up, it can be stated that withdrawal behaviours have potentially negative impact on knowledge management processes. The type of this impact or its intensity might be different, depending on kind of withdrawal behaviour that can be observed in an employee, as well as the requirements of the knowledge process. All in all, this impact is potentially negative for the organization also from the perspective of its operations and continuity of functioning. In table 2, there is the relation of particular knowledge management processes and withdrawal behaviours presented on the basis of the existing literature.

Table 2. Relation of particular knowledge management processes and withdrawal behaviours.

	Literature on KM:	**Literature on EW:**	**Conceptual overlaps:**
Sharing	Knowledge sharing is people to people process (Tangaraja *et al.*, 2016), its effectiveness largely depends on the willingness of knowledge workers to share their intellectual resources with others (Hajric, 2018).	Employee withdrawal refers to a range of negative behaviours that distance the employee from the organisation and weaken ties (Liao *et al.*, 2022). Those employees who intend to leave in the future avoid sharing knowledge with their coworkers (Jacobs and Roodt, 2007). Employee withdrawal behaviours negatively impact employee willingness to share tacit knowledge (Tian *et al.*, 2021).	Willingness to share
Creation	Effective knowledge creation depends on a high degree of personal commitment (Nonaka and Takeuchi, 1995).	"Employees who are not committed to their organizations engage in withdrawal behaviours" (Colquitt, Lepine and Wesson, 2013)	Personal commitment
Development	"The process of individual knowledge development relies on creativity (…) collective knowledge development requires an atmosphere of openness and trust" (Probst and Rohmhardt, 1997).	The disengaged employees who withdraw both physically and psychologically become emotionally disconnected from co-workers in ways that disguise their "thoughts, feelings, creativity, beliefs, and values" (Kahn, 1990, p. 702)	Creativity Emotional connection
Application	"Three factors seem important for knowledge application, they are creativity, problem solving and working with others." (Saifi, 2015)	"Deliberate intention to withhold ideas, information, opinions, or questions about the job or organizational possible issues and improvements." (Van Dyne, Ang and Botero, 2003).	Creativity Working with others
Storage	Knowledge storage requires a lot of effort on the part of organization to ensure that employees are willing and able to analyse their own knowledge and make it available to others. (Cong, Li-Hua and Stonehouse, 2007)	Withdrawal behaviours are any employee behaviour of withdrawal from duties and responsibilities as a result of a distance that grows between the employee and the organization. (Erdemli, 2015)	Connection with organization

Source: Own compilation, on the basis of sources presented in the table.

5 Conclusions

To sum up, the employee withdrawal and knowledge management literature have a few conceptual overlaps, which help in understanding how employee withdrawal behaviors may impact various knowledge processes. The characteristic features of withdrawal behaviors include reduced creativity, intent to withhold ideas, emotional disconnection, lack of commitment, and increasing distance between the employee and the organization. All of this has a potentially negative impact on all knowledge management processes, to a greater or lesser extent. It can be noticed that psychological withdrawal is potentially more severe in implications, as it can be done by an employee even if he or she is at work and is expected to conduct their duties, without noticing by a colleague or a manager. Such mentally distanced employees may neglect to engage in any knowledge activity and it will not be easily noticed by other peers or supervisors. In a sense, physical withdrawal is easier to manage, as there are no expectations from an employee who is not present at work or a meeting. However, frequent or prolonged absenteeism, and missing meetings, mean less opportunity for knowledge transfer, creation, development, or greater risk of knowledge misapplication.

The article contributes to the existing state of knowledge in both management and psychology fields. On the one hand, it presents employee withdrawal behaviors, and on the other hand, it identifies the potential link between two concepts - employee withdrawal and various knowledge processes. It presents how interdisciplinary the work of managers or leaders has become – they need to focus on humans and their motivation or its lack, as their withdrawal may harm also knowledge-related processes.

The main limitation of this study is that it is theoretical nature. By combining insights from psychology and management, it has been possible to outline some conceptual overlaps and potential relationships between employee withdrawal behaviors and knowledge processes. This relationship needs to be further explored both from a theoretical and practical perspective. Future studies could present a systematic literature review on this topic, as well as research from organizations on the perceptions of managers of withdrawal behaviors and their impact on knowledge management processes.

All in all, the paper has established the basis for a better understanding of the potential impact of employee withdrawal on knowledge processes that organizations may face nowadays. As such, the paper offers food for thought for researchers dealing with the topic of knowledge management, employee withdrawal, and human resources management in general. It also supports managers and company owners in the development of their leadership skills, indicating a new area for observation and handling.

6 Ethics declaration

Ethical clearance was not required for the research.

7 AI declaration

Artificial intelligence tools were not used to create this paper.

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Generative Artificial Intelligence: Knowledge, Perception and Use among White-Collar Employees in Companies

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Abstract

For companies, it is critical that their white-collar employees develop the necessary skills and knowledge to leverage the potential of Generative Artificial Intelligence (GAI) to improve productivity and organizational performance. To explore how employees perceive and use GAI in their daily work, and what measures companies are taking to support skills development, we conducted a practice-oriented empirical study.

The literature discusses the impacts of GAI on the economy and employment, particularly regarding efficiency gains, job transformation, and evolving skill requirements (Budhwar et al. 2023; Gmyrek et al. 2023; Haase 2024; Bremen 2023; McKinsey 2023). Several studies highlight productivity benefits and the dissemination of best practices (Brynjolfsson et al. 2023), while others, such as Slack (2025), emphasize employee skepticism as a barrier to realizing these gains. A central focus across the literature is the need for skills and knowledge referring GAI models as such (Al Naqbi et al. 2024; Cardon et al. 2024; Chandra et al. 2024).

Against this backdrop, we surveyed white-collar employees in Switzerland to assess the actual state concerning skills and knowledge in the following three areas: (1) perception of GAI-relevant skills and knowledge, (2) application of GAI in daily tasks and corporate functions, and (3) employer measures for supporting skill development.

The survey was distributed among members of Switzerland's largest white-collar professional associations. After data cleaning, responses from 1,843 participants were analyzed. As participation was based on self-selection (opt-in), the sample is not fully representative; distortions were mitigated using iterative proportional fitting (Kolenikov, 2014; Choupani et al., 2016).

A key finding shows that 80% of participants perceive a need for more GAI knowledge (25% report to almost no knowledge; 55% to have only basic knowledge), while only 15% consider themselves sufficiently knowledgeable. A second key finding show that GAI models are most used for writing, editing, and translating texts (48%). The most cited reason for non-use was a perceived lack of necessity (24%), though it remains unclear whether this reflects actual need or inexperience. Only 23% reported that their employer has a GAI strategy. Practical implications, including offering task-oriented GAI training, are discussed in the full paper.

Keywords: Generative Artificial Intelligence, skills and knowledge, white-collar employees, companies

Paper type: Practical Paper

1 Introduction and research problem

For companies it is critical that their white-collar employees have the relevant skills and knowledge in using the potential of Generative Artificial Intelligence (GAI) to increase work productivity and organisational performance. To find out more about how explicitly white-collar employees see and use GAI in their daily work and what measures companies are taking to support them in acquiring the needed skills we conducted an empirical study. The study was particularly practice-oriented, it had a strong focus on the actual workplace of the employees.

The goal of the study was to provide employees and companies insights about where they stand as well as help them with these insights to derive possible measures for using the potential of GAI in a most beneficial way.

2 Theoretical part

In the literature, much is written about the benefits and drawbacks of GAI in the economy and on jobs. Fundamental questions are discussed, such as whether it either leads to new jobs or to their displacement or if it simply promotes the efficiency of employees in doing their daily tasks (Bremen 2023, Gmyrek et al. 2023; Haase 2024, McKinsey 2023). Some studies discuss the actual and potential future advantages that the use of GAI and its models are providing for organisations (Al Naqbi et al. 2024; Brynjolfsson et al. 2023; Chandra et al. 2024; Haase 2024). Brynjolfsson et al. (2023) e.g. suggests that the use of GAI tools can increase productivity and that GAI models help to disseminate best practices of competent employees among newer and less experienced colleagues. However, a study from Slack found that most employees still are critical towards GAI which is why potential productivity gains aren't realised yet (Slack 2025; Vereckey 2024).

2.1 The question of required skills and knowledge for using GAI

Overall, most of the analysed studies discuss more or less centrally the question of which skills and knowledge are required or can/should be acquired by employees in connection with GAI and its models. Therefore, it is not surprising that many considerations, sets or frameworks of skills and competences/knowledge have been established and proposed by different authors (e.g. Cardon et al. 2024; Chandra et al. 2024; Haase 2024; Vuorikari et al. 2022). In the various contributions, there are central recurring terms, which are understood (slightly) differently from authorship to authorship. Moreover, they often overlap (e.g. data literacy or digital literacy). Generally, it does not make much sense to compare and contrast the frameworks and terms too deeply. A discussion that that goes into too much detail concerning skills-terms often gets lost in these details. The reason is that the terms and concepts themselves are simply not that precise in nature and therefore can't be defined and delimited with all accuracy. Moreover, terms and concepts in the field of GAI-relevant skills and knowledge are often changing (especially on a detailed level) because of the fast technological development in GAI.

2.2 A general categorization of skill and knowledge areas

However, on a more general level, a rough horizontal categorisation of skills-terms or areas is appropriate. Vuorikari et al. (2022) have established such a general and practice-oriented "digital competence framework" for the European Commission. Because of its characteristics[1], we oriented the followingly presented skills and knowledge areas at this framework (in spite of its title it is not only relevant for digital skills, but also for skills concerning GAI).

The first skills and knowledge area is *information and data literacy*. This includes skills in filtering, evaluating and managing data as well as information adequately. That white-collar employees have knowledge in this area is relevant for them when using GAI. The gathering of information (i.e. doing "research") for example bases more and more GAI-supported technologies. It is decisive to know how to retrieve relevant information thereof.

The second skills and knowledge area is *communication and collaboration*. This means the interactions and cooperation of employees through digital and AI technologies. For example, in their daily work white-collar employees communicate more and more also with bots, internally[2] and externally. Another part of this skill area is the management of a digital identity according to Vuorikari et al. (2022).

A third general skills and knowledge area is *developing digital content*. This skill is highly relevant for the use of GAI when writing texts (or making images etc.). For example, when somebody needs to establish a certain (digital) content and uses GAI therefore, it is decisive that she knows how to interact and use the GAI adequately to achieve her goal. Depending on the content to be written or established, the process to establish the content differs more or less fundamentally from the classical writing process. To be goal-oriented and successful it is necessary to know how to steer GAI properly in the wished direction to receive valuable content. This requires (a) the provision of adequate instructions to the GAI tool, (b) writing appropriate prompts and (c) understanding the fundamental principles of how AI works. Only then GAI tools can be managed or even customized in a way that effective object-oriented outcomes result (e.g. Haase, 2024).

Overall, there are signs that GAI is blurring the boundaries of these three general skill and knowledge areas. The reason is that GAI-supported technologies are increasingly present in the area of information and data provision, as well as in communication and digital content developing (i.e. in writing). Gathering information with support from GAI, using it for writing a contribution and later communicating it with support of GAI goes hand in hand.

2.3 Technical skills and development of GAI

Furthermore, Vuorikari et al. (2022) mention also *problem solving* as a relevant skill. This is based on the idea that employees have especially *technical skills* to solve existing or upcoming problems (e.g. "identifying needs and technological responses", "creatively using digital technology" (Vuorikari et al. 2022, p. 1)). Cardon et al. (2023) address also technical skills and describe them as hard skills as opposed to soft skills, like e.g. communication. Based also on other literature they say: "[…] the need for technical skills will change in a variety of ways. Many suggest that AI-specific digital literacies will grow in importance. These literacies involve aligning the tool with the task and understanding the strengths and limitations of various AI tools." (Cardon et al. 2023, p. 226). This is similar to what has been said under 2.2 in the skills and knowledge area developing digital content (see list (a) to (c) there).

[1] i.e. being general and practice-oriented.

[2] Many middle and large companies meanwhile have their own company-bots that are based on their internal data (documents, numbers etc.).

At the same time GAI tools are becoming more and more sophisticated and perform increasingly complex tasks by providing them with fewer or simpler (but still focussed) command inputs. Moreover, prompting as a form of quasi-programming is increasingly taking place in natural language. The need math-based or classical IT-based knowledge for users seems therefore to decrease, even for more complex command tasks. Regardless of this, knowledge of how the GAI functions in principle remains key for employees. What stays unclear up until now is the question if in the future the skills set of white-collar employees requires more or less technological and mathematical competences in view of the further development of GAI.

But, independently of how GAI will develop, the literature in this field assumes, as shown, that skills and knowledge of employees concerning GAI are crucial to the future success of a company.

Against the background of this discussion, we aimed in this study to determine firstly the current state of perception and secondly the use of GAI and its models among white-collar employees at their workplace. By taking perceptions into account, potentially critical attitudes towards GAI, as mentioned by Slack (2025), can also be recognised (see introduction to the theoretical part). Thirdly, we wanted to find out more about the GAI-related measures taken on the organisational level to support the employees. This is because not only the individual skills-level of employees is of importance for success but also what is being done on an organisational level (e.g. Haase, 2024).

As mentioned, the goal of the study was to use the findings to help employees and companies recognise where they stand and to derive possible measures to use the potential of GAI in a most optimal and effective way.

3 Methods

3.1 Perception of GAI-relevant skills and knowledge

To receive the necessary data or information we conducted the study based on a survey. Structurally, the survey considered the following three areas (oriented at the last section of theoretical part):

1. *Perception of GAI-relevant skills and knowledge* that focussed on how employees see their knowledge and that of their workplace in the context of the developments in GAI. Aspects such as how they believe they are keeping pace with the GAI developments were taken into account.
2. *Use of skills and knowledge for GAI* which considered the use of GAI models by employees in their daily work, as well as its use in different types of tasks of companies (e.g. in recruiting, efficiency control or brainstorming and strategy).
3. *Measures taken by the employer* that analysed what companies are doing to support GAI-relevant skills and knowledge among their employees as well as (e.g. if they provide education and training; how they communicate to the topic).

3.2 Distribution of survey and of respondents

The survey was distributed among the members of eight of the largest professional associations of white-collar employees in Switzerland. While the claim of these associations that they together represent 80 percent of the workforce in the service and knowledge professions (i.e. of white-collar employees) cannot be independently verified, the best-known professional associations in Switzerland in this area are certainly among them.

Furthermore, we have been able to record a statistically sufficient number of survey respondents for all sectors of the Swiss economy as well as of gender and age groups of the service and knowledge professions.

In the raw data, 58 percent of respondents identify as female and 42 percent as male. In the membership data of the professional associations (and our analyses because of the weights applied), the ratio is 52 percent female and 48 male. In the Swiss Labour Force Survey by the Federal Statistical Office (2023), we find a ratio overall professions of 47 percent female and 53 percent male.

As for the age groups, 35 percent of respondents in the raw data are under 35 years old, 53 percent are between 35 and 55 years old and 12 percent are above 55 years old. In the professional associations' membership lists, the shares are 37 percent (under 35), 46 percent (between 35 and 55) and 17 percent (above 55). The Swiss Labour Force Survey shows 22, 51 and 25 percent, respectively.

After adjustment and checking, the data of 1843 persons could be used for the analysis. As the participants recruited themselves (opt-in survey), the composition of the sample is not representative of the basis population. However, the distortions in the sample such as self-selective biases are counteracted by weighting for gender an age using the "iterative proportional fitting" method (Kolenikov, 2014; Choupani et al., 2016).

Moreover, it is important to note that surveys are reactive processes: participants are persons and answer (also) based on their subjective experience. I.e. they may under- or overestimate facts or circumstances in fact on an individual as well as on a group level (e.g. persons from different functions on a hierarchical level assess things differently).

4 Results

The results are presented along the three areas (1) perception of GAI-relevant skills and knowledge, (2) use of skills and knowledge for GAI and (3) measures taken by the employer.

4.1 Perception of GAI-relevant skills and knowledge

In this area we first show the general attitude of the participating white-collar employees towards AI at the workplace (figure 1). As can be seen with 57%[1] over half of the respondents have a basically positive attitude towards the development of new technologies based on AI. Only just over 10% are opposed to such a development. But a full 28% say that they do not have an opinion to this topic. This is a high value for the "not know"-category and show an existing insecurity among more than a quarter of the white-collar employees.

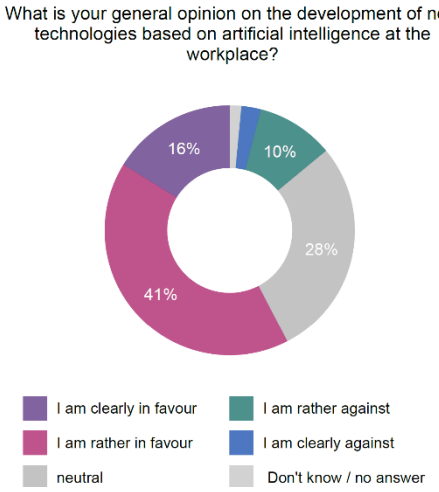


Figure 1: General attitude of white-collar employees towards AI at the workplace
Source: Authors, 2024

In the next figure 2 we move a step further down to recognise how participating employees assess their own knowledge in using GAI at work. 80% of them perceive to need more skills and knowledge to use GAI at work (thereof 25% declared to have nearly no knowledge and 55% to have basic knowledge), see figure 1. Only 15% stated to know enough and to have no need of more knowledge. Thus, overall, the feeling that one needs more knowledge concerning GAI at work is indeed widespread. What of course could be is that if someone who has already tried to work with GAI models on a basic level is more likely to realise that she or he needs more knowledge. At the same time a majority of 80% may also show a premature technological adoption: the technology is here, but it is in fact it is not clear how it can be appropriately used. Hence, there is a skills gap.

[1] = 41% + 16%.

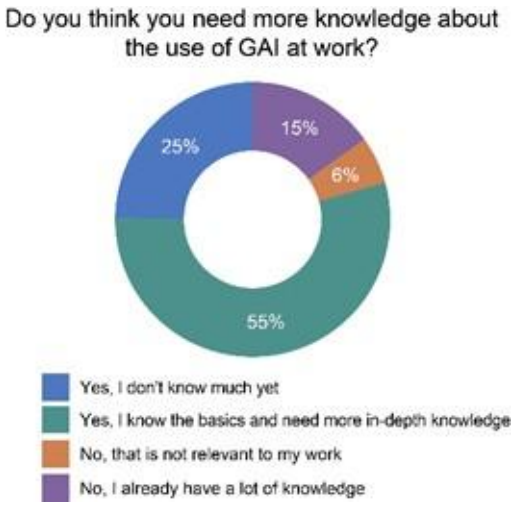


Figure 2: Perception of individual knowledge to the use of GAI at work
Source: Authors, 2024

A breakdown of participants by function showed that managers (senior, middle, lower) clearly declare to have more basic knowledge on average, namely 63%, than their non-managerial colleagues (technical experts, project managers, administrators, assistance) with 40%, see figure 3. However, if the two areas 'I don't know much' and 'I know the basics' are taken together, the differences between managers and non-managers are becoming smaller, namely maximum 10 percentage points[1]. This means overall that the knowledge and skills are distributed rather similar across the hierarchical levels. But, the difference of having basic knowledge versus (nearly) no knowledge between managers and non-managers with a maximum of 24 percentage points stays large.

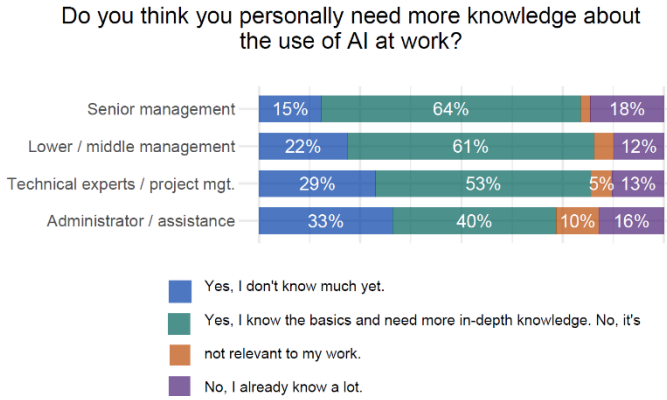


Figure 3: Perception of individual knowledge to the use of GAI at work: along functions
Source: Authors, 2024

Figures 4 and 5 go beyond the finding of figure 3 while also confirming it to a certain extent. The figures show the answers to the question 'In your opinion, what is the level of knowledge about the use of GAI in your company?'. The answers differ quite strongly between "middle and senior management" (figure 4) and "employees without managerial function" (figure 5). While the first group perceive with 44%[2] that the level of knowledge is good or very good the latter group perceive this with only around 27%[3].

Not surprisingly, on the other side there is a mirror image: "only" 38% of the middle and senior manager assess the knowledge-level as bad (27%) or even very bad (11%) whereas high 58% of the employees without managerial competences assess it as bad (41%) or very bad (17%). Hence, perceptions between high and low hierarchical levels differ quite strongly. At the same time both values of assessing the knowledge-level as bad or very bad are very high (38% and 58%, respectively) and implicate hat there is still a long way to go in companies to increase the know-how and skills of using GAI on an aimed or desired level.

[1] The difference between 83% (22%+61%) of lower/middle management and 73% (33%+40%) of administrators and assistance.
[2] = 38% + 6%.
[3] = 25% + 2%.

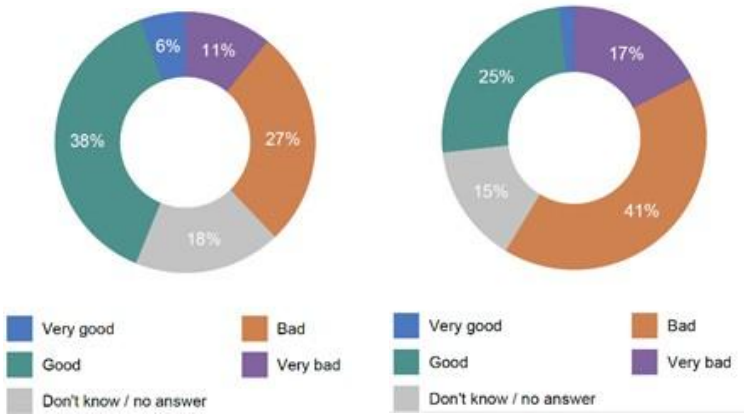


Figure 4 (left) and 5 (right): Perception of level of knowledge about the use of GAI in the own company. Left: middle and senior management, right: employees without managerial functions

Source: Authors, 2024

4.2 Use of skills and knowledge for GAI

A key item in this area asked how employees use GAI at work (see figure 6; multiple answers were possible). With 48% the option 'I use GAI models to write, edit, translate etc. texts' was rather clearly chosen most, followed by the options that GAI is used for creative support and to get inspiration (42%) and to receive answers to questions (39%). Overall, the options saying that somebody uses *no* GAI models at work are clicked clearly much less (see purple bars in figure 6 with 24% and 10%, respectively) than the options that somebody uses such models at work (turquoise bars in figure 6). Indeed, the existing basic knowledge of GAI models (see figure 2) is used in a wide variety of contexts. Presumably, employees using such models on a basic level are likely to realise while working with AI that they need deeper knowledge to be able to use their full potential.

Furthermore, the most frequently mentioned reason why GAI models aren't used by employees is that they aren't needed by them (24%). However, it remains unclear whether participants who said this indeed do not need such models or whether they just say so but never tried it.

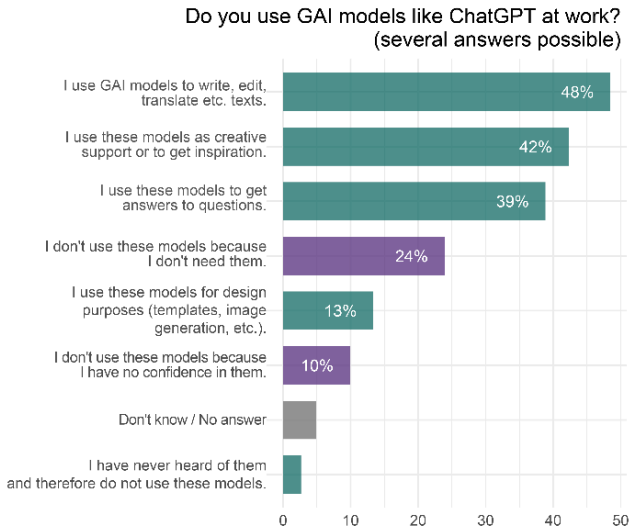


Figure 6: Fields of application of GAI in participants own work

Source: Authors, 2024

In the following figure 7 the focus is on where GAI is used in a company. As in the question to figure 6 it was possible to give multiple answers. The answer option marketing and communication has with 28% the highest value. On the second and third place follow 'don't know / no answer' (25%) and 'nowhere'" (24%). It is noteworthy that these two options do figure on such top places, even if the reasons can only be interpreted. An obvious explanation may be that employees being in certain departments do not know what is being done elsewhere. But it is also plausible to assume that the companies do not communicate enough or adequately towards employees about GAI and its use or implementation in the company. Therefore, the awareness about

GAI and how it is used across the company is low among employees. Assumingly, under such conditions the support for the employees in GAI through the company then is also low. Especially the answer option 'nowhere' with its 24% could support an interpretation in this direction because employees simply know or assume that GAI is used 'nowhere'.

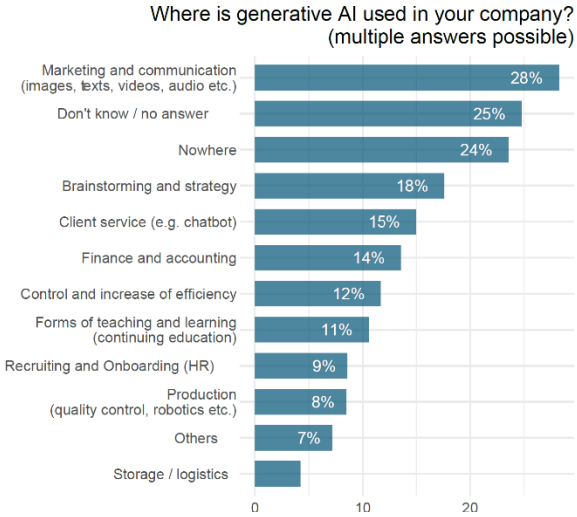


Figure 7: Fields of use of GAI in the company
Source: Authors, 2024

4.3 Measures taken by the employer

A first key finding in the third area of the survey was that only 23% of the respondents declared that their company has an AI strategy whereas 56% said no, it doesn't. 21% said that they do not know (figure 8). This finding suggests that only just under a quarter of companies have a GAI strategy that employees are indeed aware of. The question is also whether there is effectively no strategy in over 75% of the cases or whether such a strategy is not sufficiently communicated and/or visible initiatives are lacking.

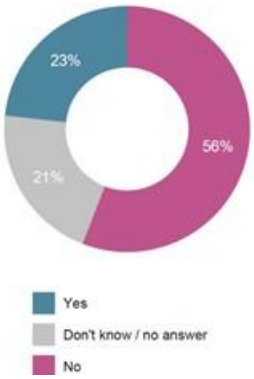


Figure 8: Answers to the question "Does your employer have a GAI strategy?"
Source: Authors, 2024

In the next figures the answers about the support of companies for employees in different subareas are shown. The basic question to all five subareas is always the same: "How does your employer support employees for GAI and its areas of application? Please evaluate the support in the following area".

The first subarea considered if guidelines for the use of GAI does exist in a company (figure 9). 31% of the respondents answered that this is the case in their company, while 47% said that this isn't the case. The picture to the subarea of sensitisation and awareness raising (figure 10) differs a little bit. Here at least 39% of participating employees said that a sensitisation of employees for GAI is existing in their company. Still 42% say that this is not the case.

In the last three subareas, which require a more active role of a company than just providing guidelines, the picture is overall similar. We begin with the support in the form of training and education: Only 29% declared that their companies offer this. 48% said that this does not apply (figure 11). In the subarea of supporting the motivation to use GAI the distribution of answers is the following: 33% say that this is applies to their company,

44% say that this doesn't (figure 12). Finally, also the subarea of supporting the integration of GAI in process optimisation is similar to the others but in fact has the lowest application-rate: only 28% say that support exists thereto (46% say that this does not apply) (figure 13).

These low rates show that there is clearly room for improvement in the (perceived) support of companies for employees. In none of the five subareas the rate of application is higher than 39%. Particularly also the low support concerning the integration of GAI in process optimisation is potentially problematic. The reason is that process optimisation is in many cases a field in which a valuable integration of GAI is quite obvious. The reason is that steps in processes normally are clearly defined and arranged why a step-by-step integration of GAI can be planned well. And, especially at the beginning but also later (when more specific knowhow is needed) the learning curve in the use of GAI is quite high. This is why training and education as a form of support is so important. Often trainings are key for getting started, they are a help for self-help. Moreover, an adequate training and education program impacts the motivation of employees positively.

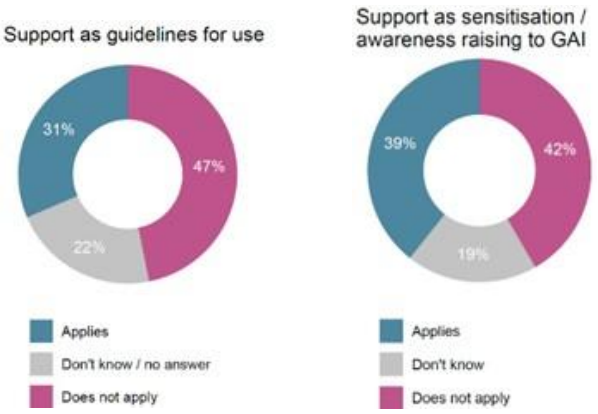


Figure 9 (left) and 10 (right): Subareas "support as guidelines for use" and "support as sensitisation / awareness raising to GAI"

Source: Authors, 2024

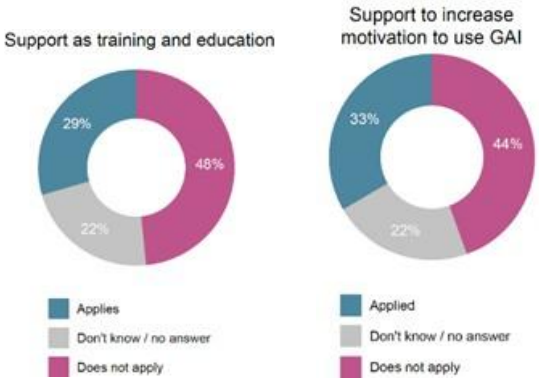


Figure 11 (left) and 12 (right): Subareas "support as training and eduction" and "support to increase motivation to use GAI"

Source: Authors, 2024

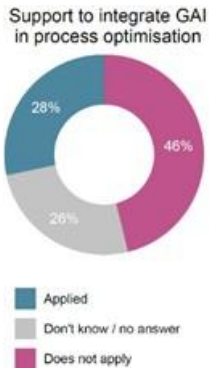


Figure 13: Subarea "support to integrate GAI in process optimisation"

Source: Authors, 2024

5 Conclusions and practical implications

The results overall show that the assumed full potential of GAI isn't utilised yet. This can be seen clearly among others in figure 2 where a vast majority of participating employees of 80% declares to have no or not enough knowledge for the use of GAI. Such a large majority indicates a knowledge and skills gap. The GAI technology is just there and the employees see it and try it out. However, often they cannot work with it on a highly effective level what may be interpreted as a premature technological adoption. Simultaneously, it seems not to be the case that companies require or motivate employees actively to use GAI. On the contrary, only 23% of the participants stated that their employer has a GAI strategy (figure 8). This speaks against a requirement or an active motivation to use it. Moreover, there is generally a low support of employees from the companies' side (figure 9 to 13).

The phenomenon combined of low utilisation and lack of strategy is probably related to the technological disruption reflected in the GAI models. GAI models are now on the market, they have become accessible to everyone, including unskilled users such as white-collar employees. Before, it was for years mainly used exclusively by experts. It is therefore difficult for both the individual employee and the company to find an suitable way of dealing with this situation.

By looking at *how* employees use GAI models at work (see chapter 4.2), we see indeed that they are using them in different ways and with different frequencies (figure 6) (although 36% of the respondents still declare to have no use of them because they do not benefit from or have no confidence in them).

Our practical recommendations, which are based on the study's results, start right here: Providing training on GAI models and areas of application that employees have to deal with in their daily work. In this way a more effective and goal-oriented proceeding should become possible. Taking this as the starting point for leveraging knowledge and skills means starting directly where the employees need it. Moreover, this serves also as help for self-help.

In a next step guidelines may be developed (if needed) because the exchanges in trainings help to establish them in a more user-friendly and focussed way. In a step after the next the ongoing development of training and education (eventually including certificates) supports assumingly also the motivation to use GAI models.

GAI measures taken by a company that are based on the needs of the employees and the experiences gained in the subsequent development steps, should facilitate the definition of a company-wide strategy for GAI.

The study presented has shown that there is still little in-depth knowhow on the employees' level and little commitment to GAI on the part of companies. As indicated, it is therefore crucial that a start with measures is initiated by a company at all. After that, a continuous further development of measures should make it easier for a company to deal appropriately with the constant advancements in GAI technology itself.

A question that is always latent in the room is how much and how deep specific knowledge is really necessary for an effective deployment of white-collar employees. Being able to program is probably going to far. But being able to prompt in a focussed, aim-oriented matter is essential (e.g. Cardon et al. 2023). Prompting in the end is a form of programming and actual developments show that this *programming by natural languag* increases in importance because it enables achieving valuable outputs.

No matter how much/less mathematical knowhow employees need to have in the future or how fast the technological developments will be: for a focussed approach of GAI, it will be important to understand the basic principles of how it in fact works (see chapter 2.3). This considers the individual employees as well as the company on its managerial basis.

6 Ethics declaration

We did not need an ethical clearance for research done in this paper.

The reasons therefore were that the recipients of the survey were able to decide for themselves whether they wanted to take part or not (opt-in survey). The participants' answers were anonymous. No conclusions could be drawn from the answers to individuals. Results in the paper are exclusively shown at an aggregated level. The survey was distributed to employees by eight of the largest professional associations of white-collar employees.

7 AI declaration

Deepl Translate was used for certain sentences. Certain sentences were written first in German and then translated by Deepl Translate to English. The sentences received in English were then checked for correctness of content and, if necessary, corrected manually before being incorporated into the paper. Moreover, to shorten the length of the abstract ChatGPT 4.0 was used. Our prompt asked ChatGPT to shorten the text without cutting

key content. The shortened text was then checked by the authors and was further adapted and refined manually by them until it was as they wanted to have it. No further AI tools were used to establish this paper.

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Improving Clinical Evidence for Medical Devices: A Lifecycle Approach

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Abstract

Background: The European Medical Devices Regulation (MDR) 2017/745 seeks to minimize clinical uncertainty – especially regarding the generation, dissemination, and quality of clinical evidence – across all phases of the medical device lifecycle: pre-market, market approval, post-market, and disinvestment. Although the MDR promotes using gold-standard methodologies, such as Randomized Controlled Trials to address clinical uncertainty, healthcare organizations face significant challenges in applying these methods. These challenges affect the effectiveness of evidence generation, dissemination, and quality. As a result, healthcare systems must incorporate technological, organizational, and managerial tools to manage these difficulties throughout the medical device lifecycle. This study aims to identify the tools that can reduce clinical uncertainty associated with medical devices.
Methods: The research adopts a case study approach, focusing on the Tuscany Regional Healthcare System, which is recognized nationally for its effectiveness, efficiency, and appropriate care delivery.
Results: The findings indicate that the majority of the identified tools are concentrated in the pre-market and post-market stages. Examples include study coordinators (organizational tools), standardized templates (technological tools), and case report forms (managerial tools), all of which improve the quality of clinical evidence. In addition, tools such as patient diaries (managerial) and surgical trainers (organizational) play a crucial role in enhancing both the generation and dissemination of evidence during these phases.
Discussion and Implications: This research provides useful insights for policymakers in guiding healthcare organizations on how to implement the MDR effectively. A key takeaway is the importance of introducing clinical registries, surveillance systems, and data collection platforms to gather real-world evidence, which are essential in the post-market phase. The study contributes to the ongoing discourse surrounding medical devices' clinical uncertainty by identifying technological, organizational, and managerial tools that can strengthen clinical evidence for medical devices.

Keywords: Clinical uncertainty; MD; Medical devices; MDR 2017/75

Paper type: Academic Research Paper

1 Background

The European Union's Medical Devices Regulation (MDR) 2017/745 represents a major step forward in the development and regulation of Medical Devices (MDs), defined as "*any instrument, apparatus, appliance, software, implant, reagent, material, or other article intended by the manufacturer for human health purposes"* (MDR Art. 2). In comparison with earlier Directives (90/385/EEC; 93/42/EEC), the MDR introduces substantial changes aimed at reducing clinical uncertainty – particularly in how clinical evidence is generated, disseminated, and how its quality is improved – across all stages of the MD lifecycle: pre-market, market approval, post-market, and disinvestment phases[1] (McDermott & Kearney, 2024; Kearney & McDermott, 2023; O'Rourke, Oortwijn & Schuller, 2020; Tarricone et al., 2020).

Table 1 outlines the primary tools recommended by the MDR to address these goals.

[1] Pre-market: phase of MD development before it is commercially available (Matinolli et al., 2019); Market approval: phase of MD evaluation by regulatory authorities to determine if it can be legally marketed (Martin and Barnett, 2012); Post-market: phase of ongoing MD monitoring to ensure safety and effectiveness (Ross et al., 2015), including Health Technology Assessment for MD introduction into clinical practice; Disinvestment: phase in which a MD is withdrawn from the market and its use discontinued due to newer technologies, obsolescence, safety concerns, or economic factors (Polisena et al., 2019).

Table 1 - MDR tools to cope with clinical uncertainty

	MD Lifecycle			
Tools	Pre-Market	Market Approval	Post-Market	Disinvestment
Exploratory Clinical Trials, Early Feasibility Studies	■			
Randomized Controlled Trials	■			
In silico, in vivo, in vitro, toxicology and biocompatibility tests	■			
Scientific Literature		■	■	
Real World Evidence			■	■
Post-Market Clinical Follow-up and GRACE checklist			■	■
Registries			■	■
Stakeholders' involvement	■	■	■	■
Patient's involvement	■	■	■	■

Previous literature brings some insights on how these tools contribute to the generation, dissemination, and improvement of clinical evidence quality throughout the lifecycle of MDs.

For example, in the pre-market phase, the MDR highlights the use of Randomized Controlled Trials (RCTs) to produce clinical evidence (Tarricone et al., 2020). Despite their status as the gold standard, RCTs have well-documented limitations (Rosner, 2012), including small and specific patient populations, ethical dilemmas, and the fast-paced evolution of medical technologies (Tarricone et al., 2020). Additionally, outcomes are often influenced by user experience and learning curves, as well as being highly dependent on the clinical setting – factors particularly relevant to MDs compared to pharmaceuticals (Jakab et al., 2020; Fuchs et al., 2017).

The Post-Market Clinical Follow-Up (PMCF) process, also mandated by the MDR, is designed to ensure continued surveillance and enable comparisons between real-world evidence and RCT data. This is intended to enhance evidence reliability. However, real-world implementation remains complex, with difficulties in patient engagement and challenges in collecting and tracing data that can compromise the quality of post-market evidence.

These are just some of the issues that impact the ability to generate, disseminate, and maintain high-quality clinical evidence across the MD lifecycle. If not adequately addressed, such challenges can lead to suboptimal outcomes – for instance, the approval of an MD that later proves ineffective, or the abandonment of a promising technology that never reaches patients.

To address these barriers, healthcare organizations involved in various lifecycle stages must integrate technological, organizational, and managerial tools to support the generation, dissemination, and improvement of evidence quality.

This research seeks to answer the following question:

- *RQ. What technological, managerial, and organizational tools can healthcare organizations adopt to support the generation, dissemination, and improvement of clinical evidence quality across the MD lifecycle?*

The identified tools may assist policymakers in shaping effective MDR implementation strategies within their local healthcare systems. While the MDR is legally binding, its practical application is delegated to each EU Member State, with implementation often decentralized further – especially in healthcare systems such as those in France and Italy.

To explore this question, we adopt a case study approach focused on Italy's Tuscany Regional Healthcare System (RHS).

The following sections describe the methodology used and present our findings and analysis.

2 Methods

A single-case study design was adopted to thoroughly explore the complex phenomenon under investigation (Eisenhardt, 1989), focusing on the RHS of Tuscany, Italy.

Tuscany's RHS was selected due to its high healthcare performance, strong integration of hospitals, universities, and research centres, and its commitment to reducing clinical uncertainty through initiatives like the Clinical Trial Offices and Health Technology Assessment developments. This collaborative and innovation-driven environment makes Tuscany an ideal case for examining challenges in generating and evaluating clinical evidence across the MD lifecycle.

Between March and July 2024, interviews were conducted both in person at the interviewees' workplaces and remotely via Microsoft Teams. Participants included professionals from various organizations within the Tuscany RHS – such as University Hospitals, CTOs, and Research Centres – who were directly involved in the development or oversight of clinical evidence related to MDs. Table 2 presents the roles of the interviewees, the phases of MD lifecycle in which they are involved, along with the number and duration of the interviews.

Table 2 - List of the interviewees, number and duration of interviews conducted with each of them

Interviewees	Number of interviews	Involvement phase of the MD's lifecycle	Duration
Director of the Business Development, Active Agreements, and Special Projects Unit at a University Hospital and her team	1	Post-market	1h 26m
Director of the Clinical Trial Centre at a University Hospital and her team	2	Pre-market; post-market	1h 30m + 1h 40m
Director of the Clinical Trial Office at a Research Hospital Foundation and her team	1	Pre-market; post-market	1h 40m
Study coordinator of a Complex Unit at a University Hospital	1	Pre-market; post-market	2h 08m
Two researchers at the Italian National Research Council	1	Market approval	58m
Director of the Operational Unit for Biomedical Technology Planning and Organization at a University Hospital	1	Disinvestment	40m
Director of the Research and Educational Centre for Computer Assisted Surgery at University Hospital and his team	1	Pre-market; post-market	35m
Director of the Pharmaceutical Services Unit and Director of Healthcare Technology Unit at a Research and Healthcare Institute and their team	1	Pre-market; post-market; disinvestment	1h 08m

The interview guide was designed to identify technological, organizational, and managerial tools that support the generation, dissemination, and enhancement of clinical evidence quality for MDs – aiming to address clinical uncertainty. Each participant discussed tools relevant to the specific lifecycle phase they were involved in.

To preserve the richness and accuracy of the collected data, all interviews were fully transcribed.

The analysis involved coding the transcripts to extract content aligned with the study's objective: identifying tools that help manage clinical uncertainty.

Coding was independently conducted by two researchers, and subsequently integrated to ensure thorough and inclusive coverage of the data. Where possible, interview findings were cross-referenced with documentation and online resources to enhance the reliability of the data and provide a more in-depth understanding.

3 Results

The results are presented according to the four phases of the MD lifecycle.

3.1. Pre-market

In the pre-market phase, clinical investigations – either commercially or institutionally sponsored – are conducted. Manufacturer-funded trials (profit) generate financial returns for hospitals, while those led by public institutions (non-profit) do not.

Trials commence with a site initiation visit, during which the sponsor or, more often, the Contract Research Organization (CRO) presents the research protocol to the hospital staff. These studies follow Good Clinical Practices (GCPs), international standards for ethical and scientific conduct in human trials. As noted by a University Hospital's Clinical Trial Centre Director, *"originally focused on medicinal products, GCPs now also apply to MDs".* Italy's Ministerial Decree of July 15, 1997, outlines these standards for trial sponsors. GCP compliance includes thorough documentation and supervision in line with quality assurance systems.

Case Report Forms (CRFs) are essential tools for data collection, requiring more detailed information than regular medical records – such as full patient history, concurrent therapies, dosages, treatment dates, and all adverse events, regardless of their relation to the MD. Early inclusion of comprehensive data in CRFs prevents the need for protocol amendments, which require complex ministerial approval. Such amendments should be reserved for MD modifications due to technological progress.

Hospitals often appoint study coordinators to manage non-clinical aspects of trials. These coordinators support the principal investigator (usually a physician) by ensuring adherence to protocol, managing follow-ups, and entering data. Their contribution is vital for maintaining data quality. One study coordinator described preparing a Word template listing CRF data field, which is added to the patient's medical chart to aid clinicians in capturing relevant information.

Both profit and non-profit trials utilize digital CRFs, which have replaced paper versions. While digital tools streamline data handling, they complicate version tracking. Commercial trials often rely on advanced, manufacturer-provided software, while institutional studies may use simpler Excel sheets. As one study coordinator explained, *"the strict documentation requirements for profit studies are too demanding to apply to non-profit studies."*

CRO monitors verify that CRF entries match source data. Monitors with clinical coordination backgrounds often better understand ward dynamics. As noted by a study coordinator, *"monitors with experience as study coordinators better understand ward activity and demand precision in data entry when needed."*

CRFs play a critical role in ensuring high-quality, consistent, and accurate data, which supports rigorous analysis and traceability. Other evidence sources include patient diaries reviewed during follow-up visits, pre- and post-operative questionnaires (sometimes left incomplete due to sensitive questions), and investigator feedback on device usability and procedural duration. These tools enrich clinical evidence by integrating patient and clinician perspectives.

Technology also supports evidence generation. For example, the Research and Educational Centre for Computer-Assisted Surgery, selected as a case study, conducts preclinical in vitro tests using simulations developed with clinician input. According to a member of the centre team, *"simulators are developed with input from the investigating clinician, who specifies the real-world surgical steps."* Clinical researchers adjust simulations to account for anatomical and procedural variations. Some variables are tested in vitro, while others may require animal studies or cadaveric trials before human use.

These simulation technologies help assess MD performance in realistic settings, enhancing both the depth and reliability of pre-market evidence.

3.2. Market approval

Two researchers from the Italian National Research Council, who developed cardiology software, observed improvements in how clinical evidence is assessed under MDR. Previously, certification review was handled by regulatory experts. Now, clinical specialists designated by the Notified Body[1] evaluate the evidence and issue formal reports, occasionally requesting additional data from hospitals.

These researchers highlighted support from scientific societies: *"The European Society of Cardiology pushed for more clinical evidence for high-risk MDs."* Involving clinical experts ensures thorough evaluation of safety and efficacy, strengthening evidence standards and benefiting healthcare outcomes. However, there is concern that these experts may lack domain-specific expertise, indicating a need for broader specialist involvement.

3.3. Post-market

Post-market studies monitor MD safety and effectiveness through vigilance and surveillance systems, as required by MDR. These are particularly critical for high-risk devices. Manufacturers must compare pre-market trial results with real-world data via structured monitoring plans.

Despite differences, pre- and post-market studies share tools: GCP standards, CRFs, study coordinators, Word and Excel templates, CROs, and monitors. Tools like patient diaries and questionnaires also remain in use. Additional post-market instruments include supplier-led training, internal surgical trainers, pre-purchase software trials, conditional supply agreements, registries, and vigilance systems.

Regarding training, the Director of the Business Development, Active Agreements, and Special Projects Unit at a University Hospital outlined two approaches: vendor-led sessions (typically covering 10–20 procedures) and

[1] A Notified Body is an organisation designated by an EU country to assess the conformity of certain products before being placed on the market. These bodies carry out tasks related to conformity assessment procedures set out in the applicable legislation, when a third party is required. The European Commission publishes a list of such notified bodies.

peer observation programs that disseminate expertise across institutions. Certified clinicians benefit from this by enhancing skills, supporting innovation, and contributing feedback to manufacturers.

Software-based MDs can be trialed for 15 days before purchase. This trial helps determine functional adequacy and clinical relevance. Likewise, "supply on approval" schemes allow temporary use of MDs before purchase decisions. Clinicians submit evaluation reports based on real-world use, improving evidence quality.

Outcome registries, such as the national breast implant registry, gather long-term safety data. Vigilance systems assign staff to validate incident reports and conduct risk assessments. As a Clinical Trial Office Director explained, pharmacists validate these reports before submission to regional and national authorities. In serious cases, MDs may be recalled, and manufacturing processes reviewed.

According to the Director of the Pharmaceutical Services Unit and Director of Healthcare Technology Unit at a Research and Healthcare Institute, *"new MDs are monitored through device-vigilance for six months. Afterwards, a report is prepared considering the purchase price, the number of orders, and reported issues."* These reports, while initially internal, inform regional procurement decisions. Nonetheless, *"everything is not formalized; shared procedures are needed to formalize this information sharing."*

Though not fully standardized, this post-market surveillance process strengthens clinical evidence and informs safer, more effective MD use.

Simulators from the pre-market phase are reused to train clinicians on existing MDs, particularly for patients with unusual anatomy. Director of the Research and Educational Centre for Computer Assisted Surgery at University Hospital remarked, "In these cases, the clinical evidence generated in earlier phases of the MD lifecycle and the clinician's learning curve are insufficient for implanting the MD on patients with uncommon anatomical conformations."

3.4. Disinvestment

Clinicians are typically the first to identify signs of MD underperformance, which can prompt disinvestment to avoid compromising care quality. As confirmed by the Director of the Pharmaceutical Services Unit and Director of the Healthcare Technology Unit at a Research and Healthcare Institute, *"every six months, a meeting is organized with ESTAR's healthcare technologies to analyse the issues that have arisen."* These regular reviews allow for evidence-based decisions on whether to retain, replace, or phase out devices, ensuring continued patient safety and care quality.

Table 3 shows the main results.

Table 3: Main research results (* T: Technological tools; O: Organizational tools, M: Managerial tools)

	Tools to reduce clinical uncertainty								
	Generation			**Dissemination**			**Quality**		
	T*	O*	M*	T*	O*	M*	T*	O*	M*
Pre-market	Template Word Excel sheet (*non-profit* trials)	Study Coordinator	Good Clinical Practices for pre-market clinical trials, Case Report Form Patient diary Questionnaires for both patients and the investigating clinician	Word template Excel sheet (*non-profit* trials)	Monitor	Case Report Form	Template Word	Study Coordinator Contract Research Organization Monitor	Case Report Form Good Clinical Practices for pre-market clinical trials
Market approval								Contact with a clinical expert appointed by the Notified Body	

	Tools to reduce clinical uncertainty								
	Generation			**Dissemination**			**Quality**		
	T*	O*	M*	T*	O*	M*	T*	O*	M*
Post-market	Template Word Excel sheet (*non-profit* trials)	Study Coordinator	Good Clinical Practices for pre-market clinical trials, Case Report Form Patient diary Questionnaires for both patients and the investigating clinician Device-vigilance Simulation	Word template Excel sheet (*non-profit* trials)	Supplier's specialist Surgical trainer	Case Report Form Pre-purchase testing and supply on approval basis Registries	Template Word	Study Coordinator Contract Research Organization Monitor Supplier's specialist Surgical trainer	Case Report Form Good Clinical Practices for post-market clinical trials
Disinvestment					Meetings				

4 Discussion

The generation, dissemination, and improvement of clinical evidence quality take place across all phases of the MD lifecycle. Evidence generation is particularly critical in both the pre-market and post-market phases. Even when excluding incremental innovations – which can quickly heighten uncertainty – clinical uncertainty does not decline linearly over time. It can persist even after a MD has been approved and marketed. Unlike traditional consumer products, evidence generation for MDs cannot be limited to the pre-market phase. Instead, continuous evidence development is necessary throughout the entire lifecycle, as early-stage data may be insufficient due to the limitations of traditional RCTs in real-world contexts (Tarricone et al., 2020).

Evidence dissemination occurs throughout the MD lifecycle, except for the market approval phase. This is likely due to regulatory bodies being primarily focused on evaluating whether the device meets the criteria for legal marketing (Martin & Barnett, 2012). As a result, healthcare organizations generating evidence in the pre-market phase must wait until CE certification is granted before they can proceed with post-market dissemination.

Improving the quality of clinical evidence is relevant to all lifecycle phases except disinvestment. This may be because evidence accumulated in earlier phases reaches a maturity level that no longer requires enhancement at the end of the product's life.

Notably, there is no one-to-one relationship between a tool's nature – whether technological, managerial, or organizational – and its function. For example, evidence generation is supported by organizational tools (e.g., study coordinators active in both pre- and post-market stages), technological tools (e.g., Word templates and Excel sheets), and managerial tools (e.g., patient diaries).

Similarly, dissemination activities rely on a mix of tools: technological (e.g., templates), organizational (e.g., surgical trainers in the post-market phase), and managerial (e.g., Case Report Forms).

A closer look at tool usage across phases shows that, apart from the monitor used exclusively in the pre-market phase, nearly all tools adopted before market entry are reused afterward for similar purposes. The post-market phase, however, introduces additional tools tailored to real-world application – managerial tools like device vigilance systems and simulations for evidence generation, and registers or pre-purchase trials for dissemination. Organizational additions include supplier specialists and surgical trainers, who help ensure quality in evidence dissemination.

In contrast, the market approval and disinvestment stages employ fewer tools, typically organizational in nature. For instance, clinical expert consultations during approval support evidence quality, while collaborative meetings in the disinvestment stage facilitate knowledge sharing. These stages likely share functions with adjacent lifecycle phases – approval often finalizes pre-market activities, while disinvestment concludes post-market processes – so tools from those phases may still apply.

In the pre-market phase, evidence quality is often ensured by roles such as study coordinators and monitors who operate independently of the clinical team. In the post-market phase, evidence integrity is further reinforced through external training led by supplier specialists and surgical educators. Delegating tasks like data entry to non-clinical staff allows clinicians to concentrate on patient care.

Interestingly, although RCTs are considered the gold standard for evidence generation in early stages, practitioners often find Real-World Evidence (RWE), generated later in the lifecycle, to be more actionable. This reflects a broader trade-off between the methodological rigor of RCTs and the external validity of RWE (Kim, Lee & Kim, 2018). While RCTs offer precision through controlled settings and selective populations, this comes at the cost of generalizability. Conversely, RWE encompasses broader, more diverse populations and practical settings, albeit with reduced experimental control. A combined use of both approaches offers a more robust, balanced understanding of MD effectiveness.

5 Contributions

From a theoretical perspective, this work contributes to ongoing academic discussions on managing clinical uncertainty in the MD field by identifying tools that improve the generation, dissemination, and reliability of clinical evidence (Graili et al., 2023; Klein et al., 2022; Torbica et al., 2022; Pongiglione et al., 2021; Dreyer, Bryant & Velentgas, 2016; Rosner, 2012).

In practical terms, the tools outlined here offer healthcare organizations and relevant stakeholders actionable solutions to strengthen clinical evidence practices – particularly in contexts where high-level evidence is limited or difficult to obtain.

From a policy standpoint, MDR 2017/745 brings heightened scrutiny to MDs, presenting healthcare organizations with the complex task of generating, disseminating, and improving the quality of clinical evidence – in other words, managing clinical uncertainty. To support this effort, policymakers should equip organizations with clear guidelines for implementing the MDR, including practical recommendations on the use of technological, organizational, and managerial tools to reduce uncertainty around MD clinical evidence.

This study offers a set of such tools for policymakers to consider, allowing for tailored recommendations aligned with the specific needs of their local healthcare systems. Importantly, it illustrates how these tools can be effectively employed at various stages of the MD lifecycle.

The findings underscore the importance of incentivizing and funding clinical evidence generation throughout all phases of a device's lifecycle – pre-market, post-market, and continuous monitoring in real-world contexts. This process should aim to integrate data from formal clinical trials with operational insights, ensuring a balance between scientific robustness and practical feasibility.

Given the critical role of RWE in the post-market phase, there is a clear need for policy initiatives that promote the adoption of clinical registries, surveillance infrastructures, and data platforms. These systems should prioritize interoperability and be designed for access by a wide range of stakeholders.

In terms of broader policy design, the research calls for a multidisciplinary strategy that fosters close collaboration among clinical, technical, and managerial professionals. This collaborative approach should operate within a regulatory environment that is adaptable to emerging innovations.

As this study is based on a qualitative design, the findings are not intended to be generalizable. Further research involving additional RHS will be necessary to validate the results and enhance the breadth and transferability of the insights.

6 Ethics declaration

Ethical approval was not required for this study.

7 AI declaration

AI has been utilized to enhance the English language proficiency.

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Exploring Frugal and Reverse Innovation: A Bibliometric Review and Conceptual Proposal

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Abstract

This paper explores the growing significance of frugal and reverse innovation, two key concepts that address challenges in resource-constrained environments, particularly in developing economies. As businesses expand globally, these innovation models offer cost-effective and sustainable solutions. Frugal innovation focuses on creating affordable, efficient solutions in developing countries, while reverse innovation involves adapting innovations from emerging markets to developed economies. Though both aim for low-cost solutions, they stem from different contexts and raise important strategic questions about their integration into corporate strategies for growth, sustainability, and competitive advantage.

The paper investigates how the intersection of frugal and reverse innovation can enhance the understanding of global business strategies in emerging markets. By examining both conceptual foundations and practical applications, this study highlights their roles in global business dynamics and their potential to transform industries such as healthcare, energy, and education.

The study reviews existing literature through a bibliometric analysis. Out of 554 publications, 365 are bibliographically coupled and assigned to 6 clusters. These interrelated clusters capture the multifaceted nature of frugal and reverse innovation, via the exploration of conceptual frameworks, organizational strategies, social impacts, real-world applications, product-market challenges, and specific sectors like water and sanitation. The findings reveal that frugal and reverse innovations are not isolated but interconnected processes that shape global innovation trajectories.

The paper contributes to both academic and practical knowledge, offering a synthesized understanding of the field, identifying gaps in research, and providing insights for businesses and policymakers. It calls for future research on the co-evolution of North-South innovation flows and empirical studies on user perceptions and adoption dynamics in reverse innovation pathways. Despite its limitations, this study provides a solid foundation for advancing the theory and practice of frugal and reverse innovation.

Keywords: Innovation Strategies, Emerging Markets, Comparative Analysis, Bibliometric Study, Corporate Strategy

Paper type: Academic Research Paper

1 Introduction

This study delves into the growing importance of frugal and reverse innovation, two prominent concepts that have attracted significant attention in business and economic literature due to their potential to address the challenges faced by resource-constrained environments, particularly in developing economies. As the global landscape becomes increasingly interconnected, businesses are recognizing the value of these innovative approaches in expanding their reach while maintaining cost-effectiveness and sustainability. Frugal innovation is primarily characterized by the ability to create affordable, efficient, and resource-conscious solutions, often in response to the challenges of limited resources and infrastructure in developing countries. In contrast, reverse innovation focuses on the development of solutions within emerging markets, which are then adapted and implemented in developed economies, challenging traditional innovation pathways.

Although these two models of innovation share a similar emphasis on creating low-cost solutions, they originate in different contexts and have evolved in parallel, each responding to distinct sets of market conditions and consumer needs. This divergence raises key questions regarding the strategic implications of frugal and reverse innovation, particularly in terms of how they can be integrated into corporate strategies to foster growth, sustainability, and competitive advantage in both emerging and developed markets.

In this context, the paper aims to address the question: "*how can the intersection of frugal and reverse innovation contribute to a more comprehensive understanding of global business strategies in emerging markets?*". By exploring both the conceptual underpinnings and the practical applications of these innovation

models, this study highlights their distinct roles in global business dynamics and examines their potential to drive change in various industries, including healthcare, energy, and education.

In this paper, the following terms are used interchangeably to refer to developing economies, including "developing countries," "developing economies," "low- and middle-income countries," "the Global South," and "emerging markets."

The remainder of the paper is structured as follows. The next section summarizes the literature context and highlights the theoretical concepts dealt with in this study. The methodology is detailed in Section 3, while the results of the study are presented in the fourth section. The paper closes with the conclusions section, followed by the ethical and AI use considerations, and the bibliography in use.

2 Literature context

Innovation is a key driver of economic progress and business growth. It encompasses technological advancements and novel approaches to problem-solving and value creation (Govindan, 2024). Within this broad spectrum, frugal and reverse innovation have emerged as significant paradigms in corporate strategy and product development.

Frugal innovation is characterized by the creation of simplified yet effective solutions that maintain product quality while reducing costs and unnecessary complexity (Qin, 2024). This approach enables companies to design affordable products that serve large and often underserved markets, particularly in resource-constrained environments (Iqbal, Piwowar-Sulej and Kallmuenzer, 2025). It supports sustainability goals by optimizing resource use and minimizing waste,, making it an attractive strategy for companies seeking to balance profitability with social responsibility.

In contrast, reverse innovation describes the process of developing products in emerging markets and subsequently adapting them for wealthier economies (Wang and Wang, 2024). This model leverages the cost advantages of developing regions to create competitive, high-value solutions that, after initial success in price-sensitive markets, are refined and repositioned for high-income consumers (Jack *et al.*, 2024). Reverse innovation allows firms to experiment with lower-cost production methods and consumer-driven adaptations before scaling up to more demanding markets.

3 Methodology

The methodology employed in this article involves a comparative bibliometric analysis to comprehend the evolution of concepts over time, drawing on information published in major research databases such as Scopus. Bibliometrics is a robust approach that can be applied to a wide array of research areas ranging including but not limited to management (Merigó and Yang, 2017) innovation (Albort-Morant *et al.*, 2017; Fisac, Morales-Alonso and Rasool, 2024) and economics (Wang and Li, 2023). It differs from literature review since it presents accurate and objective findings because of its lower subjectivity (Moral-Munoz *et al.*, 2019). Therefore, it presents a complete overview of research trends and is therefore a handy tool when measuring the research field of a specific area (Broadus, 1987; Melnikova and Gilsanz, 2024).

To understand the interconnectedness and thematic evolution within this body of work, we conducted co-citation and bibliographic coupling analyses, following methodologies established by Small (1999) and Cobo et al. (2011), respectively. Bibliographic coupling, in particular, helped identify closely related research clusters by examining shared references among papers, facilitating a deeper exploration of the research subdomains within frugal innovation. The subsequent data visualization, crafted with tools like Microsoft Excel and VOSviewer, provided insightful graphical representations of the publication trends and relationships among the analyzed documents, enriching our comprehension of the field’s developmental trajectory.

4 Data analysis

Bibliographic coupling analysis appears once two papers cite a third mutual publication in their bibliographies. It would be supposed that the more mutual references have two papers the stronger thematic connection there will be between them (Cobo et al., 2011). Out of 554 publications, 365 are bibliographically coupled and assigned to 6 clusters. As shown in Figure 1, clusters represented by green, blue and yellow colors are connected more tightly, while those coloured Red, and purple are more isolated. However interestingly the cluster represented by Cyan colour is not linked to other clusters highlighting diversity in the literature encompassing the field. The size of the bubbles indicates the frequency of citations: the larger the bubble, the higher the frequency. The distance between the bubbles indicates the coupling strength and resemblance. The

colour of the bubble indicates the research area. Coauthorship analysis shows the extent to which authors in the field collaborate, see Figure 2.

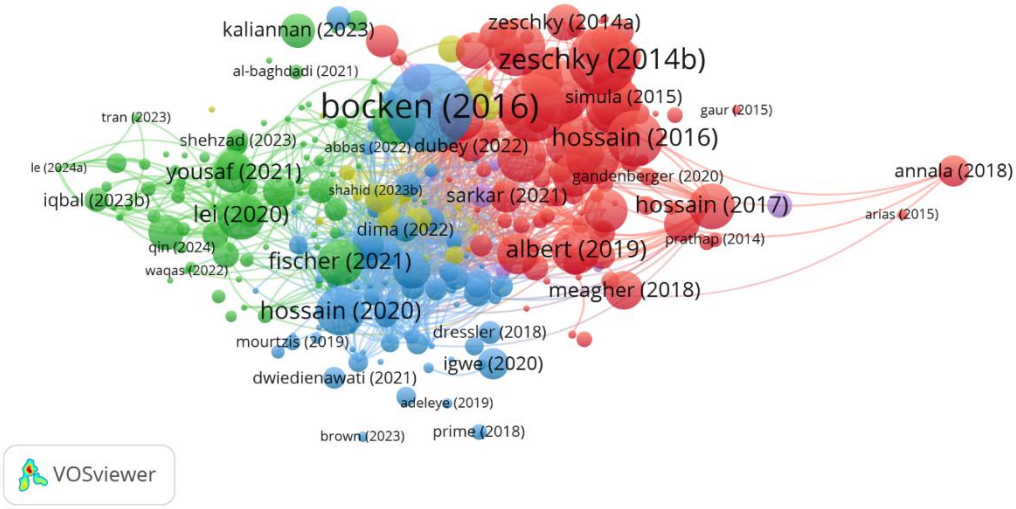


Figure 1: Results of the Bibliographic coupling analysis

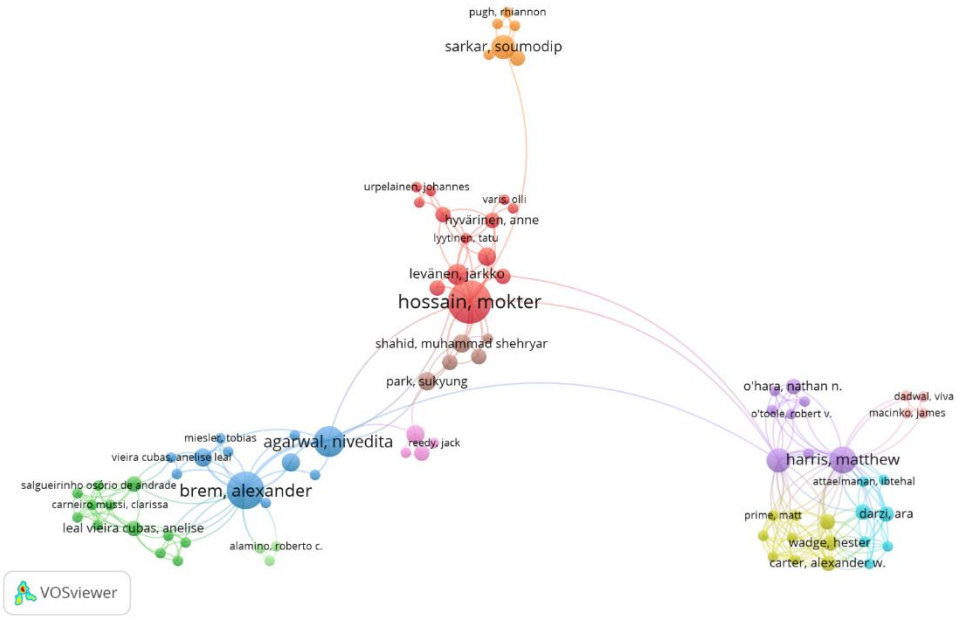


Figure 2: Results of the Coauthorship analysis

4.1 Common research trends by subject areas

This section presents the six thematic clusters of research on frugal and reverse innovation, derived from a keyword coupling analysis of the literature. Each cluster represents a dominant research theme, reflecting how scholarly attention in frugal and reverse innovation has coalesced around particular topics. Notably, while most clusters are interrelated, one cluster (Cluster 6) appears largely disconnected from the rest (Figure 1), indicating a niche research thread with minimal bibliographic overlap. Below, we outline each cluster's focus and significance, citing representative works from the dataset to illustrate the dominant research trends and knowledge gaps.

4.1.1 Cluster 1: conceptual and global perspectives on frugal and reverse innovation

This cluster focuses on the foundational and global discourse on frugal innovation, often intertwined with the concept of reverse innovation. This cluster explores frugal innovation conceptual frameworks and its links to reverse innovation and broader innovation theory. For example, Agarwal and Brem (2012) provides an early overview that explicitly links frugal and reverse innovation, using case studies of a Western multinational innovating in India and China. Such studies articulate how innovations developed under resource constraints in emerging markets can find broader application, thereby bridging global knowledge flows from the "South" to the "North" (the essence of reverse innovation).

Another key theme in this cluster is the role of frugal innovation in achieving sustainability and inclusive growth. Brem and Ivens (2013) introduce a conceptual framework asking whether frugal and reverse innovations foster sustainability, reflecting a prevalent view that cost-effective innovations can align with social and environmental objectives. Additionally, studies in this cluster examine the **institutional and policy contexts** that enable or hinder frugal innovation diffusion. For instance, some studies investigate how regulation and institutional environments affect the **commercialization of frugal solutions** in developing economies (Agarwal and Brem, 2012; Knorringa *et al.*, 2016). Others highlight how **knowledge transfer** between academia, industry, and communities is often facilitated through **social entrepreneurship** or inclusive innovation models—plays a critical role in shaping frugal innovation outcomes (Annala, Sarin and Green, 2018; Fischer *et al.*, 2021). These processes emphasize the importance of collaboration and local contextualization in achieving sustainable frugal innovation, particularly in sectors like healthcare, water, and education. Therefore, it is reported that this cluster highlights the bidirectional flow of ideas where innovation not only trickles down from high-end to low-end markets, but also "trickles up" from resource-constrained settings to affluent markets.

4.1.2 Cluster 2: organizational capabilities and business strategy in frugal and reverse innovation

Cluster 2 moves inside the firm. It asks: how do companies embed frugality in day-to-day practice? Three capability sets recur. First, dynamic sensing-seizing-reconfiguring loops. Leaders scan unmet needs, spot slim cost windows, and rebundle assets fast. Vietnamese SMEs reorganised supply chains within weeks (Le et al., 2022) , and Saudi manufacturers tied the same agility to cultures that reward disciplined improvisation (AlMulhim, 2021) . Second, digital leverage. AI surfaces hidden demand, cloud CAD slashes prototype cycles, and low-cost IoT tracks post-sale use. An Indonesian case cut design time from sixty days to eight by shifting modelling to open cloud rigs (Achmad and Inrawan Wiratmadja, 2024). U.S. med-tech start-ups crowd-sourced firmware fixes overnight with similar gains (Howell, van Beers and Doorn, 2018). Third, strategic framing. Blue-Ocean logic steers firms away from price wars, while adversity sparks bricolage that later hardens into process (Zeschky, Widenmayer and Gassmann, 2011; Winterhalter *et al.*, 2017). Framing constraint as opportunity doubled project survival odds in Ghanaian agritech ventures (Adomako *et al.*, 2024). Tensions persist. Low price points squeeze cash; premium brands fear dilution; classic KPIs ignore carbon saved or users reached. A new dashboard ranks "impact per dollar" beside ROI, helping boards balance money and meaning (Abbas and Liu, 2022). Taken together, these studies show frugal and reverse innovation succeed when capability, data, and narrative lock tightly, turning constraint into a continuous source of strategic renewal.

4.1.3. Cluster 3: frugal and reverse innovation for sustainable development and social impact

Cluster 3 frames frugal innovation as a lever for the Sustainable Development Goals. Its studies show lean design cutting emissions while improving daily life. Firm-level work links innovation capabilities to greener practice and higher export competitiveness among Indian manufacturers (Adhikari and Momaya, 2021) and identifies lean start-ups in emerging economies that turn eco-innovation into market traction (Abbas and Liu, 2022). Many papers highlight grassroots co-creation. Quadruple-Helix partnerships—community makers, NGOs, universities, local government build mobile clinics and low-cost farm tools, then refine them in fast feedback loops (Bhattacharjya, Bhaduri and Kakoty, 2023; Akhtar and Ramkumar, 2024). These bottom-up models treat users as co-owners, not beneficiaries, strengthening uptake and maintenance. Reverse flows give the cluster its second strand. Low-cost diagnostic kits born in rural India now serve remote clinics in Europe, while solar water-heating concepts tested in Brazil inform resilience plans in the United States (Busch *et al.*, 2018). SMEs in Germany have even adopted sufficiency-oriented business models inspired by these Southern experiments (Dellermann, 2017). Authors argue that such "trickle-up" learning challenges the idea that advanced economies are always technology donors and positions frugality as a source of climate-aligned disruption (Albert, 2019).

Technology alone, however, cannot secure impact. Studies on mobile health vans and water-filter roll-outs show diffusion sticks only when users keep data rights and share revenue streams (Bhatti *et al.*, 2017). Business-model research reinforces this point: framing offers as "smart and sustainable" rather than "cheap" boosts

status and adoption in affluent niches (Rosca, Arnold and Bendul, 2017). Overall, Cluster 3 redefines frugal and reverse innovation as a social–ecological contract. Cost savings matter, but the bigger prize is inclusive ownership, carbon relief, and knowledge that flows both south–north and north–south. Future work the cluster recommends includes tracing value capture along these bidirectional journeys and developing metrics that record lives improved per dollar spent, not just units sold.

4.1.4. Cluster 4: implementation and adoption of frugal and reverse innovation in practice

Cluster 4 leaves the whiteboard and enters the field. Case papers track how frugal ideas survive the jump from pilot to daily use. A well-cited example is Vortex Engineering's solar-powered ATM network in rural India; by mixing ultra-low-power chips with rooftop panels, the firm brought banking to villages that lacked stable grid access (Agarwal and Brem, 2017). Health studies echo the story. Mobile primary-care vans built on recycled bus shells serve remote patients for a tenth of the cost of fixed clinics (Akhtar and Ramkumar, 2024), while community makers in Assam co-created drip-irrigation kits that cut water use by half (Bhattacharjya, Bhaduri and Kakoty, 2023). Method papers explain how such projects move fast on thin budgets. Constraint-based thinking offers a step-by-step playbook: freeze a hard price or energy cap, then "engineer backward" to fit it (Agarwal, Oehler and Brem, 2021). Scrum sprints adapted for hardware keep prototypes rolling every two weeks; one med-tech team reported an eight-to-one cut in design time after switching to this cadence (Endres, Bican and Wöllner, 2022). Co-creation widens the safety net. University labs, NGOs, and local user groups meet in weekend build-athons, making tacit know-how explicit and locking in community ownership (Annala, Sarin and Green, 2018; Bhattacharjya, Bhaduri and Kakoty, 2023).

Adoption research digs into perception. Survey work in Jordan finds that value, peer cues, and quality signals explain 70 % of purchase intent for frugal appliances; stigma around "cheap" still bites, but "smart-green" framing helps neutralise it (Al-Refaie, Abu-Ghannam and Al-Hawadi, 2023). Crisis tests add another angle. Indonesian SMEs with modular product lines pivoted to pandemic gear in weeks, showing that frugal architectures boost resilience when supply chains snap (Achmad and Inrawan Wiratmadja, 2024). Taken together, Cluster 4 argues that successful roll-out blends tight engineering routines, inclusive design spaces, and branding that elevates thrift to savvy. When those pieces click, frugal and reverse innovations leap the "valley of death" and prove that low-resource contexts can host world-class implementation playbooks.

4.1.5. Cluster 5: design and market challenges in frugal and reverse innovation

Cluster 5 zooms in on the design bench and the showroom. The central task is a paradox: slash cost and complexity without stripping the value cues that trigger purchase. Studies start with constraint-based playbooks. Agarwal et al. (2021) describe teams fixing a non-negotiable retail ceiling often US $20 or half the incumbent's carbon load—and then "engineering backward" to meet it, trading plastics for bio-composites and combining off-the-shelf chips with open-source firmware . Brem et al. (2020) add staged filters need, usability, ecosystem to keep frugality from drifting into under-performance; one Kenyan water-pump project passed all three gates at one-third rival cost . Market trials expose the psychology behind "cheap." Al-Refaie et al. (2023) show status stigma still lingers in upper-middle segments, yet framing products as "smart-green" rather than budget lifts willingness to pay by 22 percent . Rosca et al. (2017) report similar results for modular solar kits that let households upgrade over time, turning thrift into future-proofing . Premium brands tackle cannibalisation risk by creating spin-off labels, separating low-cost lines from flagship offerings while highlighting durability and eco-benefits.

Regulation tightens the puzzle. Auma et al. (2023) document a portable diagnostic device that met EU safety norms at one-tenth incumbent cost only after early co-testing sessions with regulators, saving six months in certification . Health and energy sectors replicate this path, pairing minimum viable prototypes with "compliance sprints." Across cases, three design levers surface: rigorous cost ceilings, narrative repositioning that shifts "cheap" to "savvy," and iterative regulator dialogue. Cluster 5 thus recasts frugal design as strategic craftsmanshipbalancing engineering trade-offs, consumer perception, and rule-of-law hurdles inside one tight feedback loop.

4.1.6. Cluster 6: frugal and reverse innovation in water and sanitation technologies (isolated cluster)

Cluster 6 is the smallest node on the map yet tackles a basic need: safe water. Its papers are heavily technical, coming from environmental engineering and materials science rather than management. The signature solution is the metallic-iron (Fe^{o}) filter. By letting a thin rust layer form on cheap iron granules, these filters strip arsenic, fluoride, and microbial contaminants while staying decentralized, gravity-driven, and almost maintenance-free (Btatkeu-K. *et al.*, 2016). Field pilots in Cameroon, Tanzania, and India show toxin reductions that meet WHO

drinking-water limits with bucket-scale units costing a few dollars (Ndé-Tchoupé *et al.*, 2015, 2018). Much of the research optimizes Fe/sand ratios, corrosion kinetics, and filter life, supplying rigorous design criteria that earlier "jugaad" devices lacked. Bibliometric positioning, however, reveals an island. Cluster 6 cites almost no work from the broader frugal-innovation community and is likewise ignored by management scholars . The silo stems from disciplinary focus journals prize removal efficiency over adoption models but it creates a lost handshake. Without market studies, promising filters stall at prototype. Without the filter data, frugal-innovation theory lacks material depth.

Authors in the cluster now call for bridges. Pair lab tests with ethnography to learn why users abandon filters, enlist micro-finance to fund household uptake, and frame water devices as climate-adaptation assets to unlock public grants. Community stewardship boards already extend filter life and trust faster than top-down campaigns . In short, Cluster 6 shows that hardcore science can meet radical affordability, but scalable impact will require boundary-spanning teams that blend corrosion chemistry with business modelling and policy design.

5 Conclusions

The review shows that frugal and reverse innovation research has moved from scattered anecdotes to a coherent conversation about how scarcity, knowledge flows, and social purpose that reshape global innovation practice. By coupling 365 papers into six clusters we traced a route that loops from theory to strategy, to grassroots action, and back again, revealing a field cohesive enough to guide managers yet flexible enough to welcome new voices. Three insights stand out. First, frugality is no longer a stereotype of the Global South; multinationals now treat constraint-led design as a proving ground for resilience, then re-import streamlined solutions to mature markets where cost and carbon pressures converge, which can lead innovations that spring on developing countries to be used in developed settings (reverse innovation). Second, social value is not a by-product but the hinge that lets low-cost ideas cross borders. Case work on water filters, mobile clinics, and off-grid devices shows adoption rises when organisations share ownership, data, and gains with local users; technical brilliance alone stalls at pilot stage. Third, blind spots between disciplines still block scale. Engineering research on sanitation, for instance, rarely cites management studies and so misses distribution models that could lift laboratory success into daily life.

These patterns suggest a practical agenda. Firms should form mixed teams that pair material scientists with market strategists early, embed constraint metrics into stage-gate reviews, and track "impact per dollar" alongside return on investment. Policymakers can tilt incentives by granting premiums to products that document south-north knowledge transfers and by supporting shared-IP deals that leave part of the upside in origin communities. Scholars should shift from static taxonomies to longitudinal tracking of real product journeys, using network analysis, ethnographic shadowing, and replication studies to expose where idea flows thicken or dry up. Business schools can reinforce the shift by capping cash, carbon, and material budgets in design studios so that frugality becomes muscle memory for the next generation of innovators. Finally, the bibliometric lens reminds us of its limits: it maps dialogue but cannot hear it. Fresh ethnographies and comparative fieldwork are needed to catch nuance, measure stigma, and follow cash. Even so, the map is a useful compass. It shows that when resource mindfulness, inclusive intent, and iterative learning reinforce one another, frugal and reverse innovation cease to be niche labels and become a general method for building affordable, sustainable, and context-sensitive solutions, a lesson practitioners, policymakers, and researchers can carry forward.

6 Ethics declaration

In this research, there was no need for ethical clearance.

7 AI declaration

In this research, no AI tools have been used.

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The Use of Generative AI and Lean UX in Knowledge Engineering Projects

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Abstract

The need for user-centered and agile solutions has driven the adoption of methodologies such as Lean UX in knowledge engineering projects. While Lean UX focuses on thinking, making, and checking to enhance user experience, knowledge engineering is dedicated to building intelligent systems grounded in formalized expert knowledge. Despite the conceptual alignment between these approaches, the integration of Generative Artificial into this context remains underexplored. This study proposes a model that incorporates generative AI tools into the Lean UX process to accelerate and enhance the development of knowledge-based systems. Based on the Design Science Research (DSR) methodology, a narrative literature review and exploratory research were conducted to identify generative AI techniques applicable to each Lean UX phase: Think, Make and Check. A total of 10 generative AI approaches were mapped and organized into a model that supports small and agile teams in knowledge engineering projects. The model was instantiated through the development of GPT-based agents customized for specific tasks, such as persona generation, empathy mapping, requirements analysis, and prototype creation. These agents leverage prompts containing transcripts, observations, or interview data to generate detailed and realistic outputs, streamlining processes that are traditionally manual and time-consuming. One example presented is the Persona Generation Agent, which creates structured user profiles and illustrative images from simple textual input. This integration contributes both theoretically and practically by demonstrating how generative AI can be used to enhance user experience (UX) focused design processes in knowledge engineering. The proposed model promotes more efficient workflows, while keeping the user at the center of development. It also supports interdisciplinary collaboration, faster iteration cycles, and the creation of intelligent systems that are more aligned with user needs. Future work includes empirical validation of the model in diverse application contexts, aiming to refine its use and encourage widespread adoption in knowledge engineering and related fields.

Keywords: lean ux; knowledge engineering; generative ai

Paper type: Research Paper

1 Introduction

With the growing demand for more effective, personalized, and adaptable digital solutions, user-centered methods with iterative cycles have gained prominence in the development of products and services. Among these methods, Lean UX stands out for its agile, collaborative, and user experience (UX) oriented approach, promoting a culture of continuous experimentation, rapid learning, and hypothesis validation based on real usage evidence. By integrating cross-functional teams and reducing reliance on heavy documentation, Lean UX fosters more dynamic processes aligned with end-user needs.

These characteristics make Lean UX particularly promising for fields such as knowledge engineering, whose main goal is to develop intelligent systems based on specialized and structured knowledge. Knowledge engineering, in turn, demands methodologies that allow for a deep understanding of usage contexts, user profiles, and the specificities of the domains in which the systems will be applied. The convergence between Lean UX and knowledge engineering thus emerges as a strategic opportunity to enhance the creation of more effective, usable, and context-aware technological solutions.

Despite the potential synergies between these approaches, the literature still lacks in-depth investigations into how emerging technologies such as Generative Artificial Intelligence (Generative AI) can be integrated to improve development processes in both areas. Generative AI, with its ability to create original content from large volumes of data and interact through natural language, presents itself as a powerful tool for automating tasks, generating insights, and accelerating iterative cycles.

In this context, this study aims to conduct a narrative review and exploratory research to identify Generative AI techniques that can be applied at different stages of the Lean UX process. Based on this investigation, the study proposes a model that combines Lean UX principles with the strategic use of Generative AI tools, aiming to support the development of intelligent systems in the field of knowledge engineering, especially in environments with small teams, tight deadlines, and high demand for innovation.

2 Methodology

This study adopted the Design Science Research (DSR) model as its methodological foundation, as it is a widely recognized approach in the field of information systems and well-suited for the development of innovative and applied solutions. DSR is characterized by the construction and evaluation of artifacts—which may take the form of models, methods, system instances, or frameworks with the goal of solving real-world problems based on scientific rigor (Hevner et al., 2004). Furthermore, DSR proposes an iterative cycle that includes problem identification, artifact construction, demonstration, evaluation, and, finally, communication of the results, ensuring that the knowledge produced is relevant to both practice and academia.

In this context, the model proposed in this study is conceived as the central artifact of the research, and its applicability to knowledge engineering projects is treated as the practical instantiation of that artifact. Instantiation refers to the application of the model in real or simulated contexts, with the purpose of assessing its feasibility, usefulness, and potential for generalization.

To support the construction of the model, the study was structured around a narrative literature review aimed at identifying previous approaches that explored the use of Lean UX methods in the context of knowledge engineering. The review also encompassed foundational literature in the involved domains, particularly the conceptual and methodological underpinnings of Lean UX and knowledge engineering. The analysis focused on recent publications that highlight emerging trends and underexplored gaps, especially concerning the integration of emerging technologies, such as Generative Artificial Intelligence, into iterative and collaborative system development processes.

3 Lean UX in Knowledge Engineering

Lean UX, a method focused on the development of user-centered products, especially digital products (Gothelf and Seiden, 2021) shows potential for application in knowledge engineering, a field dedicated to intelligent, knowledge-based software system solutions (Schreiber et al., 2000), by incorporating its principles and phases into the development of intelligent systems.

The principles of Lean UX, such as cross-functional teams, product focus, and a culture of experimentation, have proven effective in knowledge engineering projects. Collaboration between human experts and the engineering team is essential for knowledge capture, while a product-focused approach—without prioritizing documentation as the main deliverable enhances the efficiency of developing knowledge management systems. Furthermore, tolerance for failure and continuous experimentation make it possible to measure user satisfaction in each iteration. Finally, keeping the user at the center of the process involves stakeholders and experts, promoting testing and contributing to the success of the solution.

The phases of Lean UX can be applied to knowledge engineering projects by drawing parallels with the CommonKADS models (Schreiber et al., 2000). The "think" phase, aimed at conception and needs elicitation, corresponds to the organization, task, agent, knowledge, and communication models of CommonKADS. The "make" phase includes the design model for system architecture and implementation, while the "check" phase focuses on user evaluation, initiating new development cycles based on the results of usability testing.

4 Generative AI in Lean UX

Several studies were identified that explore the application of Generative AI techniques in tasks traditionally carried out manually during the design of digital products. Among these contributions, those focused on automating collaborative dynamics stand out, such as the analysis of sticky notes, which are often used in workshops and brainstorming sessions. For example, the work of Walch and Karagiannis (2020) demonstrates how algorithms can interpret and cluster content written by users on physical or digital notes, generating thematic summaries and facilitating collective knowledge construction in the early stages of the Lean UX process.

Another innovative area involves the automatic generation of personas based on transcripts of user interactions, such as interviews or observational data. These approaches apply natural language models to extract behavioral traits, goals, and recurring user needs, enabling the creation of realistic, data-driven user profiles that support more informed design decisions.

Additionally, there is a growing body of research focused on the automated generation of storyboards and user flow narratives, tools that are essential for mapping user journeys and visualizing interaction logic with systems and interfaces. Studies such as those by Jansen et al. (2021), Salminen et al. (2019), Chung (2024), and Liang et al. (2024) show that AI-based tools can not only structure these elements from textual requirements but also suggest creative alternatives and flow variations, fostering innovation in interaction design. In the field

of requirements engineering, works by Ronanki et al. (2024) and Sami et al. (2024) demonstrate the feasibility of automatically extracting and organizing software requirements from textual transcripts, significantly reducing elicitation time and improving the consistency of the generated documentation.

Regarding the prototyping phase, studies by Takaffoli et al. (2024) and Chivukula et al. (2024) propose AI-based solutions for automated wireframe generation and layout optimization, drawing on usability patterns and user preferences identified in large datasets. These solutions enable faster creation of visual interface drafts, allowing for more frequent testing and refinement cycles. Other approaches, such as those by Suleri et al. (2019) address the automatic transformation of low-fidelity prototypes into medium- and high-fidelity versions, using sketch recognition and visual completion techniques to produce more detailed and interactive interfaces.

In the evaluation stage, notable contributions include the use of simulator agents, usability analysis tools based on predictive metrics, and emotion recognition systems that assess users' emotional states during interaction with prototypes. Research by Wallach et al. (2020) and Chivukula et al. (2023) suggests that combining sensors, computer vision, and predictive models can provide accurate feedback on the user experience, anticipating usability issues, measuring engagement levels, and identifying critical frustration points along the user journey. These advances make interface evaluation more robust and objective, enabling more confident decision-making in the iterative design process.

5 Proposed Model

Based on the theoretical framework explored throughout this study and focusing on the strategies, trends, and contributions of Generative AI analyzed in the research, this work proposes a Knowledge Engineering project model that leverages Generative AI to accelerate product development processes with a focus on user experience.

The core premise of this model is to involve users, domain experts, and the technical development team throughout the entire process, aiming to ensure the success of knowledge engineering projects by grounding them in Lean UX principles applied to the development of intelligent knowledge management systems. The proposed model is informed by narrative literature reviews of previously proposed approaches regarding the use of Lean UX methods in knowledge engineering, as well as foundational literature on both knowledge engineering and Lean UX, with an emphasis on identifying unexplored potential highlighted in recent studies.

To systematize the proposed model, a graphical representation was developed using the stages of Lean UX arranged in a circular format, aiming to illustrate the iterative nature of the process as applied to knowledge engineering projects. This representation is shown in Figure 1.

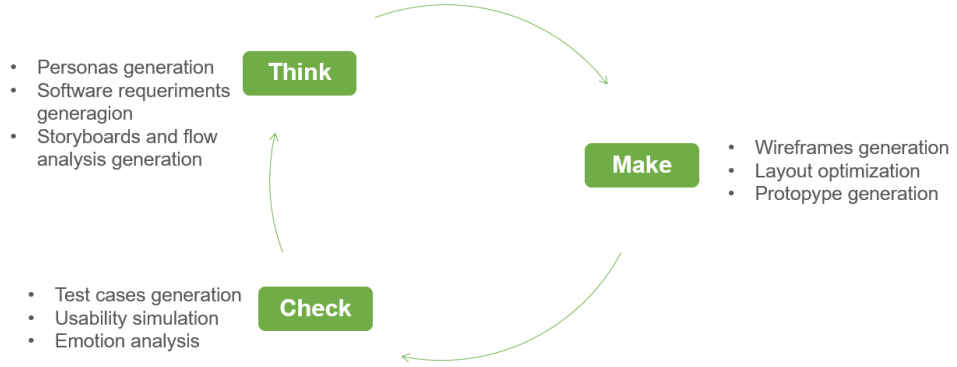


Figure 1: Proposed Model

In the “Think” stage, the use of agents and GPT models is proposed to analyze transcripts of meetings, observations, and interviews for the automatic generation of personas, software requirements, flow analyses, and storyboards. In the “Make” stage, tools for generating graphics and optimizing prototypes are suggested, aiming to test the product's MVP. In the “Check” stage, processes for testing and automatically evaluating the analyses of the prototyped product from the previous stage are proposed.

6 Results

Following the premise of DSR, in which artifacts are realized through their instantiation, and aiming to demonstrate how the model can be used in practice, the instantiation of this artifact was based on the operationalization of the proposed stages and Generative AI agents. To materialize this artifact, the stages based

on Lean UX, proposed for the development of knowledge engineering projects—were enhanced by the integration of Generative AI agents.

These agents were implemented according to the structure proposed by the model, using GPT (Generative Pretrained Transformers) technology, specifically customized versions of OpenAI's ChatGPT. GPTs are agents developed to perform specific tasks and meet particular needs. These models can be trained using databases, manuals, historical records, or other relevant sources, enabling them to understand technical terminology and the specificities of particular domains.

GPT agents can be created using tools such as OpenAI's GPT Builder and can be made available through the GPT Store, OpenAI's platform for creating, publishing, and monetizing custom GPTs. This marketplace provides an environment for developers and organizations to share their GPT-based solutions with the public.

To illustrate the instantiation of the proposed model through GPT agents, Figure 2 presents the persona generation agent. This agent accelerates the work of the knowledge engineering team by automatically constructing the ideal persona framework for use in knowledge management systems.

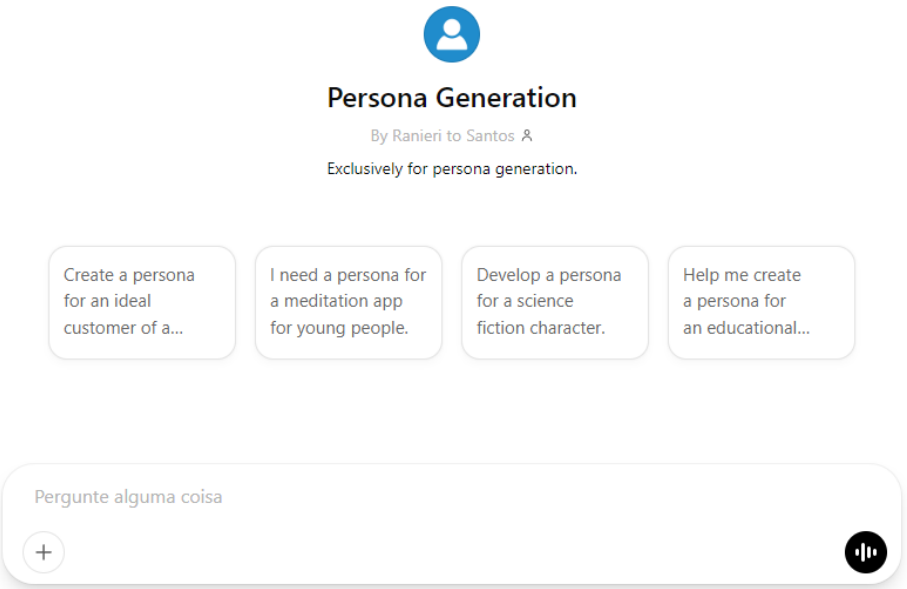


Figure 2: Persona Generation Agent

Using the specific GPT agent, the knowledge engineering specialist can generate a persona for their product by entering a prompt. The prompt may include transcripts of interviews, observations, and other details regarding the behavior of the product's users.

To demonstrate this process, Figure 3 shows a sample result from the persona generation agent, representing a user of a knowledge management product designed for higher education faculty. In the figure, it is possible to see that, in addition to a detailed persona profile, a representative image of the ideal user is also generated.

The implementation of this agent is based on the GPT's ability to process and generate personalized content from specific prompts. This allows personas to be created efficiently and tailored to the specific needs of a given product or service. The methodology used for persona generation involves the collection of demographic, behavioral, and social data, which are essential for creating realistic and relevant user profiles. This information is entered via prompt and can take the form of simple imperatives or transcripts from conversations, interviews, and observations. These inputs are then processed by the GPT to generate personas that reflect the characteristics, goals, and challenges of the target users.

The inclusion of elements such as name, illustrative photo, and contextual background helps make the personas more tangible and easier to understand for design and development teams. This promotes a deeper understanding of user needs and facilitates more informed decision-making throughout the user experience design process.



Name

Dra. Camila Ribeiro

Data

- **Age:**36 years old
- **Profession:** University Professor of Mathematics
- **Training**PhD in Applied Mathematics from the State University of Campinas

Personality

Camila is analytical,

Context

Camila teaches at a university

Wishes

It seeks to make mathematics teaching more accessible.

Figure 3: Persona Generation Agent Result

As can be observed, the output generated by the persona agent delivers a detailed and realistic profile that encompasses the essential characteristics of the target user, based on the agent's programmed pattern even from a simple prompt. The persona generated by the GPT agent not only provides general and illustrative data but also delves into personality traits, life context, desires, needs, and motivations, as well as common pains and frustrations of the intended user group.

This depth of information enables design and development teams to better understand who their users are and how they interact with the product or service.

7 Conclusions

The practical instantiation of the model through the development of agents based on customized GPTs demonstrated how traditionally manual and time-consuming processes, such as persona creation, can be transformed into faster, more systematic tasks that are deeply connected to users real needs. The customization of agents, combined with the flexibility of data input via prompts, enables their application across diverse contexts while respecting the specificities of each knowledge domain.

In addition to contributing to the theoretical advancement at the intersection of Lean UX and Knowledge Engineering, this work also offers a practical contribution by demonstrating how Generative AI tools can be integrated into project teams workflows, even in resource-constrained environments. The proposal aims not only to increase productivity but also to maintain user centrality throughout all stages, enhancing teams' ability to deliver more relevant, empathetic, and effective solutions.

As future work, there is a need for empirical validation of the model in different application contexts, through case studies and experiments with real users. It is expected that, with the advancement of AI technologies and the growing accessibility of such tools, the integration proposed here will become a common practice in Knowledge Engineering projects and related fields. Thus, the model can continue to evolve, incorporating new techniques, tools, and practical insights that will feed back into its cycle of continuous improvement.

8 Acknowledgements

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9 Ethics Declaration

For the development of this paper and for all reviews and research involved in this work, no ethical authorization was required.

10 AI Declaration

No artificial intelligence tools were used to prepare this paper. However, AI tools were used to translate and review some specific terms that involved different languages in the writing of the paper.

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Food Waste Valorisation: A Comparative Study with a Hybrid AHP-Fuzzy Approach

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Abstract

The wine industry generates different waste and by-products that can be converted into high-value goods, such as biogenic products or energy, offering new market opportunities and reducing the environmental implications. However, the variety of technologies available complicates the selection of the best valorisation option. An effective evaluation system integrating economic, technical, environmental, and social factors is essential for choosing appropriate valorisation strategies. In this study, we apply the Analytic Hierarchy Process and Fuzzy Set Theory to comprehensively assess food waste valorisation within the wine industry. Our results indicate that anaerobic digestion technology is the best option to valorise winery waste. This framework helps decision-makers evaluate waste valorisation strategies holistically, highlighting the need for investments in sustainable technologies tailored to specific company characteristics.

Keywords: Analytic hierarchy process; Fuzzy logic; Food waste valorisation; Sustainability; Technologies

Paper type: Academic Research Paper

1 Introduction

Food waste is a major concern today, negatively impacting the environment, society, and economy, affecting individual companies and the entire community (Stone et al., 2019). Every year, one-third of all food produced worldwide is lost or wasted somewhere along the food supply chain (Dora et al., 2021). This impressive statistic highlights the inefficiency of production and consumption systems and represents a significant environmental and economic challenge. In the context of a circular economy, recovering and valorising food waste is critical for the environmental and economic sustainability of the supply chain (Dora et al., 2021). The wine industry offers a relevant example of food by-product generation, such as pomace, grape seeds and peels. These by-products, if mismanaged, represent a disposal problem; however, at the same time, they offer a unique opportunity for valorisation (Abbate et al., 2024). Innovative technologies have the potential to significantly transform food waste into high-value goods, encompassing a range of valuable items, including phenolic compounds, which are essential in various industrial applications, food supplements that enhance nutritional value, cosmetics that promote skin health, and biofuels that provide renewable energy sources. Notably, producing renewable energy from waste contributes to a transition towards more sustainable systems. By converting organic waste into energy, reliance on fossil fuels is reduced, greenhouse gas emissions are minimised, and a circular economy is promoted where resources are continuously reused and recycled.

Recent research is lacking in comparing technological advancements for valorising food waste generated during production. Nevertheless, it is crucial to identify the most effective methods for disposing of and reusing such waste based on specific contexts and related variables (Eseoglu et al., 2022). As a result, this study assesses and compares different food waste valorisation technologies mainly used in the wine-growing context (i.e. anaerobic digestion and pyro-gasification) according to various economic, environmental, and social parameters. In particular, this research combines the fuzzy set theory (FST) and the analytical hierarchy process (AHP) to weigh each parameter, rank the different food valorisation technologies based on the evaluation criteria, and identify the most suitable solution.

The paper is organised as follows. The next section presents a literature review on the topic. Section 3 shows the methods adopted for the empirical investigation. Section 4 presents the study's results. Finally, section 5 highlights the conclusions, implications, and future research avenues.

2 Literature review

Given the technical, economic, environmental, and social aspects, selecting the most sustainable approach to managing food waste is challenging. A prevalent method in the food industry for recycling waste is composting. This process converts waste into a nutrient-dense natural fertiliser, enhancing crop yields and offering a sustainable and eco-friendly solution for handling food waste (Ciclia, 2021). Composting technologies,

such as the in-vessel system and the vermicomposting system, have different approaches but share the same goal of transforming organic waste into nutrient-rich compounds (Shukor et al., 2018). In addition, through polyphenol extraction processes from grape marc, it is possible to improve the nutritional and sensory attributes of foods such as meat burgers, muffins, and yoghurt (Rodriguez et al., 2023).

Furthermore, technologies that produce bioenergy from food waste (e.g. anaerobic digestion and pyro-gasification) are seen as innovative solutions, generating renewable energy and reducing the environmental impact of the sector. Different researchers (e.g. Adenuga et al., 2020; Mahjouri et al., 2017) showed that anaerobic digestion is the most eco-friendly technology when compared to other methods. This approach enables the treatment of waste with high water content to generate biogas and digestate as a by-product of processing. Similarly, pyro-gasification technology converts by-products into synthetic gases suitable for energy production. In particular, this technology works through the partial combustion of dry waste, also generating biochar, which serves as a biofuel and soil amendment, thus offering an environmentally friendly option for carbon capture (Rodriguez et al., 2023).

Compared to previous research, the originality of this study lies in several key aspects. First, we have integrated social and community criteria into the evaluation system; these factors are often overlooked in traditional models. Notably, we included considerations such as the social acceptance of the technology and its impact on sustainable development goals (SDGs), encompassing aspects like job creation and public health. Additionally, we considered technical factors, including the amount of product or energy recovered from waste relative to the total amount of waste processed and safety considerations. Finally, we performed a Delphi study to confirm the relevance of the chosen criteria and sub-criteria.

3 Methods

A thorough review of scientific literature was initially conducted to establish diverse criteria for evaluating waste-to-value technologies. In addition, we conducted a Delphi study to validate the proposed framework and ensure the relevance of the selected criteria and sub-criteria. We involved experts and professionals working in the wine sector with knowledge/experience on the sustainability (both academically and practically) of technologies used for waste/sub-product valorisation and management. This is a well-recognised approach for gathering expert input, featuring participant anonymity and structured feedback (Diamond et al., 2014). An initial questionnaire gathered expert feedback on the evaluation system based on criteria from a systematic review of scientific literature. Experts confirmed that the first-level criteria effectively captured essential aspects of evaluating waste and by-product valorisation technologies in the wine sector. However, some adjustments to the sub-criteria were suggested. The second Delphi study iteration revealed unanimous consensus among participants, leading to the final validation of the criteria and sub-criteria for evaluating wine waste and by-product valorisation technologies (Figure 1).

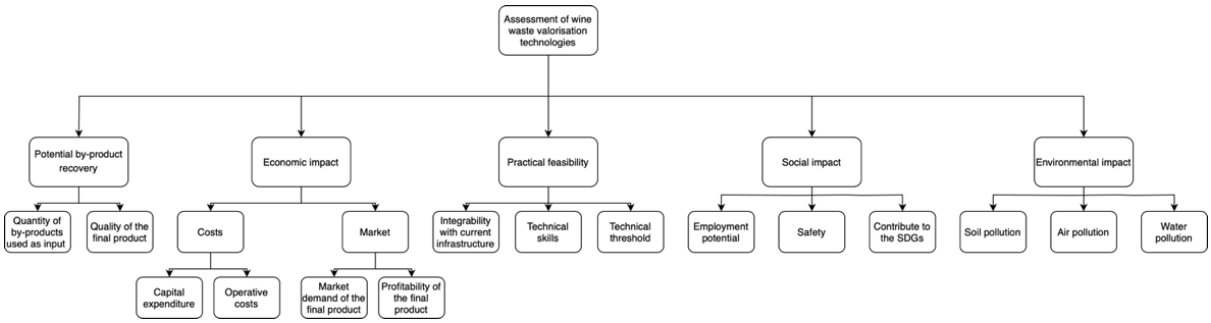


Figure 1. Evaluation system

Subsequently, we combined the AHP methodology with the FST to enhance flexibility and accuracy in addressing uncertainty (Bruno et al., 2016). In this phase, data was gathered via individual interviews and questionnaires submitted to experts from companies in the agricultural and clean-tech sectors. This heterogeneous group of participants provided a broad spectrum of skills and perspectives crucial for a comprehensive assessment of the technologies. Notably, the AHP is a structured method used to address complex decisions. It decomposes the problem into a hierarchical structure, enabling decision-makers to make comparative assessments among various criteria and available options in an organised and rational way (Jiang et al., 2011). The AHP process is developed through five main stages (Saaty, 1980), which are outlined below:

1. Organising the problem into a hierarchy, which is structured in different levels, ensuring consistency in scale and size.
2. Conducting the pair-wise comparison assessment. It defines the relative importance of criteria through two-sided comparisons. Saaty's scale, from one to nine, was used to weigh the relative importance of each item.
3. Determining the relative weights, derived from the eigenvector-based methodology.
4. Assessing the consistency ratio. It is essential to ensure that the weights of the alternatives accurately represent the judgments of the individuals who conducted the comparisons.
5. Aggregating the relative values assigned to each group of alternatives across different levels of the hierarchy.

Furthermore, the FST is a research approach that deals with uncertainty in information by using fuzzy sets instead of traditional sets (Attri et al., 2022). This method employs membership functions to assign a truth degree to each element, ranging from 0 to 1. This approach demonstrates its effectiveness in processing inaccurate data or concepts that cannot be strictly classified as true or false (Mahjouri et al., 2017). Next, defuzzification is applied to change the ambiguous ratings into measurable and clear values (Centobelli et al., 2018). Notably, our case study examines five qualitative levels to define performance criteria, and a triangular fuzzy term-set was used (Figure 2).

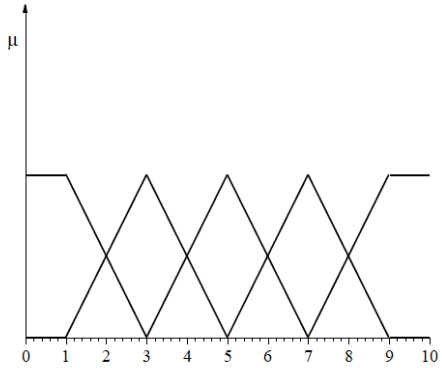


Figure 2. Triangular fuzzy term-set

In the performance evaluation phase, criteria-related indicators are evaluated through an extensive data collection process (Centobelli et al., 2018). The numerical indicators are converted into fuzzy numbers, allowing for a more nuanced and precise depiction of performance. These fuzzy performance metrics and weights are then merged with the weighted average operator, which reduces entropy spread and yields an accurate final assessment. In the final step, alternatives can be ranked according to their final fuzzy scores.

4 Results

The results of the AHP method highlight that the economic sphere (0.393) and the technological aspect related to resource recovery potential (0.325) are the factors that most influence the choice to implement a technology. In the agribusiness sector, it is vital to prioritise the economic sustainability of technology, considering both capital and operational expenses first. A technology's capacity to lower operational costs via energy efficiency and waste reduction significantly impacts its adoption. Additionally, the potential for resource recovery is essential as it enhances the value of farm by-products. This allows for the recovery of disposal costs and aids in producing high-quality outputs for successful marketing. Another critical factor is the quality of the outputs generated by these technologies. Effectively positioning products in the market, responding to demand, and meeting quality standards are crucial for economic viability. Furthermore, a technology's ability to produce marketable products at competitive prices can significantly affect the decision to implement it.

To implement the FST, two interviews were conducted with experts in anaerobic digestion and pyro-gasification. After obtaining performance values for each sub-criterion of the evaluation system, it was necessary to cross-reference these values with the triangular term set to associate each criterion with a fuzzy value. After determining the fuzzy performance values for each criterion, it was necessary to weigh these numbers with the respective AHP weights, implementing a combined approach. Tables 1 and 2 present the procedure for evaluating anaerobic digestion technology.

Table 1. Fuzzy values of the sub-criteria (anaerobic digestion)

First level criteria	***Sub-criteria***	***Crisp performance values***	***Fuzzy values***
Potential by-product recovery	Quantity of by-products used as input	7	(5, 7, 7, 9)
	Quality of the final product	9	(7, 9, 10, 10)
Economic impact - Costs	Capital expenditure	7	(5, 7, 7, 9)
	Operative costs	8	(6, 8, 8.5, 9.5)
Economic impact - Market	Profitability of the final product	8	(6, 8, 8.5, 9.5)
	Market demand for the final product	8	(6, 8, 8.5, 9.5)
Practical feasibility	Integrability with current infrastructure	6	(4, 6, 6, 8)
	Technical skills	7	(5, 7, 7, 9)
	Technical threshold	7	(5, 7, 7, 9)
Social impact	Employment potential	7	(5, 7, 7, 9)
	Safety	8	(6, 8, 8.5, 9.5)
	Contribute to the SDGs	8	(6, 8, 8.5, 9.5)
Environmental impact	Air pollution	6	(4, 6, 6, 8)
	Soil pollution	4	(2, 4, 4, 6)
	Water pollution	5	(3, 5, 5, 7)

Table 2. Weighted fuzzy values of the second-level criteria (anaerobic digestion)

First level criteria	***Sub-criteria***	***Fuzzy values***	***AHP weights***	***Weighted fuzzy values***
Potential by-product recovery	Quantity of by-products used as input	(5, 7, 7, 9)	0.482	(2.41, 3.37, 3.37, 4.34)
	Quality of the final product	(7, 9, 10, 10)	0.518	(3.63, 4.66, 5.18, 5.18)
Economic impact	Costs	(5.68, 7.68, 8.02 9.34)	0.25	(1.42, 1.92, 2.01, 2.34)
	Market	(6.00, 7.82, 8.50, 9.50)	0.75	(4.50, 5.87, 6.38, 7.13)
Practical feasibility	Integrability with current infrastructure	(4, 6, 6, 8)	0.372	(1.49, 2.24 2.23, 2.98)
	Technical skills	(5, 7, 7, 9)	0.332	(1.66, 2.32, 2.32, 2.98)
	Technical threshold	(5, 7, 7, 9)	0.296	(1.48, 2.07, 2.07, 2.66)
Social impact	Employment potential	(5, 7, 7, 9)	0.205	(1.03 1.44, 1.44, 1.85)
	Safety	(6, 8, 8.5, 9.5)	0.708	(4.24, 5.66, 6.02, 6.72)
	Contribute to the SDGs	(6, 8, 8.5, 9.5)	0.087	(0.52, 0.70, 0,74, 0,82)
Environmental impact	Air pollution	(4, 6, 6, 8)	0.29	(1.16, 1.74, 1.74, 2.32)
	Soil pollution	(2, 4, 4, 6)	0.097	(0.19, 0.39 0.39, 0.58)
	Water pollution	(3, 5, 5, 7)	0.613	(1.84 3.07, 3.07, 4.29)

To determine the fuzzy number for the top-level criteria, we summed the weighted fuzzy numbers linked to various sub-criteria and multiplied this total by the corresponding weight of the top-level criteria. Therefore, we summed them to produce the final evaluation judgment. This resulting fuzzy number was then defuzzified using the arithmetic mean to yield the precise number needed for evaluating the two technologies.

Table 3. Final evaluation

Technologies	***Fuzzy values***	***Crisp values***
Anaerobic digestion	(5.59, 7.53, 7.97, 9.21)	7.58
Pyro-gasification	(4.49, 6.51, 6.58, 8.41)	6.48

Therefore, the results of the hybrid AHP-fuzzy approach indicate a higher value for the anaerobic digestion technology. Data analysis reveals that anaerobic digestion integrates various aspects, including operational efficiency, economic benefits, and environmental impacts, which is not always true for pyro-gasification plants. Anaerobic digestion systems can achieve technical and economic sustainability by processing tens of thousands of tons of biomass. In contrast, pyro-gasification plants are typically smaller in scale and, as a result, can process a limited amount of biomass.

5 Conclusions, implications, and future research directions

This research proposes an innovative framework for evaluating and comparing different food valorisation strategies based on economic, technical, social, and environmental factors, offering a practical tool for decision-makers to choose the most suitable technological solution. By integrating these dimensions into a unified framework, this study acknowledges the multifaceted sustainability challenges in the food industry. This approach ensures that technologies are not only analysed for their immediate outputs but also for their broader impacts, fostering decisions that align with SDGs. This study emphasises that sustainable solutions in the food industry should not rely on one-dimensional assessments; instead, they should consider multiple interconnected aspects. Further, this holistic assessment is essential in a complex context such as the food industry, where technologies must not only be analysed for their technical efficiency or economic viability but also for their long-term implications on sustainability and social welfare.

While this study focuses on the wine industry, the model's variables allow the decision tree to be utilised in other food production sectors to explore additional waste valorisation options. Consequently, further research could compare the findings of this study with those derived from evaluating additional food waste valorisation technologies, such as co-composting and pelletising, for a deeper assessment.

6 Acknowledgement

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7 Ethics declaration

Ethical clearance was not required for this research.

8 AI declaration

The authors did not use any AI tool to conduct this research.

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A Framework for Assessing the Sustainability of P2P Platforms

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Abstract

The growing awareness of social and environmental topics such as climate change, social inequality, and poverty from humanity has driven global efforts toward sustainable development through concrete policy initiatives. In this changed socio-economic context and with the rise of IT technologies, the Sharing Economy model has spread thanks to digital economy platforms. The growth of digital sharing platforms has raised concerns about their role in supporting social and environmentally sustainable consumption. In line with this, the evaluation of the governance of these platforms also raises questions regarding the management of power and the balance between the interests of users and owners. In this context, current literature lacks a comprehensive framework for assessing the social-environmental sustainability of these platforms and the form of governance that characterises them. To tackle this issue, the paper proposes an innovative holistic framework to assess the sustainability of digital platforms, with a focus on Peer-to-Peer platforms. The framework is created adapting and integrating protocols, variables and framings already presents in the literature. The study aims to provide a comprehensive evaluation of the social, environmental impacts and types of governance of these platforms. Then the framework obtained is applied to a pool of forty P2P platforms, enabling a detailed assessment of their current sustainability practices and governance structures. The findings contribute to the literature by proposing a holistic framework to evaluate the sustainability of digital platforms in the sharing economy and provide a systematic approach to understanding their role in the global transition towards sustainability.

Keywords: Business Model Innovation, Circular Economy, Digitalisation, P2P Sharing Platforms, Sustainability

Paper type: Academic Research Paper

1 Introduction and Theoretical Background

Citizens in the western part of the hemisphere have experienced a continuous chase for progress and an ever-increasing lifestyle. In a globalised world, social and job opportunities have increased significantly, but along with these, the climate change is one of the most relevant which causes and consequences are now evident to everyone every day. In response to evolving social and environmental demands, the 'Circular Economy' (CE) has been introduced as "*a high-level strategy to move our societies to a state where we no longer compromise the carrying capacity of our planet's ecosystems while also meeting social goals like job* creation *and social cohesion*" (EC, 2015). This new context has stimulated the private sector to integrate sustainable development practices into their business strategies (Blinova, Ponomarenko and Knysh, 2022). Companies have engaged in efforts to integrate sustainability into their operations and better contribute to making societies more sustainable. In line with this, different tools, initiatives and approaches (TIAs) have been applied for a more sustainable society (Lozano, 2019). Among the most widely used TIAs by companies to foster sustainable management are the ESG (Environmental, Social, and Governance) standards. In general, a paradigm shift beyond the traditional model of production, consumption and disposal is essential (Bosman and Rotmans, 2016; Grin, Rotmans and Schot, 2010). According to this, the Sharing Economy (SE) has emerged in various sectors (e.g. tourism, mobility) through different modalities, such as *'sharing, bartering, lending, exchanging, renting, donating or swapping*' (Botsman and Rogers, 2010, p. 11). Although the concept of sharing is not something new, but it has always been present in human habits and life since ancient times (Khalek and Chakraborty, 2023), the digitalization has profoundly changed it (Zhu and Liu, 2021). These platforms facilitate the connection between users enabling the sharing of goods and services on a global scale and supporting the transition to a CE (Tian et al.,2024). However, the study of digital sharing platforms, particularly from a circular economic perspective, is a recent topic (Schwanholz and Leipold, 2020). Several works have analysed the socio-environmental impacts of such platforms (Lamberton and Rose, 2012; Boar et al, 2020), showing that these last can be positive or negative. A clear example of their contradiction can be, for instance, accommodation platforms like Airbnb. While they offer consumers the opportunity to enjoy the benefits of housing without owning it (Lamberton and Rose, 2012), they are also accused of contributing to gentrification of cities (Boar et al, 2020. Airbnb's case demonstrates that the impact of SE-related platforms remains unexplored (Mont et al., 2020) and highlights the need for more structured and rigorous tools to ensure a comparable and reliable assessment (Martin, 2016). The lack of clarity of the environmental and social sustainability of digital platforms is also linked to a lack of understanding of the types of governance that drive them. Indeed, digital platform

owners have accumulated power and influence over the years, playing a key role in guiding key stakeholders in creating value for their platforms (Rietveld, Schilling and Bellavitis, 2019). This implies that, without a controlling organisation, platform owners can sometimes manage digital platforms to pursue activities that benefit themselves at the expense of other stakeholders (Zuboff, 2023). These criticalities concern the stakeholders of digital platforms (Dixon, 2018). Generally, it is possible to underline that there is a lack of frameworks in the literature to assess digital platforms considering the three elements of ESG scores: Environmental, Social and Governance. These three aspects are commonly used to assess the sustainability of private corporations, which is not the case for sharing platforms. For this reason, this study aims to fill this gap by proposing an innovative framework to assess the overall sustainability of P2P platforms through the lens of ESG framework. In this way, our approach provides a more precise and comprehensive assessment, based on a combination of variables, protocols and approaches developed by other scholars (Martin, 2016; Chen, Richter, and Patel, 2020; Oberg, 2021) that focus mainly on single dimensions of sustainability, but fail to interconnect the various aspects. The developed framework is applied to a selection of forty P2P platforms. The result will be a clear understanding of P2P platforms contribution to the transition to a circular economy. Therefore, this paper aims to address the following research question:

- *How is the sustainability of digital sharing platforms evaluated according to the ESG pillars?*

The paper is structured as follows. The data and methodology of the implemented research are presented in Section 2. Subsequently, Section 3 descriptive analysis results of framework application. Finally, Sections 4 present the discussion and conclusions of the paper.

2 Data and methodology

The first step involved identifying a list of P2P platforms that aligned with the objectives of our research. Specifically, only platforms enabling a circular approach to goods were included in the study. Subsequently, it was developed a framework that enables a more holistic evaluation to assess the platforms' alignment with the three pillars of ESG scores. This approach goes beyond partial assessments, providing a clearer and more comprehensive view of the platforms' environmental and social impacts and their type of governance. For the evaluation of the impact of each of the three aspects considered, we adapted as evaluation variables different concepts, elements derived from different studies (Chen, Richter, and Patel, 2020; Martin, 2016; Öberg, 2024) and two researchers which were assigned to make independent evaluations. In cases of disagreement, a third researcher provided a final judgment. The assessment of each aspect and of the platforms' overall attitude towards social-environmental sustainability and governance was carried out through a quantitative score model, with values from -3 to +3. This range captures impacts from clearly unsustainable to highly virtuous. The model has two interpretations: for governance and social aspects, positive scores (+2/+3) indicate 'high', i.e. positive impacts, while negative scores (-2/-3) are labelled 'low'. For environmental aspects, the logic is reversed: positive scores reflect greater (i.e. negative) environmental impact and are labelled 'low', while negative values indicate low environmental impact and are labelled 'high'. This choice is made intentionally to reflect the different nature of impact in the various areas: a high impact on the environment is negative, while a high impact on society or the economy is generally positive. While in all three cases, a score between -1 and +1 (including 0) indicates an intermediate score. Next, different rating bands were defined to reflect varying levels of impact of each platform on society, and these quantitative ratings were then associated with qualitative labels: low, medium, and high, indicating the platform's impact in specific areas of interests as shown in Table 1. While in the following sections, the evaluation of each dimension is explained in detail.

Table 1**:** Different rating band for the three aspects considered.

	Low	**Medium**	**High**
Environmental	Promote sustainability through ecological practices.	Adopt some sustainable practices, but not fully oriented to sustainability.	Lead to negative environmental consequences.
Social	Limited or negative social impact.	Platforms that foster a certain inclusiveness, but do not have a radical social impact.	Improve social conditions by empowering individuals.
Governance	Decisions made by a few actors and the management of the commons is monopolistic.	Limited user participation in the management of the commons, but without a fully inclusive system.	Collective management of the commons, with broad user participation in decision-making.

2.1 Social evaluation

To assess the social dimensions of P2P platforms the frameworks developed by Martin has been used (2016). We adapted Martin's framework for evaluating platforms from a social perspective. This study offers a structured analysis to assess the social impacts of platforms on people's lives and social dynamics. This approach allows us to examine P2P platforms through the following six different perspectives: economic opportunity, sustainable form of consumption, path towards a decentralised, fair and sustainable economy, creation of unregulated markets, reinforcement of the neo-liberal paradigm and inconsistent innovation field. The first three variables (table 2) have been listed as positive indicators of social impact because they represent aspects that promote collective well-being and sustainability. While the others three variables (Table 3) are considered negative as they can tend to generate inequality and instability. Table A.1 in the appendix provides the evaluation of five SE platform out of forty as practical examples.

Table 2**:** Positive variables from Martin (2016)

Positive framings	**Meaning**
Economic Opportunity	SE provides individuals with the possibility to monetize their unused goods, free time, and skills. Those who successfully earn money within this model are often celebrated as micro-entrepreneurs
Sustainable form of consumption	SE is viewed as a new and sustainable way of consuming, where individuals no longer own goods but instead access them as needed.
Pathway to a Decentralised, Equitable, and Sustainable Economy	SE approaches are considered as a diverse field of innovation that weakens the power of centralised corporations, empowering individuals, and communities.

Table 3: “Negative” variables from Martin (2016)

Negative framings	**Meaning**
Creation of Unregulated Marketplaces	Platforms in this space are criticised for transferring risk to consumers, creating unfair competition, establishing illegal, black, or grey markets, and promoting tax avoidance.
Reinforcing neoliberalism paradigm	This perspective critiques the model for contributing to the neoliberal economic paradigm. Key drawbacks include corporate appropriation, the casualisation of labour, neglect of environmental sustainability, the assumption that individual actions alone drive social change, and the exclusivity of the peer-to-peer mode.
Incoherent field of innovation	Stronger definitions of its scope, the development of a more cohesive movement, and increased collaboration among public, private, and non-profit actors are necessary to address the perception that it lacks coherence as a field of innovation.

Once defined the ‘social variables’, a binary voting system has been implemented to evaluate each platform (yes/no system). A point was given only for each "yes" to positive aspects and for each "no" to negative aspects to evaluate how positively platforms impact society. This approach made easy to measure and compare P2P platforms’ social impacts. Based on this approach, the forty platforms selected have been categorised into three macro-categories based on their social impact score: low (ratings 1 and 2), medium (ratings 3 and 4), and high (ratings 5 and 6).

2.2 Governance evaluation

For the governance evaluation of P2P platforms, Chen, Richter, and Patel, 2020 (2020) ’s study has been considered. From the different elements they considered, three are chosen as in line with our context: incentive compatibility, community participation and role of leadership (Table 4). These three elements have been adapted as variables to analyse the governance of platforms and to understand whether they effectively favour a democratisation model or consolidate a monopolistic one. Following the literature (Petschow, 2016; Chen et al., 2021), we chose to consider platforms with decentralized governance as a sustainable form, since they promote user autonomy and foster greater collective involvement.

Table 4**:** Chen, Richter, and Patel (2020) variables for governance evaluation

Framings	**Definition**
Incentive Compatibility	Incentive compatibility is achieved when participants in a system are motivated to truthfully reveal their preferences or information, aligning their individual incentives with the overall system goals. This ensures that the system leverages all available information efficiently, promoting informational efficiency and favourable governance outcomes.
Role of Leadership	The extent to which platform leaders influence governance, balancing centralised control with decentralised participation.
Community Involvement	The degree to which platform participants (e.g., developers, users) are involved in governance processes such as decision-making and implementation.

Once the evaluation framings were identified, such qualitative evaluation have been converted in quantitative one. According to this, for each platform, a rating was given ranging from -1 (when the platform was far from the concept of decentralisation) to 1 (in the case of platform close to the concept of decentralisation) with 0 included (neutral attitude of the platform). This rating system was used for all 3 framings considered (table 5). Table A.2 in the Appendix the evaluation of five SE platform out of forty as practical examples.

Table 5: Rating system for platforms' comparison

Variable	**Ranking**	**Explanation**
Incentive Compatibility	-1	The platform fails to align individual and collective goals, creating inefficiencies and reducing stakeholder engagement.
	0	The platform achieves partial alignment, balancing stakeholder incentives with some gaps in addressing collective objectives.
	1	The platform effectively aligns individual stakeholder goals with system-level objectives, enhancing overall functionality and performance.
Community Participation	-1	Community involvement is minimal or symbolic, limiting the inclusion of diverse perspectives and shared governance.
	0	Community participation is moderate, allowing for some influence in decision-making while maintaining significant control by platform owners.
	1	Community members actively participate in governance and decision-making, fostering inclusivity, accountability, and collective action.
Role of Leadership	-1	Leadership is highly centralised, resulting in strong hierarchical control and reduced stakeholder influence in decision-making processes.
	0	Leadership provides guidance while allowing some community input, creating a balanced but still semi-centralised governance structure.
	1	Leadership empowers community members by decentralising governance control, fostering shared decision-making and collaborative platform management.

A total score ranging from -3 to -2 represents a low attitude to decentralisation model; a score of -1, 0 or +1 indicates a medium alignment with the decentralisation concept. Finally, a total score between +2 and +3 reflects a high attitude towards the decentralisation model.

2.3 Environmental evaluation

To evaluate the environmental impact of platforms, the concepts of resource use, sustainability, and scalability from Öberg (2024) has been adopted as variables in our analysis (Table 7). These concepts have been used as reference variables for the environmental assessment of platforms because they allow for an integrated analysis of how resources are used, how much a model reduces environmental impact and whether the growth of a platform compromises its sustainability. An excerpt of five examples can be found in Table A.3 in the appendix.

Table 7**:** Variable explanation by Öberg (2024).

Variable	**Meaning**
Resource Use	Describes how a platform uses and manages resources in its sharing economy model (e.g. simultaneous sharing, reuse, lending)
Sustainability	It indicates how environmentally sustainable a model is, i.e. whether it reduces waste of resources, promotes sharing.

Variable	Meaning
Scalability	It refers to the ability of sharing economy models to grow, expanding geographically or increasing the scope of operations.

In Öberg's work (2024), the variables considered take on specific values, representing different operational configurations of sharing economy models (Table 8). Since the values assumed by the variables affect the environmental impact in different ways, a quantitative evaluation has been provided, assigning a rating between -1 (negative environmental impact) and 1 (positive environmental impact), including 0 (neutral impact). In the cases of the variables “Resource use” and “Scalability” no factors are associated with the value 0, because each variable is very ‘polarising’.

Table 8: Resource use, Sustainability and Scalability factors from Öberg (2024) classification

Variable	Factors	Rate	Explanation
Resource Use	Service Created Specifically	-1	These services are designed to create new offerings, often leading to additional resource consumption and environmental impacts.
	Co use	1	Maximizes resource efficiency by allowing multiple users to share the same product or service, reducing overall consumption.
	Re use	1	Promotes sustainability by extending the lifecycle of resources.
	Repeated use of latent resource	1	Utilising latent resources, like underused assets, minimizes waste and maximizes value.
Sustainability	Not more sustainable than traditional service.	-1	The service may not provide sustainability benefits compared to traditional options.
	No added depletion	0	While the service does not cause further resource depletion, it also does not contribute positively to sustainability or resource efficiency.
	Increasing efficiency of resource.	1	Improving resource efficiency leads to reduced waste and more effective use of materials, directly supporting sustainability goals.
	Efficient use of latent resource.	1	Utilising underused or idle resources avoids unnecessary consumption.
	Sustainability created.	1	Services that actively promote sustainability contribute to environmental and social improvements.
Scalability	Scaled, spread around the globe.	-1	Global scaling often requires significant resource consumption, increased transportation, and infrastructure demands.
	Large-scale operations.	-1	Large-scale operations can lead to inefficiencies, increased waste, and a higher carbon footprint.
	Coordination issues.	-1	As services scale, moving goods and resources across locations becomes necessary, increasing transportation emissions and logistical inefficiencies.
	Provision issue.	-1	Scaling strains resource availability, requiring the movement of goods from surplus to deficit areas, which adds to environmental impacts through transportation.
	Scaling issue based on free premises	-1	Scaling strains resource availability, requiring the movement of goods from surplus to deficit areas, which adds to environmental impacts through transportation.
	Local presence required.	1	A local presence ensures shorter supply chains and reduced environmental impact, while fostering community-based sustainability practices.

2.4 Overall platform rating

The last stage of the developed framework allows a quantitative assessment of the overall sustainability of the analysed platforms. This assessment was based on a scoring system ranging from -1 to +1 (including 0) for each aspect. The score assigned to each platform depends on its performance in each aspect, as indicated in the following description: a score of -1 indicates that the platform is rated ‘low’ in a given aspect, a score of 0 indicates a ‘medium’ rating and a score of +1 indicates a ‘high’ rating in that aspect. Thanks to this last evaluation step, the framework can provide a comprehensive and clear assessment of the impact of each platform in the society, considering the three ESG pillars. The framework allows to evaluate the sustainability of the platform to

be examined and weighed on several interconnected dimension. An extract of five P2P platforms evaluation is the Table A.4 in appendix.

3 Results

Social results shows that only 17.5% of platforms have been assessed with a low social impact, while the remaining platforms are equally distributed between medium and high impact evaluations, respectively 40% and 42,5%. This indicates that, generally, P2P platforms tend to have a positive social impact. Despite it, there is room for improvement.

About environmental results, the 30% of platforms are characterised by having a minimal impact on the environment, and over 60% are classified as having a "medium" impact. Interestingly, only two platforms (five percent of the total) show a "high" environmental impact, this can be considered a positive result. In line with their wider reputation as sustainable alternative to conventional models, these findings prove that P2Ps platforms avoid serious environmental harm.

Governance results prove that platforms predominantly operate with low decentralisation (62.5%). While only 15% of P2P platform adopt medium decentralisation models and 22,5% of them operate with high decentralisation. This polarisation highlights the challenge of creating and implementing hybrid governance models that balance centralisation and decentralisation. It may also reflect a preference for more well-defined and extreme governance systems rather than intermediate approaches. This result underscores a clear market trend favouring distinct governance systems, either highly decentralised to empower users or highly centralised for efficiency. Platforms with low decentralisation prioritize reliability, efficiency, and managerial control, while highly decentralised models often aim to foster autonomy and community-driven interactions A practical example of the application of Chen's (2020) variables (Table 20). While Table A.3 in the appendix an extract of 5 examples.

IN conclusion it is worth underlining that 52.5% of platforms exhibit a medium "attitude for the sustainability", indicating that the majority adopt a balanced approach. These platforms integrate both growth-oriented and sustainability-driven elements, seeking to achieve operational and societal goals without heavily prioritising one over the other. Meanwhile, 32.5% of platforms are categorised by a high attitude, highlighting a stronger alignment with limiting society's growth. This indicates a commitment to principles like sustainability, resource efficiency, and societal equity, often at the cost of rapid scalability or expansion. These platforms may have the potential to bring significant positive change, albeit with challenges in scaling or resource allocation. The remaining 15% of platforms are categorised as ‘low’ reflecting a limited alignment with the principles of limiting societal growth. These platforms are more likely to focus on traditional growth models, emphasising efficiency and profitability over broader societal or environmental considerations. This distribution highlights a clear trend where most platforms aim for a middle-ground strategy, while a significant portion leans toward transformative models aligned with growth limitations, offering avenues for innovation and sustainable development.

4 Discussion and conclusion

This research emphasises the importance of taking a balanced and sustainable approach to the development and governance of P2P platforms. The results of the application of the framework highlight several key elements. The prevalence of platforms with a “medium” environmental impact suggests the existence of significant potential for improvement, as demonstrated by the presence of low-impact platforms that have successfully integrated resource efficiency, waste reduction and circular economy principles. On other hand, the social analysis indicates a positive trend, with most platforms exhibiting medium to high levels of social impact, particularly in terms of economic inclusion, sustainable consumption practices, and community engagement. Nevertheless, the presence of platforms with lower social impact highlights the persistence of areas requiring further development. Regarding governance, the limited diffusion of semi-decentralised models points to a lack of governance structures capable of effectively balancing user autonomy and centralised control. These findings not only provide a detailed picture of the current state of P2P platforms but also generate a series of operational and strategic implications for policy makers, companies and academic world. For policy makers, this research can offer a basis to develop policies that encourage the adoption of sustainable practices and at the same time reducing negative effects such as job casualization or gentrification of cities. Companies, on the other hand, can use this framework to analyse their business models, improving their practices in a sustainable perspective and responding to growing social and environmental expectations. Finally, in the academic world, the developed framework allows overcoming the difficulties caused by the lack of clear and structured evaluation tools by offering a methodological basis for future empirical and comparative studies on the sustainability of P2P

platforms. However, the research has limitations due to the small sample and the subjective component of the evaluations. Future studies could expand the sectors areas analysed, improve metrics and analysis techniques, and explore clustering methodologies to identify homogeneous groups of sustainable platforms.

5 Ethics declaration

The authors declare that no ethical approval was required for this research.

6 AI declaration

The authors declare that no AI tools were used in the preparation of this article.

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Appendix A

Table A.1: An excerpt from the application of the variables taken by Martin (2016) according to our social evaluation system on all the platforms analysed.

Platform	Economic Opportunity	More Sustainable Form of consumption	Pathway a decentralised equitable	Unregulated Marketplace	Reinforcing neoliberal Paradigm	Incoherent Field of Innovation	Total Social Impact	Social Impact
Airbnb	Yes	no	no	yes	yes	yes	1	Low
BlaBlaCar	No	yes	yes	no	no	no	5	High
Buy Nothing Project	No	yes	yes	no	no	no	5	High
Catawiki	No	yes	no	no	no	yes	3	Medium
CouchSurfing	No	yes	yes	yes	no	no	4	Medium

Table A.2: An excerpt from application of the framings proposed by Chen, Richter, and Patel (2020) according to our governance evaluation system on all the analysed platforms.

Platform	Incentive Compatibility	Incentive Compatibility's Rate	Community Participation	Community Participation's Rate	Role of Leaders	Role of Leaders's Rate	Total Attitude of Decentra-lisation	Attitude of Decentra-lisation
Airbnb	Low	-1	Low	-1	High	-1	-3	Low
BlaBlaCar	Medium	0	Low	-1	High	-1	-2	Low
Buy Nothing Project	High	1	High	1	Low	1	3	High
Catawiki	Low	-1	Low	-1	High	-1	-3	Low
CouchSurfing	High	1	Medium	0	Medium	0	1	Medium

Table A.3: An excerpt from application of the framings proposed by Öberg (2024) according to our environmental assessment system on all the platforms analysed.

Platform	Resource use configuration	Resource Use Score	Sustainability	Sustainability Score	Scalability	Scalability Score	Total Environmental Impact	Environmental Impact
Airbnb	Service created specifically	-1	Not more sustainable than	-1	Scaled, spread around the globe	-1	-3	High
BlaBlaCar	Co-use	1	No added depletion	0	Coordination issues	0	1	Medium
Buy Nothing Project	Re-use	1	Increasing efficiency of resource	1	Local presence required	1	3	Low
Catawiki	Re-use	1	Efficient use of latent resource	1	Provision issue	-1	1	Medium
CouchSurfing	Co-use	1	Sustainability created	1	Coordination issues	-1	1	Medium

Table A.4- An excerpt from the quantitative evaluation of all the analysed framings, to obtain an evaluation of the attitude to sustainability of all the platforms.

Platforms	Social Impact	Social Rate	Environmental impact	Environmental Rate	Attitude of Decentralisation	Attitude of Decentralisation Rate	Total	Attitude to sustainability
Airbnb	Low	-1	High	-1	Low	-1	-3	Low
BlaBlaCar	High	1	Medium	0	Low	-1	0	Medium
Buy Nothing Project	High	1	Low	1	High	1	3	High
Catawiki	Medium	0	Medium	0	Low	-1	-1	Medium
CouchSurfing	Medium	0	Medium	0	Medium	0	0	Medium

Innovation in Entrepreneurship and Performance: An Empirical Research on Italian Innovative Startups

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Abstract

Innovative start-ups play a crucial role in fostering innovation and driving economic growth while enhancing technological competitiveness. In Italy, the emergence of these start-ups has significantly influenced the landscape of economic development and technological advancement, acting as a key engine for generating and integrating knowledge into new products and services. This introduction sets the stage for a deeper exploration of the dynamics surrounding Italian innovative start-ups and their impact on the broader economic and technological landscape. This study analyzes the factors affecting the economic performance of these start-ups, with a focus on governance aspects and corporate resources, particularly team composition, company size, and the impact of gender diversity. It also investigates how sector and geographic location may influence access to resources, often linked to public policies and local innovation ecosystems. Using the AIDA (Analisi Informatizzata delle Aziende) database, managed by Bureau van Dijk—a leading global provider of financial information specializing in the collection and storage of economic-financial data on Italian companies—we studied a sample of 5,669 innovative start-ups across Italy. Through OLS regression models, the article reveals how regional context and policies can serve as either a competitive advantage or a barrier for firms. The findings indicate a positive effect of female leadership on business growth in terms of profitability and sustainability, suggesting that diverse governance and locations within developed entrepreneurial ecosystems can significantly enhance business performance. These insights are valuable for policymakers and entrepreneurs, contributing to a deeper understanding of the economic dynamics of innovative start-ups in Italy. To our knowledge, this is the first attempt to examine regional differences in the performance of Italian start-ups by including all Italian regions.

Keywords: Innovative Start-up, gender, regional development, economic growth, OLS

Paper type: Academic Research Paper

1 Introduction

The landscape of economic growth and technological advancement in Italy has been significantly influenced by the emergence of innovative start-ups, which serve as a crucial engine for the generation and integration of knowledge into novel products and services (Ghio et al., 2016). Recognized under the Italian Startup Act, formalized by Legislative Decree 221/2012, these high-tech enterprises benefit from a supportive regulatory framework designed to foster their establishment and growth through various incentives, including tax benefits and support for innovation investments (Cavallo et al., 2018; Reina et al., 2018). Operating predominantly in advanced sectors, these innovative start-ups thrive within an institutional ecosystem that encourages collaboration among universities, research institutions, and private enterprises. This introduction sets the stage for a deeper exploration of the dynamics surrounding Italian innovative start-ups and their impact on the broader economic and technological landscape. Understanding the unique challenges and opportunities faced by these start-ups will provide valuable insights into their contributions to innovation, job creation, and competitiveness in an increasingly globalized market. Moreover, the geographical distribution of innovative start-ups across Italy reveals significant disparities that could influence their overall effectiveness in driving economic growth. Addressing these discrepancies is crucial for ensuring that the benefits of innovation are more evenly distributed throughout the country, potentially leading to broader national competitiveness and resilience in the face of global economic challenges. Creating targeted policies that support entrepreneurial ecosystems in underserved regions can help bridge this gap, empowering local talent and fostering innovation outside the traditional hubs. In this context, the gender of the business leader, the size and composition of the management team, and the region in which the company is based emerge as key factors in the economic performance of start-ups, influencing variables such as profitability and growth potential. Gender diversity within founding teams can foster more prudent management and a greater focus on long-term sustainability, aspects that are reflected in improved economic performance (Harris and Jenkins, 2006). In particular, in start-ups led by women, the focus also includes objectives of social well-being and job quality, distinguishing them

from male-led firms (Justo et al., 2015). However, female entrepreneurs often face significant challenges, including reduced access to capital and limited networking opportunities, which can hinder the growth of their businesses (Fairlie and Robb, 2009). The territorial context represents another determining factor for the success of innovative start-ups. Northern Italian regions, equipped with more advanced entrepreneurial ecosystems and developed infrastructure, offer greater networking opportunities and access to financial resources than southern regions, where start-ups encounter more obstacles and less institutional support (Balata et al., 2016; Fasano et al., 2023). Local public policies also play a crucial role, with initiatives aimed at supporting entrepreneurial development through funds and incentives, especially in high-tech sectors such as IT and biotechnology, where technology transfer represents a competitive advantage (Ramaciotti and Rizzo, 2017; Neffke et al., 2011). This study aims to analyze the main governance, territorial context, and gender factors that influence the economic performance of Italian innovative start-ups to identify the variables that promote the profitability and sustainable growth of these enterprises.

2 State of the art

The concept of an innovative start-up is linked to the ability to combine new ideas with practical solutions, transforming scientific and technological knowledge into valuable products or services (Ghio et al., 2016). These companies often emerge in cutting-edge sectors such as biotechnology, artificial intelligence, and renewable energy, and are characterized by a specific lifecycle that goes through various stages, each with unique challenges and opportunities (Passaro et al., 2016). In Italy, the Italian Startup Act has been a turning point for this sector, providing tax incentives and easier access to venture capital to foster the growth of knowledge-intensive start-ups (Cavallo et al., 2018). In this context, the literature has dedicated significant attention to the role of gender diversity in start-up performance, offering important insights into the differing approaches between male- and female-led businesses. Many studies shown that gender-diverse leadership teams are associated with higher ROA, ROE, and overall financial success (Maji and Saha, 2021; Imes et al., 2024; Fairlie and Robb., 2009). Female-led start-ups tend to adopt more sustainable business models focused on employee well-being and promote strategies that encourage corporate social responsibility (Harris and Jenkins, 2006; Justo et al., 2015). The literature suggests that encouraging female participation in start-up leadership roles could contribute to more inclusive and sustainable growth across the sector (Demartini, 2018; Welsh et al., 2016). Gender diversity impacts startup performance through several interconnected mechanisms. It influences strategic orientation, innovation, and fundraising outcomes, while also being shaped by gender stereotypes and biases in investor evaluations (Nguyen et al., 2023). These dynamics indicate that promoting gender diversity in startup management not only advances social equity but also improves the overall performance and resilience of emerging ventures (Guzmán and Kacperczyk, 2019; Ebersberger and Pirhofer 2011). The composition of a startup's management team, including its size and diversity, plays a critical role in influencing the venture's performance. Research has examined several aspects of team composition (Debrulle et al., 2021), including team size (Agarwal et al., 2013), functional diversity (Eesley et al., 2014), heterogeneity (Wang et al., 2017), and how well team characteristics align with the firm's strategy and environment. Smaller teams are typically more agile and efficient in decision-making, which can be advantageous in the early stages of a startup, however, as startups expand, larger teams may be better suited to manage the growing complexity of operations (Forbes et al., 2006; Agarwal et al., 2013). Startups with a larger team often see improved sales and funding performance. This is largely due to their greater market visibility, access to diverse talents, and enhanced networks that attract more investor interest (Gloor et al., 2020). It is important to strike a balance, as overly large teams can encounter coordination difficulties and communication breakdowns that can hinder decision making (Qian, 2018; Hernandez et al., 2018). Team diversity is important, as research shows that teams with diverse backgrounds often demonstrate higher levels of innovation and creativity (Chen et al., 2023; Moussa et al., 2024). The sector in which an innovative start-up operates is another crucial aspect of its success. Start-ups in high-tech industries, such as biotechnology, nanotechnology, and artificial intelligence, require significant investments in research and development and often need privileged access to advanced scientific knowledge to remain competitive (Barra and Zotti, 2018; Neffke et al., 2011). These sectors are characterized by rapid technological evolution and intense global competition, which necessitates continuous skill and production capacity updates. Additionally, the presence of a favorable entrepreneurial ecosystem, such as incubators and accelerators, is often crucial for the success of start-ups in high-tech sectors, as it facilitates access to strategic resources and industrial partners (Reina et al., 2018). The geographic context is another factor influencing the performance of innovative start-ups. Recent studies have shown that regions with an advanced innovation ecosystem, such as Lombardy and Emilia-Romagna, offer better growth opportunities for start-ups, thanks to the presence of universities, research centers, and adequate infrastructure (Fasano et al., 2023). These regions provide a favorable environment for

technology transfer and interaction with other companies, facilitating access to financial and knowledge resources (Balata et al., 2016). Conversely, southern Italian regions are characterized by a less developed entrepreneurial ecosystem, with limited public and private funding availability and lower density of professional networks (Reina et al., 2018). According to Colombelli et al., (2023) digital knowledge spillovers and digital skill endowment support the creation of digital innovative start-ups. The rapid diffusion of digital technologies has generated new opportunities for developing innovative entrepreneurship, which is essential for employment growth, new job creation, and socio-economic wealth. Therefore, investigating the enabling conditions of digital innovative startup creation is essential to define appropriate support policies (Barilli, 2015).

3 Sample and data

Using the AIDA (Analisi Informatizzata delle Aziende) database, managed by Bureau van Dijk, a leading global provider of financial information specialized in the collection and storage of economic-financial data on Italian companies, an initial sample of 12,781 innovative start-ups located across Italy was identified. After a careful data-cleaning process using R software, we have cleaned the dataset of missing values (NA), unavailable data (n.b.), and outliers—anomalous values that could have compromised the accuracy of the analyses and results. By eliminating values that rendered some observations without essential attributes, the sample was reduced to 5,669 innovative start-ups. Most variables in the dataset were formatted as "character," meaning that most numerical values would have been interpreted by the software as strings. For this reason, we performed a mass conversion of these variables into numeric values, while categorical variables were simply converted into factors. From the AIDA database, the relevant variables were extracted for analysis in the following sections. Among the most significant variables are those related to sector (industry), geography (region), and gender. Particular attention was given to the gender of the highest-ranking figure on the board of directors within each start-up, focusing specifically on the board composition. The study expanded upon the studies by Sciarelli et al. (2021) and Algieri et al. (2013), which analyzed university spin-offs in Southern Italy and across Italy by grouping them into three clusters: North, Center, and South, while we have categorized with respect to all 20 Italian regions. We identified the top 20 sectors by the number of observations and grouped the rest under the "Others" category. Finally, we proceeded by grouping the top 20 sectors into 5 macro-sectors to ensure a more generalized and less specific analysis. The macro-sectors are: 1.Production and Online Trade; 2.Consulting and Professional Services; 3.IT Services and Software Products; 4.Marketing, Web Portals, and Training Courses; 5.Research and Development and Design

The remaining less frequent sectors were aggregated into a single residual category.

4 Methodology

This study employs Ordinary Least Squares (OLS) regression models to analyze how independent variables influence the economic performance of innovative Italian start-ups, consistent with Sciarelli et al. (2021). The dependent variables considered are revenue growth (Δ REV), EBITDA Margin (EM), and Return on Assets (ROA), transformed using the asinh function to improve data distribution and reduce the influence of outliers. The independent variables include governance indicators, such as the size of the management team (N_EX) and the leader's gender (GEN); economic variables, such as total assets (TA), intangible assets (IA), and net worth (PN); and contextual variables, such as sector (SECTOR) and geographic region (REGION). Additionally, interactions between key variables, such as gender and macro-sectors, were analyzed to highlight combined effects.

4.1 Variables

To ensure comparability with previous studies (Sciarelli et al., 2021), we used proxy measures consistent with existing literature, employing dichotomous and ratio measures for the dependent and independent variables, along with specific transformations for variables with high distributional skewness. In selecting the variables, we considered both endogenous factors relevant to the operations of innovative start-ups. Finally, we included analysis of the gender of the prominent board member, as well as the start-up's sector and region, to understand how these factors influence the economic and financial performance of the start-ups. Variables are presented in a detailed view in Table 1.

Table 1: Definition of Variables

Variables	Description	Measure
Performance Variables		
∆ REV	Measure of startup revenue growth compared to the second-to-last available year in €	asinh
EM	EBITDA/Revenues, measures the operating profitability of start-ups	asinh
ROA	EBIT/assets, measures the efficiency with which start-ups use resources to generate revenue	asinh
Governance Variables		
N_EX	Total number of members on the board of startups, represents the size of the governance team.	Nr.
GEN	Gender of the leader of the governance team, influencing gender diversity in corporate management.	Factor with 2 levels
EMP	Number of employees of the start-up, related to organizational structure and internal management capacity.	Nr.
Control Variables		
TA	Total assets, an indicator of the total economic value of the start-up.	Log
IA	Value of intangible assets such as patents and other intellectual property.	Value
MA	Value of physical assets such as buildings or machinery, indicating the tangible assets of the enterprise.	Value
PATENTS	Number of patents held by the start-up	Nr.
CR	Total accounts receivable	Value
Control Variables		
PN	Net worth of the company, which is the difference between assets and liabilities.	Value
DB	Total debts of the start-up	Value
YEARS	Age of the start-up	Nr.
SECTOR	Industrial sector	Factor with 6 levels
REGION	Geographical region	Factor with 20 levels

5 Results

Understanding the data's structure and key patterns is a crucial step in any research, as it lays the foundation for interpreting analytical results and deriving meaningful insights. In line with this, the descriptive analysis and data visualization provided an initial overview of the sample characteristics, offering valuable context for the subsequent regression analysis. This approach is consistent with prior studies that emphasize the importance of exploring the dataset to identify potential biases, trends, or anomalies that could affect the robustness of the results

5.1 Descriptive statistics

In this chapter, the main numerical variables of the dataset, both dependent and independent, will first be analyzed statistically (Table 2). Next, a series of graphs will be presented to illustrate the correlation between the key variables. Table 3 below presents descriptive statistics for the numerical variables. Most variables are expressed in thousands of euros, except for EBITDA Margin and ROA, which are expressed in percentages, and for the number of employees (EMP), board members (N_EX), and YEARS, which are expressed in units. For the variable Δ REV, a significant variation can be observed between the minimum and maximum values, highlighting a high dispersion in revenue growth among start-ups, indicating that a minority of companies achieved considerable revenue growth, while the majority of firms are closer to modest or negative values. The negative mean and very low minimum value (-996.93%) of EM (EBITDA Margin) indicate that many start-ups are operating with substantial operational inefficiencies. ROA shows a negative mean (-6.903%), which points to a low capacity among firms to generate income relative to their assets.

Table 2: Descriptive Statistics

Variables	Min	Median	Mean	Max	Standard Deviation
REV	-3356	17	98.96	23343	*504.92*
EM	-996,93	8,16	-35,1	482,04	*147,65*
ROA	-925,660	0,650	-6,903	192,31	*38,87*

Variables	Min	Median	Mean	Max	Standard Deviation
N_EX	1	1	1.773	26	*0.38*
EMP	0	1	2.087	164	*4.95*
TA	1	158	487.2	57086	*1304.84*
IA	0	17	110.9	6413	*307.26*
MA	0	2	52.28	8151	*265.09*
PATENTS	0	0	4.5	2260	*61.49*
CR	0	42	168.1	29.602	*654.00*
PN	-2621	38	182.1	41.770	*810.74*
DB	0	81	279.1	21.298	*734.79*
YEARS	2	3	3.347	5	*1.29*

5.2 Main results

In this study we conducted the analysis using Ordinary Least Squares (OLS) regression, with the aim of examining how independent variables influence the economic performance of innovative startups. To this end, three distinct models were developed, each focused on a different dependent variable: Revenue Delta, ROA, and EBITDA Margin. The models incorporate governance and control factors, which are detailed in Table 3. The purpose of these models was to test the validity of the three hypotheses, related to revenue growth, profitability, and operational performance. To identify the best models, we adopted a stepwise procedure with backward elimination, which removes variables based on their statistical significance. As reported in Table 3, the OLS results are presented. The variable TA (Total Assets) has a positive and highly significant effect on revenue growth (TA: 0.668; $p < 0.001$), contrasting with some studies, such as Sciarelli et al. (2021). Female gender (GEN_F) has a positive and significant effect on revenue growth (GEN_F: 1.353; $p < 0.05$), in line with Demartini (2018), but the interaction between Female Gender and various macrosectors is predominantly negative. The analysis of regional variables shows a complex picture, with disparities between Italian regions. None of the variables are significant after the stepwise approach, but it can be noted that regions in the North, such as Veneto, show negative and significant coefficients in relation to revenue growth for startups led by women, highlighting greater difficulties compared to regions like Abruzzo (reference category).

In the ordinary least squares (OLS) regression model, with ROA (Table 3), it can be observed that TA (Total Assets) emerges as one of the most significant variables (being strongly correlated with ROA), with a positive effect on ROA (TA: 0.336; $p < 0.001$), consistent with what was observed in the model for ΔREV and with findings reported by Sciarelli et al. (2021). Sector analysis shows significant and somewhat contrasting results. In particular, the Marketing and Web Portals and Production and Trade sectors show a significant negative impact on ROA (SET_Marketing & Web: -0.667; $p < 0.01$, SET_Production and Trade: -1.037; $p < 0.001$). In contrast, the Consulting and Professional Services sector (reference category) seems to represent an exception, where startups perform better, as also suggested by Sestino and Guido (2021).

In the OLS regression model on EBITDA Margin (Table 3), interesting results emerge, very similar to the ROA analysis. However, the variable related to the gender of the leader (GEN_F) does not show significant results, unlike other analyses where gender diversity had a more significant impact (Demartini, 2018). Sectoral analysis confirms that startups in the "Marketing & Web" and "Production and Trade" sectors face significant challenges in maintaining high operational margins (SET_Marketing & Web: -0.855; $p < 0.01$; SET_Production and Trade: -1.322; $p < 0.001$), and this impacts EBITDA Margin more than ROA. Regional disparities for EBITDA Margin show regions such as Lombardy and Piedmont presenting significant negative coefficients (REG_Lombardy: -1.258; $p < 0.001$; REG_Piedmont: -1.320; $p < 0.01$).

Table 3: OLS linear regression model (stepwise backward approach)

	Model 1			**Model 2**		
	Dependent Variables			**Dependent Variables**		
	Δ REV	***ROA***	***EM***	***Δ REV***	***ROA***	***EM***
Indipendent Variables						
N_EX	0.058	-0.245 ***	-0.318 ***	0.058	-0.245 ***	-0.327 ***
GEN_F	1.148	0.037	0.181	1.353 *	-	-
EMP	0.003	0.001	-0.016	0.108 ***	-	-
Control Variables						
TA	0.646 ***	0.339 ***	0.356 ***	0.668 ***	0.336 ***	0.350***
IA	-0.001 ***	-0.002 ***	- 0.001***	-0.001 ***	-0.002 ***	-0.001***
MA	-0.001 **	-	-	-0.001*	-	-

	Model 1			Model 2		
	Dependent Variables			Dependent Variables		
	Δ REV	***ROA***	***EM***	***Δ REV***	***ROA***	***EM***
DB	-	-0.0005 ***	- 0.0007 ***	-	-0.0005 ***	- 0.0007***
CR	-	0.001 ***	0.001 ***	-	0.001 ***	0.001 ***
PN	-0.0003 ***	-	- 0.0002*	-0.0003 ***	-	- 0.0002*
YEARS	-0.554 ***	-	0.179 ***	-0.542 ***	-	0.179 ***
GEN_F:EMP:Emilia-Romagna	-0.820 ***	-	-	-	-	-
GEN_F:EMP:Lombardia	-0.237 . -1.195 ***		-1.258 ***	-	-1.191 ***	-1.258 ***
REG_Piemonte	-	-1.155 ***	- 1.320 **	-	-1.155 ***	- 1.320 **
REG_Trentino-Alto A.	-	-0.782 *	-	-	-0.785 *	-
GEN_F:EMP:Toscana	-0.527 .	-	-	-	-	-
GEN_F:EMP:Veneto	-0.434 *	-	-	-	-	-
GEN_F:Marketing &Web	-2.247 **	-0.669 **	- 0.855 **	-2.299 ***	-0.667 **	-0.863 **
Control Variables						
GEN_F:Prod. & Commercio	-1.526 .	-1.037 ***	- 1.322 ***	-1.528 *	-1.037 ***	-1.319***
GEN_F:R&D e Design	-1.304 *	-0.140	- 0.317	-1.339 *	-0.141	-0.303
GEN_F:Servizi IT & Softw.	-1.430 *	-0.245	- 0.276	-1.417 .	-0.247	-0.298
GEN_F: Other sectors	-1.282 *	-0.554 **	- 0.656 **	-1.282 *	-0.553 **	-0.653**
RSE	3.561	3.03	3.889	3.569	3.028	3.888
R^2	0.118	0.094	0.084	1.000	0.093	0.084
R^2_Adjusted	0.103	0.088	0.079	0.099	0.088	0.079
F-Statistic	7.706 ***	16.62 ***	14.9 ***	35.55 ***	20.01 ***	16.71 ***

p<0.1; *p < 0.05; **p < 0.01; ***p < 0.001

In addition, we undertook a series of steps to ensure the reliability of the estimates. Initially, we employed an Ordinary Least Squares (OLS) regression to estimate the coefficients; however, we suspected that some of the independent variables might be endogenous, meaning they could be correlated with the model's error term. To formally test for endogeneity, we applied the Wu-Hausman test, which compares the OLS and Instrumental Variables (IV) estimates. The test returned a statistically significant result (p-value = 0.0125), confirming the presence of endogeneity in our model. Therefore, OLS estimates would not have been consistent, providing strong justification for the use of an IV approach. In constructing the IV model, we selected exogenous instruments for the variables suspected to be endogenous, namely N_EX, TA, and EMP. Specifically, we used IA, MA, PATENTS, CR, PN, DB, REGION, SECTOR, and GEN_F as instruments. The results showed very strong instruments across all three variables, with highly significant F-statistics (N_EX: F = 22.174, p-value < 2e-16; TA: F = 35797.491, p-value < 2e-16; EMP: F = 109.067, p-value < 2e-16), thus ruling out concerns about instrument weakness. Given these diagnostic tests, the use of the IV approach via Two-Stage Least Squares (2SLS) was fully justified, providing consistent estimates in the presence of endogeneity. The first-stage regressions, indicate that female governance (GEN_F) is significantly associated with a reduction in firm size indicators. Specifically, firms led by women show a reduction of 0.276 in the number of board members ($p < 0.001$), 0.095 in total assets ($p < 0.05$), suggesting that gender plays a meaningful role in shaping the structural dimensions of startups. Regionally, firms in Lombardia and Veneto display significantly higher board sizes (+0.523 and +0.440 respectively) and total assets, while Southern regions like Calabria and Sicilia exhibit strong negative associations with the number of employees (−1.452 and −0.817 respectively), pointing to territorial asymmetries. In terms of sector, IT & Software services show a positive association with employees (+0.640; $p < 0.01$), reinforcing the importance of digital industries in job creation. In the second stage, the fitted values from the first-stage regressions are used to estimate the impact on performance outcomes. The number of employees (fitted_EMP) shows a positive and significant effect on all three metrics: +0.114 on sales growth ($p < 0.01$), +0.327 on EBITDA margin ($p < 0.001$), and +0.292 on ROA ($p < 0.01$). In contrast, total assets (fitted_TA) have a negative association: −0.193 on sales growth (weakly significant), −0.314 on EM ($p < 0.05$), and −0.477 on ROA ($p < 0.01$), suggesting diminishing returns or inefficiencies related to capital intensity. The number of board members (fitted_N_EX) positively influences sales growth (+0.385; $p < 0.05$), but negatively affects EM and ROA (−2.409 and −1.661 respectively, both $p < 0.001$), highlighting the possible cost or coordination burden of larger governance bodies.

6 Discussion of the results

The results for economic variables such as TA (Total Assets), IA (Intangible Assets), and PN (Net Worth) have shown consistent findings across all three models, suggesting that the idea of having greater asset availability

can foster business development. These results contrast with studies like Sciarelli et al. (2021), who, analyzing data on revenues from university spin-offs in Southern Italy, found a negative relationship between total assets and revenue growth, suggesting that an excess of resources could, in some contexts, reduce business efficiency. The results highlight a positive impact of female leadership on business growth in terms of profitability and sustainability. This is likely due to a less risky and more sustainable approach to managing startups, with goals that prioritize preserving business integrity, employee well-being, and not just economic targets. However, challenges faced by female-led startups in sectors like marketing and research and development may be related to cultural barriers or the lower representation of women in STEM disciplines. In this regard, in the Consulting and Professional Services sector, female managers seem to achieve better results than in other macro-sectors, aligning with literature that highlights the sector's greater opportunities for female entrepreneurs, as over 75% of female-led startups operate in the professional services sector, which offers greater opportunities for women entrepreneurs (Paoloni and Modaffari, 2018). The regional disparities show surprising results. While northern regions such as Veneto and Emilia-Romagna present greater challenges for female-led startups, Southern Italy, particularly Abruzzo, Calabria, and Campania, seem to offer a more favorable environment. In the analysis of EBITDA Margin, in particular, the reduction in operating profitability in these regions appears even more pronounced, possibly due to specific local challenges influencing business resource management, as suggested by Algieri et al. (2013). These results are entirely new in a literature that typically highlights a historical North-South disparity in terms of opportunities for women entrepreneurs, and they contrast strongly with recent studies indicating that operating in Northern Italy increases the likelihood of success by 71% compared to the South, while operating in Central Italy increases the likelihood of success by 45% (Algieri et al., 2013). From a sectoral perspective, startups in the marketing, production, and trade sectors struggle to achieve positive results. The 2SLS estimates offer a deeper understanding of the structural and performance determinants of innovative startups, especially in how gender, region, and sector dynamics interact with firm governance and scale. The OLS model had suggested a less pronounced gender effect, possibly because it failed to address the potential simultaneity between governance choices and firm outcomes. Regionally, the 2SLS model reinforces the presence of strong territorial asymmetries. Compared to OLS, where regional effects may be diluted or confounded by other correlated variables, the instrumental approach confirms that geography independently constrains organizational capacity, especially when coupled with gender. Sectoral effects are also more visible in the 2SLS estimation. Turning to the second stage, the 2SLS model reveals that expanding the workforce has a consistently positive impact on performance outcomes, particularly in profitability and growth. This suggests that human capital plays a central role in scaling startups and that employment levels are a meaningful lever of success.

7 Conclusion, implication, limitation and further research

Several relevant implications emerge for Italian start-ups and the actors who support them, including investors, policymakers, and institutions. The negative result associated with the number of members on the board (N_EX) indicates that a governance team that is too large can hinder decision-making speed and efficiency. Start-ups are advised to maintain lean boards composed of members with complementary skills but without an excessive number of components, which could slow business dynamics. A lean governance structure could favor faster decision-making and more flexible adaptations in highly competitive contexts. The positive effect of Total Assets (TA) and the importance of net worth suggest that start-ups with a solid capital base can operate more efficiently and better face operational challenges. The Marketing & Web and Production and Commerce sectors appear to be more exposed to low operating profit margins, suggesting the need for more aggressive strategies to increase margins or explore new business models. Start-ups in these sectors should consider expanding into niche markets or integrating high-value-added services to compensate for the sector’s structural challenges. Start-ups located in Southern Italy, as evidenced by regions like Calabria and Campania, show signs of positive growth compared to traditionally more favorable northern areas. This suggests an opportunity to continue investing in regional development policies, promoting innovation and supporting start-ups in these regions, as less developed areas can represent fertile grounds for entrepreneurship. The use of indicators such as EBITDA Margin and ROA offers a limited view of economic performance, which might not see immediate returns from investments in research and development (R&D). These indicators may not fully capture the long-term growth potential, particularly for businesses focused on innovations with a long economic return cycle. Future studies could adopt more comprehensive measures, including long-term success indicators such as innovation rate, human capital growth, or international market penetration. The analysis also relies solely on quantitative data, without considering more qualitative aspects that could better explain performance differences among start-ups. Corporate culture, leadership style, and the quality of human capital are crucial factors not included but

could significantly impact innovation capacity and business growth. Including these elements in future research would help understand how internal dynamics influence economic performance. Finally, although the model considers differences between Italian regions, a finer segmentation of local dynamics could reveal further nuances not explored. In the future, it would be useful to consider more specific regional factors to understand how start-ups can fully leverage the local ecosystem.

8 Ethics declaration

This research did not require ethical clearance. All data used were obtained from publicly available sources.

9 AI declaration

No AI tools were used in the development or writing of this paper.

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Meaningfulness Reshaping Technology, Knowledge Co-Creation, and Leadership

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Abstract

The development of human skills through technology, knowledge co-creation, and meaningful work drives successful change, well-being, and societal cohesion. Technological advancements have raised concerns about job displacement and skills shortages, necessitating a human-centric approach to leadership. The study explores the relationship between meaningfulness and meaninglessness (m&m) experiences at work, emphasizing that meaningfulness is not tied to formal job descriptions and can be supported by leadership. Transformational leadership, with its four dimensions Idealized influence, Inspirational motivation, Intellectual stimulation, and Individual consideration, is examined for its potential to foster meaningfulness in education and elderly and caregiving sectors. The research, based on the "The m&m of work" project, aims to enhance organizational practices by leveraging employees' experiences of meaningfulness and meaninglessness. This research focuses particularly on transformational leadership (TL) entity of the survey and the identification of four dimensions of TL (visioning, challenging, engaging, and leading by example) in the real-life experiences of the education and elderly and caregiving sectors at both individual and organizational levels. The study found that Transformational Leadership (TL) had significant influence in the education and caregiving sectors. At the organizational level, TL influenced areas such as responsibility and ethics, work environment safety, and discussions about the meaningfulness of work. At the individual level, TL fostered trust within the work community, encouraged the use of employees' creativity, and supported their success. Additionally, a method was co-created during the research to enhance leadership, facilitate knowledge sharing, and promote discussions within organizations, addressing even challenging experiences of meaninglessness and their effects.

Keywords: Meaningfulness, Knowledge Co-Creation, Transformational Leadership, Change

Paper type: Academic Research Paper

1 Introduction

Developing and enhancing human skills and capabilities through technology, knowledge co-creation, and meaningful work are key drivers of successful change, individual well-being, and societal cohesion. The past decade of technological advancement has brought about the looming possibility of mass job displacement, untenable skills shortages, and challenges to the unique nature of human intelligence posed by artificial intelligence. These challenging prospects in the digital era require human-centric approach and leadership to reshape a future of work that fulfils individual potential and experiences and creates broadly shared prosperity in diverse organizations and industries (World Economic Forum, 2020; Henderikx & Stoffers, 2022).

The experiences and relationship between meaningfulness and meaninglessness (m & m) for employees are not yet fully understood. The experience of meaningfulness does not depend on the profession or job role. A waste management professional can experience as much meaningfulness in their work as a teacher, nurse or a doctor. Managers or leadership theories are not the sources or providers of the experience of meaningfulness at work. However, they can easily destroy the perception of work's meaningfulness – even create a sense of meaninglessness. Generally, creating meaning in work is an individual endeavour, while reflecting the experience and attributing meaning requires other people or support for community from the entire organizational system. (Martikainen & Oikarinen, 2023; Martikainen, 2022; Bailey & Madden, 2016)

The study specifically examined the theoretical model of transformational leadership to determine whether its four dimensions (Idealized influence, Inspirational motivation, Intellectual stimulation, and Individual consideration) can be identified in the work of education and healthcare professionals, and whether it could be developed to foster experiences of meaningfulness and protect against experiences of meaninglessness. Additionally, various leadership models and theories were explored, as the experience of meaningfulness is strongly associated with discussions on values, trust, emotional intelligence, ethics, and hope. (Goleman 1998; Piccolo ym. 2010; Mathew & Gupta 2015; Lips-Wiersma et al., 2020; Sahimaa 2020)

The data for this study is based on the research project called "The m&m of work" in 2022-2023 and the survey data collected in spring 2022. This research focuses particularly on transformational leadership (TL) and the identification of its four dimensions in the real-life experiences of the basic and higher education and caregiving sectors at both individual and organizational levels. In this context, this study aims to enhance

technology, knowledge co-creation and leadership within organizations by leveraging both meaningful and meaningless (m&m) experiences of employees.

2 Transformational leadership supporting m & m experiences at work

In leadership research, there is usually an effort to define the difference between management and leadership. On the other hand, it can be thought that only people can be led. Things cannot be led – they can only be managed well or poorly (Rousu & Lanne-Eriksson, 2021, 8). Achieving good leadership results generally requires expertise in the field, but leadership is usually viewed as a phenomenon independent of the specific field. Leadership is typically given a formal managerial position within the organization, but it is also a role that can be held by someone without a formal leadership position. Leadership can also be shared among different individuals, and various forms of leadership are practiced simultaneously in the workplace, regardless of official job descriptions. Leadership can also be understood as influencing another person, in which case it can be thought that all members of the organization practice leadership, particularly in the education and healthcare work environments, and leadership is always a two-way and interactive social activity. (Rousu & Lanne-Eriksson, 2021; Ojala, 2016; Hyypiä & Parjanen 2013)

Experiences of meaningfulness at work can become blurred due to factors such as continuous technological advancement, high-pressure work environments, limited opportunities for influence, or a lack of appreciation. Experiencing contemporary work as meaningful affects employee well-being, motivation, and endurance. In the workplace, this is reflected in the atmosphere, commitment, knowledge sharing, and interest in developing collective activities. Conversely, experiences of meaninglessness lead to feelings of alienation, distress, and worthlessness, as well as organizational inefficiency. (Bailey et al., 2019; Bailey & Madden, 2016; Martikainen, 2022; Martikainen et al., 2022)

Research on transformational leadership (TL) emphasizes the importance of shared information and goals, collaboration, and interaction, and previous studies show a positive impact on work efficiency, workplace atmosphere, well-being, and innovation. The transformational leadership aims to align the needs and goals of both leaders and employees into a unified effort, supporting for innovations and new ways of thinking. On a moral level, TL should be an uplifting form of leadership, "where people collectively pursue ultimate values that are higher ideals than the individual goals of any single person." (Bass & Riggio, 2006; Hyypiä & Parjanen, 2013) The four dimensions (Idealized influence, Inspirational motivation, Intellectual stimulation, and Individual consideration) of transformational leadership is introduced next in the figure 1.

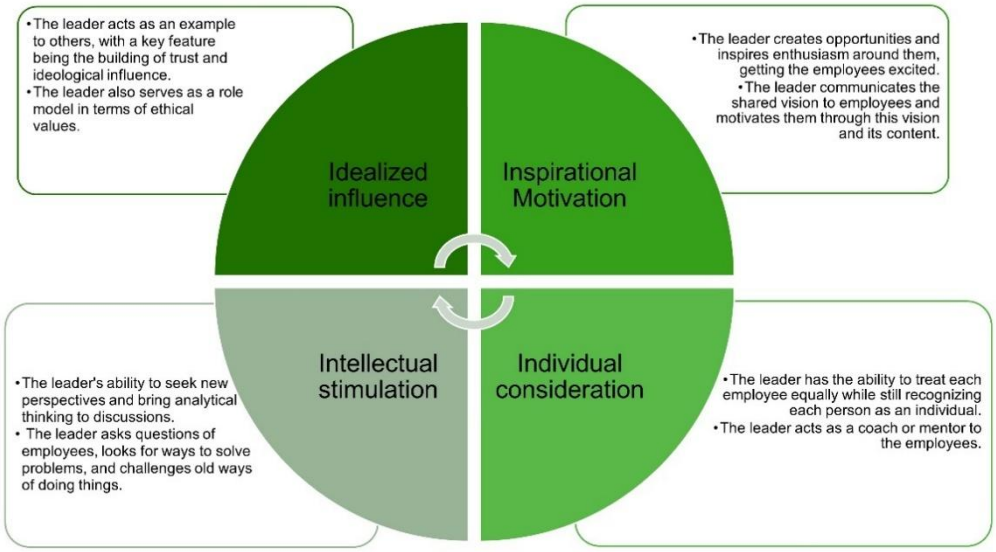


Figure 1: Four dimensions of transformational leadership

TL does not shy away from or avoid conflicts; instead, it leverages the tensions and conflicts that arise within employees' value structures. These are used to guide the formation of employees' individual meaning structures, and their effects should be visible, for example, in the distribution of responsibility, knowledge sharing and in encouraging innovation and development. (Birasnav et al., 2011; Boer et al., 2016; Mathew & Gupta, 2015)

Hence, this study demonstrates the necessity to reshape leadership requirements and the crucial importance of human-centric approach of transformational leadership in an increasingly digitalized world (Henderikx & Stoffers, 2022).

3 Data, method and analysis

This study is based on the wider research project called "The m&m of work" in 2022-2023. The study utilized various data collection methods, employing both quantitative and qualitative approaches. Collaborating partners in this research project were services for the elderly and caregiving and basic education, in Finland.

3.1 Data gathering and methodological approach

The research collaboration was initiated in early 2022 with a survey. Representatives of the collaborating parties received the designed questionnaire for approval and distributed the survey as a Webropol link to be answered within their own organizations. The survey received a total of 63 responses from elderly and caregiving services and 125 responses schools from basic education. Additionally, the survey was distributed to employees of higher education and received 116 responses. Thus, the total number of responses to the survey was 304.

A 4C-evaluation method was developed to collect assessment and experiential data on the meaningfulness and meaninglessness of work. The evaluation is based on experience dimensions identified in previous qualitative research (Martikainen et al., 2022). The 4C-evaluation includes four experience dimensions: contribution, connection, conversion, and confinement (Martikainen & Oikarinen, 2023). The survey was firstly constructed by operationalizing these experience dimensions into different statements. The survey was further developed with the dimensions of transformational leadership (TL), including 14 statements (further details of the statements available in the tables 1, 2, 3 and 4 below).

The leadership statements were a separate entity of the survey. Responses to the statements were given on a five-point Likert scale: 1 strongly disagree – 2 somewhat disagree – 3 neither agree nor disagree – 4 somewhat agree – 5 strongly agree. Additionally, there was a "cannot answer" option available. Thus, the responses related to the TL entity of the survey is analysed on this study.

In the section of the survey related to the 14 statements on transformational leadership, the four different dimensions (Idealized influence, Inspirational motivation, Intellectual stimulation, and Individual consideration) of TL were not distinguished in advance, nor were respondents required to specify whom they were reflecting on in terms of leadership (e.g., immediate supervisor or top management team). Moreover, the background information of the respondents (age, gender, workplace, length of employment at the workplace, and length of employment in the education or healthcare sector) is not further acknowledged in the analysis.

3.2 Analysis

There were 63 respondents from elderly and caregiving services and the average of responses for all 14 statements of TL was 3.6. The highest average was 4.2 and the lowest was 3.2. There were 125 respondents from schools of basic education and the average of responses for all 14 statements of TL was 3.6. The highest average was 4.2 and the lowest was 3.2. There was a total of 116 respondents from higher education and the average of all responses for all 14 statements of TL was 3.3. The highest average was 4.1 and the lowest was 2.6.

Table 1**:** Responses rates and average relative to Idealized influence statements

Idealized influence in elderly and caregiving services							
Statements	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree	Cannot answer	Average
1. It is important for our organization to act responsibly and ethically.	3,2%	3,2%	14,5%	21,0%	53,2%	4,9%	4,2
2. Our organization has a safe working environment.	1,6%	8,1%	11,3%	43,5%	33,9%	1,6%	4,0
3. In our work community, we are united by mutual trust.	4,8%	8,1%	12,9%	37,1%	33,9&	3,2%	3,9

Idealized influence in basic education							
Statements	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree	Cannot answer	Average
1. It is important for our organization to act responsibly and ethically.	1,2%	0,0%	12,6%	47,1%	35,6%	3,5%	4,2
2. Our organization has a safe working environment.	1,2%	4,6%	5,7%	48,3%	39,1%	1,1%	4,2
3. In our work community, we are united by mutual trust.	3,5%	9,4%	12,9%	24,7%	2,4%	2,4%	3,8
Idealized influence in higher education							
Statements	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree	Cannot answer	Average
1. It is important for our organization to act responsibly and ethically.	1,8%	7,8%	12,2%	36,5%	40,0%	1,7%	4,1
2. Our organization has a safe working environment.	0,9%	14,8%	8,7%	43,5%	29,5%	2,6%	3,9
3. In our work community, we are united by mutual trust.	7,0%	14,8%	13,9%	45,2%	16,5%	2,6%	3,5

With idealized influence dimension trust and respect from employees must be earned through honesty, ethical behavior, and consistent actions.

Table 2**:** Responses rates and average relative to Inspirational motivation statements

Inspirational motivation in elderly and caregiving services							
Statements	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree	Cannot answer	Average
4. Management communicates clearly about the future of the organization's operations.	6,4%	22,6%	6,4%	35,5%	19,4%	9,7%	3,4
5. In our organization, employees' creativity is utilized.	6,4%	19,4%	21,0%	35,5%	16,1&	1,6%	3,4
6. At our workplace, the meaningfulness of work is discussed.	8,1%	12,9%	24,2%	32,2%	22,6%	0,0%	3,5
7. I am proud of my workplace.	4,8%	6,5%	16,1%	33,9%	4,8%	4,8%	3,9
Inspirational motivation in basic education							
Statements	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree	Cannot answer	Average
4. Management communicates clearly about the future of the organization's operations.	10,6%	16,5%	20,0%	42,3%	9,4%	1,2%	3,2
5. In our organization, employees' creativity is utilized.	5,8%	6,9%	13,8%	49,4%	21,8%	2,3%	3,8
6. At our workplace, the meaningfulness of work is discussed.	8,0%	18,4%	27,6%	36,8%	8,0%	1,2%	3,2
7. I am proud of my workplace.	2,3%	6,9%	11,5%	51,7%	26,4%	1,2%	3,9
Inspirational motivation in higher education							
Statements	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree	Cannot answer	Average
4. Management communicates clearly about the future of the organization's operations.	7,8%	23,5%	9,6%	45,2%	12,2%	1,7%	3,3
5. In our organization, employees' creativity is utilized.	6,1%	28,1%	17,6%	29,8%	14,9%	3,5%	3,2
6. At our workplace, the meaningfulness of work is discussed.	19,1%	35,7%	13,9%	21,7%	6,1%	3,5%	2,6
7. I am proud of my workplace.	2,6%	8,8%	25,4%	29,0%	34,2%	0,0%	3,8

By inspirational motivation dimension and a shared vision, a sense of purpose and direction is created, which helps employees and colleagues connect their work to a larger value.

Table 3**:** Responses rates and average relative to Intellectual stimulation statements

Intellectual stimulation in elderly and caregiving services							
Statements	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree	Cannot answer	Average
8. In the development of the organization, employees' perspectives are considered.	6,5%	22,6%	17,7%	37,1%	12,9%	3,2%	3,3
9. In our organization, old working methods are challenged.	4,9%	14,5%	29,0%	37,1%	11,3%	3,2%	3,4
10. I have the freedom to develop the organization's operations and working methods.	8,1%	21,0%	24,2%	30,6%	11,3%	4,8%	3,2
Intellectual stimulation in basic education							
Statements	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree	Cannot answer	Average
8. In the development of the organization, employees' perspectives are considered.	8,0%	20,7%	16,1%	39,1%	14,9%	1,2%	3,3
9. In our organization, old working methods are challenged.	4,6%	10,4%	19,5%	51,7%	11,5%	2,3%	3,6
10. I have the freedom to develop the organization's operations and working methods.	7,0%	16,3%	16,3%	37,2%	20,9%	2,3%	3,5
Intellectual stimulation in higher education							
Statements	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree	Cannot answer	Average
8. In the development of the organization, employees' perspectives are considered.	11,4%	31,6%	19,3%	27,2%	7,0%	3,5%	2,9
9. In our organization, old working methods are challenged.	9,6%	21,7%	20,0%	34,8%	9,6%	4,3%	3,1
10. I have the freedom to develop the organization's operations and working methods.	10,5%	22,6%	22,6%	31,3%	7,8%	5,2%	3,0

Intellectual stimulation dimension encourages curiosity, creativity, critical thinking, and innovation. These create opportunities for colleagues and employees to explore new ideas, take risks, and advance their unique perspectives.

Table 4**:** Responses rates and average relative to Individual consideration statements

Individual consideration in elderly and caregiving services							
Statements	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree	Cannot answer	Average
11. We dare to give constructive criticism.	7,9%	19,1%	20,6%	33,3%	15,9%	3,2%	3,3
12. In our organization, employees' wellbeing is valued.	11,1%	14,3%	20,6%	36,5%	15,9%	1,6%	3,3
13. My personal needs are recognized in my work.	6,5%	14,5%	14,5%	50,0%	12,9%	1,6%	3,5
14. Management supports success in my work.	6,6%	14,8%	16,4%	34,4%	22,9%	4,9	3,6

Individual consideration in basic education							
Statements	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree	Cannot answer	Average
11. We dare to give constructive criticism.	3,4%	11,5%	16,1%	56,3%	11,5%	1,2%	3,6
12. In our organization, employees' wellbeing is valued.	10,4%	10,5%	18,6%	38,4%	22,1%	0,0%	3,5
13. My personal needs are recognized in my work.	4,6%	10,3%	27,6%	39,1%	14,9%	3,5%	3,6
14. Management supports success in my work.	6,9%	8,1%	26,4%	34,4%	21,8%	2,3%	3,6
Individual consideration in higher education							
Statements	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree	Cannot answer	Average
11. We dare to give constructive criticism.	7,9%	14,0%	14,9%	49,1%	8,8%	5,3%	3,4
12. In our organization, employees' wellbeing is valued.	9,6%	19,1%	18,3%	33,9%	15,6%	3,5%	3,3
13. My personal needs are recognized in my work.	4,3%	12,2%	27,0%	40,0%	13,9%	2,6%	3,5
14. Management supports success in my work.	14,9%	17,5%	16,7%	35,1%	14,0%	1,8%	3,2

Individual consideration dimension prioritizes and recognizes each employee's and colleague's unique strengths, needs, and aspirations. This supports guidance and development opportunities, enabling individuals to reach their full potential.

4 Findings

According to the results, the influence of Transformational Leadership in the experiences of education and elderly and caregiving sectors were evident at the organizational level in areas such as responsibility and ethics, the safety of the work environment, and discussions about the meaningfulness of work. At the individual level, TL's impacts were highlighted in aspects such as trust within the work community, utilization of employees' creativity, and support for success. Generally, role modelling and inspirational motivation are more required from higher strategic leadership levels, while intellectual stimulation and individual consideration dimensions are primarily addressed by immediate supervisors and colleagues. However, no single dimension of TL emerged as more or less important in the study, indicating that each of the four dimensions is beneficial for supporting experiences of meaningfulness and sharing common meaning within organizations through leadership.

Leading meaningfulness at work means creating an environment where employees feel connected to a sense of purpose, find value in their work, and experience satisfaction. Meaningfulness is a personal and individual experience. It is important to understand and respect the unique perspectives, values, and aspirations of employees and colleagues. By creating an encouraging and future-oriented work environment, leadership can nurture meaningfulness and ultimately support greater commitment, satisfaction, and productivity among employees. (Ojala 2016; Mathew & Gupta 2015; Hyypiä & Parjanen 2013; Birasnav et al. 2011; Bass & Riggio 2006).

By acting as an example and role model (*Idealized influence*), leadership creates a sense of trust and authenticity and aims to align colleagues and employees' values with the organization's values. This alignment enhances the meaningfulness of work, as employees see their contributions as part of a larger purpose. A vision-driven approach (*inspirational motivation*) enhances motivation and the meaningfulness of work. By showing and involving employees in how their contributions are essential for achieving common goals. *Intellectual stimulation* aims to promote autonomy and a sense of growth and development, which enhances the meaningfulness of work by leveraging engagement and continuous learning. By caring for employees' growth and well-being, with *individual consideration*, transformational leadership can create an environment where employees feel valued and understood, leading to a greater sense and experiences of meaningfulness.

According to the results and previous studies in meaningfulness and leadership research it is also suggest that supervisors and management can achieve and support more meaningful work experiences by showing appreciation, providing feedback (including on personal skills and expertise), offering responsibility and freedom, ensuring adequate resources and frameworks, improving communication, creating a culture of care, engaging in active leadership, and serving as role models. (Sahimaa, 2020)

5 Conclusions

Transformational leadership (TL) requires skills in nurturing emotional connections. Leadership demonstrates empathy, compassion, and genuine care for the well-being of employees and colleagues. By creating an encouraging and positive atmosphere, a sense of belonging, trust, and psychological safety is achieved. This emotional connection enhances the sense of meaningfulness when employees feel valued and supported in their work (Goleman 1998; Caruso et al. 2002; Mathew & Gupta 2015).

Although the literature also criticizes TL theory for its relatively positive perspective and broad applicability, the digital era require human-centric approach and leadership to reshape a future of work. The transformational leadership approach offers several advancements over other leadership theories when it comes to fostering meaningfulness at work.

Additionally, it should be noted that the TL approach surpasses immediate task-oriented goals and focuses on long-term development and growth (Birasnav et al. 2011; Hyypiä & Parjanen 2013). By investing in the personal and professional growth of employees, transformational leadership can support employees see the long-term impact and significance of their work. This emphasis on development and growth enhances the meaningfulness of work by allowing individuals to see how their contributions align with their own aspirations and future goals.

The most important "tool" of leadership and means of influence, however, is the organization and the people (Ojala 2016; Rousu & Lanne-Eriksson 2021). With the help of a discussion card set developed together with the staff of basic education and the healthcare sector, it is possible to gather in the same place virtually or in person and discuss meaningfulness or experiences that affect meaningfulness. The level and tone of the discussion may differ from the original idea – through the themes, the organization's operations may also be developed as such or a common meaning may be created for different experiences. The role of leadership in this is to enable time and place, as well as to listen to open discussion and sharing of experiences. Of course, it is also possible that through the discussion, concrete areas for development are identified in the work community, and new ways of working are agreed upon to promote or support the work, technology, knowledge co-creation and meaningfulness in organizations.

The study has some obvious limitations: the basic analysis is part of a wider survey and therefore, any findings can be treated as exploratory, and no generalizations can be made. For further analysis, software, for example SPSS will be utilized. Furthermore, the study was conducted in an elderly and caregiving services and education in Finland and thus does not represent a ‘conventional’ business environment in management and leadership research.

6 Ethics declaration

The ethical clearance for the research referred to in this paper was not required.

7 AI declaration

AI-based tool assistance of Enterprise Microsoft Copilot 365 was utilized in proofreading parts of the text.

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Materiality Analysis for SDG Prioritization: Is Multi-Criteria Decision Making Helpful?

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Abstract

The UN Agenda 2030 and its 17 Sustainable Development Goals (SDGs) represent the most comprehensive framework ever formulated to address the global environmental, social, and governance (ESG) challenges. Prioritizing SDGs is crucial for companies to integrate SDGs into corporate decision-making by identifying the most relevant goals and making informed strategic decisions for corporate sustainability. Materiality analysis, as identifying the sustainability issues most relevant to a company and its stakeholders, becomes thus a valid tool to determine priority SDGs. Nevertheless, the existing international managerial guidelines that promote materiality analysis for aligning corporate initiatives with SDGs are often too generic difficult to implement, and open to ambiguous interpretation, which hampers its practical adoption. The present paper proposes an exploratory study by adopting the qualitative approach of semi-structured interviews to gather insights from strategic decision-makers on the relevance, applicability, and potential challenges concerning the adoption of a Multi-Criteria Decision Making (MCDM) method for performing materiality analysis in the process of SDG prioritization. As a result, the multi-criteria approach to materiality analysis is widely accepted by all involved interviewees, who agree on its usefulness in providing a standardized procedure for the prioritization of SDGs. In addition, as highlighted by the suggestions of the experts involved in the study, integrating the potentialities of Artificial Intelligence (AI) technologies into materiality analysis appears to be a promising direction for shaping future developments in the application of materiality analysis to SDG prioritization decisions.

Keywords: Sustainable Development Goals (SDGs), Materiality Analysis, Multi-Criteria Decision-Making Method (MCDM), Semi-structured interview, Artificial Intelligence (AI)

Paper type: Academic Research Paper.

1 Introduction

With the 17 Sustainable Development Goals (SDGs), the United Nations' Agenda has presented the most urgent need to safeguard a responsible future for people and society as a whole (Fiandrino et al., 2022; Elalfy et al., 2020; UN, 2015). Engaging with the SDGs goes beyond an ethical obligation and becomes a strategic pathway for companies that can catch concrete advantages (Boar et al., 2020), such as improved cost efficiency, greater corporate attractiveness, enhanced risk mitigation, and stronger stakeholder relationships (GRI, 2018). However, several challenges characterize the strategic integration of SDGs into corporate decision-making. The relevance of each of the 17 SDGs varies depending on a company's operational context, the nature of its business activities, and the specific expectations of its stakeholders (Ike et al., 2019). As a result, prioritizing SDGs becomes crucial for companies to identify the most relevant goals and make informed strategic decisions for corporate sustainability (Berrone et al., 2023; Patuelli et al., 2022). Indeed, priority SDGs refer to the goals that best capture the areas where the most significant impacts on the economy, environment, and people, both positive and negative, occur (Menichini & Salierno, 2023; Adams et al., 2021). To this aim, a large body of literature recognizes that materiality analysis, identifying the sustainability issues most relevant to a company and its stakeholders, is a valid tool to determine priority SDGs (Heras-Saizarbitoria et al., 2022). Materiality analysis helps in gaining an overview of the company's performance, enhancing company credibility and stakeholder awareness, and ensuring the inclusion of stakeholder needs in company decisions (Torelli et al., 2020; Gromis di Trana et al., 2024). Open-source managerial guidelines, developed to support companies in transparently accounting to stakeholders, such as those proposed by the Global Reporting Initiative (GRI), focus on materiality analysis (GRI, 2016; 2021). Particularly, the "SDG compass" proposes materiality analysis to guide the SDGs prioritization process, by defining those Goals that the company acknowledges it can actively pursue through viable initiatives (GRI, 2015). Accordingly, managerial literature emphasizes the importance of effective stakeholder engagement, as it ensures that stakeholders' perspectives and expectations actively shape corporate sustainability (Torelli et al., 2020; GRI, 2018; GRI, 2016).

Nevertheless, how companies effectively set their decision-making process to operationalize their commitment to the SDGs is yet to be clearly defined (Fallah Shayan et al., 2022; Grainger-Brown & Malekpour, 2019). According to existing international standards for sustainability reporting and accounting, materiality

analysis certainly represents an important first step in helping companies prioritize their efforts toward the achievement of the SDGs (van Tulder & Lucht, 2019; GRI, 2015). However, relevant literature highlights how the provided managerial guidelines allow ambiguity in interpretation, hindering materiality analysis practical adoption within the company's strategic decision-making (Fiandrino et al., 2022; Hsu et al., 2013). This is especially true for Small and Medium-sized Enterprises (SMEs), which often lack the necessary resources (in terms of financial and human resources, specific skills, and/or time) to undertake an effective materiality assessment process (Cantele & Zardini, 2020; Verboven & Vanherck, 2016).

By leveraging materiality assessment potentialities, researchers have developed different models, with MCDM methods emerging as a practical approach for conducting the materiality analyses and aiding SMEs (Cinelli et al., 2014). Indeed, MCDM methods are widely recognized as suitable to handle the complexity and subjectivity of corporate sustainability decisions, making them a potentially effective approach to standardize the integration of SDGs into SME strategic decision-making (Calabrese et al., 2017; 2016). As common practice, the MCDMs are often enhanced by incorporating fuzzy logic to effectively manage the ambiguity and fuzziness that may affect experts' evaluations (Chowdhury and Paul, 2020; Faizi et al., 2020; Sahoo and Goswami, 2023). In addition, recent studies have highlighted a clear evolution in MCDM methods from conventional frameworks to advanced AI-driven models (Kumar, 2025). Particularly, the integration of AI along with machine learning and other evolving technologies such as IoT and blockchain emerges as a significant improvement for MCDM approaches, marking a major development in decision-making processes (Kumar, 2024). By making them more accurate, responsive, and capable of handling real-time data, the MCDM approaches, together with the AI solutions, are proving essential for optimizing decision processes in environments characterized by massive and continuously updated data (Abdulla & Baryannis, 2024).

Accordingly, the present paper proposes an exploratory study to understand the perception and acceptability of a standardized MCDM method for performing materiality analysis for SDGs' prioritization. The study adopts a qualitative approach using semi-structured interviews to gather insights from strategic decision-makers on the relevance, applicability, and potential challenges concerning the adoption of an MCDM-based approach to prioritize SDGs.

The rest of the paper is structured as follows. The next section details the proposed interview protocol, including the process of the experts' involvement. This is followed by results. Finally, the discussion and conclusions complete the paper.

2 Method

Qualitative research aims to understand the perspectives and experiences of individuals or groups, as well as the contexts in which these perspectives or experiences are placed (O'Brien et al., 2014). Particularly, semi-structured interviews go beyond merely collecting information, providing a deeper understanding of the motivations, opinions, and reasons behind respondents' answers (Flick, 2018; Kallio et al., 2016). Therefore, the approach becomes particularly effective for exploratory studies aimed at understanding attitudes and perceptions about a topic (Brinkmann, 2014). Indeed, semi-structured interviews involve identifying and administering a predefined set of key questions while maintaining the flexibility needed to explore emerging topics and dynamically manage participants' contributions (Brinkmann, 2014). Several studies highlight the effectiveness of semi-structured interviews in gathering information to understand decision-making dynamics within sustainable development contexts characterized by various complex factors (Flick, 2018; Kuckertz & Wagner, 2010). The in-depth and contextualized data collected from the different responses of interviewees provide valuable insights, helping to refine a methodological proposal and ensure the relevance and practical applicability of a method (Kallio et al., 2016). Therefore, the present paper involved the development of an interview protocol and its subsequent administration to reach the aim of the present research. The interview protocol was specifically designed for semi-structured interviews, ensuring flexibility and depth in data collection. A set of 17 questions, listed in Table 1, was identified to cover all the key aspects of an MCDM method based on a materiality analysis approach to prioritize SDGs.

Table 1: Final Interview protocol

	Questions
General Questions	**Q1.** Is your company currently engaged in sustainability initiatives?
	Q2. Are you aware of the 17 SDGs established by the United Nations as part of the 2030 Agenda for Sustainable Development?
	Q3. In your opinion, are companies aware of the economic and social implications (benefits, opportunities, efforts, and commitments) related to integrating the SDGs into their business practices?
Specific Questions	**Q4.** Do you think it is necessary to clearly understand, identify, and select the most relevant sustainability issues to prioritize the SDGs most relevant for the company?
	Q5. Do you consider it useful to examine the alignment between sustainability initiatives and the company's long-term strategy to identify the most relevant sustainability issues?
	Q6. Do you think it is useful to consider sustainability performance and achieved results to identify the most relevant sustainability issues for the company?
	Q7. Do you consider it useful to integrate stakeholders' specific needs and, therefore, take into account the sustainability issues they consider most relevant?
	Q8. Do you find it beneficial to adopt a structured method that considers multiple criteria simultaneously to identify the most relevant sustainability issues and prioritize the SDGs accordingly?
	Q9. Do you believe that involving different stakeholders or groups, both inside and outside the company, can improve the quality of decision-making?
	Q10. When identifying the most relevant sustainability issues for the company and prioritizing the SDGs, do you think it is useful to assign different weights to each evaluation criterion to ensure decisions that align with the company's specific context?
	Q11. In your opinion, is it important to adopt an approach that allows stakeholders to provide their evaluations in linguistic form?
	Q12. When identifying the most relevant sustainability issues for the company, do you find it effective to start from a predefined and standardized list of topics (such as those provided by GRI)?
Questions on implementation	**Q13.** How realistic do you think it is (in terms of time and resources) to implement a method like this proposed?
	Q14. What aspects do you think have not been considered in the proposed method and should therefore be improved?
	Q15. Do you believe that the proposed method can provide useful information to make the reporting of corporate sustainability initiatives more transparent, rigorous, and effective in communicating with stakeholders?
	Q16. Do you think the proposed method could support internal monitoring of the sustainability initiatives undertaken by the company?
	Q17. Do you believe that the results obtained from the application of the proposed method could enable comparisons between different companies?

It should be noted that the numbering assigned to each question does not reflect the actual order in which they were posed. Indeed, to accurately capture the respondents' perceptions, the semi-structured approach enabled the interviewer to follow a flexible guide, adapting the order of questions according to the flow of the conversation and the respondents' answers (Bhattacharyya & Shah, 2022). Moreover, questions Q14, Q16, and Q17 were initially designated as follow-up questions, intended to further explore the discussion whenever a respondent's initial answer warranted additional clarification. The questionnaire was structured to begin with general questions aimed at engaging participants while preventing the main research objectives from being immediately evident. Only afterward, based on the respondents' actual level of engagement, were more specific questions introduced. Particularly, the final interview protocol consisted of three main groups of questions. The first group was composed of general questions aimed at understanding the level of awareness of companies about the integration of the SDGs into their business practices. The second set of questions was designed to assess the perceived usefulness of different aspects and procedural steps of an MCDM approach to materiality analysis. Particularly, the latest GRI guidelines, the "Universal Standard" (2021), which recommend identifying and assessing both actual and potential material impacts, along with stakeholder demands, have been considered as a reference framework for materiality analysis and, thus, decisional criteria of the standardized multicriteria approach. As suggested by the guidelines, the relevance of economic, environmental, and social impacts needs to be evaluated taking into account their likelihood of occurrence considering the company's strategic decisions, as well as the intensity of the benefits/malus generated by the company's performance (GRI, 2021; Menichini & Salierno, 2023). Finally, the remaining questions were designed to explore the managerial implications of the approach and its practicability. The interview was conducted involving three experts with different professional backgrounds (Table 2), enabling an extended picture of different points of view by SMEs as well as feedbacks on long-term strategic complexities of large industries.

Table 2: Interviewees' details

Details	Interviewee A	Interviewee B	Interviewee C
Position/role	CEO	CEO	ESG manager
Size of company	SME	SME	SME, MNE, Large
Sector	Consultancy	Consultancy	Automotive
Temporal perspective	Short-term	Short-term	Long-term
Application context	Company	Company	Industry

Indeed, Interviewee A and Interviewee B are CEOs of two distinct Italian SMEs operating in the consulting sector, actively engaged in developing practical, short-term measures to quickly respond to external demands for sustainability certifications. Meanwhile, Interviewee C was an ESG manager at an association representing companies of various sizes committed to sustainability initiatives within the automotive industry. The contribution of Interviewee C offered a multi-perspective view of the level of involvement across different business dimensions. This feedback allowed for an assessment of how the method can support companies in managing sustainability-related risks and opportunities, with a particular emphasis on a long-term perspective throughout the entire value chain.

3 Results

The present section describes the results of the proposed exploratory study conducted through semi-structured interviews. All interviewees are aware of the 17 SDGs of the UN 2030 Agenda and confirm their involvement in sustainability initiatives (Q1, Q2). Nevertheless, a common and interesting aspect that emerges from all responses, particularly highlighted by the two SMEs involved, is the need for greater awareness of the actual business benefits that can be achieved by engaging with the SDGs (Q3). According to Interviewee A, the guarantees of an economic return on investment in adopting sustainability practices remain unclear. For Interviewee B, the SDGs are designed to address global issues, making them very ambitious and not particularly relevant to the daily activities of SMEs. This perspective is further confirmed by Interviewee C, who argues that the larger the company, the greater the level of attention and involvement in sustainability issues. The ability to facilitate a structured approach to prioritization has emerged as a key factor to ensure the usefulness of MCDM approach to identify material SDGs. All interviewees consider prioritization essential to clearly understand the most relevant sustainability issues to select the SDGs that are most aligned with the business (Q4). Indeed, according to Interviewee A, prioritization is essential for SMEs, as not all sustainability issues can be effectively addressed due to their limited resources. For Interviewee B, it is crucial to identify the most relevant sustainability issues to implement targeted operational measures aimed at obtaining the necessary certifications that ensure compliance and business continuity in the market. Interviewee C also confirms the importance of prioritization, emphasizing the long-term responsibility of companies, particularly large enterprises, in managing the most pressing sustainability issues.

The use of evaluation criteria based on the GRI materiality's principle has been widely embraced, since defining the most effective path to achieving the SDGs requires not only a clear understanding of the impacts of both current and future initiatives but also a systematic consideration of all external stakeholder demands (Q5, Q6, Q7, Q8). Particularly, all interviewees emphasize the importance of a careful selection of different stakeholders, so that the company can effectively address their requests (Q9), thus confirming the validity of the multistakeholder approach to decisions. The possibility to assign different weights to the different evaluation criteria has been confirmed as effective to ensure that the final decisions are more closely aligned with the company's specific context (Q10). In addition, the ability to express stakeholders' evaluations in linguistic form has been appreciated by all interviewees, confirming the validity of fuzzy logic for the design of the MCDM-based approach (Q11).The adoption of the GRI standard to support the selection of the most relevant sustainability topics was universally welcomed by all interviewees (Q12). However, Interviewee C suggested that, despite the recognized effectiveness of the GRI Standards, it would be beneficial to allow for customization to avoid excluding topics that may emerge and do not currently fit within the existing standards.

Regarding the adoption of a MCDM approach to materiality analysis in real cases, all interviewees acknowledge its potential usefulness. However, SMEs emphasized the challenges of investing in the implementation and management of a structured decision-making process (Q13). Once again, the need emerges for a targeted approach to raise awareness among management and key stakeholders about the importance of integrating the SDGs into business strategies, clearly and concretely highlighting the tangible benefits that can be achieved. To facilitate the effective adoption of an MCDM-based approach to prioritize SDGs, the interviewees suggested organizing training sessions aimed at supporting its practical implementation. Additionally, they emphasized the need for broader training to help companies concretely recognize the

importance of adopting a structured decision-making to prioritize sustainability issues (Q14). Finally, the multi-criteria approach to materiality analysis was positively evaluated as helpful for sustainability reporting (Q15). The usefulness is also recognized as valuable for internal monitoring (Q16) and benchmarking with companies operating in the same sector (Q17).

4 Discussion and conclusions

The present paper proposes an exploratory study to understand the perception and acceptability of a standardized MCDM method for prioritizing SDGs through materiality analysis. Accordingly, a qualitative approach based on semi-structured interviews was adopted, allowing for the collection of contextualized insights from the stakeholders involved. The distinctive procedure of semi-structured interviews, based on a flexible protocol, allowed the interviewers to maintain a balance between ensuring the comparability of responses and exploring emerging themes, tailoring the sequence and focus of questions to each participant's expertise and perspective (Bhattacharyya & Shah, 2022).

The MCDM approach to materiality analysis results as widely accepted by all interviewees, who agree on its usefulness in providing a standardized procedure for the prioritization of SDGs. Particularly, interviewees confirmed that the adoption of GRI-based criteria, the inclusion of multi-stakeholder perspectives, and the integration of fuzzy logic represent valuable features to enhance the clarity, transparency, and sustainability of corporate decision-making. Nevertheless, the study also highlights significant barriers, consistent with the main challenges identified in the literature—namely, the limited awareness of the tangible business benefits of engaging with the SDGs, and the operational complexity of implementing structured decision-making processes in resource-constrained contexts (Cantele & Zardini, 2020; Verboven & Vanherck, 2016). Wider training initiatives are required to help companies fully grasp the strategic importance of using structured decision-making processes to address sustainability challenges. In addition, the direct interaction with the different interviewees enabled the identification of strengths and suggestions for defining future developments about the use of a materiality analysis to SDG prioritization. Integrating the potentialities of Artificial Intelligence (AI) technologies into materiality analysis through the use of machine learning algorithms and natural language processing (NLP) seems to be a promising direction (Suarez & Caetano, 2021). AI technologies support the automated analysis of large volumes of data from various sources, such as social media, industry regulations, and stakeholder feedback, enabling companies to gain a more dynamic and predictive understanding of material sustainability issues, and then align strategies to evolving economic, environmental, and social contexts.

5 Ethics declaration

This study did not require formal ethical clearance as it involved interviews with voluntary participants and did not collect any personal or identifiable data.

6 AI declaration

Artificial intelligence tools (Grammarly, ChatGPT) were used to avoid grammar mistakes and improve the language style. All conceptual content, research design, data analysis, and critical interpretations were entirely developed by the authors.

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Enhancing the Acceptation of Insects as Food: A Sustainable Strategy?

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Abstract

Entomophagy, so the consumption of insects as food for humans, is a contemporary topic of discussions on food security, sustainability, and cultural adaptation. Scientific literature has shown growing interest in the acceptance of insect-based foods but also a marketing potential, also with reference to the 4Ps model, for example Specifically, high prices have been identified as a significant deterrent to the purchase of insect-based food products while, in terms of products consumer responses are strongly influenced by packaging visuals and wording. In this paper, which represents an ongoing research, we further show the first results of a survey between Italian consumers.

Keywords: Food, Insects, sustainability, marketing, consumers

Paper type: Academic Research Paper

1 Introduction

The advancement and commercialization of sustainable protein sources have become an urgent global imperative in light of the escalating challenge of feeding a rapidly growing population with nutritionally adequate, environmentally sustainable, and economically viable food. Among the most compelling solutions to this complex "diet-environment-health trilemma" is the promotion of entomophagy—the human consumption of insects as food.

According to the Food and Agriculture Organization (FAO) of the United Nations, entomophagy is not a marginal or novel phenomenon; it is a long-standing dietary practice embraced by an estimated 2 billion people globally (FAO, 2013). Historically rooted and culturally embedded, insect consumption has persisted from prehistoric times to the present across numerous regions, particularly in Asia, Central America, and Africa. Over 2,000 insect species have been identified as edible and are consumed as traditional food sources, underscoring the ecological and cultural validity of insect-based diets (van Huis et al., 2013).

Despite these precedents, Western societies remain deeply resistant to adopting insects as food. This aversion is primarily cultural, with insects frequently perceived as contaminants or survival food associated with poverty and underdevelopment (Ruby et al., 2015). Such stigmatization persists even in the face of robust evidence regarding the environmental, nutritional, and socioeconomic advantages of incorporating insects into the human diet. Compared to traditional livestock, insects require significantly less land and water, emit fewer greenhouse gases, and offer high feed conversion efficiency (Oonincx & de Boer, 2012). Nutritionally, they are rich in high-quality protein, essential amino acids, and micronutrients such as iron and zinc (Rumpold & Schlüter, 2013).

Regulatory approaches to edible insect commercialization vary widely across the globe. Broadly, three legal and cultural trends are observable. In Anglo-Saxon countries like the United States, regulatory authorities such as the Food and Drug Administration (FDA) have adopted a relatively permissive stance, allowing commercialization with minimal regulatory hurdles (EFSA, 2015). In contrast, non-English-speaking Western nations—particularly within the European Union—have opted for stricter controls, requiring comprehensive safety assessments and formal authorizations under the Novel Food Regulation (EU Regulation 2015/2283). Meanwhile, in non-Western countries where insects are traditionally consumed, formal systems for packaging, exporting, and importing insect-based foods remain limited, often preventing these practices from achieving commercial scale (van Huis, 2020).

Entomophagy, therefore, occupies a critical intersection in contemporary discussions on food security, sustainability, and cultural adaptation. Realizing its full potential requires not only scientific and regulatory progress but also a profound cultural shift in consumer attitudes—especially within Western food systems where acceptance remains low.

2 Literature review

The development and commercialization of sustainable protein sources are becoming increasingly crucial in addressing the global challenge of providing protein-rich foods for a growing population while minimizing health and environmental costs.

Scientific literature has shown growing interest in the acceptance of insect-based foods. Valesi et al. (2024) conducted a study involving 929 participants and found that acceptance of insects as food is not primarily driven by sustainability or health concerns but rather by hedonic motives, which positively influence willingness to try them. Similarly, Hemar-Nicolas et al. (2022) observed that cultural disgust towards insect consumption could be mitigated through social interactions, making the experience more engaging and enjoyable. Other research, such as that by Puteri et al. (2023), applied the 4Ps framework to encourage novel food consumption. Additionally, studies by Wang and Park (2023) explored the impact of anthropomorphism as a strategy to promote insect-based foods. Given the strong cultural association between insect consumption and disgust, Pozharliev et al. (2023) suggested that product design and packaging—such as avoiding direct imagery of insects—could help enhance consumer willingness to try these products.

Puteri et al. (2023), in particular, summarize findings from various studies within this domain, and organizing them according to the classic 4Ps of marketing—Product, Price, Place, and Promotion—it is possible to obtain a comprehensive overview of the most effective marketing strategies aimed at fostering consumer acceptance of insect-based food products. Special attention is given to those interventions that have been empirically tested for their impact on Western consumers' preferences, acceptance, and willingness to try, consume, or purchase these products.

2.1 Price

Across multiple studies, high prices have been identified as a significant deterrent to the purchase of insect-based food products, particularly when coupled with negative perceptions related to taste or limited availability. For instance, research conducted in Germany revealed that consumers often associate price with product quality, using it as a heuristic to judge the overall value of insect-inclusive foods. Conversely, in New Zealand, after receiving information about entomophagy, many consumers perceived such products as expensive. Price variability is substantial across product types and formats. Cricket flour-based snacks, such as protein bars or crackers, typically range from €2 to €5 per unit, while insect flour for home use may cost between €15 and €20 per 100 grams. More complex preparations—such as burgers or pasta incorporating insect powder—tend to be up to 50% more expensive than conventional counterparts. These prices reflect the relatively nascent and specialized nature of production, as well as the need to position these items as sustainable alternatives to traditional animal proteins. It is anticipated that prices will decrease as production scales and consumer acceptance grows.

2.2 Place (Distribution)

The integration of a novel food product into mainstream diets hinges on its accessibility and distribution. While insect-based foods are primarily sold through online platforms, some studies have explored their presence in health food stores and convenience outlets. Strategic placement within retail environments is also crucial; for example, it has been suggested that insect-based burgers should be stocked alongside vegetarian or meat-alternative products in supermarkets.

Restaurants may play a particularly effective role in introducing insect-based foods, as consumer apprehension tends to be lower in dining contexts compared to retail settings. This channel not only facilitates initial exposure but may also lend credibility and reduce perceived risk.

2.3 Promotion

Effective promotion in Western markets hinges on the communication of benefits that can reshape consumer perceptions and stimulate trial behavior. Since many consumers have no prior experience with insect-based foods, clear messaging regarding environmental benefits, food safety, cooking methods, social value, sensory attributes, and novelty is essential. However, informational content alone often fails to overcome psychological barriers such as disgust.

The success of promotional strategies varies according to the promotional mix employed. For instance, emphasizing sensory quality without additional reinforcement may be insufficient, but combining such messages with celebrity endorsements can significantly enhance consumer engagement. Segmenting the audience and

tailoring messages accordingly improves promotional efficacy. First-time consumers appear more receptive to advertising than those already familiar with these products.

Health-related claims tend to positively influence willingness to pay more than environmental arguments — particularly for products like insect-based pasta, which is often selected for its nutritional value. In contrast, environmental messaging has greater long-term influence for items such as insect-based chocolate bars.

Message framing also plays a critical role. Emotionally charged, affective messaging—focusing on personal well-being—has proven more persuasive than fact-based content, especially among audiences less attuned to environmental or health issues. Additionally, providing opportunities to sample insect-based foods through tasting events or product trials can significantly enhance acceptance.

Social influence has also emerged as a key factor. Endorsements from peers, experts, or celebrities, and interactions on social media, can positively shift consumer attitudes. For example, favorable reviews from friends or influencers have been shown to increase trust in product quality and taste. Visible support—such as "likes" and shares on social media—can make marketing messages more compelling. However, simply knowing that others consume insect-based foods does not automatically increase willingness to try them. The effectiveness of such strategies depends heavily on the product type, the spokesperson involved, and the resonance of the messaging with the target audience. Poorly aligned celebrity endorsements, for instance, may backfire, underscoring the need for carefully designed, audience-specific marketing tactics.

2.4 Product

Packaging and labeling serve not only functional purposes but are also instrumental in shaping consumer perceptions. Packaging design—through visual appeal, protective function, and convenience—can attract consumer attention, ensure product integrity, and enhance user experience, particularly in the context of e-commerce where unboxing becomes a pivotal brand interaction. Eco-conscious packaging using recyclable or biodegradable materials can further reinforce brand reputation.

Labels, on the other hand, are the product's voice, conveying essential information such as ingredients, nutritional content, and usage instructions. In food and cosmetic sectors, these details are not just informative but also legally mandated. Labels also act as persuasive tools by highlighting product strengths via claims like "100% natural" or "preservative-free," quality seals, and QR codes linking to additional digital content. Together, packaging and labels form a cohesive communicative unit that enhances the product's market positioning and informs purchase decisions.

When it comes to insect-based foods specifically, consumer responses are strongly influenced by packaging visuals and wording. Studies indicate that using vague, rather than realistic, insect imagery and descriptions on retail packaging or restaurant menus can reduce perceptions of risk and mitigate negative emotional responses such as fear and disgust. For example, in Belgium, labeling insect-based burgers as containing insects—accompanied by statements about their benefits and food safety—positively influenced consumer quality perceptions.

Interestingly, Wang and Park (2023) discussed about the effect of anthropomorphism of insects as food. In recent years, the consumption of edible insects as a sustainable food source has garnered increasing attention from both the general public and the academic community. It is estimated that by 2050, the global population will reach approximately 9.6 billion people, leading to a 73% increase in food demand. This projected growth raises critical concerns about the sustainability of current food systems and the future availability of food resources. Edible insects are emerging as a viable solution to this challenge, offering high-quality protein in a more sustainable, cost-effective, and environmentally friendly manner compared to conventional meat production. This potential has fueled the growth of the edible insect market, which is expected to reach a global value of $9.6 billion by 2030. However, despite growing interest in certain Western countries, low consumer acceptance remains a significant barrier to the widespread adoption of insect-based foods. Among the various strategies aimed at improving consumer acceptance, the development of appealing product packaging has proven particularly effective. In this context, anthropomorphism—defined as the tendency to attribute human-like characteristics, motivations, intentions, or emotions to non-human agents, whether real or imaginary—has emerged as one of the most commonly used marketing techniques. Research has shown that anthropomorphism can influence consumer purchase intentions, particularly in the case of insect-based foods. Incorporating anthropomorphized images of insects on packaging has been found to enhance consumers' willingness to purchase these products. While insect illustrations are often used to highlight ingredients, realistic depictions may evoke feelings of disgust and reduce product appeal. Conversely, using anthropomorphized imagery can foster a sense of familiarity and comfort. Drawing on the familiarity theory, studies have demonstrated that anthropomorphizing insects can create a sense of psychological closeness in consumers,

thereby increasing their interest in purchasing such products. However, the effectiveness of this strategy varies depending on individual levels of food neophobia—the tendency to avoid novel or unfamiliar foods.

A study conducted in Japan explored this phenomenon for two main purposes: first, to examine whether anthropomorphism influences psychological closeness and purchase intention; and second, to determine whether psychological closeness mediates the relationship between anthropomorphism and purchase intention. The findings revealed that anthropomorphizing a cricket image on packaging can indeed enhance consumer purchase intentions for cricket-based food products. Furthermore, the study confirmed that psychological closeness mediates the effect of anthropomorphism on consumer behaviour.

3 A first empirical analysis and findings

To gain deeper insight into the perception of insect-based foods in Italy, we initiated an ongoing study using a questionnaire combined with images of packaging referenced in existing literature. The survey aims to examine consumer attitudes toward insect-based foods, particularly focusing on the influence of anthropomorphic packaging in facilitating acceptance. Questions addressed participants' willingness to try insect-based foods, their perceptions of visual packaging elements, and the impact of anthropomorphic design on purchase intention. The study involved 101 respondents, with a demographic profile predominantly consisting of women (63.4%) and young adults (aged 18-24 and 25-34, making up 28.7% of the sample). Additionally, 79.2% of participants did not have children.

To assess consumer familiarity and openness to insect consumption, the questionnaire included specific inquiries about previous exposure, experience, and overall attitudes toward entomophagy. The findings provide valuable insights into awareness and potential market acceptance of insect-based foods in Western societies. Notably, 95% of respondents reported having heard of insect-based foods, indicating that the concept is widely recognized, even if its integration into daily diets remains unclear. However, actual consumption remains low, with 97% of participants never having tried insects and the remaining 3% consuming them only once or twice a year. The majority of participants expressed feelings of disgust, while 23.8% had a neutral attitude. Only one participant was enthusiastic about eating insect-based foods. These data suggest that, despite some open-mindedness, most people are still hesitant about consuming insects. Culturally, this hesitation aligns with the fact that 79.2% of participants had never encountered insect-based products in supermarkets, confirming their limited market availability.

The study also explored the role of packaging in influencing consumer behavior, particularly how anthropomorphic packaging impacts purchase intent. Most participants considered packaging an important factor. On a scale from 1 (not important) to 5 (very important), the majority selected option 3 (36.6%) and 4 (32.7%), while 16.8% rated packaging as "very important." This suggests that well-designed packaging can positively influence purchasing decisions. However, most respondents remained hesitant to buy insect-based foods, even with appealing anthropomorphic packaging (40.6% had no intention, 31.7% showed slight curiosity, and 17.8% expressed moderate curiosity). Health benefits appeared to be the primary motivation for considering this diet, followed by taste.

Participants also evaluated different insect-based food packaging. The first comparison was between chili larvae and dark chocolate-covered crickets.

Most participants preferred the crickets, as the anthropomorphic packaging reduced the sense of disgust. Conversely, when packaging displayed realistic images of insects, as with the chili pepper larvae, consumers were less inclined to purchase. The second comparison involved edible dehydrated insects (grasshoppers, crickets, worms, silkworms) versus spiced cricket cereal.

Again, anthropomorphic packaging was the preferred choice.

When asked about their willingness to pay extra for insect-based foods with attractive packaging, most participants indicated they would pay an additional 1 to 5 euros. However, a significant portion stated they would not pay any extra, highlighting resistance to associating added value with packaging alone.

These findings indicate that insect-based food consumption is still uncommon in Italy, primarily due to cultural barriers and Western eating habits. However, the growing curiosity and openness to trying novel foods suggest potential market development. Packaging design could play a crucial role in increasing acceptance, as anthropomorphic elements are perceived as more appealing and approachable, particularly for first-time buyers. Moving forward, enhancing consumer confidence through widespread supermarket distribution, along with emphasizing taste, quality, and nutritional benefits, will be essential in fostering long-term adoption of insect-based foods.

4 Ethics declaration

We ensure that all research conducted will respect participant confidentiality, adhere to ethical guidelines, and contribute to the academic community with honesty and integrity.

5 AI declaration

We used AI to check correct spelling and grammar of the words used in the text

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Enhancing Organizational Knowledge Management through Retrieval-Augmented Generation and Large Language Models

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Abstract

Retrieval-Augmented Generation (RAG) systems address critical limitations of large language models (LLMs) such as hallucinations, static knowledge, and context constraints-by dynamically integrating organizational data to enhance accuracy and relevance in knowledge management (KM). This RAG LLM development integrates the generative strengths of large language models with the precision of real-time information retrieval, enabling responses grounded in both structured and unstructured organizational data. The development process involves data collection, preprocessing, embedding, and indexing, followed by retrieval and prompt augmentation, ensuring that the model can access and utilize up-to-date, domain-specific knowledge at response time. By leveraging authoritative internal sources and advanced vector search, the RAG system overcomes the static knowledge and hallucination limitations of traditional LLMs, delivering more accurate, contextually relevant, and transparent answers. This approach not only enhances the reliability of generative AI in business scenarios but also offers a scalable, low-code framework adaptable to diverse enterprise needs. Our research employs low code approach for RAG system development and open source LLM.

Research results demonstrate how a low-code RAG architecture, leveraging open-source LLMs and real-time data retrieval, transforms KM through three key contributions: (i) enhanced accuracy and operational efficiency, (ii) cost-effective scalability and customization, (iii) managerial and strategic impact. The RAG system reduced hallucination rates compared to standalone LLMs, achieving higher accuracy in various tasks.

Future work aims to integrate multimodal data and hybrid architectures, further advancing collaborative human-AI knowledge ecosystems. Addressing these challenges involves robust system architecture, scalable data pipelines, advanced retrieval and ranking techniques, and strong governance over data quality and security.

Keywords: Generative artificial intelligence, Large Language Models, Retrieval Augmented Generation

Paper type: Academic Research Paper

1 Introduction

The rapid evolution of generative artificial intelligence (genAI) and large language models (LLM) presents transformative opportunities for organizational knowledge management. LLMs have great abilities in creating content and natural language processing (NLP), solving NLP tasks with just few simple instructions, performing math reasoning, and demonstrating human-level on standardized tests (Naveed et.al., 2023). LLM comes with various advantages: understanding and generating human-like text across languages, task versatility (handling translation, summarization, coding, analysis, and creative writing), scalability (handling multiple queries simultaneously), quick learning from prompts without requiring traditional programming, pattern recognition, and cost-effectiveness compared to human labour. On the other hand, LLMs suffer from various limitations including: (i) hallucinations: LLMs can generate convincing but incorrect information, especially when faced with questions outside their knowledge base, (ii) lack of context: models don't have access to specific contextual information that may be crucial for accurate responses, (iii) limited context: LLMs can only process a limited amount of text at once. Retrieval augmented generation (RAG) is an innovative approach that solves LLM limitations and enhances LLM by dynamically retrieving relevant external information from a knowledge base to supplement the model's internal knowledge during answer generation. RAG refers to the process of retrieving information from external knowledge sources and generating result with the help of LLM (Gao et.al., 2023). Unlike traditional LLM that rely only on pre-trained parameters, RAG systems first search through a corpus of documents to find contextually relevant information and then use this retrieved context to generate more accurate, informed, and contextually precise responses. In this way, RAG addresses limitations of LLM enhancing organizational knowledge management.

This research presents an implementation of a RAG system, leveraging open LLM and organizational data, to transform processes in business environments. Main research objective is to develop and evaluate RAG system based on LLM for one business organization.

Key research steps include: (i) designing a low-code RAG system architecture, integrating open-source LLMs with organizational data, (ii) performance evaluation of the developed system and analyzing practical

implications for knowledge management strategies. Comprehensive methodological approach encompassing a systematic method of RAG system development was employed. Components of the RAG are (Wang et.al., 2024): Vector store, Retriever, Embedder, Indexer and LLM. Retriever function is applied to use vector store for finding documents and send that augment the prompts (Salemi and Zamani, 2024). Embedder does an encoding of documents into vector representations that the retriever can use (Zhang et.al, 2024). An indexer breaks source documents into manageable parts for embedding (Fleischer et.al., 2024). Phases of the system development are as follows. First, the selection of an appropriate LLM for RAG integration is performed based on these factors: model quality, model reliability in retrieving relevant and current data and model customization capabilities. Second, an effective document retrieval strategy is employed for optimizing RAG system performance including indexing strategy and advanced embedding techniques. Particular focus in RAG system development in this research is in examination of different types of data sources for RAG implementation, exploring various text chunking strategies for optimal performance. The study also analyzes how different LLM temperature settings affect response generation, where lower values produce more focused, predictable outputs and higher values increase response diversity and creativity.

2 Related work

Large Language Models (LLMs) are advanced AI systems capable of processing and generating text with coherent communication, as well as generalizing across various tasks. The historical progress in natural language processing (NLP) has evolved from statistical to neural language modelling, and then from pre-trained language models (PLMs) to LLMs (Naveed et.al., 2023). Their capabilities include handling a wide range of natural language tasks, pattern recognition, content generation, and providing answers and recommendations across different domains. However, LLMs have limitations such as a tendency toward hallucinations (generating inaccurate information) and challenges with accuracy on specialized or less-represented topics. Retrieval-Augmented Generation (RAG) is an approach designed to mitigate hallucinations in large language models. The RAG system extends the capabilities of LLMs by dynamically retrieving relevant data from external knowledge bases (Lewis et.al, 2020.). RAG combines two components: (i) retrieval, which fetches relevant documents from external sources using vector search, and (ii) response generation, which integrates the retrieved information with the LLM's inherent knowledge. This approach enables the system to avoid hallucinations and provide verified answers, making it crucial for applications across a wide range of domains.

3 Methodology

The study employs a comprehensive, multi-phase methodological approach, encompassing both technical development and empirical validation in a business context:

1. *System Architecture Design*: A low-code RAG system architecture was designed, integrating open-source LLMs (Llama and DeepSeek) with diverse organizational data sources. The architecture consists of five key components: an Embedder (for encoding documents into vector representations), an Indexer (for segmenting source documents into manageable chunks), the Vector Store (for efficient similarity search), the Retriever (for identifying contextually relevant documents), and the LLM generator (for producing final responses).
2. *Data Integration and Preprocessing:* Organizational data, including structured databases (Excel files), unstructured documents (PDFs, emails, reports), and semi-structured sources (internal knowledge bases), were ingested and normalized. Various text chunking strategies (256–1024 tokens) were tested to optimize retrieval performance, with a chunk size of 512 tokens and 10–15% overlap yielding the best balance between context preservation and search efficiency.
3. *Model Selection and Customization*: Open-source LLMs were evaluated based on model quality (BLEU, ROUGE, and F1 metrics), reliability in retrieving relevant and current data, and customization capabilities. Llama demonstrated 89% factual extraction accuracy in preliminary benchmarks.
4. *Retrieval Strategy Optimization*: The retrieval pipeline combined semantic search (BM25, dense vector search) and metric learning for document ranking. The FAISS library was used for efficient vector similarity search.
5. *Empirical Validation*: The RAG system was deployed in a public sector organization over. Evaluation involved A/B testing with end-users across few business units, benchmarking against ISO/IEC 25022 software quality standards, and ROI analysis based on productivity gains.
6. *Performance Metrics:* Key evaluation metrics included response accuracy, reduction in hallucinations, average information retrieval time, user satisfaction, onboarding time for new employees, and maintenance costs.

4 Research results

The empirical validation of the RAG system demonstrated significant improvements over both traditional LLM-based solutions and existing AI-driven knowledge management systems:

- Reduction in Hallucinations: The RAG system reduced the rate of hallucinated (incorrect or fabricated) responses from 23% (pure LLM) to 4.1%.
- Response Accuracy: Achieved 89% accuracy in contract analysis tasks, compared to 54% for baseline LLMs and 81% for advanced chatbot solutions.
- Information Retrieval Time: Average time to access relevant information was reduced from 34.7 seconds (legacy NLP systems) to 9.2 seconds.
- Onboarding Efficiency: Time required for onboarding new employees was reduced by 40%, as the RAG system enabled personalized knowledge delivery and contextual Q&A.
- Cost Savings: Monthly maintenance costs were reduced from $4,500 (traditional systems) to € 1,200, with a projected annual savings of € 45,000.
- Comparison with Existing Solutions: A comparative analysis was conducted between the proposed RAG system, traditional knowledge management systems, and advanced AI-based chatbots.

Table 1 compares three approaches by six metrics.

Table 1**:** A sample table

Metric	**RAG System**	**Traditional Knowledge Base**	**AI Chatbot**
Data Accuracy	Auto-sync	Manual weekly updates	Static data sets
Scalability	Linear (€ 0.12/GB)	Exponential (IT overhead)	Variable (licensing)
Query Flexibility	Semantic, contextual	Boolean search	Limited intents
Onboarding Time	89% reduction	Baseline	40% reduction
Regulatory Risk Detection	3.4× higher precision	Moderate	High (but static)
Maintenance Cost	€ 1,200/month	€ 4,500/month	€ 2,900/month

The RAG system outperformed both traditional and AI-driven alternatives in terms of data accuracy, query flexibility, cost efficiency, and precision in regulatory risk identification.

5 Results discussion

Research results are interpreted in terms of managerial implications and practical recommendations for decision-makers.

5.1 Managerial implications

The deployment of the RAG system has direct and measurable impacts on managerial decision-making and operational efficiency:

- Strategic Decision-Making: Integration with business intelligence platforms (e.g., Tableau) enables automated generation of SWOT analyses, with high alignment to human expert evaluations. Managers can access synthesized insights from both structured and unstructured data sources, supporting more informed and timely decisions.
- Process Optimization: The system automates 6high level of routine queries to support teams, freeing up human resources for higher-value tasks. This leads to a significant increase in overall operational efficiency and a significant reduction in response times for critical business queries.
- Risk Management: Real-time monitoring of regulatory changes across multiple jurisdictions is enabled, with automatic compliance report generation achieving high accuracy. This reduces the risk of non-compliance and associated financial penalties.
- Change Management: The phased implementation approach-starting with non-critical processes and gradually integrating with core systems +minimizes disruption and facilitates organizational buy-in. Training “AI champions” in each department ensures effective adoption and continuous feedback.
- Ethical and Governance Considerations: The system incorporates audit trails for generated content and regular bias checks in retrieved documents, supporting transparency and compliance with data governance standards.

In summary, the adoption of RAG systems empowers managers with faster, more accurate, and context-rich insights, directly supporting better decision-making and operational agility. By streamlining knowledge access and automating routine queries, RAG enhan

5.2 Practical recommendations for decision-makers

Retrieval-Augmented Generation (RAG) supports quick and informed decision-making by combining real-time information retrieval with advanced language generation. Unlike traditional AI models that rely solely on pre-trained data, RAG dynamically searches organizational knowledge bases or external sources to provide accurate, up-to-date, and contextually relevant answers. Key ways RAG accelerates and improves decision-making include:

- Instant Access to Relevant Information: RAG retrieves and synthesizes pertinent data from vast, distributed sources, drastically reducing the time decision-makers spend searching for information. This enables faster responses to market changes and operational challenges, which is especially critical in industries where timely decisions impact outcomes.
- Enhanced Accuracy and Consistency: By grounding responses in current, verified knowledge, RAG reduces errors and inconsistencies that can arise from outdated or siloed information, ensuring that decisions are based on the latest and most reliable data.
- Reduced Cognitive Load: RAG distills complex data into concise, actionable insights, allowing decision-makers to focus on evaluating options rather than gathering or interpreting raw information. This streamlining is particularly valuable in complex or high-stakes scenarios.
- Context-Aware Responses: RAG tailors information to the specific context and intent of the query, providing nuanced and directly applicable recommendations rather than generic answers. This contextualization helps leaders act confidently and appropriately in dynamic environments.
- Operational Efficiency: By automating information retrieval and knowledge synthesis, RAG minimizes manual research and analysis, freeing up time and resources for higher-value strategic activities.

In practice, organizations using RAG report significant reductions in decision latency, improved productivity, faster onboarding, and greater consistency in knowledge sharing-all of which contribute to more agile and informed decision-making at every level

5.3 Scientific Implications

The deployment and evaluation of the RAG (Retrieval-Augmented Generation) system offer several significant scientific contributions that advance both the theoretical and practical understanding of AI-driven decision support:

- Advancement of Hybrid AI Architectures:

This study demonstrates the practical viability and benefits of hybrid models that combine retrieval-based and generative AI components. By empirically validating the performance of RAG in real-world contexts, the research contributes to the growing body of evidence supporting hybrid approaches as superior to standalone generative or retrieval models for complex, knowledge-intensive tasks.

- Methodological Contributions:

The research introduces a robust methodology for evaluating RAG systems, including metrics for operational efficiency, accuracy, and user adoption. These evaluation frameworks can serve as a reference for future studies aiming to assess AI-driven knowledge management solutions across various industries.

- Implications for Explainable AI (XAI):

This study addresses a number of things that really are core challenges to having AI be explainable and, importantly, to having it be something that humans can trust. Because if humans can't trust it, then why use it? And if we use it, then we must be accountable for the decisions it makes. One way to enhance both our collective interpretability and our individual understandings of how something like a core decision-making system can produce outputs is to audibly trail every decision it makes.

- Cross-Disciplinary Relevance:

The impact of RAG systems clearly cuts across many disciplines. Natural language processing, information retrieval, and even the behavioral sciences have been advanced by what these systems can do. And the enhancement of decision-making and operational agility that this work promotes appears to be useful in an impressive variety of contexts—finance, healthcare, compliance with regulations, and many more.

The scientific implications of this research extend beyond immediate business applications, offering foundational insights into the design, evaluation, and deployment of retrieval-augmented generative models.

The findings pave the way for future research on scalable, transparent, and context-aware AI systems that can effectively augment human expertise in complex environments.

Based on the empirical findings, the following recommendations are proposed for organizations considering RAG adoption:

1. Start with Pilot Projects: Focus initial deployment on non-critical knowledge management processes to demonstrate value and build organizational confidence.
2. Iterative Evaluation: Regularly assess the impact on key performance indicators (KPIs) and adjust system parameters (e.g., chunk size, temperature settings) for optimal performance.
3. Invest in Change Management: Provide targeted training and support to ensure smooth adoption and maximize the benefits of the new system.
4. Monitor and Update Data Sources: Implement automated data synchronization and regular audits to maintain data freshness and relevance.
5. Address Ethical Considerations: Establish clear guidelines for content generation, bias monitoring, and data privacy compliance.

The implementation of a low-code RAG system powered by open-source LLMs demonstrates substantial benefits for organizational knowledge management, including enhanced decision-making, operational efficiency, and cost savings. The system's ability to dynamically integrate and contextualize information from diverse sources addresses critical limitations of both traditional and AI-driven knowledge management solutions.

5 Conclusion

Research results demonstrates that low-code RAG systems powered by open-source LLMs brings added value to organizational knowledge management. By reducing technological complexity and implementation costs, RAG system, provides businesses with a practical pathway to leveraging advanced genAI capabilities. RAG systems are already changing how LLMs interact with data in real-time. The future of RAG systems points to a synergy between artificial and human intelligence, fostering collaborative problem-solving and innovation and thus enhancing knowledge management practices.

Key scientific contributions here include an innovative approach for integrating generative AI technologies with existing organizational knowledge infrastructure, providing actionable insights for businesses while reducing time and costs for performing tasks.

Future research will focus on developing multimodal RAG systems that integrate textual, visual, and numerical data, further enhancing the comprehensiveness and utility of organizational knowledge platforms. Additionally, the exploration of hybrid architectures-combining RAG with long-context LLMs and multi-agent frameworks-holds promise for addressing increasingly complex business challenges.

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Ethics declaration

Ethical clearance was not required for the research.

AI declaration

AI tools were not used for the creation of the paper.

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