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D-SITE

Drones - Systems of Information on Cultural Heritage for a spatial and social investigation

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Praface


Pixel author Bomb998, (2015). Online Source (mobile.twitter.com/bomb998998/).

Drones and Digital innovation: a new scenario in Digital Dimension

Sandro Parrinello, Anna Dell'Amico
University of Pavia, DICAr - Department of Civil Engineering and Architecture

Digitalisation, intended as the conversion of analogue dimensions and quantities into digital information, is the mechanism that nowadays governs entire social and societal systems on a global scale. The transition from analogue to digital systems has wholly changed everyday actions and the ways of communicating, reading, storing, and using information, which found in the digital a new form of content transmission. The slow process of data and information adapting and adjusting to this new condition involves all the spheres of knowledge which find new horizons and propensities in this revolution. Occupying a new role within the digital world is among the individual's most imminent concerns when confronting society, thus establishing a digital relationship with the things he makes, the materials he works with, the works he creates, and the people with whom he shares thoughts, spaces, and culture, which become digital themselves.

Just as Renaissance man understood the world around him from a different perspective employing a different configuration of mathematical and geometric principles; today, it is necessary to acquire a new literacy level that could be defined as "*technological literacy*"[1], a renewed type of language and expression that marks and characterises our time.

The massive use of these procedures contaminates daily life, customs, and habits, marking out different generations[2] (Y, Z, millennials, etc.) who, on the contrary, become almost unaware of digital extensions. The neurological connection to these digital prostheses, upon which Cronenberg still these days bestows a dystopian meaning, is now well attested, as well as how they can alter the perceptual systems that govern the entirety of living and inhabiting a specific space.

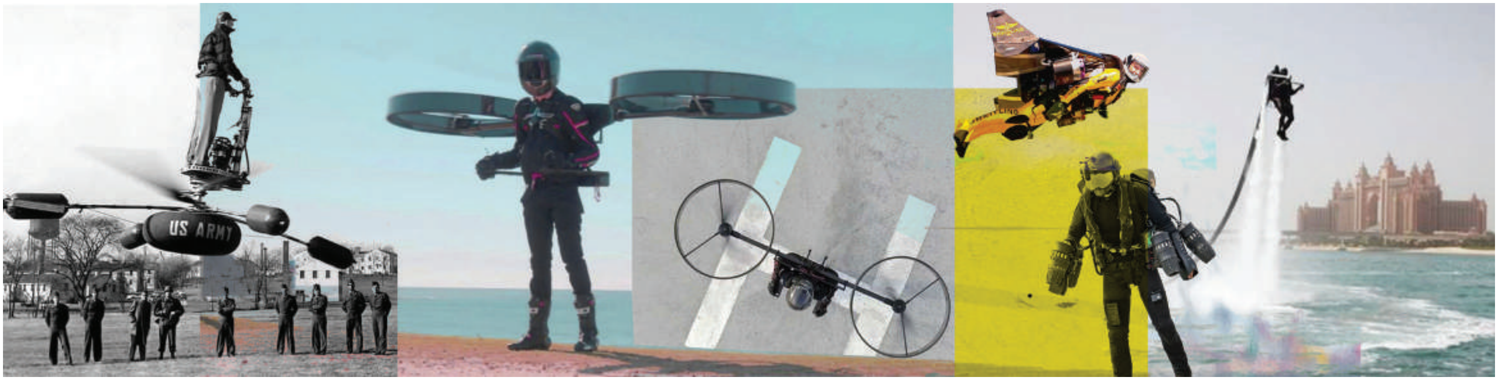
However, the structural specificities that characterise the digitalised space make it reveal an abundance of possibilities and potentialities, actively configuring a new *plateau*[3]. It constitutes an abstraction that, even now, although it begins to appear understandable, at the same time eludes comprehensive scrutiny.

By accessing a new digital stage, it is possible not just to picture an immersive projection of what is our real world, which was already widely imagined, theorised, and finally put into practice, but also a hybridisation of the two systems that penetrate one another right down to their most intimate structures[4].

When talking about digital transformation and evolution, the term wave is often associated with it since technological change is comparable to an overwhelming ocean wave, and it changes just as fast[5].

Indeed, many people today feel overwhelmed by technology and all its opportunities. Still, suppose we try to figure out how to master the wave via cultural insights and scientific research and investigating methods and systems; in that

Figure 1. As the digital returns to the real, also in the world of drones the ambition to see from above corresponds to that desire to fly that leads man to try to soar through the use of drones or devices of various kinds. Technological innovation and the possibilities of harnessing different kinds of engines converge in a landscape of tools and equipment to promote the flying man. Inspired by the world of comics, movies and science fiction in these images we see some examples of vehicles that enable humans to fly. Several companies are working on the design of light aircraft systems and vehicles for humans. So far, powered flight suits have only been seen in video games or science fiction films. A new frontier of transport using special rockets in a backpack or on platforms could soon become the normalcy. Starting from left, the first model designed in 1956 for the US Army, followed by CopterPack,



case, we will realise that, once the tide has gone, we will be capable of navigating and moving forward toward new directions. Digital acquisition disciplines are experiencing a dizzying increase in the available technologies, contaminated by digital development and a profound change in production and social patterns.

The topic of the valorisation and preservation of the memory of Cultural Heritage is closely connected to experimenting with innovative processes of knowledge documentation, management, and fruition. The development of instrumentation for rapid on-the-move surveying leads to generating new categories and acquisition protocols for setting up models that could be used as tools for specialised knowledge processes and for the dissemination and preservation of the historical heritage memory.

This application holds particular resonance when it comes to extensive surveying; the latest technological developments aim to improve mobile, wearable or transportable acquisition, significantly reducing working time. Traditional scanning systems and new digital photogrammetry algorithms are combined in technological apparatuses together with the latest *Simultaneous Localisation and Mapping* (SLAM) algorithms, which allow the simultaneous construction and monitoring of the three-dimensional point cloud model[6].

In the last two years, *Unmanned Aircraft Systems* - (UAS), commonly known as drones and initially originated for military purposes - have become increasingly popular tools for aerial data collection, specifically in many technical-scientific fields related to the science of surveying, topography, engineering, architecture, and agronomy. Through monitoring and surveying activities, drones offer an opportunity to develop constantly more efficient and faster photogrammetric and videogrammetric acquisition protocols for environmental management.

Jetman (Jetwing), Gravity Jet Suit, JetLev Flyer, Alauda Airspeeder MK3, Zapata Flyboard Air, Jetman, Jetpack JB-10, Big Drone, Lazareth LMV 496, LIFT Aicraft HEXA. The drone, in this case improperly understood in this way, becomes a real vehicle through which one can not only experience the sky remotely, but be transported through scenarios that still seem to belong to the world of science fiction but are already reality.

Photogrammetric mapping applied to architectural and engineering sciences finds a new application in the simplicity and automation of today's solutions that enable professionals to integrate these flying robots, available in a wide economic range, within their consolidated workflows. The mapping of extensive portions of land to produce metrically reliable high-resolution 3D models that can eventually be prototyped is a long-established practice. Thanks to digital development, the world around us not only becomes more accurately and rapidly representable but also digitally inhabitable.
Considering the Cultural Heritage documentation, drones represent just one more tool to acquire extremely valuable information in a very short amount of time.
Today, the scientific focus on this topic refers to the definition of a vast spectrum of application possibilities, which is not yet well-delineated and requires a scientific debate that takes into account different technological and regulatory aspects. Furthermore, new acquisition methodologies not only influence the workflows and practice of specialists but also affect how these are generated and transmitted through the processing of digital representation models, i.e., CAD design, 3D Modelling, Rendering, Scripting, GIS, BIM, Simulation, Big Data, and Machine Learning, to name only some of them. Therefore, we continue to focus on how Cultural Heritage can be digitised and measured through drones.
The event "*D-SITE - Drones Systems of Information on Cultural Heritage*", in its second edition, aims at the admirable purpose of staging the discussion at an international level, connecting professionals and research institutes, for a conjoint definition of the state of arts regarding the phenomenon of the UAV utilisation in the Cultural Heritage fields.
The conference, jointly organised by the Department of Civil Engineering and Architecture of the University of Pavia and the Department of Civil Engineering of the University of

Figure 2. The use of drones is becoming part of the definition of new strategic programmes for the city of the future, and there are several Italian cities that confirm their desire to evolve towards increasingly innovative technological models to respond to new needs and new demands. From the transport industry to security systems, the use of drones is conceived as an auxiliary system to the operation of urban facilities

Figure 3. In the film 'Spider-Man Far From Home', the illusions produced by Mysterio, the villain of the Marvel episode, are generated by swarms of drones controlled and programmed before the superhero fights.

Salerno, focuses on topics concerning data acquisition and management methodologies and processes, while it also opens up the debate to those research areas focusing on earth sciences and drone production.

The research actions collected within this volume result from experimentations conducted by research laboratories of excellence on a national and international level. This is a collection of papers on the different application possibilities of UAV technologies through an excursus on methodological investigations and theoretical insights, which lays the foundations for developing new analysis systems and the rise of innovative multidisciplinary methodologies.

From the application to fortified complexes, archaeological areas, urban centres, landscapes, and complex territorial systems, the proceedings of this conference bring together the most up-to-date documentation practices carried out in this field, providing a broad and multidisciplinary overview.

As organisers of the event, we considered the involvement and participation of the business sector in the initiative to be fundamental for cultural exchange between academic and corporate realities. This connection aims to promote research developments in architectural representation and documentation of Cultural Heritage by initiating synergetic actions between university research centres and companies. The objective is to transfer technology and investigate the possibilities of optimising heritage digitisation services through research activities based on a continuous exchange of viewpoints stemming from different experiences and technical expertise. Thus, the technical and theoretical foundations are laid for developing innovative methodologies and systems at the heritage service through scientific exchange between professors and researchers dealing with these very issues.

Drones have found their use and strong appeal not only in the technology sector but also in digital art, with cities such

Figure 4. Pixel art composition, the process of archiving digital products for global dissemination. Photo collage elaborated by the authors.

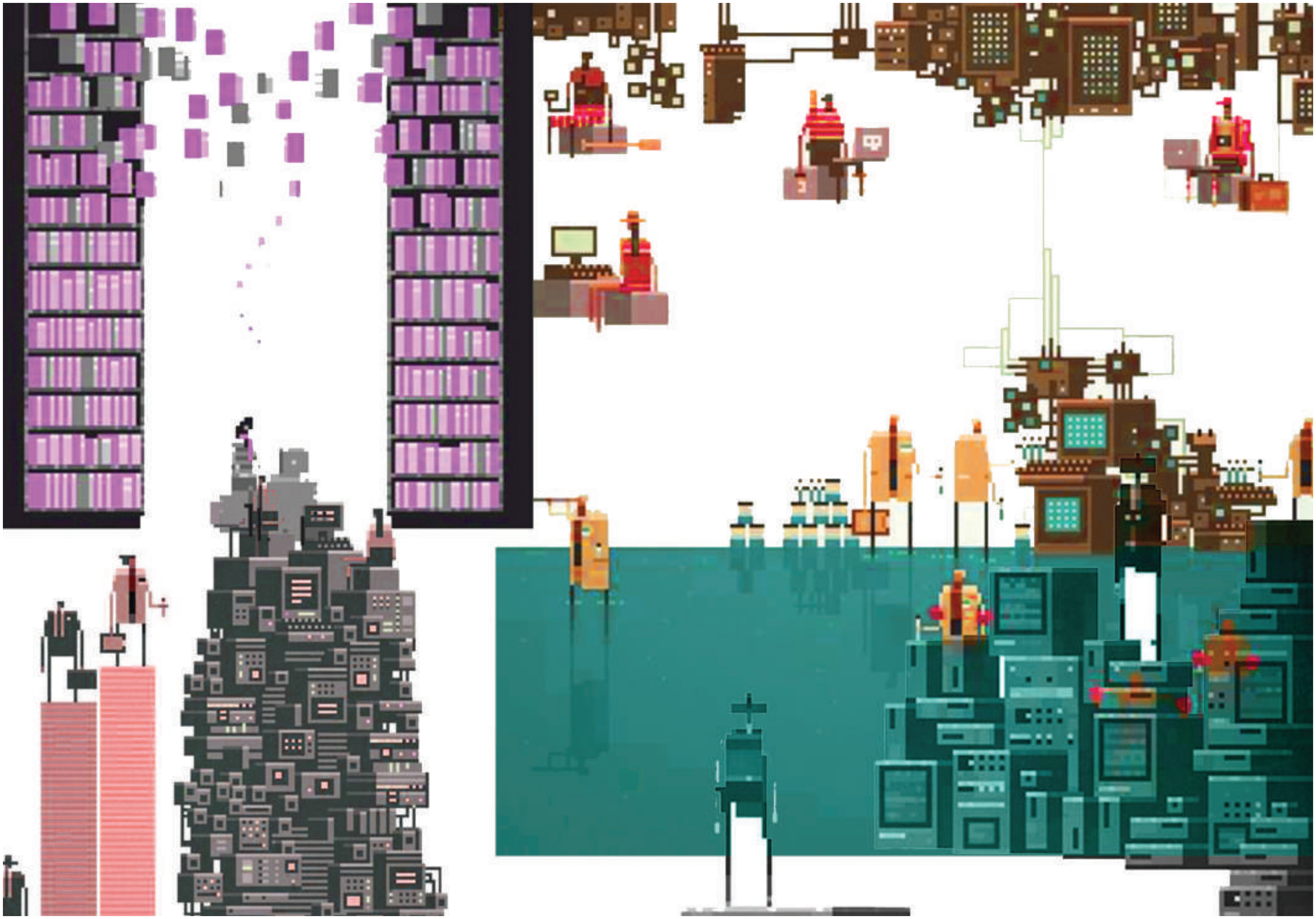


Figure 5, 6, 7, 8. Some pictures of drone light shows, one of the first was held in Shanghai on New Year's Eve 2020, (Figures 5, 6, 7). Light Show at Disneyland in Santa Monica, California (2021) Hundreds of drones flew in a controlled pattern to create outlines of Baby Yoda, the Handmaid, and Captain America's Shield over the Santa Monica Pier (Figure 8).

as Shanghai employing swarms of drones for communication campaigns, high-tech performances or art installations since 2020. Art and technology are increasingly interconnected, exchanging languages and new forms of expression.

This could almost make people think of drones as an art form from the future, a trend of the near future. Let us think of the most recent performance organised on the occasion of the Venice Biennale, when Studio DRIFT (Ralph Nauta and Lonneke Gordijn) used a swarm of drones for their Venetian performance. The multitude, set to fly coordinately inside the church of San Lorenzo (Venice, Italy), consisted of one hundred small glowing drones that synchronously staged a typical dynamic of the natural world.

Here the digital becomes again a simulation of the reality in an ongoing dichotomy and quest to replicate, via the digital, features belonging to the real world; in this concrete case, the motion of the "artificial creatures" simulates the typical behaviour of the animal kingdom, such as schools of fish, colonies of insects, flocks of birds, and herds of mammals, that use to move in large groups, resulting in complex self-organising systems. This is called 'swarm intelligence' and is an example of collective intelligence. The topic is now more relevant than ever and subject to constant developments and updates; the use of drones, together with the training of people qualified to pilot them, is exponentially increasing thanks also to the different application possibilities involving various fields: from engineering disciplines to the art and film sector to the management of emergencies, the monitoring of agricultural land, and the use for the creation of virtual models in the building sector.

The evolution of technology and the adoption of rules and regulations will contribute, whether we like it or not, to shaping the collective system that will provide tomorrow's infrastructure of a global civilisation. In the near future, communication networks and digital memories will encompass most of how data is represented and communicated. A virtual world can prove to the collective intelligence to be as charged with culture and beauty as it is dangerous if not governed wisely. The digital extension opens up unknown itineraries for humankind, but to make this happen, we need to invest in this new dimension[7]. At the academic level, the propaedeutic action is to believe in these new areas by promoting research and study activities concerning data management systems. These actions will then be directed toward the preservation, valorisation and scientific dissemination of the obtained results.

Notes

1 We are now in a situation in many ways not unlike 15th-century Europe. With the onset of the Renaissance, secular certitudes dissolved and new sciences, new arts, new philosophies, and new perspectives, both literal and metaphorical, opened up new frameworks for understanding the world by following new ways of interpreting and shaping it. See Ludger Hovestadt, Oliver Fritz, Urs Hirschberg (2020). Atlas of Digital Architecture: Terminology, Concepts, Methods, Tools, Examples, Phenomena. Germany: Birkhauser, pp. 34-40. However, the very term "Renaissance", belies the meaning of new birth, yet makes it clear that not everything attributed to that period was "new"; much of this new conceptualization was based on ideas that had already been understood, settled and used before. Nevertheless, the change that took place then was categorical, wide-reaching and revolutionary, just like the change that is taking place in these years in the field of technology. For more on literacy, see Midoro, V. (2007). Quale alfabetizzazione per la società della conoscenza?. Ortona: Ed. Menabò, Ortona, Italy.

Figure 10, 11, 12. Some art installations by Studio DRIFT: Breaking Waves 2022 (Figure 10) light performance with hundreds of illuminated drones illuminated the Elbphilharmonie Hamburg for their fifth anniversary (photo credits moka studio); Franchise Freedom (Figure 11) at Burning Man 2018 is a flying sculpture of hundreds of luminous drones in a bird swarming formation (photo credits Studio DRIFT); Social Sacrific at Venice Biennale 2022, DRIFT presents their first-ever indoor aerial drone performance (Figure 12), (photo Credits Ossip van Duivenbode).

2 See Howe, Neil; Strauss, William (1991). *Generations: The History of America's Future, 1584 to 2069*. New York: William Morrow & Company. Neil Howe and William Strauss were the first to subdivide the generations based on sociological behaviour modified by technological development. They identified Generation Y as the class born between 1982 and 2000. Also known as Millennials, they are masters of new technologies, they surf social networks, and they spend every moment of their lives on the net from morning to night. See Luca Tomassini (2015) Connected Lives. The challenge of the future in the digital age. Milan: Franco Angeli. Recently, Barclays, together with the University of Liverpool, proposed a different classification based on data from a database that identifies Generation Y among those born in 1981-1995. The classification refers to the UK target group, the data is, however useful to understand where the differences that each profile presents arise.

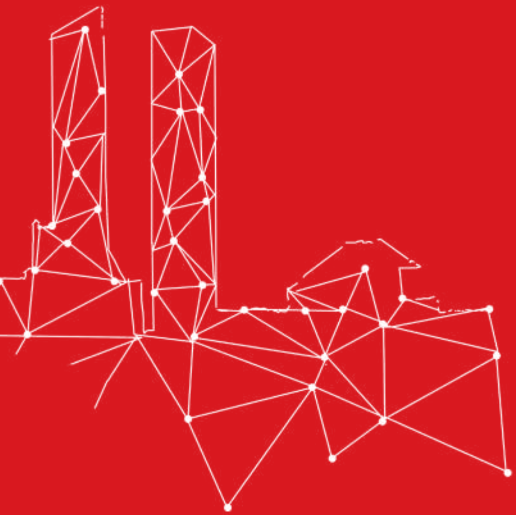
3 The term *plateau* is used in this context with the meaning of a "tray", i.e., basket of proposals that metaphorically generate new possibilities in the field of digital Cf. Ludger Hovestadt, Oliver Fritz, Urs Hirschberg (2020). Atlas of Digital Architecture: Terminology, Concepts, Methods, Tools, Examples, Phenomena. Germany: Birkhauser, pp. 34-40.

4 Cfr. Lévy P. (1999). *Cybercultura. Gli usi sociali delle nuove tecnologie*. Milano: Giangiacomo Feltrinelli Editore.

5 Cfr. Ludger Hovestadt, Oliver Fritz, Urs Hirschberg (2020). *Atlas of Digital Architecture: Terminology, Concepts, Methods, Tools, Examples, Phenomena*. Germania: Birkhauser, pp.34-40.

6 Cfr. Nespeca R. (2018). *Towards a 3D digital model for management and fruition of Ducal Palace at Urbino. An integrated survey with mobile mapping*. In SCIRES it, vol 8, issue 2, pp.1-14.

7 Cfr. Lévy P. (1996). *L'intelligenza collettiva. Per un'antropologia del cyberspazio*. Milano: Giangiacomo Feltrinelli Editore. pp.125-126.



Conference Papers

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ABSTRACT

The research is an opportunity to discuss topics of study in which multidisciplinary areas related to geomatics, restoration and representation that can collaborate for the preservation of damaged historic buildings. In this regard, the contribution focuses on lowcost technologies of acquisition, interpretation, reconfigurative operation and use of an interactive digital space aimed at new forms of documentation for the mountainous territory of Abruzzo. Object of the survey and digital reworking is the Tower of Forca di Penne, that in compatibility with a VR experience, could constitute also a valid alternative to information sharing systems aimed at enhancing Cultural Heritage.

3D modeling from UAV for the reconfiguration of oxidation systems in Abruzzo. The case of the tower of Forca di Penne, an immersive archival resource for the lost Historical Heritage

1. Historical Introduction

The tower of Forca di Penne is located in Abruzzo, in the middle of the pass that constituted the only passage of the Abruzzo Apennine ridge. The position of the tower had great strategic value, both economically and militarily. In the Middle Ages it was used as a watchtower and until the last century it played a crucial role during the transhumance of the shepherds who moved from the Tavoliere of Puglia to the Campo Imperatore plateau. With a square plan, originally about 20 meters high, situated on a rocky plain, it has very ancient origins and was restored in the 15th century. Today it is in a critical structural condition, caused by the two earthquakes of 2009 and 2016 (Figure 1). Traces of ribs are visible around the structure, which testify to the presence of architecture attached to the tower in the past.

Figure 2. Photogram taken from drone, part of the package for graphic data processing in Metashape.

The three windows in the remaining wall suggest that the tower had four floors above ground. An interesting document is a drawing from 1651 that illustrates the stages of the route of the "Tratturo Magno", a wide strip of land used during transhumance: it would testify to the presence of a second tower forming a small castle (Brusaporci, 2016).

2. The Survey

The careful inspection of the area of interest for the survey led to the conclusion that the survey by means of a UAV system was effective. The site where the remains of the tower are located has a conformation suitable for the photogrammetric survey carried out by drone, as the artefact stands on a spur that looks out over the wide surrounding valley, open on all sides and free of obstacles. The large surrounding space facilitates the aerial maneuvers of the drone and allows photographs to be taken with a good depth of field. The only hindrances were the strong wind blowing from the north and direct sunlight, which in some places made it difficult to take the photographs (Figure 2). The drone used for the acquisition of the photographs is the DJI Mini 2, a low-cost drone that stands out for its excellent resistance to wind speed: 8.5-10.5 m/s (scale 5) is the declared resistance, but a recent experiment carried out by the site www.droneitalia.online (in which some drone models are compared during flight in a wind tunnel) shows that the MINI 2 withstands a good 12 m/s + 12 seconds of turbulence, far beyond the maximum limit set by the data sheet. The integrated camera has a

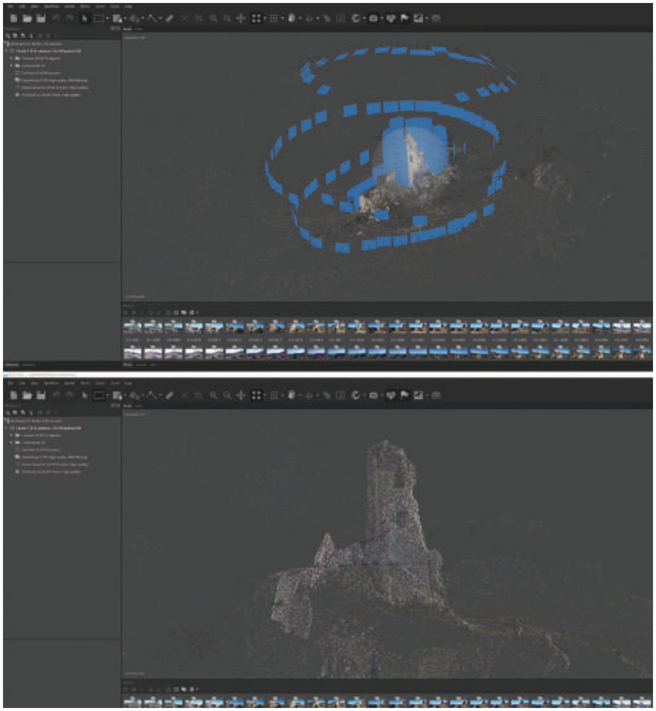

Figure 3. Camera alignment and sparse point cloud in Metashape software.

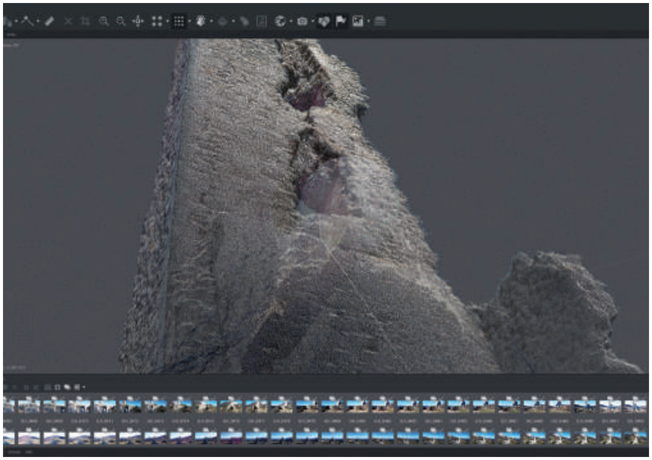

Figure 4. Metashape dense point cloud of the current state of conservation of the tower.

1/2.3″ CMOS sensor with 12MP, an 83° FOV lens with 35mm equivalent 24mm format, an aperture of f/2.8 and a shooting distance of 1 m at ∞; the maximum image size (the format used for the survey is 16:9) is 4000x2250 and the supported file formats are jpeg/dng (RAW). The photographs taken for the survey are 4000x2250 pixels at a resolution of 72 dpi, the exposure time is 1/500 sec, ISO 100, focal length is 4 mm. In order to carry out a correct survey of the structure, a flight plan was structured in two phases: the first phase consisted of a helical flight at a distance of 20 meters (90 photographs) starting from the base of the tower (also framing a portion of the surrounding terrain) and ending at the top of the structure; the second phase consisted of 8 elevation changes (one for each elevation and for each edge of the structure) starting from the base and ending at the top (130 photographs) at a distance of about 5 meters. Considering the average distance of 20 meters of the helical flight, the distance of the central points between two pixels is estimated to be around 8 mm in real space (taking the vertical surface of the tower as a reference). Therefore, the GSD, measured based on the camera parameters and the pixel dimensions of the shots, is 8mm[1] (Palestini, Basso, 2017). The software used for data processing is Agisoft Metashape, with which the four phases for processing the three-dimensional model based on the Structure from Motion algorithm were managed. The first phase is the alignment of the photographs in which the software analyses the photos finding the corresponding points of each shot generating the 'point cloud based'(Figure 3). This consists of key points that the software needs for the second stage of the process, the generation of the dense cloud, from which the software extracts information about the color and plastic detail of the objects (Figure 4). With the consequent process of manipulation of the dense cloud, which involves cleaning the excess points that are not useful for the construction of the 3D model, we arrive at the construction of the mesh, the third phase of the processing. The fourth phase of the survey processing is the creation of the texture (in this case of 16k) and the export of the 3D model in the.obj format (Figure 5) (Palestini, Basso, 2020).

3. Digital Configuration of the current and historical model

The phases of digital reconfiguration under study contemplate multiple implementation steps that can be structured on the optimization of models generated by photogrammetry in relation to the actual state, together with the manual polygonal modeling of 3D assets and different modular elements, related to the construction of alternative historical configurations proposed in the subsequent phase of virtual migration. The digital reconfiguration must therefore start from the analysis of environmental UAS data of a space constituted by a structural complexity related to damaged buildings, towers and traces of walls, and related to the rendering of the wide surrounding territorial spaces[2]. In the operations of coding, optimization and generation of 3D textured assets, a series of software and plug-ins are used, through which it is possible to edit ex-novo models, representative of the previous conditions based on historical sources and graphic documents, and explorable models of the actual state related to the 'structure for motion' survey obtained by drone and integrated methods (Argelaguet et al. 2016).

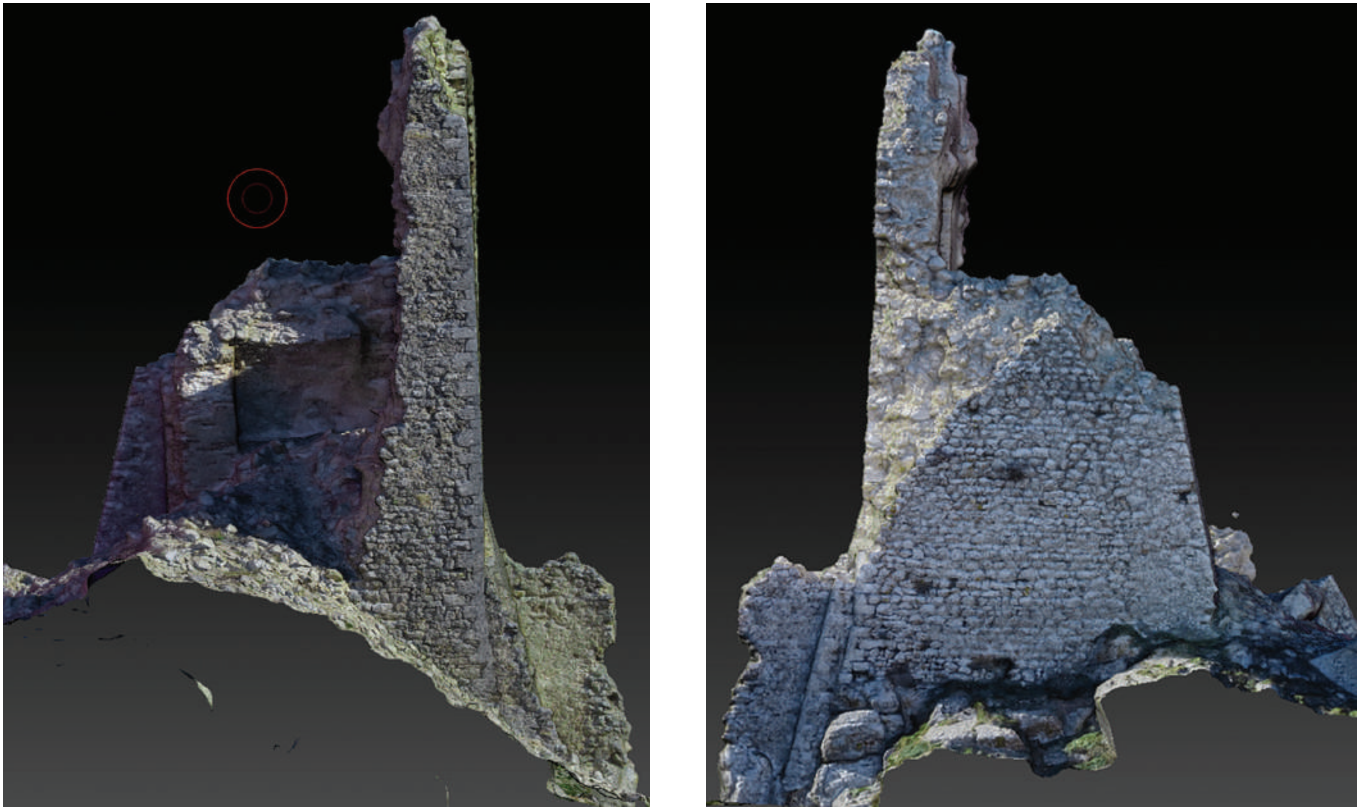

Figure 5. East-west elevations of the tower processed in high detail on Zbrush software to acquire colour and depth data.

4. Actual state recontruction workflow

Regarding the creation and editing of the macro spatial spaces and high detail environments related to the tower area, the self-modeling operations were developed directly using Agisoft Metashape for meshing, through which it was possible to generate a hyper-detailed polygonal model that included a correct arrangement of normals, a UVMap for assets already structured with relative textures, and the Color Vertex Map component, useful for an export configuration compatible with most compositing software[3]. The models obtained are then scaled and exported to Pixologic Zbrush, according to some of its excellent features, such as automatic retopology, HD detail cloning, non-destructive management of vertex color components and correction functions and UVmap creation (Basso, Vattano; 2020). The first operation was then to duplicate each 3d asset in two versions, one subject to polygonal optimization through ZRemesher, which allowed a quad retopology based on morphological recognition of the model through AI functions Voxel based (Figure 6), so as to obtain a lighter version of the same 3d object without generate shape artifacts, and the other version with the native HD detail, consisting of millions of polygons, which preserves both the color component, through Vertex Color and Texture, and the original very dense polygonal resolution. Thus it was decided to take two different paths, on one side bringing forward the project only contemplating the use of the models at maximum resolution, to be able to use them at an experimental level directly within the Unreal 5 platform,

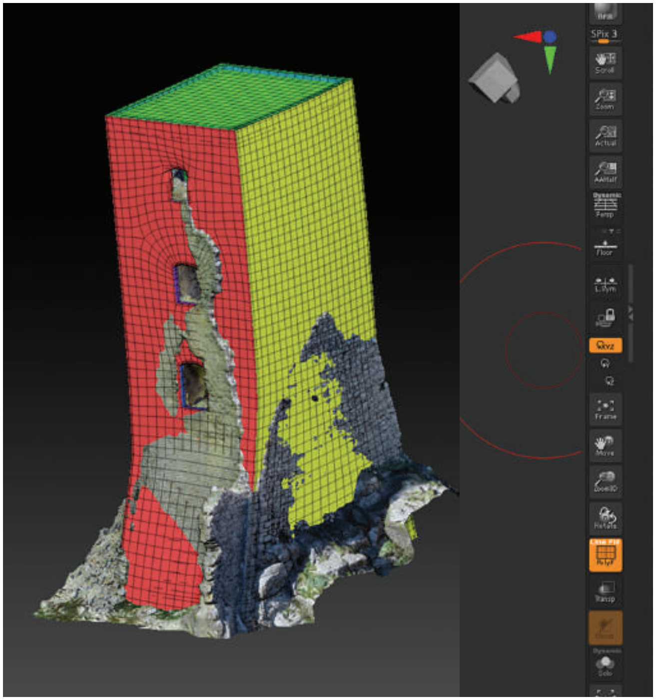

Figure 6. Model related to the historical reconfiguration of the tower using Zremesher retopology tool of Zbrush.

Figure 7. Unreal Engine 4 and 5, game visualization of the digital current state scenario and asset management.

on the other side we used the canonical optimization workflow[4] to proceed on the more stable RTR Unreal 4 and Twinmotion[5]. For both procedures, but especially in the one where the goal is that of the retopological simplification, Zbrush 2022.5, was used by integrating various proprietary tools, such as the very useful Historical brush or the new Project BasRelief tool, or third-party plug-ins, compatible directly within the software, such as ZWrap, capable of cloning detail and color of the sample model at high density on the target model optimized through ZRemesher[6] (Basso, 2020). The obtained textures related to the Diffuse, Occlusion, Bump/Displacement and Normal Map channel are used for the creation of complex shaders ensuring a photorealistic visual result for the virtual tour on Epic Games software: Twinmotion, Unreal Engine 4 and 5 (Figure 7).

5. Historical reconfiguration workflow

Researches on visual elaboration tools aimed at the documentation and digital communication of Cultural Heritage always inspect a correct description of the three-dimensional geometry in a possible historical configuration, integrating the 3d acquisition of the actual state, data useful to recover the scale and the metric disposition of proportional elements, with knowledge concerning historical aspects related to uses, customs and styles of the time, basically a peculiar interpretation of the architectural space that allows comparisons, verifications and overlapping. A historical reconfiguration thus implies the analysis of graphic elaborations that unfortunately, in the specific case study under analysis, have not been received in large quantities. The problem lies in the fact that much historical information is present in maps and treaties of war but there is no detailed survey on the site[7] and no particular archaeological investigations on the ascertained Roman pre-existence have been received. From the historical information received in the *Annali* and in the *Corografia* of Antinori, it can be deduced that in the medieval period up to 1600, the hamlets surrounding the tower of Forca di Penne, which in reality at that time was a small fortified fortress, housed the monastery of San Vito and a small center (Feud of the Baron of Carapelle)[8] (Figure 8). Therefore, it is necessary to reconstruct through historical sources, but also through the few pre-earthquake photographs, the configuration of the tower before its almost total destruction. On the one hand, models have been recreated through photomodelling of cloneable modular elements, such as parts of walls and curtain walls of existing buildings, sharing the same stone (and brick) building technique, acquired in neighboring villages (Figure 9). On the other hand, we opted for a completely manual modeling of new elements based on the graphic and descriptive sources that were received, in order to recreate the scenario assets and elements that could be visualized from a distance. At the operational level, the modeling flow was based on the decomposition of compositional elements through criteria of similarity of material or other characteristics taking into account the subsequent RT visualization. This procedure has allowed the continuity of the operation in the passage from the modeling software to the other of visualization without incurring any interruptions (Figure 10). The digitized models have been developed in particular using M.O.I 3d, for what concerns the nurbs modeling of macro-structural

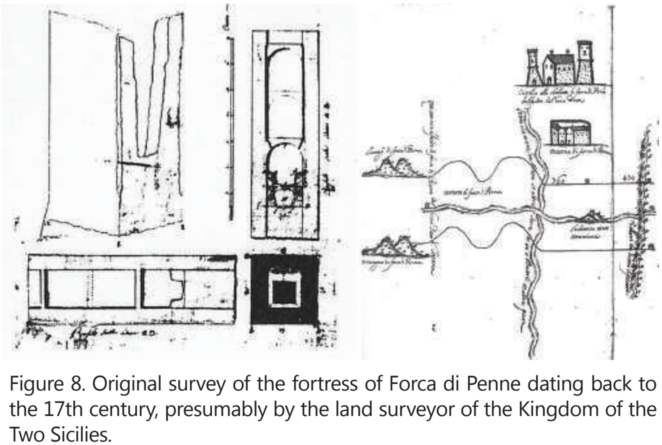

Figure 8. Original survey of the fortress of Forca di Penne dating back to the 17th century, presumably by the land surveyor of the Kingdom of the Two Sicilies.

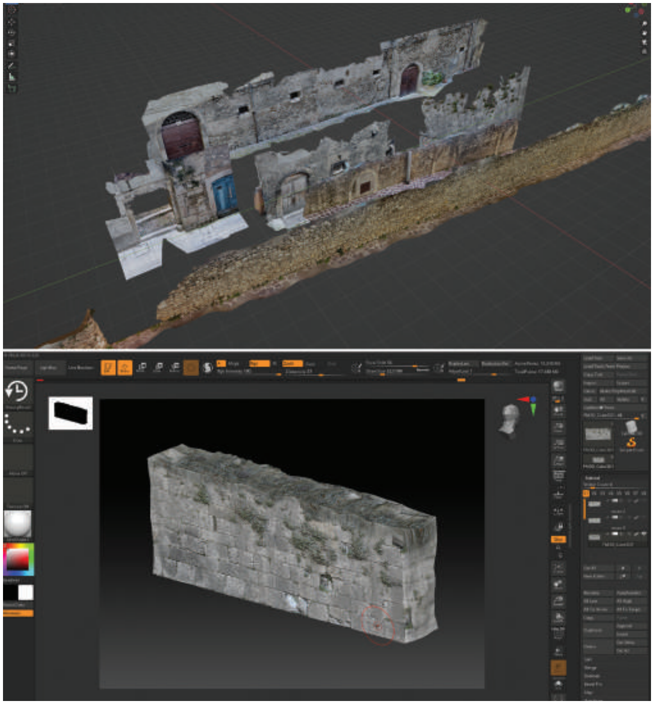

Figure 9. Creation of assets relative to the walls of Forca di Penne from photogrammetric scanned data. The 3d asset is processed for export to RT virtual platforms to be used as a modular clone instance in historical configuration.

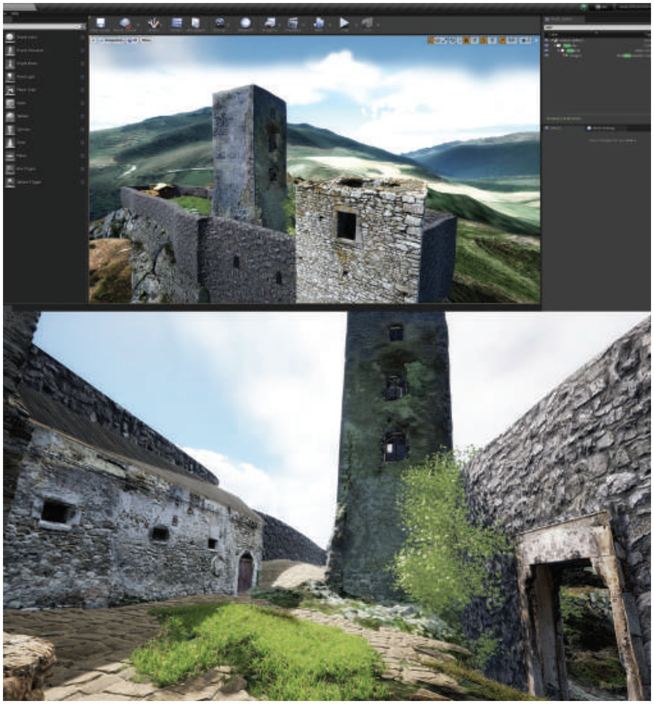

Figure 10. Unreal Engine 5 RT rendering of the historical 3D reconfiguration of the hypothetical buildings adjacent to the tower.

elements (the perimeter walls, the towers or the stone portals) while for the props, that is the outdoor assets, it has been preferred to use some functions of polygonal modeling within Zbrush or Maxon Cinema 4d.

6. Virtual migration on Twinmotion_Unreal Engine 4 and 5 platforms

The real-time graphics rendering technology of Unreal Engine has now reached levels of photorealism comparable to those of the most popular pre-computed rendering engines based on CPU processors, with the advantage of eliminating calculation times by returning the possibility of exploring digital scenarios in real time in a fully interactive manner. The interactive 3D reconfiguration of Forca di Penne covers the 1600s, when the fortified fortress still retained its integrity, having however already lost its strategic importance and population density, and the current period, in which it is possible to explore the tower taking full advantage of the 3D scenario inferred from the image-based survey (Basso, 2016). The scenario reconfigurations, before switching to the Unreal Engine 4 platform, are first built on Twinmotion, which offers shortcuts and easy-to-use element management, mapping and arrangement of direct and indirect light sources (Figure 11), taking advantage of the older version of the Unreal Engine[9]. The detailed digital terrain and the cloning of vegetation instances, far simpler procedures on the Twinmotion platform, were also imported correctly into Unreal. BPR shaders[10], managed by both platforms, give the optimized model the detail of the

Figure 11. Unreal Engine 5 RT rendering of the historical 3D reconfiguration of the hypothetical buildings adjacent to the tower.

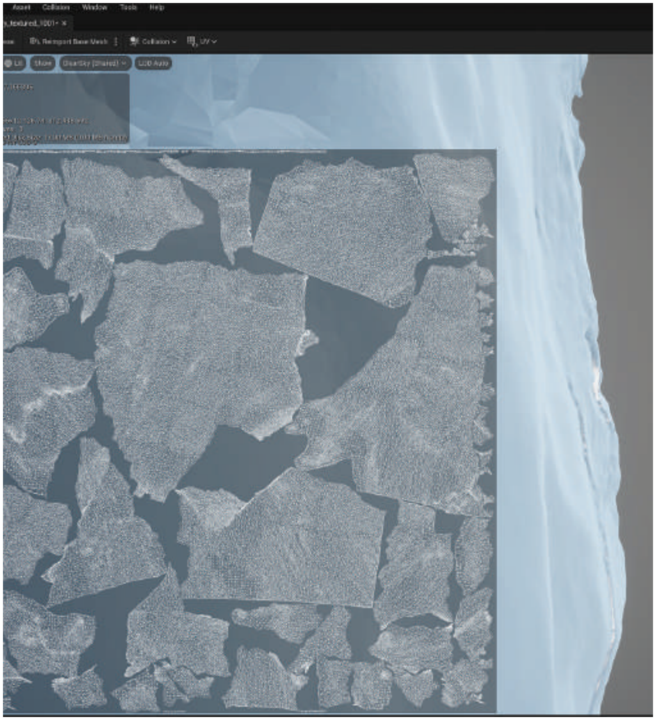

Figure 12. Using Nanite algorithm of Unreal Engine 5 to handle millions of polygons, UVMap visualization.

original high-resolution model, correctly simulating the behavior of real materials, such as translucency, reflection and refraction. Epic Game's lighting software gives us real time Raytracing/Path Tracing, working with the hardware acceleration support of the new NVIDIA RTX GPUs, eliminating light map computation time and making minimal use of Unreal's 'Build' feature for 'texture Baking'[11]. Finally, the experimentation of Unreal Engine 5 Preview (Figure 12), which can support RTR visualization even of high polygonal weight/bytes assets, thanks to the compatibility of the Unreal 'uproject' format, offered the possibility to manage the lighting through the new dynamic lighting systems 'Lumen GI' and new and more photorealistic rendering parameters (Screen Tracing, Distance Field Resolution Scale, Async tick physics, etc.), together with a smoother compositing flow thanks to the integrated 'Nanite' system, ignoring at each representation scale, the polygonal weight of each single element[12]. Thanks to the combined use of these two main algorithms, geometry can be visualized in much greater detail than before, obtaining normal detail at full resolution, while also calculating indirect illumination at a lower resolution for much faster real-time performance and with less expenditure of computational resources.

6. Conclusions

The research focuses primarily on the experimentation and comparison of different Image based photogrammetric survey methodologies, integrating the use of the drone with ground shots, in order to obtain concrete three-dimensional data relating to the digitization of a large and complex environment, which due to catastrophic upheavals it has considerably changed its structure, almost completely losing its original appearance. The data acquisition thus aims to disseminate information on the historical architectural structure through a digital reconstruction whose goal is to recover the lost historical configuration using only low-cost means, within everyone's reach, through a fluid workflow. In conclusion, a possible choice to develop an integrated project, aimed at compiling a serious game based on these interactive digital environments, in compatibility with the VR experience, conceptually enhances even more the innovative reference system, which nowadays constitutes a valid alternative to information sharing methods aimed at enhancing Cultural Heritage. (Figure 13).

Figure 13. Unreal Engine 4, tower actual state reconstruction, digital spaces in different weather and environmental conditions (summer and winter) in gamification modality.

Notes

1 GSD = d: D = f: H = 8 mm where d is the size of the pixel obtained as a ratio of the sensor size and the number of pixels in each frame in the same size (data contained in the EXIF of the photos); sensor size 1 / 2.3 ", sensor length in millimeters 6.4, length in pixels of the shot: 4000, ratio: 0,0016; D is the distance of the central points between two pixels (8mm); f is the focal length (4mm) and H is the distance from the vertical surface of the tower (20000).

2 Digital Elements that need polygonal simplification to obtain a model suitable for the passage on interactive platforms.

3 Each polygon of a mesh can in fact store a RGB color value (an average of the color applied to the three or four vertices that constitute the polygon itself, and possibly a monochromatic black and white value that the computer interprets as Depth map, usable to obtain, through some generative algorithms, not only the eventual albedo channel, that is the effective component of material color applied to the model without effects of light and shadows, but also particular effects that affect the visual plastic rendering of the 3D asset, such as transparency, environmental occlusion, Bump or Normal map.

4 Useful to generate the detail exploiting the Normal maps and the Displacement Maps applied to the simplified versions of the relative 3d models.

5 The latter procedure has greater compatibility with almost all real time rendering engines both off-line and on-line (e.g. SketchFab).

6 Once a new quad mesh has been obtained for the 3d models, it is therefore possible to increase the subdivision levels in a non-destructive way, thus maintaining the lower polygonal levels.

7 Other than the survey conducted by the Royal Guard by order of the Kingdom of the Two Sicilies in 1800, which conveys rather superficial graphical information.

8 The fortified construction was of strategic interest for the control of the territory and was composed in synthesis of some buildings that inside the walls housed the shelters of the soldiers and wooden warehouses, while next

to the tower under study, there would have been a lower tower, at least one floor lower, also connected to the walls and that today has not left obvious traces if not a protrusion in the corresponding perimeter embankment.

9 Twinmotion is an excellent shortcut for speeding up times, thanks to its full compatibility with the more powerful Unreal Engine 4, on which the already composed scene was then imported with exceptionally fast results thanks to the Data-Smith system.

10 BPR (Physically based rendering) perfectly simulates the behaviour of light on materials in a photorealistic manner. Quick and practicable approximations of the bidirectional reflectance distribution function and the rendering equation are of mathematical importance in this field. Photogrammetry can also be used for a more correct encoding of physically correct material properties. Shaders can be used to implement physically correct/unbiased PBR principles.

11 The new versions of Unreal use new lighting rendering algorithms instead of the methodology called Texture Baking, where light and shadow effects are directly imprinted on textures, greatly easing the burden of calculations and defining lighting once so that it does not have to be recalculated for each frame during interactive exploration, a methodology that is very useful for less powerful hardware but negligible in view of the powerful new GPU architectures.

12 The level of detail is managed automatically, through proprietary AI algorithms, and no longer requires manual setting for the LOD of individual meshes.

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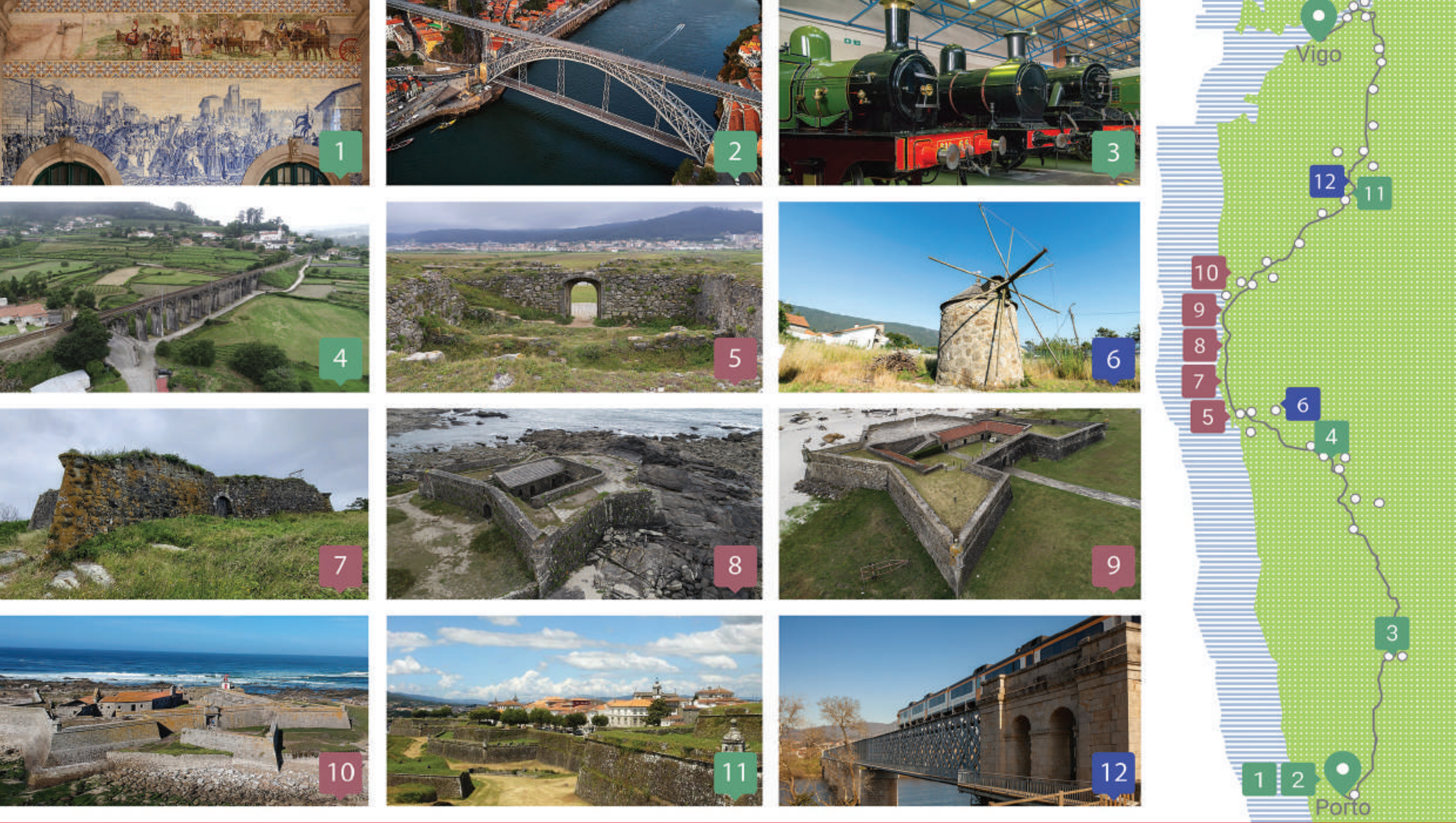

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Keywords:
Cultural Heritage, Terrestrial Laser Scanning, Aerial Photogrammetry, 3D Survey, 3D Model optimization.

ABSTRACT

This paper presents the digitization of 12 cultural sites displaced along the railway line Porto-Vigo. Carried out within the RAILtoLAND Erasmus+ project, the 3D survey integrated UAV, TLS and GNSS-RTK acquisitions in order to generate effective reality-based models to support travellers in discovering the Railways Landscape thanks to a mobile geo-localised app.
The obtained results demonstrated the flexibility of digital reproduction, able to offer not only an accurate documentation of the state of conservation of cultural sites, but also to enable effective ways for their promotion.

Data integration and optimization for Cultural Heritage fruition. The case study of the Rail to Land Project

1. Introduction

The digital representation of landscape is a very challenging field, above all according to the need of representing and creating narratives about multidimensional and complex systems. In fact, the landscape is featured by different interdependent dimensions: the spatial dimension, the time dimension, the perceptual dimension and its meaning's resignation. Thus, the codification and signification of such multifaceted heritage result in a complex work of interpretation. Till now mainly maps and digital terrain models played a major role in the scenario of analysis and interpretation of landscape, but their objectiveness and technical appearance is often lacking in terms of communication and common acceptance.
Similar general challenges are deeply boosted in the project RailToLand (RTL)[1], which aims to represent in an innovative way the railways landscape and heritage. The values of this heritage and the particular perception arising by crossing territories with a train trip was already envisaged by Ettore Sottsass in (Sottsass 2009). The book is a collection of instant pictures, with related captions, of worlds and realities that rarely we are able to see, but even more to observe, assimilate and describe in such an immediate and essential way.
Building up on our expertise in digital representation of Cultural Heritage, a specific approach was the cultural focus on the landscape. It means to highlight what is generated by man in the landscape in terms of life and customs, knowledge, identity, symbols and meanings, artistic representations, development of ideas, etc. In this context the use of digital technologies was intended to promote the Cultural Heritage systemized by the railway, also exploiting the visualization of 3D models. A secondary goal in this experimentation was also to verify the potential of digital tools for the democratization of Cultural Heritage. This way the RTL project aims of involving the target population in decision-making processes and designing landscape enhancement inititives, as expected by European Landscape and Faro Conventions (Europe Council Treaty Office 2005).

2. The Rail to Land project

The survey and drawings, here presented, are part of a larger project: the RAILtoLAND, Collective ideation platform to develop innovative tools to communicate the European Cultural Landscapes by train. It is a project co-funded by the Erasmus+ programme which aims to explore the social and educational value of the railway landscape as a common heritage and as a catalyst for the consolidation of European identity and the formation of local cultures. The project involves 6 partners from Italy, France, Spain and Portugal, selected on the basis of their expertise to deal with different project goals.
The themes of the train and travel act as the fil rouge of the project: the railway is seen as an infrastructure characterising the territory, a way through which the cultural landscapes of Europe can be appreciated from a new perspective.
The main output of the RTL project is a geo-localised mobile app accessible for free, which is not only a container of educational information, but also an

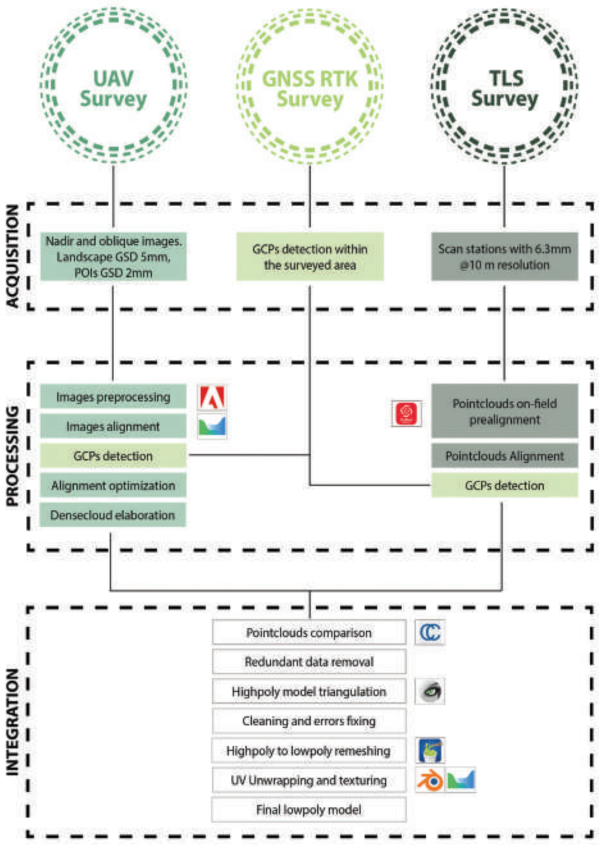

Figure 2. Block diagram of the proposed methodology.

interactive virtual laboratory promoting culturally and historically relevant points of interest (POI) through the recreation of a journey. Due to the specificity of the content and functioning of the application, for now it has been designed for a pilot project, focusing on the Porto-Vigo railway line.

The core of this application is the “Experience” tab which enables to inform and entertain the user, who has the possibility to explore the landscape thanks to different multimedia such as panoramic images, videos and 3D models of Built Heritage and landscapes.

For this reason, one of the expected outcomes of the digitisation process was a set of 3D models having both lightweight and high visual quality, to be effective in supporting travellers in discovering the railway landscape in a fast and intuitive way.

The RTL project is aligned with the purposes of the European Landscape Convention: the population is involved in decision-making processes and in the design of actions for the understanding, appreciation and conservation of landscapes.

In particular, it proposes formal and informal learning dynamics that privilege learning in an international and intercultural context. To do this, it tests innovative educational methodologies aimed at improving horizontal skills and competences in communication, creativity and critical thinking. One of these is the “Learning by doing” training week to be held during June 2022 in Cagli (Marche region): this will allow all project participants to meet, discuss, confront each other and participate in a workshop dedicated to data acquisition and processing, experimenting new media in support of co-design practices.

3. Prior works

3D technologies for digital surveying and visualization provide effective solution for Cultural Heritage documentation and dissemination (Galeazzi 2017 ; Liuzzo et al. 2020 ; Cardaci et al. 2020).

Concerning digital surveying, is well known that each technology has its own advantages and disadvantages (Baltsavias 1999).

The possibility to combine the use of different tools allows to offset the individual weaknesses, exploiting the strengths of each technique (Barba et al. 2020). In particular, the integration of Terrestrial Laser Scanning (TLS) and digital photogrammetry using Unmanned Aerial Vehicle (UAV) offers the potentials of

both active and passive sensors, enabling terrestrial and aerial acquisitions for a complete documentation and digital reconstruction of the investigated object (Liang et al. 2018).
As for dissemination, reality-based models have proven to be extremely effective in making CH accessible through easy-to-use applications, spreading cultural awareness of heritage assets to a generic public (Clini et al. 2022 ; 2020 ; 2019). One of the main challenges in this field remains getting from the huge amount of data gathered during the survey campaigns 3D models performing in this regard (Bertacchi et al. 2022; García-León et al. 2018).

4. Methodology

Aimed at enhancing and promoting the Cultural Landscape crossed by the railway, the RTL project includes among its Intellectual Outputs the elaboration of high-quality 3D models to be implemented as narrative element of a mobile app (Quattrini et al. 2021). Starting from the list of 50 POIs located along the Porto-Vigo line, pertaining to different categories (Built, Natural and Cultural Heritage), 12 POIs were selected to be 3D surveyed (Figure1). Facing these case studies, the methodological approach was mainly driven by the need of documenting widely differing cultural sites, ensuring a complete digital reproduction.Therefore, the integration of UAV, TLS and GNSS-RTK was mandatory, making possible also the visualization of the surrounding territory, being the Cultural Landscape the storyline of the whole Rail to Land project.
The following paragraphs describe the main tasks carried out: data acquisition, referring to the specifications of the used equipment and to the different survey operations, data processing, detailing procedures for each kind of acquired raw data, for their integration and further optimization, and finally the proposal for 3D models visualization and exploitation within the mobile app (Figure 2).

Figure 3. The technologies applied for the integrated survey.

4.1. Data acquisition

The survey campaign was carried out in five days, moving from Porto to Vigo, by following the railway from one POI to another. As previously stated, different techniques and related tools were applied (Figure3).
Concerning the UAV photogrammetric acquisitions, a DJI Mavic 2 was used. This drone weighs approximately 907g and it is capable of shooting image with a resolution of 5472x3648 px. The camera is equipped with a 20 MP 1" CMOS sensor and lens with a Field of View (FOV) of about 77°. The camera is integrated in the gimbal to maximize the stability of the images during the flight. For each POI, the image acquisition was planned to provide first a comprehensive recording also of surrounding landscape, then a more focused one on the object. Taking the example of Ponte Seca, three flights were performed. The first one was carried out flying over an area of 250x200 m, following a "grid" plan at a constant altitude of 40 m from the ground and with the lens inclination set at -90° to capture zenithal pictures. The second and the third ones were symmetrically performed on the two sides of the bridge

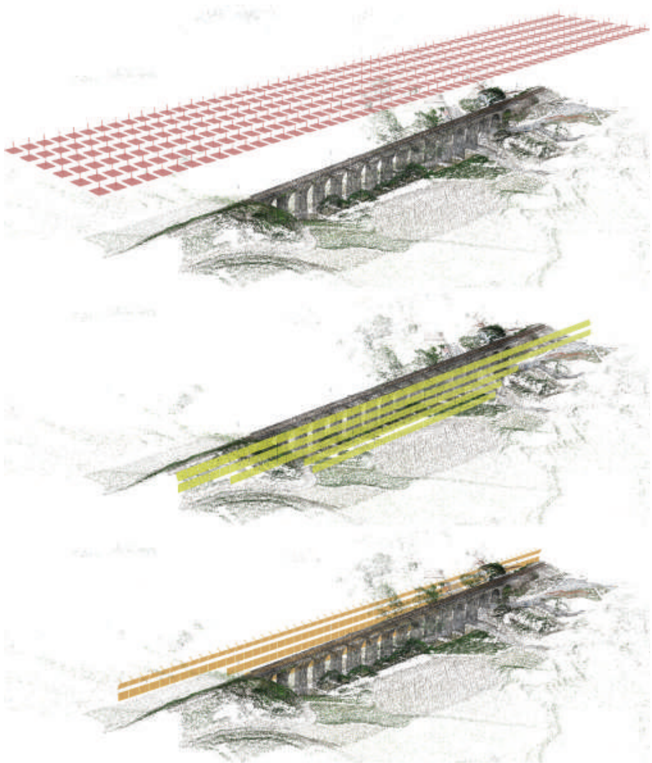

Figure 4. Ponte Seca, Durraes, Portugal. Shown in red, the flight pattern to take zenithal pictures of the whole area, in orange and yellow, the two symmetrical flights focused on the bridge structure.

from 15 m, flying parallel to the vertical surface with the lens inclination set at 0° and an inclination of -10° and -20° for the last two rows focused on the upper part of the bridge. The first flight was automatically performed, the second and the third manually, in both cases a minimum image overlap and sidelap of 70% was provided. All the acquisitions related to the different POIs were similarly executed, aiming at a Ground Sampling Distance (GSD) of 5 mm for the surrounding landscape and of 2 mm for the specific POI (Figure 4).

The TLS acquisitions were carried out using a Leica RTC360, scans were particularly useful to survey areas not documented by UAV and to gather geometrically accurate data of the different POIs. The scanning resolution was set at 6.3 mm@10 m and panoramic images were taken from the scanner to colorize TLS point clouds.

To provide data geo-referencing, Ground Control Points (GCP) were displaced within each surveyed area. Being visible both to UAV and TLS, they were detected using a Spectra Precision SP60 in RTK mode (Figure 5).

4.2. Data processing

For each cultural site, the different raw data were first separately processed. UAV raw images were pre-processed using *Adobe CameraRaw*, then imported in *Agisoft Metashape* to be automatically aligned. After this first step, GCPs were manually recognized within the images and the alignment was optimized also removing some of the detected key points, evaluating their reconstruction uncertainty, reprojection error, the number of images in which they appear and projection accuracy. A dense cloud was finally built restricting the limit box to the area of interest. Taking as example the Forte Lagarteira, 745 pictures were aligned and 8 GCPs were placed on the images, obtaining after the optimization an average GCPs error of 1.619 cm (0.783 px). A dense cloud made of 16.4k of points was built setting the limit box to an area of 150x150 m. TLS pointclouds were pre-aligned during the survey campaign thanks to the *Leica Field 360 app*, that allows an auto-alignment based on the Visual Inertial System technology of the Leica RTC360. Using the software *Leica Cyclone*, the alignment was optimised and registered. Again, with reference to the Forte Lagarteira, a maximum RMS error value of 1 cm was obtained among all the registration pairs. GNSS data were also imported within the same software, manually recognizing the GCPs, also the final TLS pointcloud were georeferenced. The data integration, which were already referred to the same coordinate system (ETRS89/Portugal TM06), was carried out with the same software used to process TLS data. The UAV densecloud was imported and aligned to the TLS pointcloud, obtaining among the different surveyed POIs a maximum RMS error value of 2 cm (Figure 6).

Before going through the 3D modelling phase, to remove redundant data, for each POI, the final TLS pointcloud and densecloud were imported in *CloudCompare*. This software allows to estimate the distance between a reference point cloud and a compared one, making possible to select points on the second one that are further of a set distance. Having a higher level of precision, TLS pointcloud was set as reference, comparing to it the UAV densecloud, whose overlapping points were deleted (Figure7). The 3D modelling phase was structured to get a final output optimized for visualization on mobile devices. The point clouds of each POI were imported in *Agisoft Metashape* to automatically triangulate a 3D meshes. The obtained geometric reconstructions are rich in details, but also large sized files.

To get more affordable outputs to be managed within a mobile app, 3D meshes were cleaned and fixed in *Meshlab*, removing topological errors and unwanted parts, filling holes and smoothing surfaces.

The low-poly versions were then obtained using retopology filters, also applying UV unwrapping and baking normal from the high-poly models to keep the same visualization level of detail. Finally, each optimized model was imported in *Agisoft Metashape* to be textured (Figure8). The final outputs demonstrated the flexibility provided by data integration in generating high-quality digital reproduction of the heritage sites investigated.

The integration of different technologies for data acquisition and procedures for data processing offers not only the opportunity of an accurate documentation, but also to enable effective ways for the storytelling and promotion of complex cultural sites thanks to visually high-detailed but lightweight models (Figure 9).

Figure 5. Raw data from different survey applied technologies.

4.3. Data visualization

The processed data will then be displayed on a mobile device, within the special application where the POIs will be both listed and visible on a map, alongside the route taken by the train. Each POI will then be enriched with information, photos, also taken by drones, 360° images and 3D models that can be accessed by the user through the Discover tab. In this way, the experience of the journey is amplified: users can access heritage beyond what is visible from the train, discovering not only the architecture and landscape of the point of departure and the point of arrival, but also those they pass through on the train.The 360° images and the 3D models will allow the user to virtually visit monuments and infrastructures that they will pass through during their journey, but that sometimes, due to the speed of the train, they will not be able to see. The user will be able to rotate and manipulate the 3D model of the POI inserted in its context and interact with some clickable hotspots in order to obtain further information about the artefact, while thanks to the 360° images he will be able to immerse himself and enjoy some of the fundamental places of his journey.

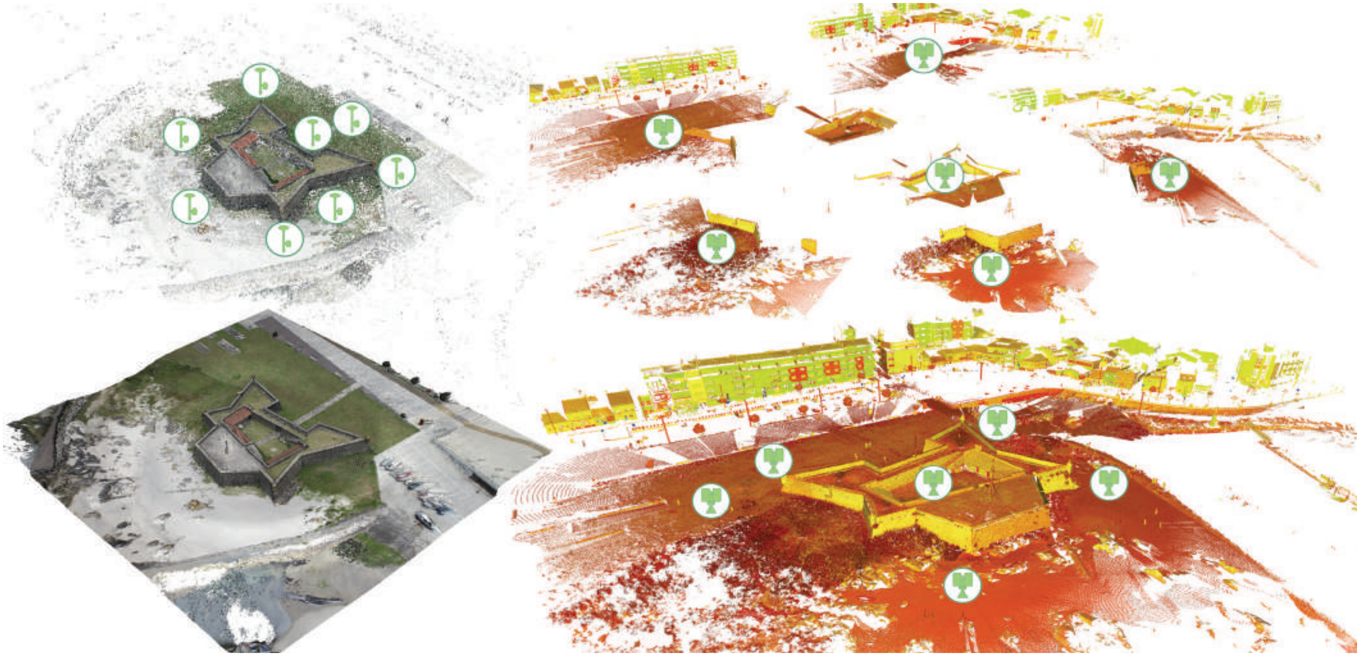

Figure 6. Lagarteira Fort, Vila Praia de Ancora, Portugal. To the right, the close-range photogrammetry sparsecloud (439K points) showing the 8 GCPs and the densecloud (16M), to the left, TLS single stations pointcloud and the final TLS pointcloud (270M points), also georeferenced thanks to the GNSS RTK data.

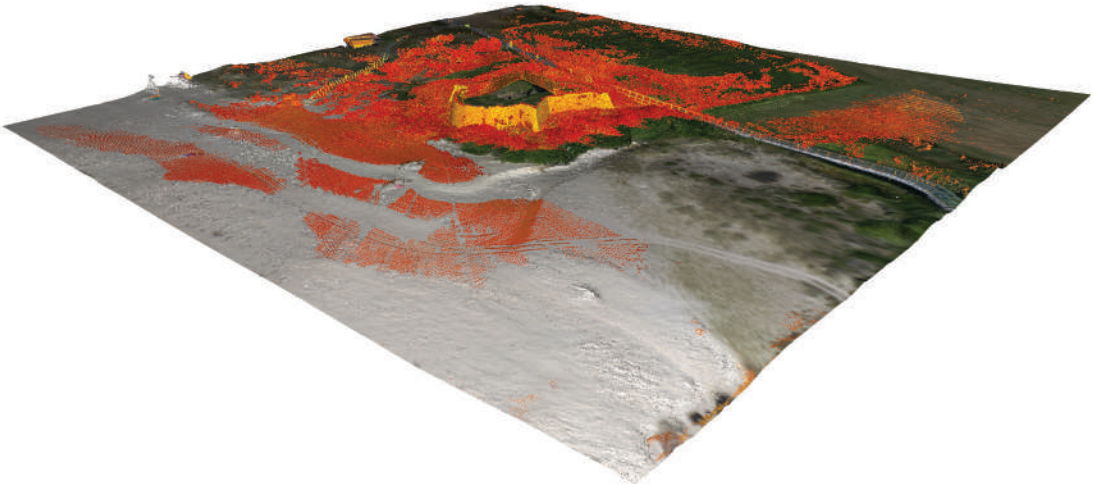

Figure 7. Paco Fort, Viana do Castelo, Portugal. View of the TLS pointcloud overlapping the close-range photogrammetry densecloud.

5. Conclusions and further developments

Concerning the railway and the huge quantity of natural landscape and human artefacts, the digital solution here presented might deeply boost the access to heritage influencing the perception. The main idea of the app, to turn the journey in an experience that goes beyond going from the origin to the destination, is convincingly carried out and will be tested in the next months.

An additional result is the cross-fertilization of skills obtained so far inside the RTL partnership, that will be also increased in the final steps of the project by the residential learning activity under the supervision of our research group.

This meeting will also be an opportunity to discover the tracks of the railways that ran through the inner area of the Marche Region with a view to a recovery image (already partly in progress) for tourism purposes.

The outcomes and the synergies created by RTL therefore fully reflect the objectives of the "European Year of Railways"[2]: to encourage the use of the train not only as an ecological and safe means of transport, but also as a symbol of a more united and interconnected Europe.

Notes

1 Erasmus+ KA203 project Rail to Land - Collaborative platform to design innovative tools for communicating European cultural landscapes from the train. Lead partner Polytechnic University of Madrid, 2019-1-ES01-KA203-065554 (2019-2022). The UNIVPM unit (scientific responsible Ramona Quattrini) has in charge the 3D contents and narrative about landscape and heritage from the train as well as the organization of learning activities that will be held in Cagli in 2022. More details on https://railtoland.eu/

2 The EU has designated 2021 as the European Year of Rail (EYR). The European Commission initiative wants to highlight the benefits of rail as a sustainable, smart and safe means of transport. A variety of activities has put rail in the spotlight throughout 2021 across the continent, to encourage the use of rail by both citizens and businesses and to contribute to the EU Green Deal goal of becoming climate-neutral by 2050.

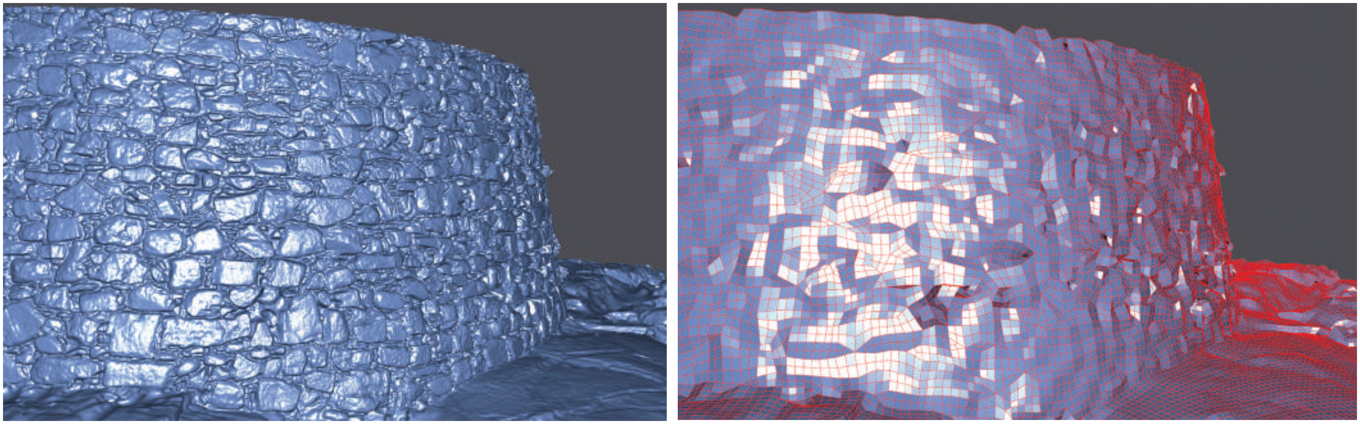

Figure 8. Cao Fort, Vila Praia de Ancora, Portugal. High-poly and low-poly 3D model comparison.

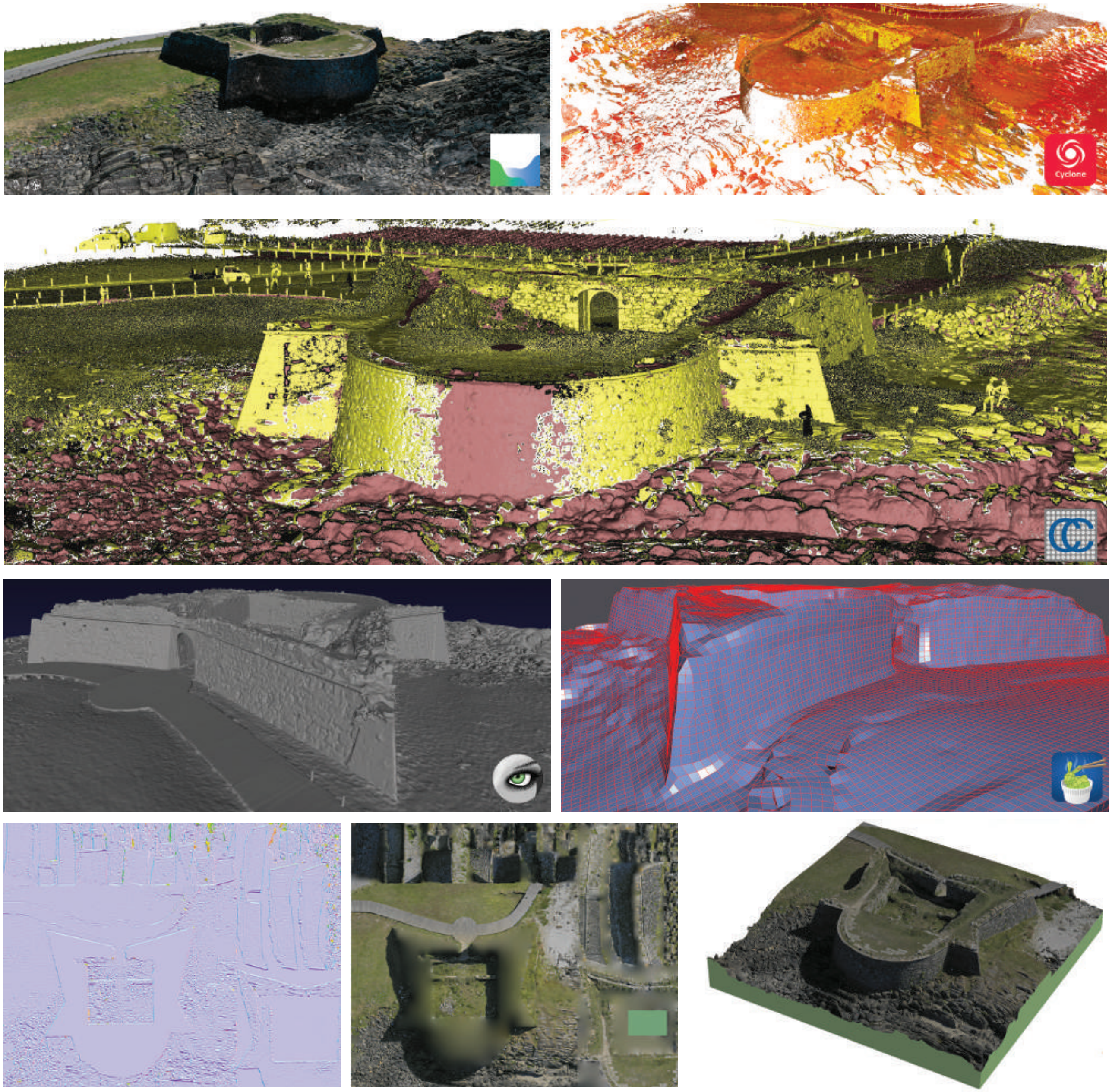

Figure 9. Current and opposite page. Vinha Fort, Viana do Castelo, Portugal. The densecloud obtained from UAV images and the TLS pointcloud are merged into a single georeferenced pointcloud, by meshing it, the high-poly 3D model is obtained and optimized in a low-poly one, that is finally unwrapped and textured.

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ABSTRACT

The essay shows a research aimed at building a digital database of Sardinian military architectures of Second World War. Following an activity of cataloguing employed in other case studies in Sardinia and Spain, this contribute deepens the knowledge of the IIWW heritage placed in the territory of Quartu Sant'Elena (CA). The examples identified show different levels of accessibility, a limit that can be exceeded with the use of drones. This choice also allows to extend the survey area to the landscape surroundings in turn to investigate the territorial system reaching a good level of documentation that needs to be shared. The main goal becomes to communicate this Cultural Heritage; this result can be reached through an interactive map to which different types of bunker information are linked and can be viewed and consulted by users.

Design models and landscape form of Sardinian IIWW Heritage. The Simbirizzi Lake in territory of Quartu Sant'Elena

1. Sardinian IIWW military architectures. Knowledge and enhancement of a Cultural Heritage

Bunkers and batteries built during the Second World War and the network of towers built starting from the 16th century characterize Sardinia's coastal landscape. Both architectures belong to the historical Cultural Heritage, however, while the coastal towers are protected and the interested by restoration and enhancement projects, the bunkers are not involved in these programs, even though they represent the oldest ruins of reinforced concrete in 20th century modern architecture. These contemporary sentinels are still present, silent, and immobile along the sandy coasts and the edges of the ponds, apparently still guarding the isolated creeks and rural routes, controlling the communication routes of land and sea, hidden and intent on scanning the sky and a landscape embellished by them through the use of forms that tend to blend chameleon-like with it (Figure1). Therefore, today, in an era of sustainable progress and recovery of the historical built heritage, perhaps the time is right for these architectures to be reused. To this aim is necessary to define a complete cognitive framework of the existing heritage with a cataloguing work that has already done for the Atlantic Wall in terms of typological aspects (Rolf 1988) and restoration (Virilio 1994) and in Sardinia for historical-cultural aspect (Carro, Grioni 2014), census architectural-landscape value (X,Y,Z 2020, 2021) and in the most recent period involving Spanish researchers (Martínez-Medina 2016) and the heritage inherited from the Civil War (Martínez-Medina, Molina, Juan-Gutiérrez 2019).

However, at the moment there is a lack of attention for the Sardinian military architectures of Second World War, with a subsequent lack of planning for their preservation and valorization.

For this reason the first and the most important step of the research has been to create a digital database to support the process of knowledge of these heritage and to highlight their important rules in the characterization and understanding of the landscape they were built in.

To this aim it is necessary to identify what kind of data is needed and which tools can be used to achieve the desired results. In this case the information must be such as to provide a description as complete as possible of every single object as well as their relations with the landscape context. Necessary information includes dimensional and geometric data, materials, state of decay, the geographic position and other points of interest near the single bunker.

An integrated survey becomes the way to achieve all the information required to build digital models and thematic maps. This work is not enough; it is necessary to communicate this Cultural Heritage (Parrinello et al. 2019); a result that can be reached through an interactive map to which different types of bunker information are linked and can be viewed and consulted by users.

Figures 1. On the cover and above: some examples of bunkers in the territory of Quartu sant'Elena (CA).

2. The Simbirizzi Lake. Data acquisition and design of the digital geo-database

The design of the geo-database requires the choice of a cartographic base to link the data obtained through the use of integrated survey and representation methods.

This choice fell on the regional technical map in scale 1:10.000, a geo-referenced map compatible with the historical series of aerial photos and historical IGM maps. The latter are particularly useful because they show the defence project carried out in the 1940s and allow to plan the field operations and verify the location of the individual bunkers built in the 1942.

These maps show in the study area the project of numerous bunkers organized to create a line of defence of inhabited centres and Cagliari in particular. This line was called the "containment arch of Quartu

sant'Elena" and included a vast coastal territory and the hinterland to the east of the regional capital. A portion of this line of defence was planned along the roads that through the rural landscape of Quartu sant'Elena led to Cagliari. Along this path there is Lake Simbirizzi, a place characterized by a landscape of great interest although currently in a state of decay and abandonment. Here we find numerous small groups of bunkers, some of which are the subject of our investigation.
This subdivision of the small artefacts, designed with models adapted to the morphology of the site and modified if compared to the schemes indicated in the archival documents, becomes functional to the surveying operations but not only.

Figure 2. Survey area (ortophoto generated by point cloud with 0,025 m/pix of GSD).

In order to create a digital interface capable of communicating this heritage, the survey area is divided into macro and micro sectors that can be viewed and queried by users.
The survey area, that contain a great part of the defence line, has been divided in different areas as "Simbirizzi/Buoncammino" "Gannì" within the rural inland, "Poetto", "Capitana", "Flumini" along the coastline and "Quartello" within the urban area, each of them divided into sector.
As already applied in other case studies, the surveying operations take place at the architectural scale, in order to produce a catalogue of the plan schemes (for a comparison with the models provided by the Military Engineers) and acquired dimensional and material characteristics of the bunkers, and at the landscape scale to define three-dimensional models.
The bunkers identified in the area "Simbirizzi/Buoncammino" are 24 and each of them is surveyed through photogrammetric methods using the UAV (unmanned aerial vehicle) that integrate the necessary direct survey applied inside the small artefacts. The use of the drone is a low-cost alternative to aerial photogrammetry both for topographic survey of small-areas and for architectural and archaeological (Ebolese et al. 2019, Pepe, Costantino 2021).
The flights were performed with a DJI MINI 2 drone with a MTOM (Maximum Take Off Mass) of 249 grams equipped with a camera with a 4:3 sensor 12.4 MPX and a FOV (Field-of-View) of 83°, equivalent to 24mm compared to the 35mm format. Different flight plans have been planned for the restitution of a model of the survey area (Figure 2) and of each bunker.
The first were set on a cross-meshed trajectory at a maximum altitude of 110 meters, taking advantage of the maximum permissible flight altitude, which guaranteed a GSD (Ground Sample Distance) of 4.1 cm/pix. The distance between the strips of 50 metres and a cruising speed of 6 m/s was maintained with an interval between shots of 5 seconds; this choice has led an overlap of at least 70% both longitudinally and laterally.

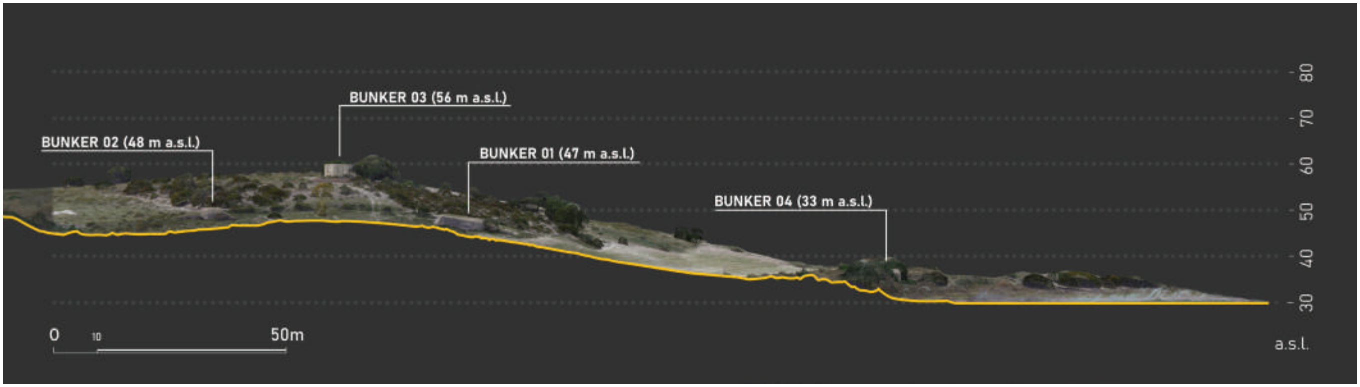

Figure 3. Bunker 01. Environmental section.

The flights for the survey of the bunkers were set with orbit trajectory and camera facing the axis of revolution, shooting images at different altitudes and distances between 20 and 40 meters.
Image processing using the SFM process was managed with the Agisoft Metashape software.
After analysing the quality of the images in order to process only those without imperfections, the process followed with the construction of the Sparse Cloud, analysed and treated so that all the photos were aligned correctly.
Last step has been the calculation of the dense cloud; it measures for the Territorial survey (300 x 350m): 65.539.000 points, Bunker 01: 2.092,000 points, Bunker 02: 1.317.000 points, Bunker 03: 2.312.000 points.
Starting from the data acquired different models were produced; among these the environmental sections that allow to observe the relative position between each bunker and his and its relationship with the landscape context (Figure 3).

3. Communicating WWII built heritage

Once the structure and contents of the database were established, so that they could facilitate the knowledge and awareness of the architectures studied, it was decided to develop a prototype of a web-based portal. This portal consists of two main components: the interactive map and the consultation sheets. The first one acts as an overall viewer of the themes and as an access point to the sheets (Prus et al. 2020); the sheets provide detailed information on the single artifacts (De Fino et al. 2020).

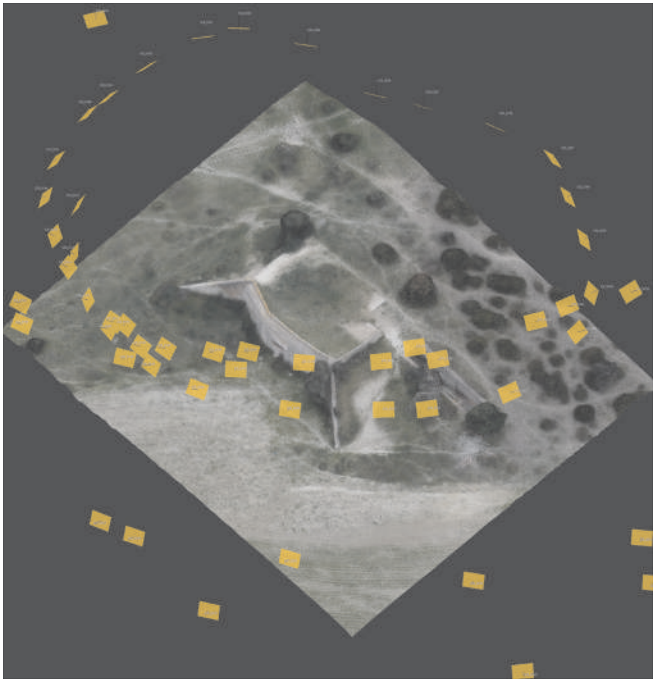

Figure 4. Bunker 01. Mesh model obtained by point cloud.

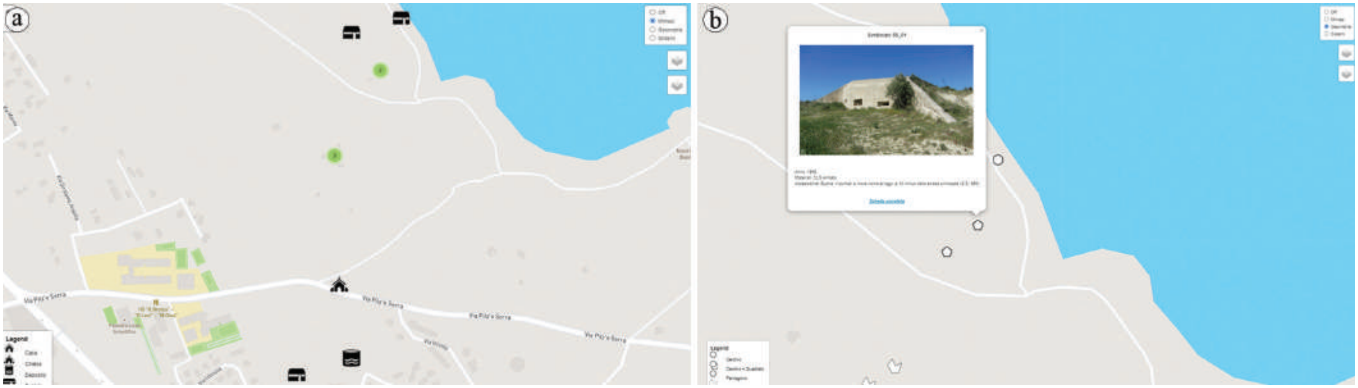

Figure 5. (a) An example of clusters and mimicry thematism. (b) The shapes thematism and the general sheet.

3.1 Interactive map

For the realization of the map, Leaflet.js library was used (Agafonkin 2018; Edler, Vetter 2019); it allows the setting and the configuration of maps based on the main online cartography services, such as Google Maps or Open Street Maps. Among the basic functions of Leaflet there are tools for the creation and management of Marker that, starting from the geographical coordinates, are positioned on the map and made interactive; a marker is associated to each bunker detected, whose characteristics are read directly from the database. The reading phase is entrusted to a routine in Ajax which, allowing a dynamic update of the page, deals with querying the database and returning the requested data in JSON format. The thematisms are managed through layers containing the various markers. In order to ensure a better readability of the map at very small scales or in the presence of numerous markers, these have been managed through a Leaflet expansion for the clustering of the markers (Figure 5a); the clustering is independent from the symbology for the thematisms, thus allowing its use in combination with the set of icons for the representation of mimicry systems or basic geometries (Figures 5a, 5b). As shown in the images, by controlling the layers, it is possible to switch the individual thematic elements for an overall view of the bunkers at the various scales; by clicking on the clusters, the library zooms in to allow the expansion of the cluster and view the individual objects. Each object is clickable to open a general sheet containing basic information about the bunker as well as a link to the detail sheet. The contents of the sheets, general and detailed, will be discussed in more detail in the next chapter. The layers control allows to change, in addition to the thematisms, also the base cartography; in the figure 6a is shown the combined visualization of satellite photos, by Google Maps, and of the thematism of the identified systems. In particular, the thematism of the systems is represented by overlaying on the map polygons whose vertices are represented by bunkers; the interaction with the polygons opens a drone photo that includes the entire area of the system, flanked by a mosaic of images of individual bunkers belonging to the system (Figure 6b). Each of these images can be clicked on to open the detail sheet for the selected bunker. Leaflet also allows the overlapping of images and maps, which can also be managed as layers; in this specific case it was decided to make visible extracts of IGM cartography in which the bunker systems are present (Figure 7). This overlay allows to analyse the differences in positioning compared to the initial project, as well as to see how infrastructures and territory have changed; this can be useful for the study of the original positioning of the bunkers in relation, for example, to their defensive functions.

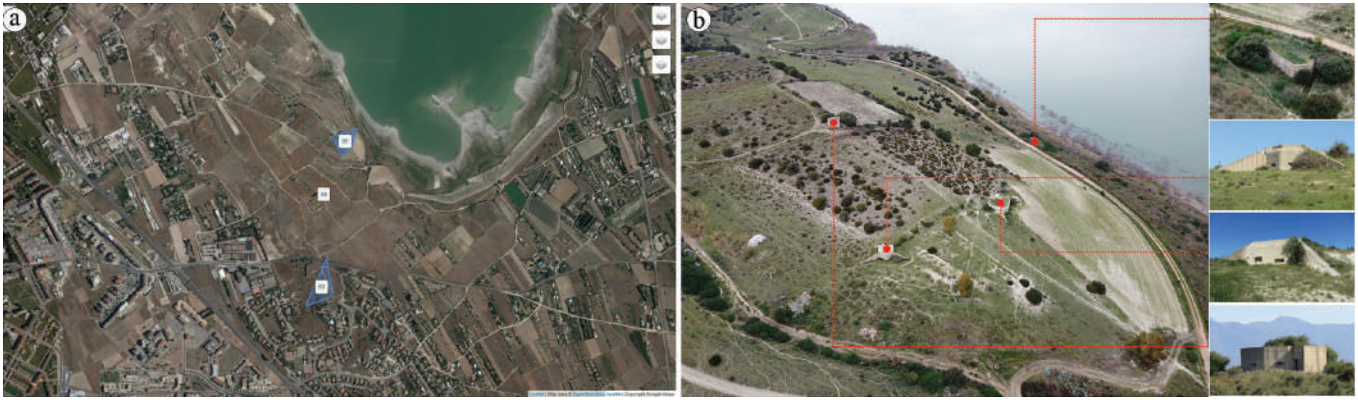

Figure 6. (a) The systems thematism on satellite photos. (b) Wide view of the area of a system and interactive detail photos.

Figure 7. Example of the overlay feature: historical IGM map on actual map by Open Street Map.

3.2 Consultation sheets

As said, the interactive map is flanked in its function of consultation by two types of sheets: one of general synthesis accessible through the direct interaction with the markets on the map (5b), and one of detail accessible both from the general sheet and from the wide photos of the area. The general sheet contains an explanatory photo of the artifact in question and a series of information such as the year of construction, the materials used and a brief description of the accessibility to the bunker.

Regarding the detail sheet (Figure 8), this contains the most common information that may be useful to study these architectures. The list of items displayed, the same in the database, is the result of a progressive implementation articulated during the progress of the surveys and the increase of the case studies analysed. Each bunker is assigned a unique name that allows a quick recognition, in terms of geographic area and system of belonging; in addition to the name each bunker has an ID, also unique, for easier management within the database

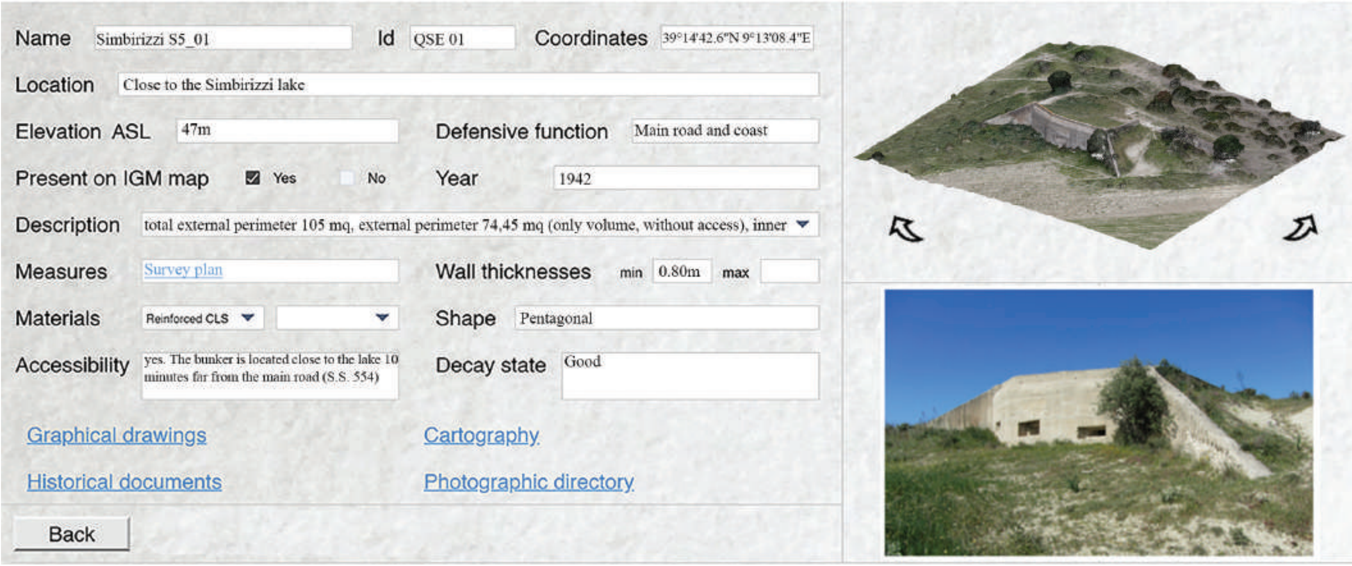

Figure 8. Detail sheet related to one of the bunkers. On the up right the routable 3D model.

and consultation systems. There is also information on the location of the bunker, such as geographical coordinates, a textual description of the location and the altitude above sea level. These are followed by data regarding the defensive function, the year of construction and whether or not it is present in the IGM cartography. In addition, a synthetic description of the artifact is provided for those specific characteristics that are difficult to classify and/or standardize. With regard to the physical dimensions of the object, where possible the classic information of width, depth and height are provided, accompanied by the wall thicknesses; the latter are indicated by a range between a minimum and a maximum. When the articulation of the construction is excessively irregular for it to be possible to describe its dimensions effectively, a link to a survey scheme is provided in place of the dimensions. Finally, among the information provided, the data on the materials used, the identifiable basic shapes, the state of accessibility to the surrounding area and to the bunker itself and the state of conservation of the latter are all included in the sheet. At the end of the sheet, links are proposed to possible additional elaborations, such as the quoted scheme of the surveys, the cartography in which the bunker can be identified, a collection of historical documents relative to the single artifact or to the typology it belongs to, and finally a photographic archive of the materials produced during the survey phase. The information listed is flanked by one of the significant photos shown on the side of the sheet. All the entries in the sheet are extracted directly from the online database through a routine written in Ajax for query execution. For a better understanding of the individual bunkers, it was decided to offer the user the additional possibility to view within the detailed sheet, even the 3D model produced by the photogrammetric survey; the model shown can be both a cloud of points and a mesh model generated directly from the point cloud and can be orbited at will by the user in order to view it in its entirety. For the visualization of the model inside the sheet the library three.js was used; through its loaders, it can manage and visualize numerous formats inside of an iframe opportunely inserted in the structure of the sheet. In this way it has been possible to concur the access to all the present information in the database through a dynamic web page, consultable exclusively through browser and without the use of other software.

4. Conclusion

A deepening of knowledge is certainly necessary for the construction of a database aimed at the recovery and enhancement of the architectural and landscape heritage of the Second World War. But this is not enough to increase the attention of a large audience. The creation of an intuitive portal, and therefore immediately accessible to a wide range of users, can be the key to raising awareness and a new attention to these “stubborn ruins”.

The proposed contribution shows a first application to a restricted area but rich in elements of sure interest, an implementable system easy to consult, whose main potential is given by the use of relatively simple web tools and, now, extremely widespread. If often the dissemination of “uncommon” architectures implies the use of extremely specific informative tools, the present contribution tries to demonstrate how the dissemination and awareness of architectures too often underestimated, can benefit from an articulated but not complex approach, also suitable for users outside the scientific community. Tools such as interactive maps, nowadays commonly used for the most common activities, can also be used as a first approach to targeted issues such as the preservation of defensive architecture of the twentieth century.

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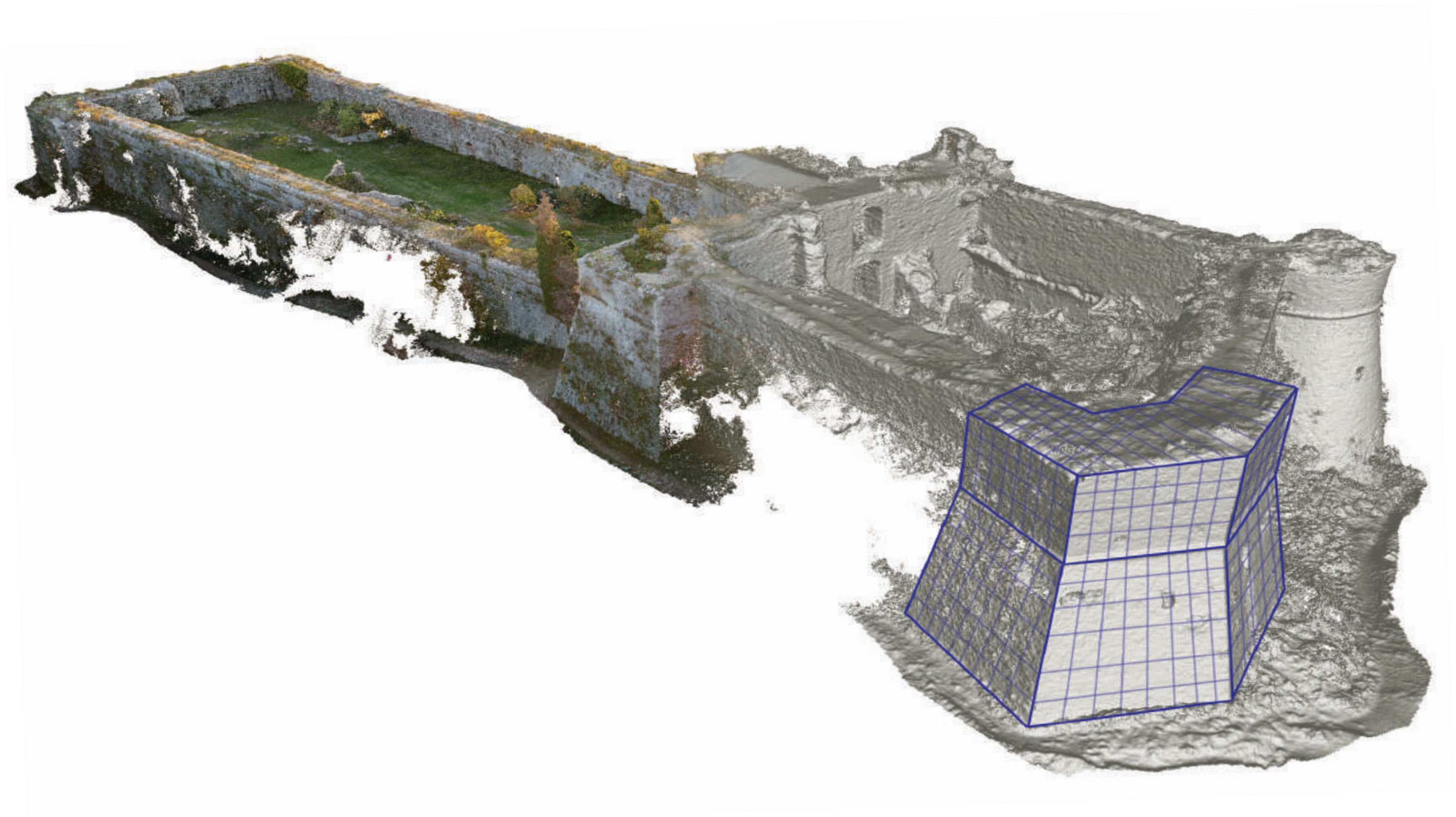

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ABSTRACT

The 3D digital survey techniques are a real advantage for managing the complexity of the architectural heritage, for the UAV tools allow reach places that are difficult to access. Aerial photogrammetry also investigates and models the landscape of which the architecture is an integral part. This paper aims to analyze complex architectures and the landscape in which they are. It describes the first results of the architectural analysis with a geometric/metric algorithm that integrates the UAV cloud point models longitudinal and transverse sections, defining geometric deformations. The procedure is applied to the case study of San Casto castle in Sora, Lazio.

UAVs for the analysis of geometrical deformation of fortresses and castles. The case study of Sora Castle

1. Introduction

Surveying and drawing have always been privileged tools for investigating, knowing, and understanding the architectural and Cultural Heritage. As Migliari stated, "the architectural survey is the reconstruction of the project of the studied work. [...] Survey is a process of knowledge" (Migliari, Roma 1999, p.33). These disciplines are beneficial for understanding the design matrices of ancient and medieval architectural heritage based on the iterated use of recurring geometries. The interpretation of architectural complexity is today even more facilitated by the 3D virtual survey and the modeling technologies that iconically reproduce real objects, restoring a coherent perception of the artifact's raison d'être. SfM photogrammetric procedures, for example, and the use of UAVs are fundamental to document complex architectural systems such as fortresses or castles or any heritage located in difficult and sometimes inaccessible sites and to analyze the close relationship between architectural artifacts and place. SfM technology returns 3D models and digital orthoimages of objects with high precision by processing point clouds and recorded digital images. In particular, shortrange digital photogrammetry offers crucial opportunities, such as automatic orientation and measurement procedures, 3D vector data generation, digital orthoimaging, and digital surface modeling. In addition, the Unmanned Aerial Vehicle (UAV) and Structure from Motion (SfM) algorithms also meet the needs for versatility, effectiveness, and portability required by current analysis standards. Thus, precise documentation, or rather a photograph of state of the art of Cultural Heritage, is essential for its protection and vital for the scientific studies carried out during the restoration process. These new tools can then be used for knowledge and understanding but also to identify and describe degradation phenomena and any structural deformations that reduce the performance of existing structures.

The research aims to develop a systematic study that can serve as a qualitative and partly quantitative method for analyzing the deformation of architectural objects, focusing on the study of the individual components of the building.

The experimentation involved the San Casto Castle located in Sora, a small urban center in southern Lazio. The methodology involved a survey in the geographical region of all existing fortresses (towers or castles), including any linguistic repetitions in the organization of architectural spaces. The interest in this geographical area arises from the presence of numerous fortified architectures, which gave rise to the phenomenon known as the "construction of fortresses." Again, digital GIS technology was of great help. Subsequently, attention was paid to the single selected case study on which the digital surveys were performed, the drone photogrammetric surveys. The articulation of the postprocessing and the identification of the geometric algorithm capable of reading coherences or inconsistencies between the geometric digital model simplified on a theoretical basis and the empirical one, obtained with the acquisition of the state of things, are described in the paragraphs subsequent.

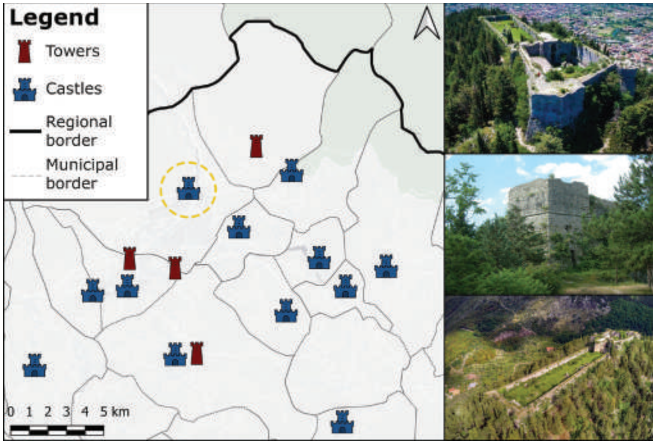

Figure 1. Geolocalization of the castle of San Casto in the database FortLiriGIS. It highlights how the Sorano Castle was a historical fulcrum of a defensive system around which satellite fortresses were articulated.

2. Case Study: The San Casto Castle

This paper focuses on the San Casto castle in Sora, in the region of southern Lazio, created for the control over a geographically significant territory. Rocca Sorella, subsequently transformed into the castle known as San Casto, had a fundamental role in the Duchy of Sora, which constituted a vital fiefdom located on the border between the Kingdom of the Two Sicilies and the Papal State (Beranger, 1981). It represented a critical gate, considered an ingressu regni because it allowed access to the Kingdom of the Two Sicilies (Rosa, 2010, p.19). The hypothetical historical evolution of the fortress is described in three main phases (as shown in figure 3). The architectural layout presents a first early medieval nucleus, most likely surrounded by circular towers; then it had a subsequent extension with the insertion of a keep in the more or less central area of the original core built with more regular masonry, and then bastions arose for the defense against firearms. Enlargements and transformation occurred over time due to violent earthquakes and destructions provoked by the struggles for control over territory. The Sorano castle was also equipped with numerous accessory fortifications,

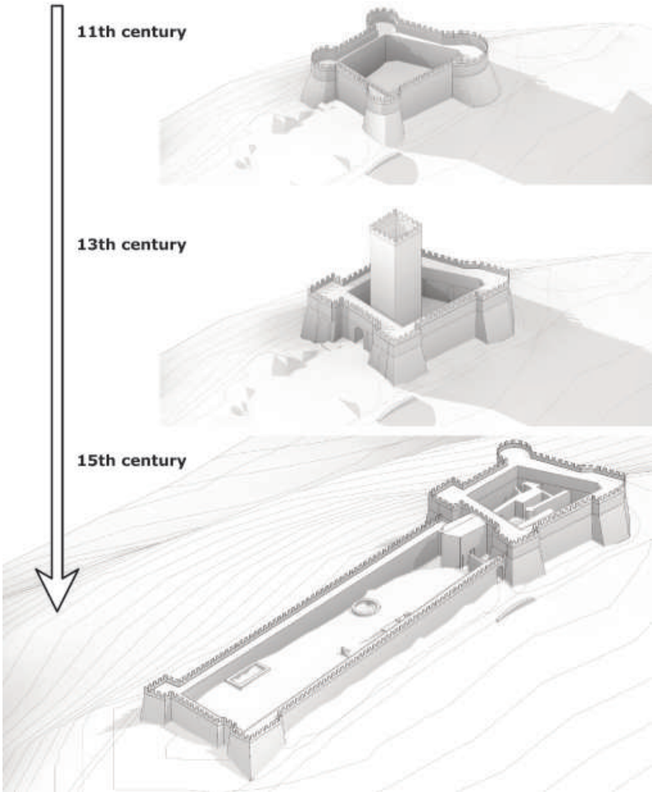

Figure 2. HBIM elaboration by the author. Historical evolution of the San Casto castle, based upon archival and historical research.

being at the top of a defensive system articulated on the mountain and formed over the centuries by various elements such as walls, isolated towers, and ground roughness. In the second half of the fifteenth century, the new buildings for military purposes were arranged to defend the fortress in the pivotal points of the entire hill of San Casto, and many of the existing walls were strengthened and extended. Judging by the remains, they also raised towers along the curtain walls. The defensive measures were accurate and updated to more modern canons of war engineering. The set of fortifications reached its peak in the viceregal period when a complete rationalization of the existing defenses was carried out, including the expansion of the castle.

3. METHODOLOGY

3.1 3D Digital documentation: tools and procedures

A digital photogrammetric survey was performed to reconstruct the geometry of the complex and coherent structure of the castle San Casto. The survey was carried out adopting the capturing scenario technique with the drone DJI Mavic Pro II, taking 581 frames in favorable sunlight conditions to limit shadows and no wind to guarantee at least 50% overlapping of images, using a camera with 12Mpx resolution. The drone has been set up to move at a speed of 2 m/s, taking photos every 2 seconds, in timedshooting mode. It followed two routes, starting at 3 pm till 6 pm on the 20th of November 2021; the flight altitude was 70mt.
The alignment of frames in the post-processing, using the open-source software Meshroom, generates a dense point cloud, subsequently transformed into a textured model. A return cloud point has been created, corrected, layered, and imported into 3D modeling software. Point cloud orientation operations were performed with Autodesk's ReCap Pro software. The subsequent processing phases were dedicated to sampling and rotation with the freeware CloudCompare software of the point clouds. The sampling process allows obtaining a regular distribution of the cloud points by removing redundant or superabundant points. The last phase of the elaboration process is dedicated to converting the point clouds into formats that allow their visualization and manipulation in the software used for the 3D drawing and modeling operations.

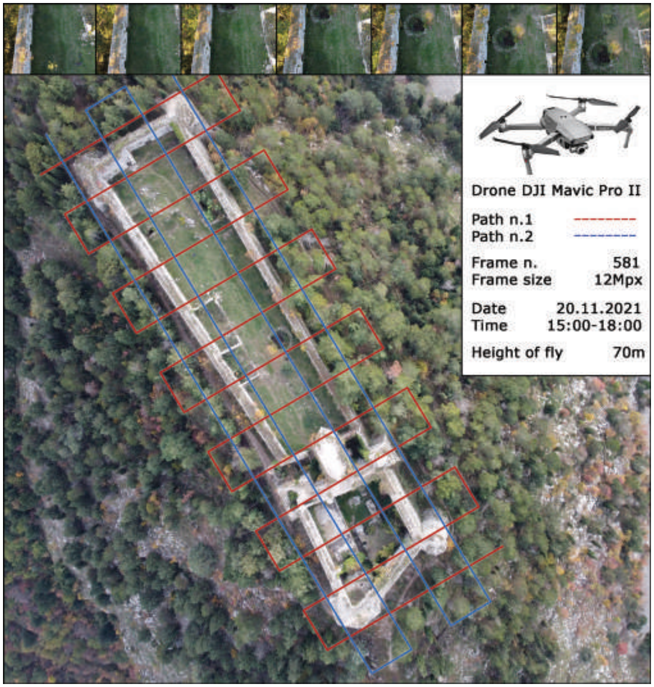

Figure 3. Project of the survey conducted on the case study San Casto Castle and flight technical data.

3.2. Elaboration of the theoretical model based on the digital reconstruction

The accurate digital reconstruction allowed the development of a 3D digital model, geometrically corresponding to the empirical one. Then it was possible to identify and isolate the different towers of the castle, defining the geometry for each type and creating a theoretical model to which they can refer (the circular tower, square and polygonal one).

3.3. Geometric algorithm for the comparison of theoretical and empirical digital models

The definition of a geometrical-mathematical-based model, elaborated after the digital reconstruction, constitutes a more precise reference for analyzing deformations occurring on the towers. This paper shows the procedure applied to the one circular tower remaining in the San Casto castle. The procedure consists of two stages. The first step concerns the 3D digital modeling of the architectural components of the building, which returns their most probable geometry based on the most recurrent architectural typologies

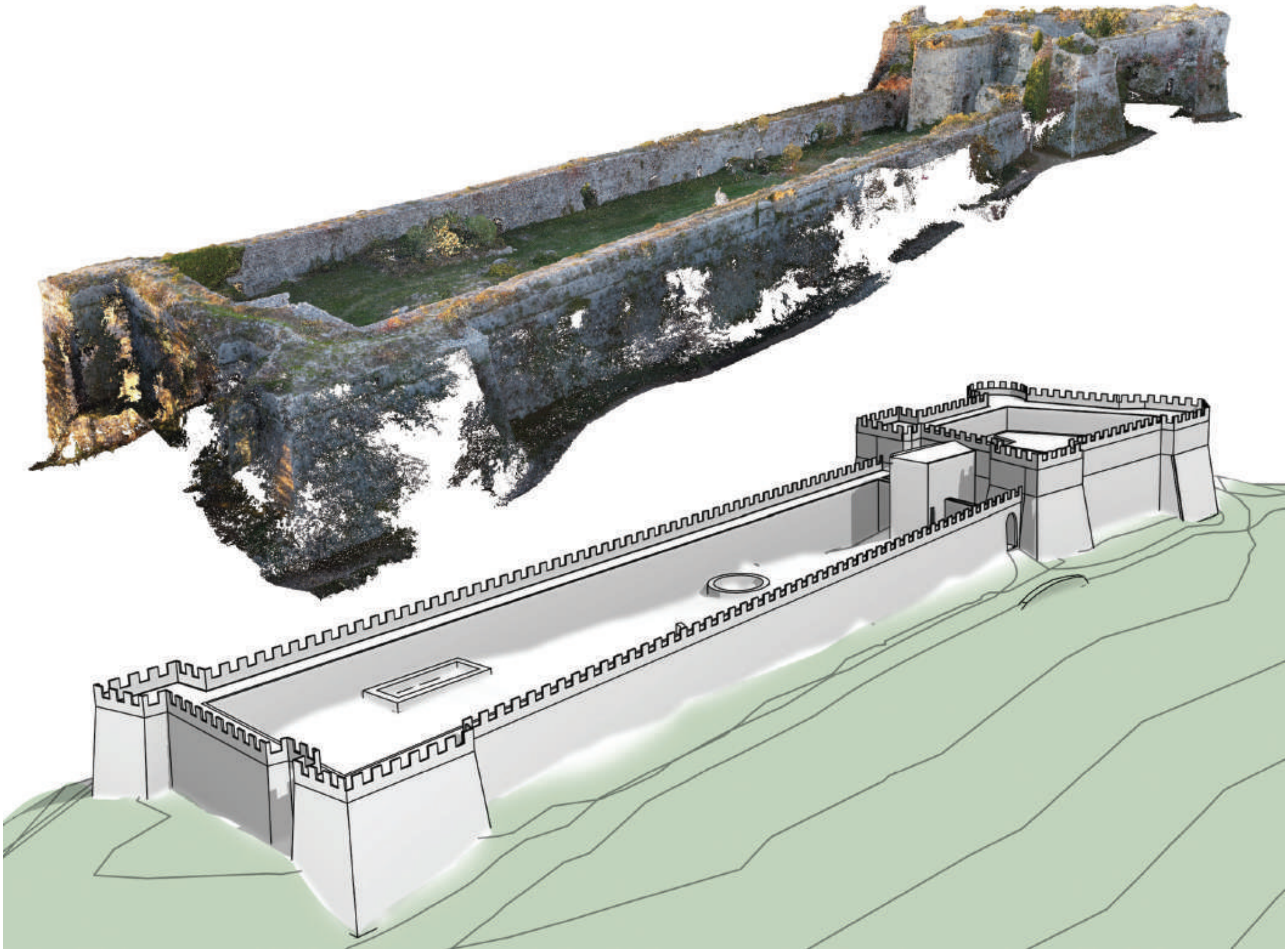

Figure 4. Elaboration of the HBIM model based on the digital reconstruction.

of the time. Based on the digital survey, the second phase models the state of the art, returning the actual geometry, which could contain any discrepancies to the geometric/theoretical model.
The crosssections and longitudinal sections were performed on the geometric model and then on the point cloud with the free Cloud software to understand the reliability of the theoretical model. Sections with a span of 2 m were obtained according to the size of the masonry blocks. Furthermore, the choice of the distance between two consecutive sections is also determined by the awareness that it is the minimum dimension in which any deformation of the legible element of the wall occurs. The shape of the different sections was reported and analyzed, on the same reference system allowing the comparison of the

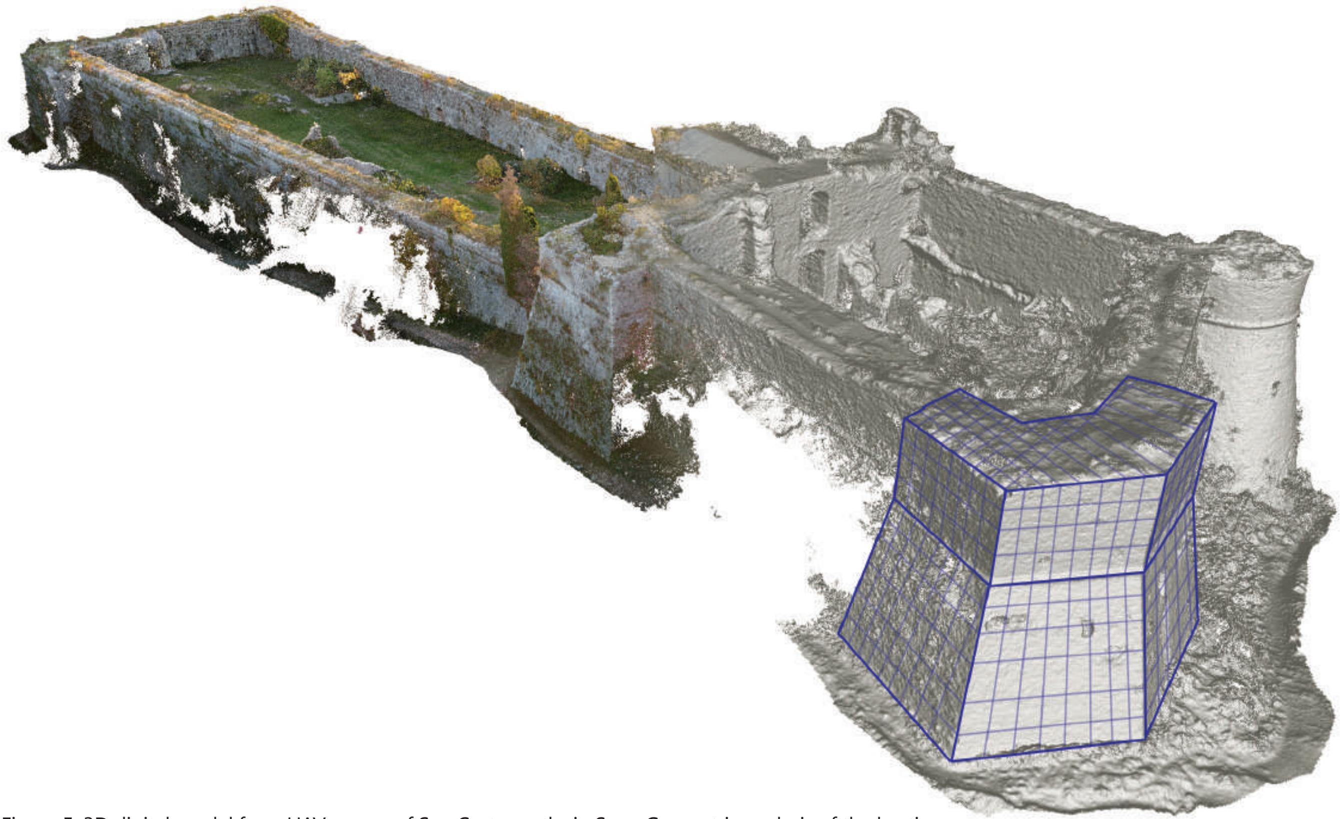

Figure 5. 3D digital model from UAV survey of San Casto castle, in Sora. Geometric analysis of the bastion.

tower's two models, theoretical and empirical. The overlapping makes it possible to subtract the area of the theoretical section from that of the empirical one, to indicate the deformation of the element. Figure 7 shows that the deformation is a typical tendency of the cylindrical structures, called "ovalization," giving a qualitative analysis of the deformation.

4. Conclusion

SfM technologies are of great help in enhancing the existing building heritage and in the increasingly accurate and complex analyses required by the current time. In this paper, the author tested a procedure based on digital photogrammetry from drones to verify the reliability of the geometric virtual models obtained with traditional processes and defined as theoretical because they are based on a simplified 3D reconstruction of the real object. The procedure, divided into two phases, through the use of a geometric algorithm, compares the theoretical model with the empirical model obtained from the digital photogrammetric survey.

This procedure allows us to appreciate any deviations between the two geometries and intercept any structural deformations. The identified procedure is relatively fast, inexpensive, and requires limited manual processing. Future developments concern the

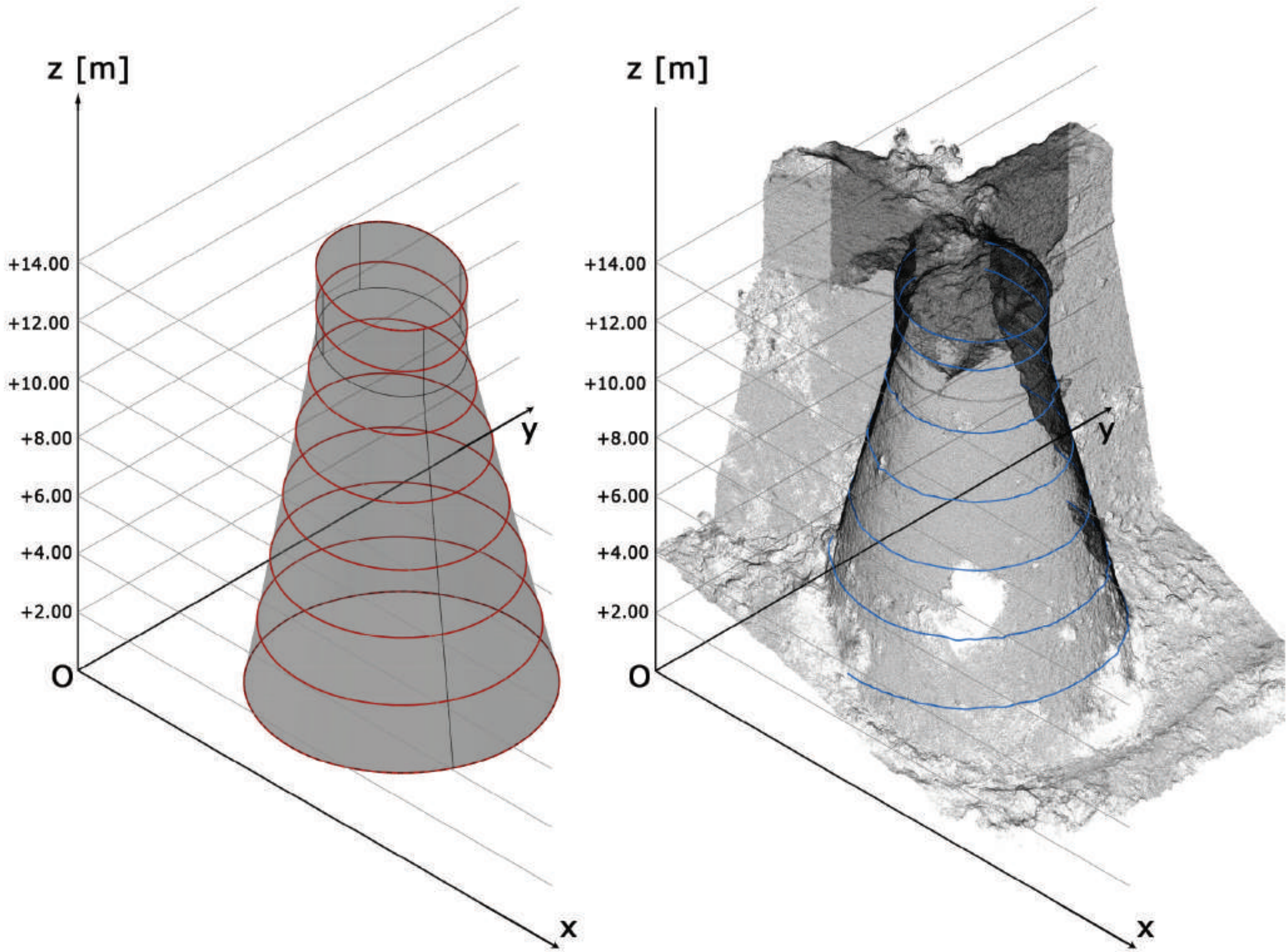

Figure 6. Geometric model and empirical model: Cross-sections in the XY plane with a span of 2 mt.

possibility of verifying, with the same methodology, any structural deformations with the insertion of fixed points on the building organism, iterating the procedure over time and experimenting with it both on the castle of San Casto and in other fortified structures of the apparatus, the defensive system of southern Lazio.

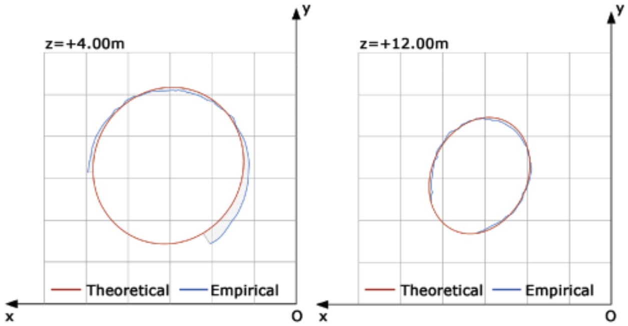

Figure 7. Comparison of the theoretic and empirical sections: deformation analysis.

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UAV survey, Cultural Dissemination, 3D virtual reconstruction, Archaeological site.

ABSTRACT

The object of the present research is Euryalus Castle in Syracuse. The complexity of the archaeo-logical site has led to a methodological approach based on the use of integrated surveying tech-niques and on their combination for the modeling of significant cultural sites with UAV applications. Site surveying and the critical analysis of historical sources aimed at the construction of a virtual geometric model which makes it possible to distinguish the on-site archaeological remains from what has been lost becoming an absence.

UAS applications for the protection of archaeological heritage. From the interpretative complexity of absence to 3D visualization of Euryalus castle

1. Introduction

The protection of Cultural Heritage represents one of the objectives and at the same time one of the biggest challenges of our time. In particular, the implementation of digital technologies for the representation and interpretation of Cultural Heritage contributes to its protection and access. Nowadays, the scientific community considers digital technology a key driving force for the development of new paradigms for Cultural Heritage understanding (Clini et al. 2021), anyway, its application to Cultural Heritage is a constantly evolving branch of research in an ongoing validation process.

This digital transition involves the implementation of methodologies aimed at Cultural Heritage virtual reconstruction with the creation of 3D models which adopt scientific replicable approaches. During 3D modeling procedures the consolidated system of data acquisition from laser scanning technology has been supported and, in some cases, even surpassed by terrestrial and aerial photogrammetry. More specifically, UAS (Unmanned Aerial System) based photogrammetry allows fast and accurate mapping of Cultural Heritage (Valenti et al. 2021).

Its application to large and complex archaeological sites is a very interesting field of research which enables the processing and restitution of visually high-quality products. The present study[1] focuses on the implementation of different survey methodologies and their combination for the modeling of significant cultural sites applying UAV technology to the case study of Euryalus Castle in Syracuse (Figure 1).

Such a vast archaeological context and its morphology cause problems due to the difficulty of unitary perception and access to disabled visitors. The purpose of the study is to develop a methodological scenario implementing the appropriate instruments of the ongoing digital transition along with the advancement of representation technology according to a scientifically valid process. The present study has a dual purpose: the methodological and visual points of view. Firstly, the research presents a survey operational area implementing integrated techniques focusing on data acquisition from different UAVs. The aim of these operations is the construction of a 3D model of the surviving archaeological site as a further instrument of knowledge and as Cultural Heritage on its own easily accessible to a larger audience.

Figure 1. The archaeological site of Euryalus Castle.

Figure 2. Point cloud from TLS and scan station position.

Secondly, the research deals with the topic of reconstruction giving shape to the "absent structure" of Euryalus Castle through an accurate revision of historical sources and of previous studies. 3D reconstruction aims at helping researchers and users to conceptualize the historical building as a whole, including the missing parts obtained from the dialogue between the surveyed area and the assumptions made by scholars such as Francesco Saverio Cavallari (1810-1896) and Luigi Mauceri (1850-1940).

2. Related work

The Digital Era or Information Age has radically changed the way people communicate bringing a great turnover on the field of Cultural Heritage as well. Virtual representation and 3D digital reconstruction of monuments and archaeological sites are extremely important for the protection and access to Cultural Heritage allowing the spread of information for tourist and scientific purposes.

In this context, there have been significant developments in Humanities Computing or Digital Humanities (Scianna et al. 2020), a computer-based field of study, research, teaching with computing applications in all areas of research, analysis and dissemination of knowledge. The applications of computer-based methodologies, languages and instruments to Humanities, including archaeology, involve fields of study such as digital communication, protection and enhancement of Cultural Heritage. In particular, the applications of innovative 3D data acquisition technology to archaeology allows 3D exploration of archaeological sites and the restitution of detailed digital models (Campana et al. 2014; Ippolito 2015; Monego et al. 2019; Cannella 2021).

The already existing TLS 3D data acquisition systems (Terrestrial Laser Scanners) are supported by automatic digital photogrammetry based on Structure from Motion (SfM) algorithms for a fast virtual model reconstruction from a set of photos. Recently, innovative UAS systems are increasingly implemented for the acquisition of aerial, nadir and oblique, imagery improving the applications of automatic digital photogrammetry to a wide range of complex sites and architecture (Achille et al. 2015; Waagen 2019; Arza-Garcìa et al. 2019; Demetrescu et al. 2020; Anastasios et al. 2021).

SfM and TLS are different strategies which are being combined and exploited for survey operations because correct 3D data acquisition is fundamental for the construction of virtual environments. Even if it is a relatively young discipline, virtual reconstruction is, at the same time, a scientific instrument for the expert users, extending the approach towards the recording

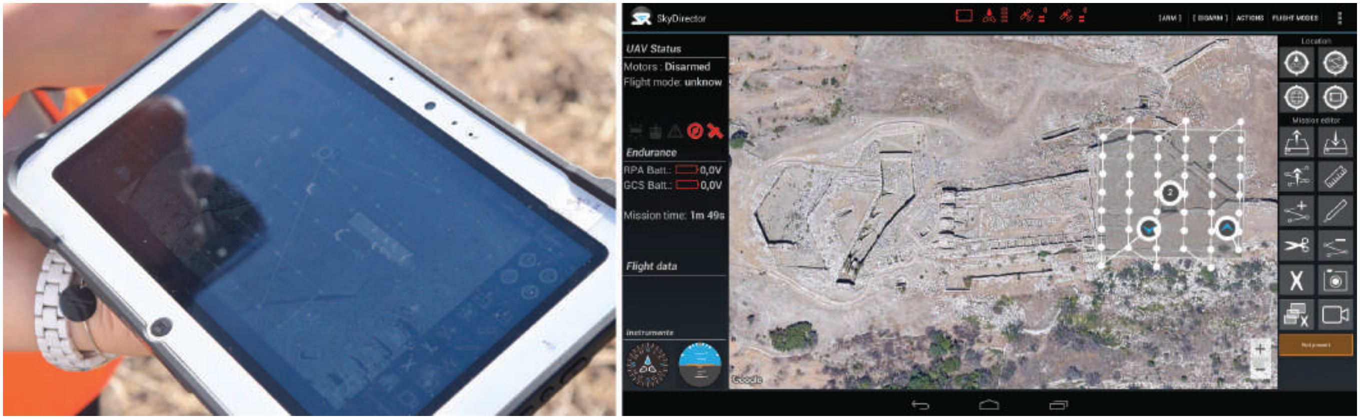

Figure 3. Survey operations with SkyRobotic SR- SF6 Hexacopter.

and managing of a great amount of data useful for future researches and as a dissemination tool designed to promote awareness among non- expert users.

3. 3D SURVEY

The present study adopts a combined record acquisition methodology which exploits survey potential through terrestrial laser scanning and UAV photogrammetry.
Obtaining point cloud restitution of complex environment with a good range of geometric accuracy represents a strong point for these technologies. Data acquisition campaign was carried out in two different moments. Firstly, the study concentrated on the analysis of the northern sector of the castle (Valenti et al. 2020) surveyed with Leica ScanStation C10[2]. More specifically, 6 scans were taken and automatically combined with the recording of 6 targets. Scan resolution was 0,006m at a distance of 10m (Figure 2).
Secondly, the study included the whole archaeological site. Therefore, it was not necessary to integrate the previous survey with UAV photogrammetric survey able to reduce acquisition time and to allow the restitution of a detailed 3D model. These devices are widespread in archaeology being versatile and cheap for the surveying of wide areas and for the collection of accurate spatial records. Unmanned Aircraft Systems can be employed in high-risk situations and can reach inaccessible areas. Moreover, UAV data not only improve acquisition time and mapping accuracy also their processing provides 3D models which give information about geometric features, materials and about the monitoring of Cultural Heritage. In particular, two drones were used, the SkyRobotic SR- SF6 Hexacopter for the acquisition of nadir imagery (Figure 3) and the DJI Spark quadcopter for the acquisition of closer oblique imagery.
The hexacopter was equipped with a Sony 20.2 MP digital camera. Flight plans were filed in laboratory assuming a 5-10 min period each with a 65% setting of the overlap and sidelap of the photos (Figure 4).

Figure 4. Flight plans of the area of interest.

Also, in order to obtain a distance lower than 1cm from the GDS (Ground Sample Distance) the flight altitude was set to 30m.

The second drone was used for the acquisition of oblique imagery at a closer distance and in particular several flights were conducted in manual mode and photos were shot every 2-3sec to guarantee an optimal image overlapping. The average flight altitude was set to 10m.

4. Post-processing and digitization

Survey operations provided the restitution of three different dense point clouds, the first obtained from TLS surveying, the second obtained from the photogrammetric reconstruction of nadir imagery acquired from UAVs and the third one obtained from the photogrammetric reconstruction of oblique imagery acquired from UAVs.

Data imported from terrestrial laser scanning have been processed with Cyclone software while data imported from drone have been separately processed, with 3DF Zephyr.

Zephyr has been also used to merge all dense point clouds. More specifically, the dense point cloud acquired from TLS surveying was imported as .pts file into 3DF Zephyr environment and other two dense point clouds have been aligned with the previous one. It was necessary to generate a first coarse alignment and then after manually detecting 4 GCPs (Ground Control Points) it was possible to register the control points defining as a static object the point cloud generated from TLS and as mobile objects the other two-point clouds. The introduction of GCPs before the construction of the polygonal model is extremely important when operating with different sensors and platforms. Any SfM software requires at least 3GCPs to achieve resizing, rotation and position of the model. The last steps of the procedure dealt with the generation of a mesh from the point cloud and the creation of texture files which, combined, defined the appearance of the final model (Figure 5). The proposed multi-sensor approach provides the construction of 3D photorealistic models able to investigate, manage and analyze shape and dimension of represented objects in terms of accuracy and resolution.

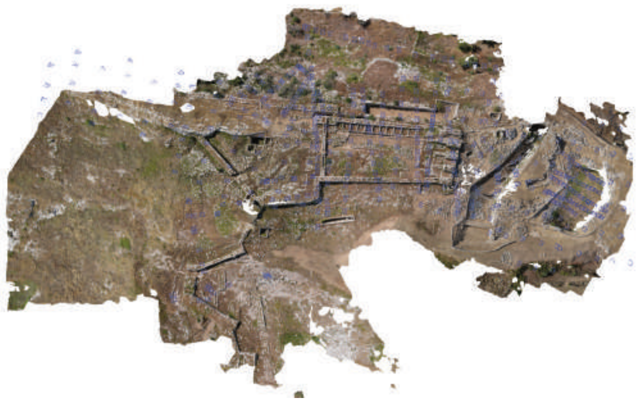

Figure 5. Mesh model with camera position.

5. Euryalus castle: comparison between Cavallari's and Mauceri's sources

Euryalus Castle, established by the great tyrant of Syracuse, Dionysius I, together with the fortification of the same name, to protect the city from land and sea sieges, goes back to 4th century b.C. and in the course of time has been adapted and transformed according to the different demands. From 19th century until the first decades of 1900s the castle has been the object of different researches and archaeological excavations conducted by Francesco Saverio Cavallari, Paolo Orsi and Luigi Mauceri who provided lots of information useful for its constructive analysis.The bibliography used in preparing the present research is represented by Francesco Saverio Cavallari's, Adolf Holm's[3] and L. Mauceri's[4] writings, in particular Mauceri's, where the authors conducted a careful survey to describe each single part of the Castle reporting specific features with the publication of dimension tables. The instrumental and photogrammetric survey, the 3D model constructed by the Laboratory of Representation of SDS, Syracuse (University of Catania) gave the possibility to compare F.S. Cavallari's and A. Holm's planimetric restitution (Figure 6, Table X) and L. Mauceri's (Figure 7, Table I), from 1883 and 1928 respectively, which present

Figure 6. Plan of the Euryalus Castle made by F.S. Cavallari.

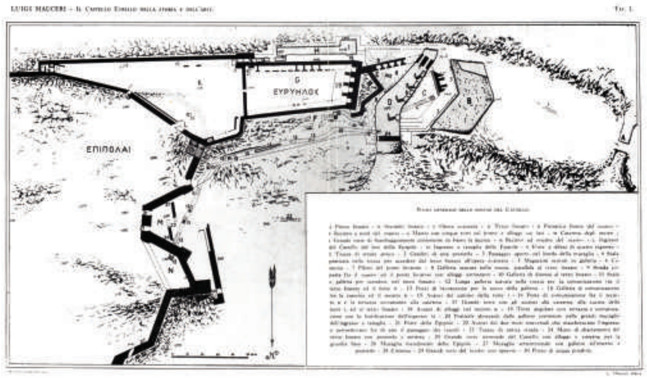

Figure 7. Plan of the Euryalus Castle made by L. Mauceri.

some differences and incongruities also with reference to the status quo. The fundamental differences deal with the area where the pincer fortifications are located. Not only there is a difference about the thickness of the walls and their angles, also, at the back of the entrance there are parallel protective walls, not indicated in Cavallari's text, which were used to conceal the near posterns.What is also missing in Cavallari's planimetry is any trace of the old tower going back to the period earlier than the construction of the five towers.

This is probably due to the fact that the area has been brought to light only in the early 1900s, as Paolo Orsi's writings confirm[5].

However, there are some clear elements which Cavallari drew in plan, not included in Mauceri, dealing with other structures close to the already mentioned fortifications, which Cavallari assumed as extensions of the cranked fortification (Figure 8 letter a) connected with the frontal wall.

The missing correspondences, for example, are clearly illustrated in Figure 8 where the perimeter colored in blue mark the parts present in Cavallari's plan but not in Mauceri's, vice versa is meant for the red parts.

Studying the sources has been extremely important to understand the historical and cultural context where the castle was built and to understand the phases and transformations it has undergone in the course of time to be adapted to the present techniques and military strategies.

6. A 3D THEMATIC MODEL ABOUT LUIGI MAUCERI'S CONJECTURAL HYPOTHESIS

The carried-out observations have brought out the creation of a thematic model of the Castle (Figure 9) which was made starting from the 3D model of the existing situation generated from the point cloud with reference to the conjectural reconstruction proposed by Luigi Mauceri (Figure 10, Table II) and to the drawing particulars assumed for the tower front (Figure 11, Mauceri, 1939 p.55).

This phase dealt with the metric comparison of the different portions of the castle between the 3D model in full scale and the 2D drawings in planimetry and in the section of the central courtyard of the castle in order to analyze and determine the correspondences between the two surveys. Moreover, after an accurate observation of the 3D model of the castle, some incongruities arose about Luigi Mauceri's hypothesis as, at present, there are traces neither of towers nor of fortifications. So, three different themes have been considered about the model which can enable a better interpretation of the conducted study.The first theme deals with the parts of the castle corresponding to the status quo and to Mauceri's

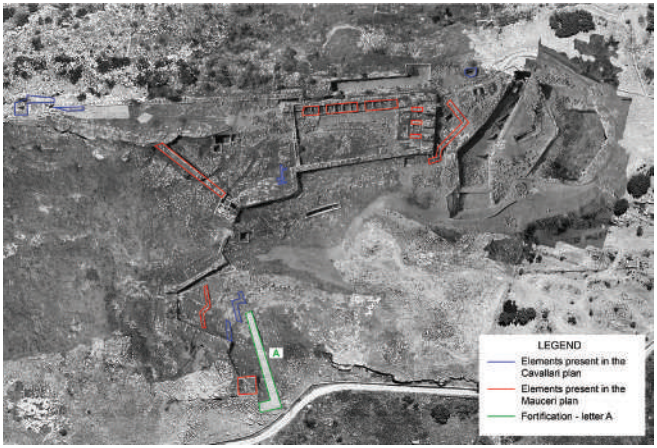

Figure 8. Orthophoto of the castle highlighting the discordant elements between the Cavallari and Mauceri plans.

reconstruction (visible in grey); the second category highlights the portions which have been hypothesized and whose correspondence or trace cannot be found, in particular, the towers flanked by the wall enclosing the third moat (visible in red); finally, the third theme refers to the very few, but perfectly clear, elements present in the situation as it is, not marked in Mauceri's planimetry. The research, supported by instrumental survey, can be considered a first step towards a new historical investigation and towards a critical interpretation taking into account all the tangible surviving elements and at the same time a possibility of digital enhancement of the stunning and immense Cultural Heritage.

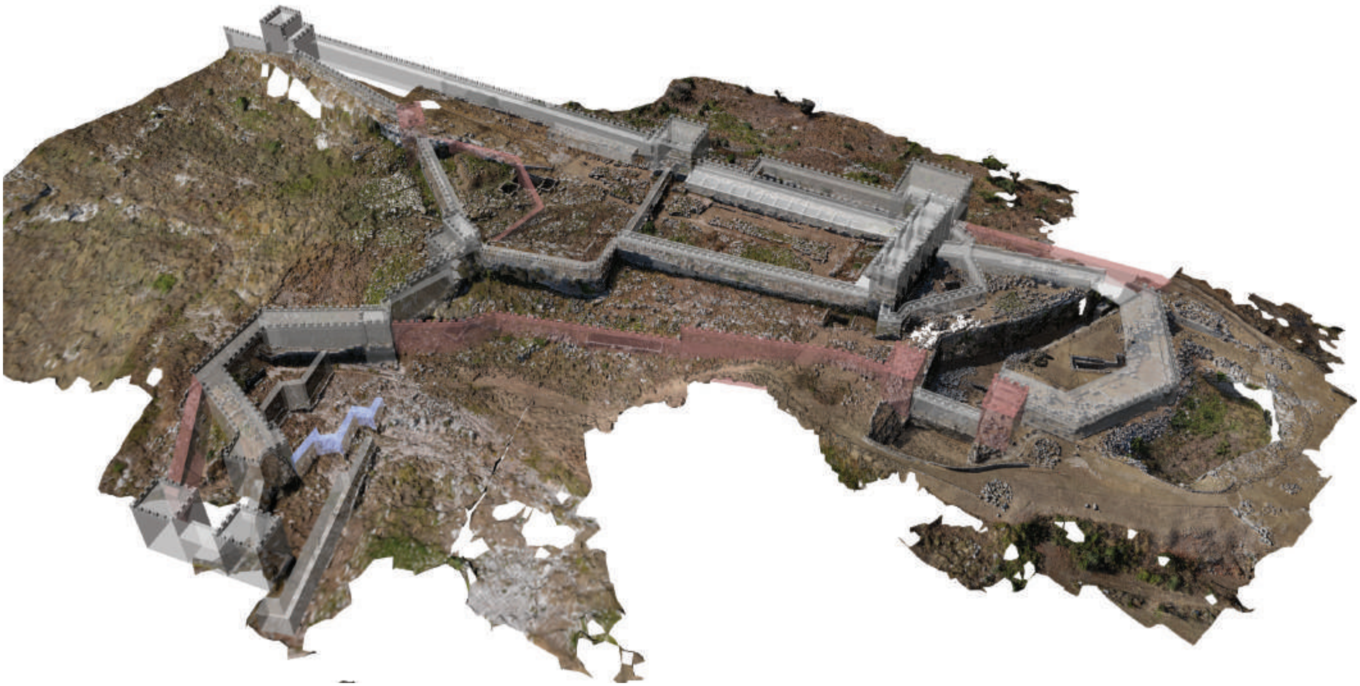

Figure 9. Thematic model created on the basis of instrumental and photogrammetric survey and bibli-ographic sources.

7. Results and conclusions

The conducted research can be summarized in three main phases: data acquisition, data processing, virtual reconstruction (Figure 12).

In the first phase bibliographic research was integrated with information acquired from survey operations carried out on site. In the second phase data were processed creating a photorealistic polygonal model. Starting from there it was possible, then, to make some hypotheses which enabled the creation of a virtual geometric model where it is possible to distinguish what is still existing and what is definitely lost.

The thematic model allows the syncretic visualization of historical evidence coming from previous surveying and appears as a visual instrument of the detected anomalies. The experimentation connected with the present study outlines an operative workflow which could represent a new strategy aiming at the development of knowledge and dissemination of Cultural Heritage. The purpose is to promote virtual tours of Cultural Heritage still existing in the form of ruins and to appreciate what is still visible and at the same time to visualize the complexity of an absence through the suggestion of a reconstructive hypothesis, offering everybody a complete and complex perception of a structure extended over a vast area.

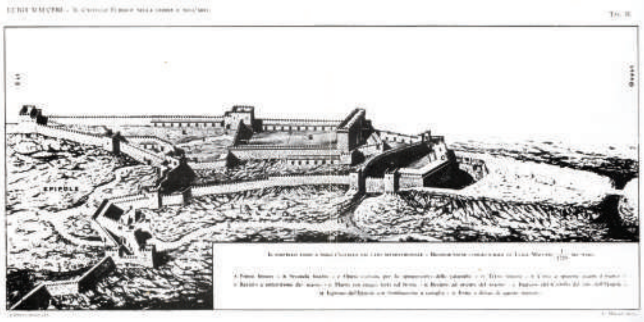

Figure 10. Conjectural reconstruction hypothesized by L. Mauceri.

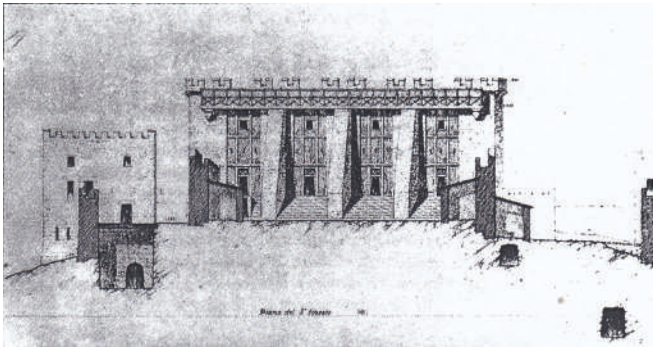

Figure 11. Section corresponding to the central courtyard of the castle with a view of the internal front composed of the five towers, designed by L. Mauceri.

Notes

1 Authors would like to thank Lieutenant Colonel A.A.r.a.n. M. Fanciulli and Inspector R. Cosentino for their authorization to fly over the concerned area; the Parco Archeologico of Neapolis in Siracusa represented by Director Architect C. Staffile and Dr. A. Musumeci for their authorization. Translation by Dr. M. Granca-gnolo. The study conducted within the research program named "Visibile e Invisibile: percorsi interdiscipli-nari per una fruibilità diffusa dei beni Museali. Ricerca-Azione per una didattica inclusiva" (University re-search PIA.CE.RI 2020-2022) is the result of the collaboration between the two authors. In particular, R. Valenti wrote the following paragraphs Introduction, Results and conclusions; E. Paternò wrote the para-graphs Related work, 3D Survey, Post-processing and digitization; G. Cusmano wrote the paragraphs Eu-ryalus castle: comparison between cavallari's and mauceri's sources, A 3D thematic model about Luigi Mauceri's conjectural hypothesis.

2 Scanning provides 3D coordinates for each point on the surface of the object with the measurement of 2 angles (azimuth and zenith angles) and distance. This value can be obtained with the Time-of-Flight principle (ToF) measuring the distance on the time taken by the laser signal (with an infrared wavelength) to travel the double trip from the device to the object.

3 Cavallari F.S., Holm A. with the collaboration of engineer Cavallari C. (1883). Topografia archeologica di Siracusa. eseguita per ordine del Ministero della pubblica istruzione. Palermo: Tipografia del Giornale «Lo Statuto»; Cavallari F. S. (1893). Euryalos e le opere di difesa di Siracusa con talune annotazioni sulla popolazione della Sicilia: seconda appendice alla topografia archeologica di Siracusa. Palermo: Tipografia Filippo Barbavecchia e figlio.

4 Mauceri, L. (1939). Il castello Eurialo nella storia e nell'arte, Ristampa della II edizione (1993), Catania: Edizioni Dafni.

5 Orsi P. (1904). Le notizie dagli scavi di antichità. Roma: Tipografia della R. Accademia dei Lincei.

Figure 12. Virtual reconstruction of the castle with photo insertion in the real context.

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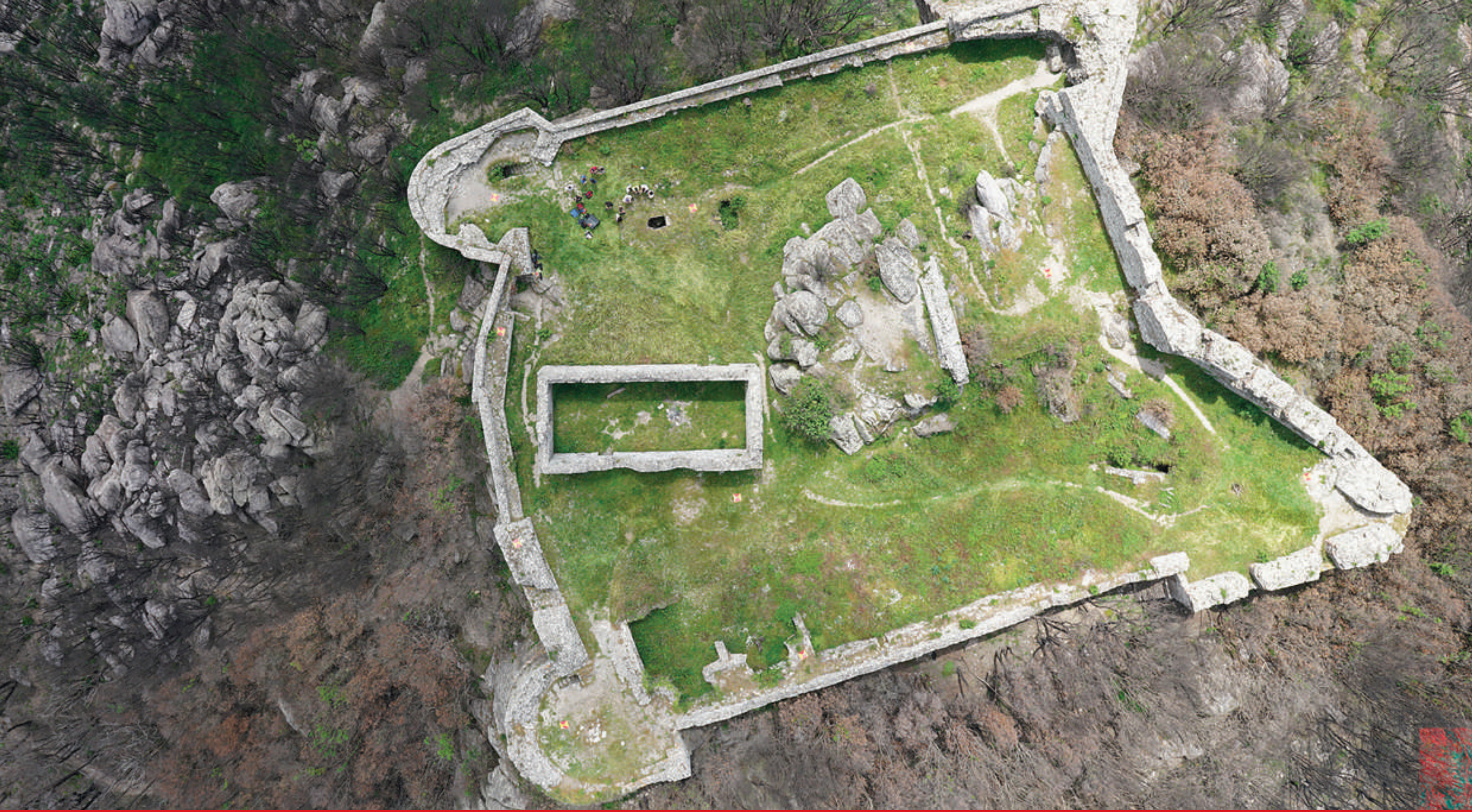

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UAV, photogrammetry, data reliability, point cloud, Verruca fortress.

ABSTRACT

The paper describes the digital survey project of the Verruca fortress, which is located on the summit of Monte Serra, in the Pisan mountains. Today the fortress is in a state of ruin, and recently a summer fire caused the loss of the vegetation that had massified around the building, thus allowing to program the analysis of the walls of the fortress to deepen its construction history and state of material and structural conservation.

the fortress survey project integrates range based, image based and UAV technologies, focusing attention on the methodologies used to ensure the high morphological reliability of the data obtained from the survey, in a very complex area to reach.

The results of the survey made it possible to reconstruct a whole series of graphical drawings that made it possible to deepen the architectural and historical analyzes on the fortress.

The aerial photogrammetric survey for the documentation of the Cultural Heritage: the Verruca fortress on the Pisan Mountains

1. Introduction

The paper describes the digital survey project of the Verruca fortress, which integrates range-based, image-based and UAV technologies, focusing attention on the methodologies used to ensure the high morphological reliability of the data obtained from the survey in an area that is very difficult to reach. (Figure 0)

The fortress is located on the summit of Mount Serra, in the Pisan mountains with the aim of controlling the valley of the Arno river, near its outlet to the sea. It was built by the Pisans in the 10th century and has always been considered of great strategic importance for the maintenance of power (Francovich, Gelichi 2003). Florence and Pisa in the 15th century fought over the possessions and strategic points on the Pisan mountains for a long time until the fortress was definitively taken in 1503, the year in which it was visited by the great Florentine military architects, Sangallo and Leonardo, at the behest of Machiavelli (Pedretti 1972); immediately afterwards the defenses are modernized, in such a way as to be able to defend itself from the shooting of firearms. A few years, due to the loss of strategic importance of these lookout points, the fortress was slowly abandoned. Today it is in a state of ruin, and recently a summer fire caused the loss of the vegetation that had massified around the building, thus allowing to program the analysis of the walls of the fortress to deepen its construction history and state of material and structural conservation. (Figure 1)

In May 2019, a collaboration began between the municipality of Vicopisano, on which part of the fortress property stands, and the Department of Architecture of the University of Florence to carry out the architectural surveys of the fortification; the fortress survey project involved the experimental use of the most up-to-date laser scanner, drone and GPS digital survey tools, to create a highly reliable digital model; the fortress had already been partially surveyed in the past finding great difficulties in measuring the external parts, along the steep slopes, where it is possible to see how the building rests directly on the rocks that characterize the Serra mountain and make it derive its name. The 3d models deriving from laser scanner survey and drone photogrammetry have been joined together in a single highly reliable textured model. To ensure the reliability of the digital models reconstructed with the different acquisition techniques, particular attention was paid to the comparison between the morphologies of the point clouds obtained and to the simultaneous verification

Figure 1. View of the mountain top from the remains of the nearby convent of San Michele alla Verruca.

of significant points measured both in local and geo-referenced coordinates; to ensure the reliability of the individual models, it was also necessary to pay attention to the data registration phase.
The results of the survey made it possible to reconstruct two-dimensional and three-dimensional graphs that allowed to deepen the architectural and historical analyzes of the fortress; it raises a lot of interest in the study of the evolution of fortresses at the end of the 15th century and in the activity as a military architect both by Sangallo and by Leonardo da Vinci.

2. Architectural survey

The position of the Verruca fortress does not present optimal conditions to be able to plan the measurement operations: the survey of the areas inside the walls is not so complex, as the outside, which is arranged on a steep slope with thick vegetation that does not facilitate the passage of operators, instruments and measurements. Despite this, some instrumental surveys have been carried out in recent decades, which did not however allow the detailed description of the walls, and presented some approximations as regards the morphologically more complex parts of the structures: the need for a detailed survey to interpret, following a scientific method, the state of conservation and the evolution of the building led to the design of a more modern and accurate survey campaign.
The recent arson attacks, which hit the top of Mount Verruca, have at the same time partly favored the design and implementation of new measurement campaigns, adopting in this case digital data acquisition systems. In particular, three different acquisition campaigns were carried out:

- laser scanner equipment to create a model that describes the morphology of the building in detail;
- SfM photographic acquisitions from the ground to create three-dimensional models that describe the materiality of the walls;
- aerial photogrammetry with the use of drones, to create a mapped model of the whole complex.

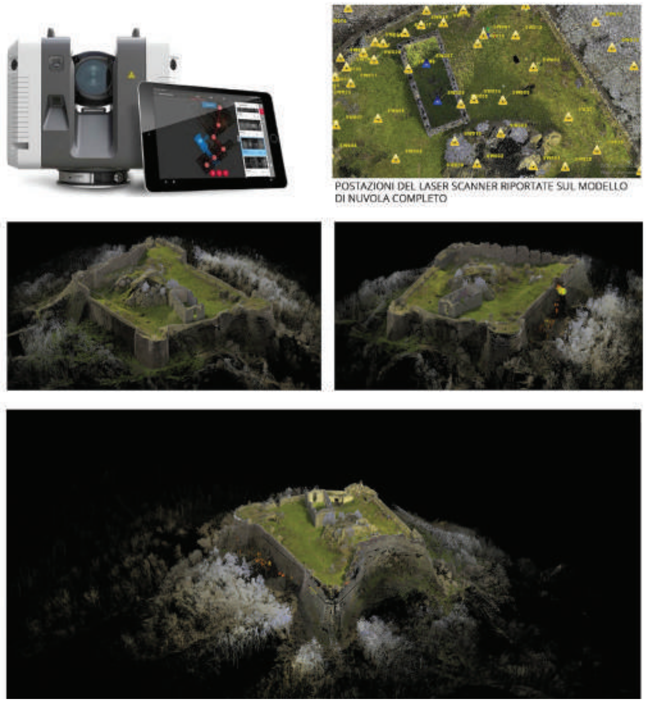

Figure 2. Range-based survey methodologies, used for the reconstruction of the fortress.

In this article we will not go into the acquisition methodology used for each acquisition campaign, which will be further explored elsewhere, but in particular we will deal with the photogrammetric survey from drone and the integration with the other acquisition systems.

3. Methodologies

The laser scanner survey of the Verruca fortress was designed to describe all the surfaces of the architecture with a definition that would allow the graphic rendering of the drawings necessary for the preparation of the diagnostic investigations (Bigongiari, Pancani 2020).
The scans were carried out with the Leica RTC360 instrument, whose characteristics allowed the rapid completion of highly reliable measurements: the scanner

Figure 3. Image based and UAV survey methodologies, used for the reconstruction of the fortress.

in fact is able to measure over two million points per second, creating hd panoramic photographs; the 5 cameras positioned on the edges of the instrument also allow the recognition of the scene in which the scanner is located and its movements, allowing the alignment of the scans directly on the field. The result of the acquisitions produced a point-cloud in local coordinates resulting from the alignment of 145 scans. (Figure 2)

The 3d photogrammetric survey was carried out with the main purpose of producing rectified images of the architectural surfaces to be used for diagnostic investigations; to obtain this result it was useful to combine acquisitions from the ground with the acquisitions obtained from drone flights to solve some problems.

The photographic survey of the Verruca was particularly complex due to a series of environmental conditions that made shooting difficult: the greatest difficulties were encountered along the outer perimeter of the fortification, which, being on the top of a particularly rocky mountain, did not allow move easily around it to build a three-dimensional model; moreover, the vegetation around it, even if not particularly luxuriant after the fires, forced constant movements and changes of framing and definition on the wall surfaces, as well as causing considerable differences in lighting due to the filtering of light through branches and trunks. Beyond this, in some areas it was impossible to resume the wall texture due to the degradation caused by spontaneous vegetation.
The photographic shooting campaigns were therefore organized to solve these difficulties and to obtain a textured model that could describe the surfaces with a definition at least on a 1:50 scale.
In choosing the correct instrumentation to use for shooting, the condition of poor lighting was considered, which causes dazzling points of light where the sun's rays enter. For this reason, it was necessary to provide for the use of tools that were able to create high quality frames despite the light present being significantly unfavorable for photographic shooting. A full frame Sony A 7R II camera (42.4 MP CMOS sensor) mirrorless was used, in order to guarantee a high level of definition, which was able to describe the walls in its details, and a frame of good quality at the level of exposure: this camera is able to return high quality frames even by setting a rather high sensitivity, in such a way as to encourage shooting without a tripod; the same camera body was mounted for drone shooting, on the Leica Aibot AX20 model. (Figure 3)

Figure 4. Three-dimensional model after the reconstruction integrated by laser scanner and photogrammetry.

To best reconstruct the surfaces of the fortress, it was decided to shoot frames following three levels of investigation: a first from the ground moving around the object at close range, a second plane shooting zenith images, a third still aerial but tilting the camera to shoot at best the elevations.

Each of these photographic sequences, shooting objects from different distances, required the use of lenses with different focal lengths. For the first sequence, from the ground, a Sony FE 28mm f / 2 28mm was used, ideal for moving around objects even at close distances, less than 2 meters: with this lens all the external and internal surfaces of the fortification were acquired. A Sony Zeiss Sonnar T * FE 55mm f1.8 ZA 50mm was used for the second and third sequence, rotating around the fortress at a more or less fixed distance.

The choice of the focal length was based on the study of the resolution that must be guaranteed to the frames in order to fall within the definition scales of the three-dimensional model; if, in the case of the laser scanner survey which is directly acquired in metric scale, it is possible to evaluate the definition on the basis of the set point grid, as regards the photographic survey, the evaluation of the definition values must be designed on the basis of the pixels with which the surfaces are defined. The photographic acquisitions maintained a ratio of at least 6px / cm with a minimum margin of overlap between contiguous frames of 50%.

9 targets were also positioned on the ground and the corresponding GPS coordinates were obtained, useful for scaling and georeferencing the point clouds.

At the end of the data collection phase, 682 final images were imported and oriented in the 3DF Zephyr software during the 3D reconstruction process. The photogrammetric point cloud was then joined to the laser scanner point cloud to obtain an even more detailed model, as well as scaled and georeferenced. (Figure 4)

Before proceeding with the data processing for the reconstruction of the three-dimensional scene, a careful quality control was made on the frames: although we had always tried to keep within the safety shutter speeds to avoid the blur effect in the photographic shots (Forti 2006), especially with regard to acquisitions from close distances in which, moving around the object, one incurs repeated changes in light exposure, the risk of having frames out of focus or with incorrect exposure had to be avoided. For this reason the frames in raw format have been imported into a special software with the aim of verifying their correct focus and adjusting their parameters. In this way, the white balance was equalized for all the shots so as to have a color as uniform as possible. Due to the different light exposures of the surfaces, it was also decided to limit the presence of over-lit and shaded areas to a minimum, reducing the Highlights and Shadow parameters to a minimum. Finally, we tried to make the exposure of the surfaces as homogeneous as possible by varying the parameter according to the shutter speed of the frame.The data from different acquisition systems were used to create the technical drawings (plans and sections) according to the traditional system that involves the extraction of the geometries from the laser scanner point clouds, the materiality of the surfaces from the photogrammetric acquisitions: both databases have been suitably subjected to data certification protocols in order to verify

Figure 5. Drawing of the plan of the fortress.

Figure 6. Drawing of the access elevation to the fortress.

the reliability of both the registration of the scans and the calibration of the photoplanes on the point cloud (Pancani 2017). (Figure 5, Figure 6) The verification of the reliability of the reconstructions took place by comparing the different three-dimensional survey systems: the survey integrated different methodologies, producing multiple digital copies of the Verruca with different levels of reliability. We can synthesize the acquisitions in three different reconstruction systems: laser scanner, SfM and satellite. Two of these measurement methods are able to provide a measurement within certain error parameters: the single laser scan in fact, depending on the model of instrument, guarantees high reliability, in our case millimetric; in the same way, the GPS has guaranteed centimetric measurements on the xy plane; 1.2 cm on the vertical axis. Unfortunately, it is not possible to say the same about photogrammetric reconstructions, although the positioning of the trigger point is supported by the presence on the drone of a high-precision GPS: in fact, the positioning of the trigger point does not guarantee the correct reconstruction of the point clouds that are influenced. from numerous and different problems related to the light source (Pancani, Bigongiari 2019). For this reason, after an accurate control of the registration process, the laser scanner survey was taken as the morphological basis, whose polar coordinates were used to verify the control points of the photogrammetric survey, both from the ground and from the drone. At the same time, the union between laser scanner alignment and photogrammetry was experimented, obtaining interesting results in terms of reliability of the mesh model: together with the developers of 3d FLOW with whom a collaboration has been active since 2019, there is the intention to improve these algorithms for make the photogrammetric survey even more an integrated survey.

4. Conclusions

The Verruca survey made it possible to experiment with numerous data acquisition systems in order to integrate the results from the different instruments.
The three-dimensional model obtained by the drone, necessary for the reconstruction of reliable textures, has been verified to be reliable per cm compared to the laser scanner model. Highly reliable drawings were obtained which are useful for analyzing the state of conservation of the architecture; thanks to the use of the drone it was possible to measure points that were not accessible until now. The research on methodologies by the research group in collaboration with the software house 3d FLOW will be increasingly directed to the study of rapid systems that integrate the use of laser scanner and drone acquisitions to obtain increasingly reliable data.

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Keywords:
UNESCO, Digitalization, UAVs, KAARTA, Enhancement, Reuse project, Verona.

ABSTRACT

The paper presents the case of the Rondella delle Boccare, the first circular military fortification entirely built following new forms, whose realization dates back between 1518 and 1522. This bulwark is located along the Scaliger walls in the northern area of the city of Verona and has been subject to numerous interventions over the years.

The goal of the research is therefore the elaboration of a project of conservation and enhancement of the fortified structure of the Rondella delle Boccare aimed at promoting actions of protection and enhancement of the site in order to maintain its authenticity and integrity.

Application of fast survey technologies for knowledge, valorization and conservation: the case study of Rondella delle Boccare

1. Introduction

The digitisation of Cultural Heritage is among the six missions that the Italian government has set for itself, to improve valorisation actions and tourism, based on advanced accessibility, thereby eliminating physical and social barriers for everyone. In the aftermath of the pandemic crisis, Italy has set up a recovery plan outlined in the PNRR (National Recovery and Resilience Plan)[1], which represents the investment programme planned by the state to benefit from the Next Generation EU (NGEU)[2]. The three main axes, also shared at the European level, are digitalisation and innovation, ecological transition, and social inclusion. Specifically for culture, investments will incentivise learning processes (reskilling) and improve existing ones (upskilling) (Guida 2021).

Focus on digitisation began in the mid-1970s: within many European research institutes, major projects began to digitise library materials and paper documents, the consultation of which was allowed in the late 1990s. In the same years, attention was also paid to art and architecture, facilitating the sharing of three-dimensional manmade artefacts (Niglio 2013). The desire to preserve the memory of Cultural Heritage in a digital form arose from the increasing natural and artificial threats, which include but are not reduced to pollution and erosion caused by winds, and to which digitisation was proposed as a possible solution. Indeed, digitisation turned out to be a valuable means for the protection, preservation, restoration, research, dissemination of material, and promotion of tangible and intangible assets.Through extensive actions, the European Commission supports the cultural policy of its member states, focusing on digitisation and online access to cultural material, as well as digital preservation and curation activities (Caffo 2013). Digitisation of heritage is also one of UNESCO's key points, promoted for the 20th anniversary of the Memory of the World project[3]. UNESCO, together with the University of British Columbia, has presented a document, i.e., "The Memory of the World in the Digital age: Digitization and Preservation"[4], which outlines the digitisation and archiving principles and assumptions to be followed to ensure knowledge of the world through digital preservation.

Special attention is paid to the use of the term conservation because "Conservation is [...] essential in defining and maintaining cultural value [...]. Conservation of cultural material is an intrinsic part of our need as a society to collect, organise and display culture. It is a complex intellectual and physical process that raises many ethical, technical and philosophical challenges; and it is through those challenges that we gain a better understanding of the world as it was, as it is, and to some degree, will be" (Respini 2018). While the advancement of digital technology allows for a massive extension of the amount of data to be collected, optimizing digital models, exporting databases in different formats, and revolutionizing the ways in which heritage can be enjoyed, on the other hand, we live in the awareness that, due to their nature, digital resources are subject to a continuous and inevitable process of transformation that, in the light of the evolution of models and systems, may in the future deny access to the very same digital products. This topic is addressed in the Charter for the Preservation of the Digital Heritage[5], a text adopted by UNESCO; "Article 3" states that "The world's digital heritage is at risk of being

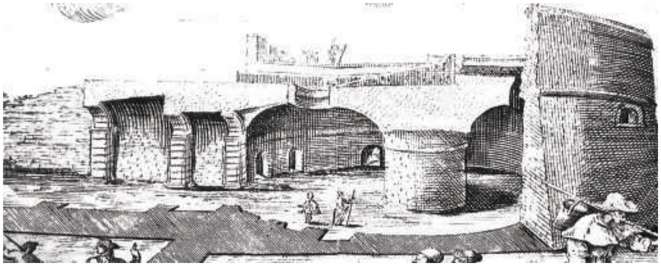

Figure 1. "Prospect, Cutaway and Plan of the Washer known as the Terraglio, 1700 drawing by unknown author (B.c.Vr., sez. Stampe, 1.g.99)" (Zorzi M. (2019), Le mura di Verona. Da castrum romano a fortezza austriaca: storia di un capolavoro d'arte militare, Treviso: Edizione Chartesio, 2019, pp. 124-125)

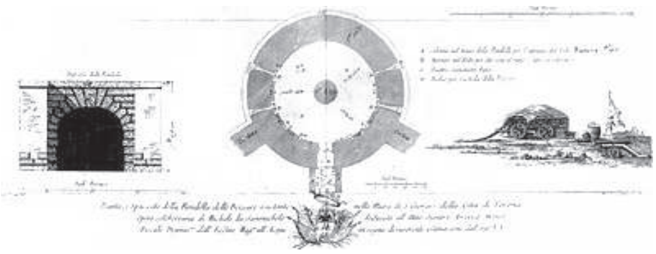

Figure 2. Historical image depicting the plan and a detail of the access of the Rondella delle Boccare before the Austrian intervention.

lost to posterity. Contributing factors include the rapid obsolescence of the hardware and software which brings it to life [...]" and "[...] Digital evolution has been too rapid and costly for governments and institutions to develop timely and informed preservation strategies" (UNESCO 2003). The desire to preserve Cultural Heritage is demonstrated by the cultural actions promoted by the UNESCO office of the city of Verona, which was inscribed on the UNESCO World Heritage List in 2000[6]. Many initiatives have taken place since 1990, among which is the project for the redevelopment and enhancement of the Cinta Magistrale so as to integrate it with the city. In relation to the desire to preserve the walls, several actions have been carried out by the City of Verona, including the implementation of the Verona Città Murata project[7], with the intention of promoting and making known the different fortified elements that make up the Magistral Walls (Parrinello 2018).

This initiative has stemmed from the uniqueness of the system and has led to the creation of a 3D digital database as a tool for the management of the UNESCO site, with the aim of documenting its state of conservation and materiality in order to activate enhancement processes. The Veronese fortified system, built over 2,000 years and more than 9 km long, consists of towers, washers, bastions, forts, entrenched camps, storehouses, and barracks. These elements are the results of continuous updates and adaptations that began in Roman times and continued throughout the Middle Ages. During the Renaissance, when the Venetian Republic regained control, it decided to improve Verona's defensive structures taking into account new attack technologies and, therefore, modifying several sections of the walls during the War of the Cambrai League. Consequently, after the war, the walls were repaired and adapted to the new needs by inserting embankments and washers, or circular bulwarks. Thus, in order to strengthen the medieval walls, multiple circular fortifications were erected, including the Rondella della Bacola (1517-20), which took over an existing defensive tower, the Rondella di San Procolo (1520-22) built on the walls of the existing imperial bulwark, and the newly constructed Rondella delle Boccare (1518-22) (Figure 1) (Zorzi 2019 pp. 74-75).

The desire to include circular fortifications within the medieval walls was due to their geometry, which enabled the flanking firing and provided the possibility of accommodating a greater number of artilleries either on open-air upper squares or sheltered in blockhouses equipped with low gunports, set up for grazing shooting.

As part of the extensive survey program of the city wall, a survey campaign was carried out in October 2021 aimed at digitising the spaces of the Rondella delle Boccare, a circular-shaped bulwark located is in the northern part of the city of Verona, settling along the city wall that connects the Breccia di San Giorgio with the Torricelle (Figure 2). The fortification was built in the Renaissance period, specifically between 1518 and 1522, when the city was ruled by the Republic of Venice, who then began to plan fortifications

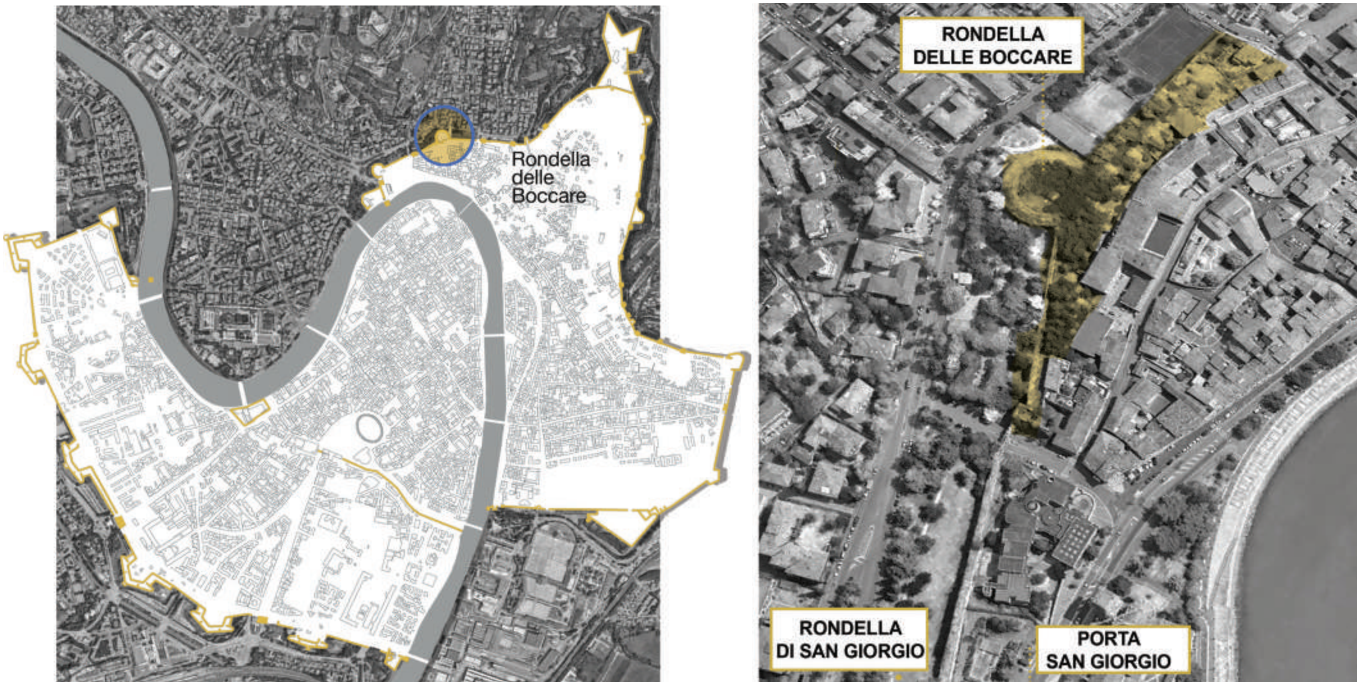

Figure 3. Contesualization of the Rondella delle Boccare within the magisterial wall and aerial view of the bulwark.

to protect his territories. The reinforcements included the addition of embankments, esplanades, and circular bulwarks as well as the construction of additional portions of the walls (Zorzi 2019 p. 72).

2. The case study and acquisition methods

The Rondella delle Boccare today is barely noticeable within the morphology of the city of Verona, as it is concealed by the buildings attached to it. The process of hiding the architectural asset within the landscape began with the construction of the former Maternity Building, now the Marco Polo State Technical Institute in 1932 (Zorzi 2019 p. 133), continuing with the construction of other building up to its current state. Therefore, the state of preservation of the Rondella delle Boccare is aggravated not only by the lack of interventions but also by the construction of buildings with various destinations close to the bulwark (Figure 3).

The purpose of the documentation is the definition of a geometric and spatial awareness of the fortification with the aim of implementing the 3D digital database for the UNESCO site, as well as creating a basis for carrying out investigations and possible processing that can be used in various fields, including intervention for the rehabilitation and reuse of the artefact. Digitisation of the Rondella delle Boccare was performed through different types of digital technologies that allow obtaining qualitative results both during the survey activity and in the representation and visualisation (Piani 2013). In particular, for the documentation of the fortification, from the architectural to the detailed scale, three acquisition systems were set up: UAVs (Unmanned Aerial Vehicles) for aerial photogrammetry using the DJI Mavic Mini 2 drone[8]; MLS (Mobile Laser Scanner) for rapid documentation of the asset and the surrounding urban environment, via the STENCIL KAARTA 2-16 Edition; TLS

Figure 4. Collection of images depicting the condition of the bulwark: the Boccare Washer shows obvious signs of degradation as a result of abandonment.

(terrestrial laser scanner) for more accurate documentation of the fortification as a whole, using the Laser Scanner FARO Focus S CAM2®[9].In addition, a documentation campaign of all the rooms, pertaining to the later phases, was also carried out through a Canon EOS 2000D reflex camera, Nikon D7200 camera and Ricoh Theta S camera. The necessity to resort to three types of instrumentation for the survey is mainly related to the complexity of the fortification and allowed for an integration of the data in order to mitigate the limitations that each instrument possesses. Therefore, the result is an accurate digital database of the site, which can be useful for the designing of the reuse project of the Rondella delle Boccare. Moreover, this allowed for excellent results in the survey phase but also in the final representation and visualisation, producing an accurate description of the area and buildings. Due to the complexity of the interior spaces, exterior spaces and crowning spaces as well as the extension of the Rondella delle Boccare, a breakdown of the rooms was set up in order to improve and speed up the documentation project. Another important aspect to keep in mind for documentation planning, that arose from the complexity, was the planning of all phases in order to obtain macro-groups of digitised portions that could be easily related to each other (Figure 4). The first documentation phase involved the upper shooting platform of the Rondella delle Boccare, together with the two wings connecting with the Breccia di San Giorgio and Via Madonna del Terraglio. In this phase, all three documentation systems were used. Due to the southern exposure of the space, it was possible to acquire coloured Laser scans, of different durations (Figure 5, 6). The TLS acquisition was supplemented via the Kaarta Stencil (MLS), for the entire space, and an aerial UAV survey of the upper portion of the wall section. This wall connects the firing platform to the Breccia di San

Figure 5. During the documentation phase, a breakdown of the bastion and its surrounding environments into portions was made in order to facilitate activities.

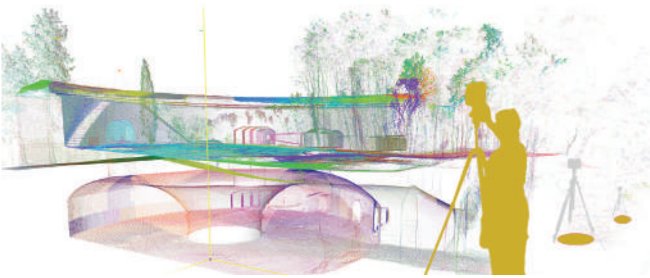

Figure 6. Documentation using TLS instrumentation (Terrestrial Laser Scanner) and cutaway of the point cloud given by recording scans organized by groups, developed to tree-like subsets, according to polygonal path hierarchies defined in the field.

Figure 7. Collections of point cloud images obtained by Terrestrial Laser Scanner FARO Focus S CAM2® demonstrating the high quality of the data obtained.

Giorgio, covering a distance of about 5 meters; thus, a linear acquisition path along the wall section and a spiral one – on the tower that marks the end of the wall portion and is connected to the open-air firing platform – were planned. The spiral acquisition covered around 15 meters (Figure 7, 8). The second phase involved the casemate and annular gallery, crowning the central space characterized by a centrally located pylon and was carried out using the FARO Laser Scanner. Due to the lighting problems of these two spaces, the scans carried out via the TLS were set in color for the central space, and in black and white for the rooms pertaining to the annular gallery of the blockhouses.
A photogrammetric survey campaign was also set up for the blockhouses, using a Canon reflex camera, in order to enrich the material data in the post-production phase so as to better understand any possible degradation phenomenon present (Figure 9).

Finally, the spaces surrounding the bulwark were documented: the first one was adjacent to the back of the Technical Institute, while the second one involved the Nievo playground and the near Nievo Polisportivo, to thoroughly survey the outer perimeter of the Rondella delle Boccare. In this last phase, MLS and TLS acquisition systems were used (Figure 10, 11), complemented by photogrammetric acquisitions. During the laser scanner acquisition campaign, it was necessary to break down the area into subparts following specific criteria based on the morphology and complexity of the structure.
In addition, for all documented spaces, the photogrammetric acquisitions were performed using a Canon EOS 2000D reflex camera and a Nikon D7200 camera. The objective was to acquire the state of the art, paying particular attention to the degradation phenomena and to significant elements for subsequent analysis during the post-production phase.

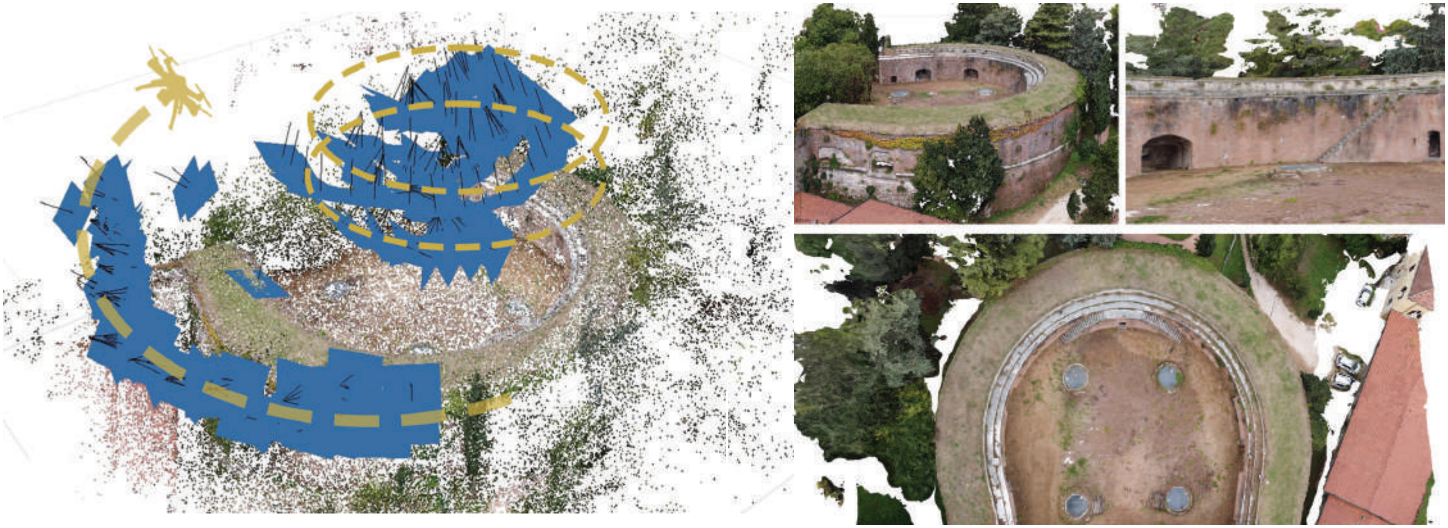

Figure 8. Scheme acquisition with UAV through the use of DJI Mavic Mini 2 drone of the open-air shooting platform that characterizes the bastion. At right, a collection of images of the 3D model generated from the point cloud aligment, using the software Agisoft Metashape.

Figure 9. Scheme acquisition with UAV through the use of DJI Mavic Mini 2 drone of the tower. The drone data was subsequently processed through optimization operations of the point cloud and alignment of the data acquired by laser scanner. This operation made it possible to have an integrated and stratified 3D point cloud database.

Special attention was paid to the connections between the various scans in order to optimize the registration phase: during the preliminary phase of the survey, the positioning of the targets, i.e., checkerboards and spheres, was particularly relevant for the integration of the various type of surveys, such as the TLS and the UAV.

3. Data analysis and comparison

The data processing phase generated outputs suitable for analysing the data according to the different levels of investigation. This makes it possible to build up a database for the future generation of a three-dimensional model adequate for reuse, analysis and preservation of the artefact (Figure 12). The database was obtained by integrating the range based and image based[10] point clouds, once they had been referenced in the same coordinate system. An assessment of the three acquisition systems can be performed to define the quality and metric reliability, through a cloud-to-clo<ud comparison between couples of obtained point clouds. The first comparison between the TLS and the drone data shows that the latter

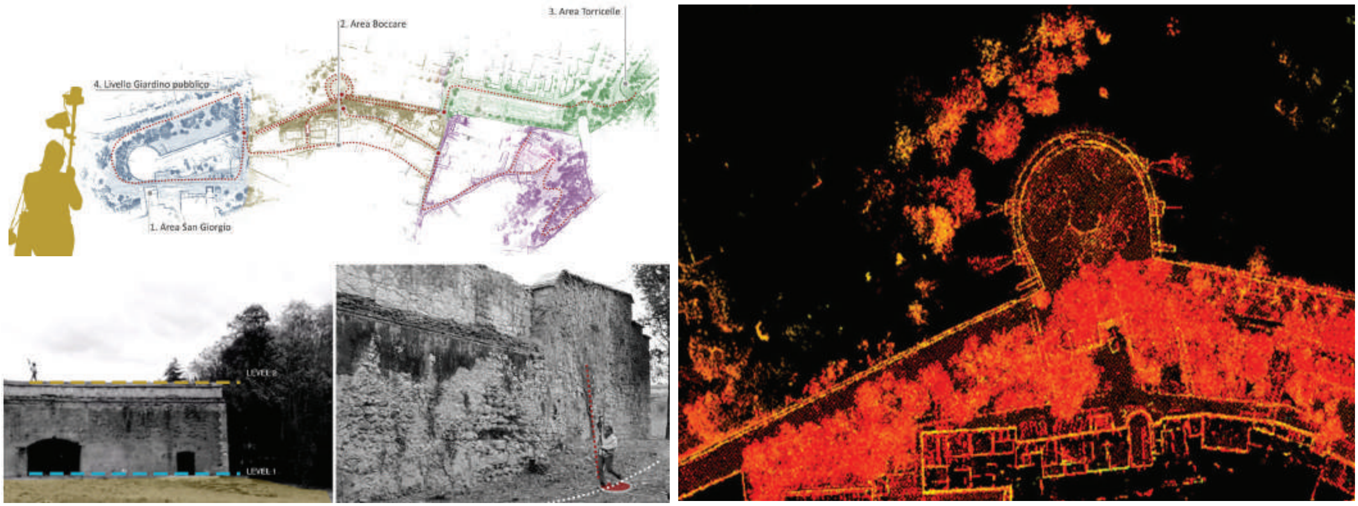

Figure 10. Scheme of acquisition with MLS (Mobile Laser Scanner) using STENCIL KAARTA 2-16 drone. The documentation was carried out on four different areas, which were subsequently processed into a single point cloud. During the acquisition phases, the laser paths were designed taking into account the morphology of the place. In this sense, paths have been carried out taking into account the different height levels of the fortified system.

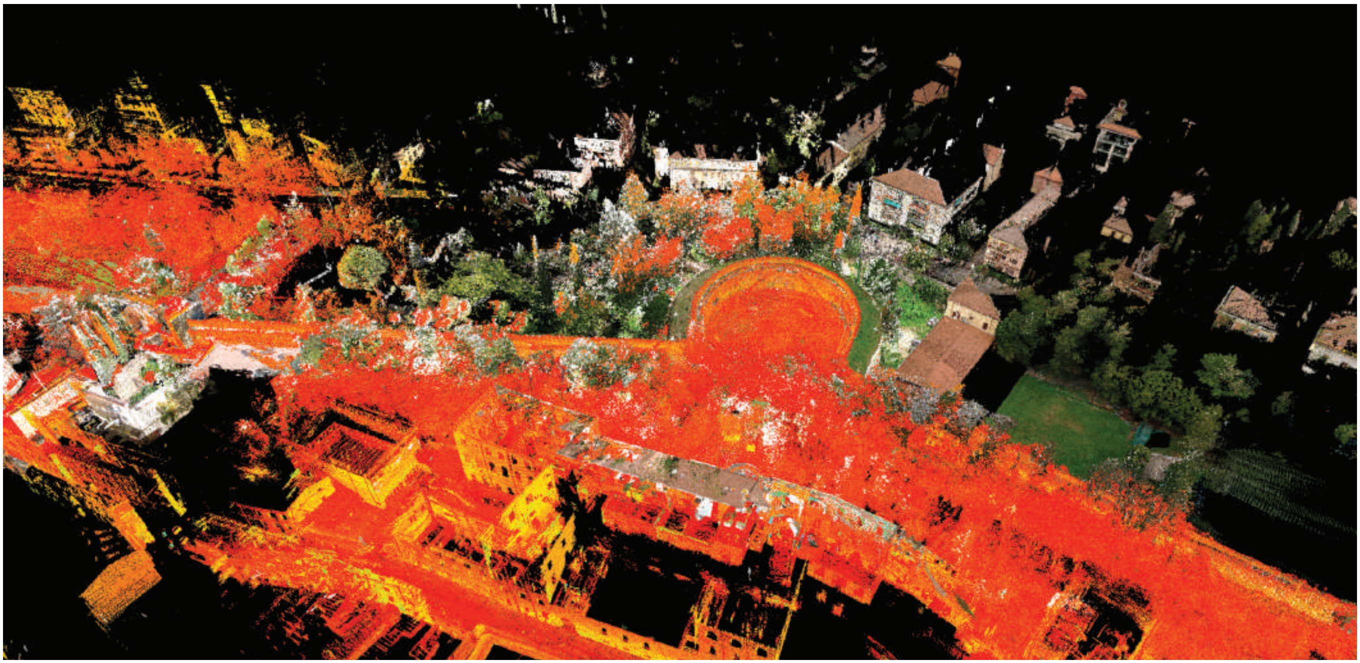

Figure 11. Point Cloud views as a result of data registration between the point cloud of Mobile Laser Scanner and the UAVs acquisition.

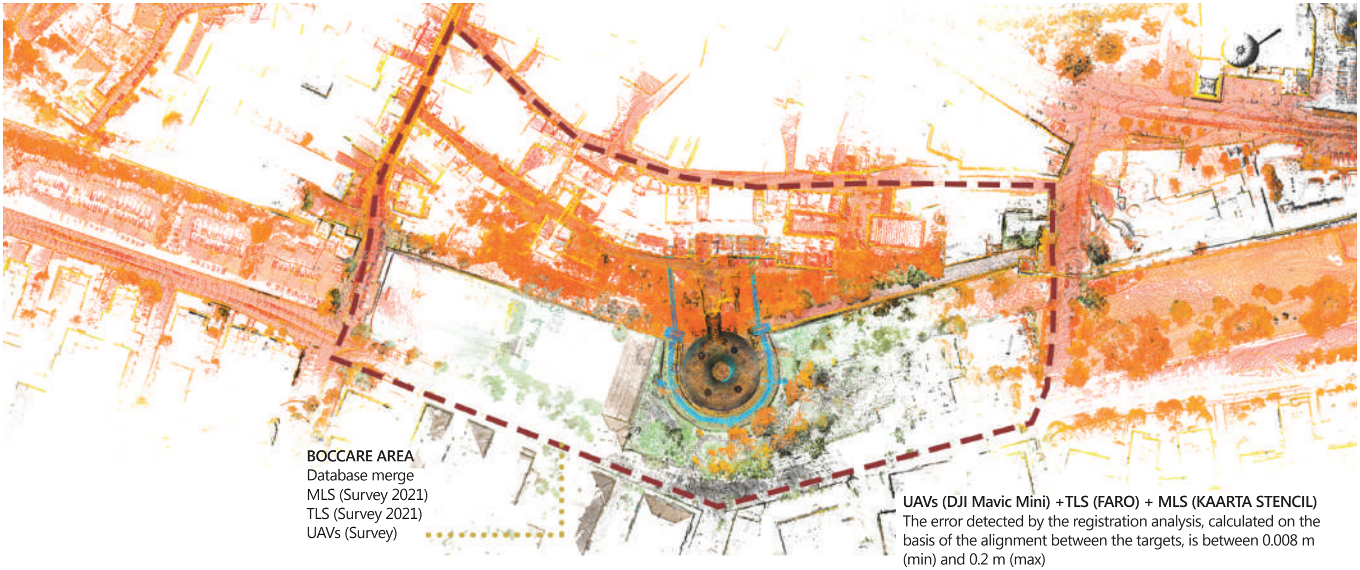

Figure 12 The results obtained from the UAVs (Unmanned Aerial Vehicles), MLS (Mobile Laser Scanner) and TLS (Terrestrial Laser Scanner) instrumentations were integrated with each other to form a single database.

presents a deformation in the geometry of the elements, especially on sharp edges. The second comparison between KAARTA and FARO highlights the unreliability of the mobile laser scanner data on extended surfaces for complex elements and geometry. Furthermore, it became clear during the survey phase that the MLS scanner does not work well in indoor environments with circular geometries and dim lighting, such as blockhouses, due to the loss of the Lidar signal. In addition, it resulted that the point cloud of the shooting platform suffered data drift.The comparison between these three survey methodologies shows an overlapping error of the point clouds less than 10 cm, for limited extension portions and in relation to the instrument used.From the standpoint of generating a database suitable for the study of the building's state of affairs, it is then clear that the data obtained from the errestrial laser scanner is certainly indispensable as it is more reliable. On the other hand, the datum obtained from the mobile laser scanner allows integration with the urban context, while the datum obtained from the drone ensures the acquisition of high-altitude elements as well as their state of preservation.

4. Conclusions

The preservation of the collective monumental heritage is a goal aimed at future generations, but it also needs to imply the availability of that asset to citizens in the present. This means working together with the disciplines of conservation and restoration and without neglecting the cultural approach to the monumental asset. Underlying asset preservation actions is the need to develop an adequate information database of the monumental asset. Integrated documentation is a valuable tool to achieve a final product enriched with information capable of providing the data necessary at different scales and levels of detail. The integration of data from fast survey instrumentation, such as those used for the survey of the Rondella delle Boccare, allows for a complete 3D model with appropriate metric accuracy. The high reliability of the database provides a valuable tool useful for defining multiple levels of detail. Moreover, it provides an excellent project basis for designing realistic intervention hypotheses for the restoration, valorisation and reuse of inaccessible places characterized by complex geometries, such as the case study.

Notes

1 The PNRR is a document prepared by the Italian government designed to outline how to invest EU funds, providing a roadmap of reforms aimed at modernising the country. The PNRR organises the investment projects into 16 components, which are themselves gathered into 6 missions: Digitalization, Innovation, Competitiveness, Culture and Tourism; Green Revolution and Ecological Transition; Infrastructure for Sustainable Mobility; Education and Research; Cohesion and Inclusion; and Health.

2 The NGEU, also referred to as the Recovery Package, is a temporary European instrument aimed at the recovery of the EU member states. The initiative provides 750 billion euros to repair the economic and social damage caused by the coronavirus pandemic in order to make post-COVID-19 Europe greener, digital, resilient and fit for the challenges.

3 The UNESCO Memory of the World program was created in 1992 to preserve the treasures of humanity and mobilise resources so that future generations will have the possibility to enjoy this legacy. Underpinning this project remain the principles of preservation to which is added the need to digitise and "duplicate" the heritage, thus ensuring that its use does not imply its deterioration.

4 International Conference The Memory of the World in the Digital age: Digitization and Preservation, 26-28 September 2012, Vancouver (Canada), organized by UNESCO in cooperation with the University of British Columbia (Canada).

5 The Charter for the Preservation of the Digital Heritage is a text adopted by UNESCO's General Conference at its 32nd session held in Paris and concluded on October 17, 2003.

6 On November 30, 2000, the XXIV Plenary Assembly of the World Heritage Committee (W.H.C.) inscribed Verona onto the World Heritage List (W.H.L.) with the name "City of Verona" based on Criterion (II) and Criterion (IV).

7 The Verona Città Murata project was born in 2015 as a result of the intention to document and preserve the Magisterial Walls of the city of Verona. It is a project, coordinated by Prof. Sandro Parrinello, involving a collaboration between the City of Verona and the Department of Civil Engineering and Architecture of the University of Pavia, in which professors, researchers, and students are called upon to participate.

8 The DJI Mavic Mini drone features a 12 MP camera for high-performance capture of artefact materiality, and a sensor that can help save time during topographic surveys by reducing the number of GCPs (Ground Control Points) needed.

9 The Laser Scanner FARO Focus S Terrestrial from CAM2® has a built-in 8-megapixel HDR camera, capable of capturing detailed images to enrich the colorimetric data of surfaces.

10 The survey was carried out through the use of modern three-dimensional range-based instrumentation, through the use of laser scanners. In this specific case, this typology refers to the MLS and TLS types. This was later supplemented with image-based procedures, from digital photogrammetry, which allow the attribution of information necessary for the reproduction of the texture and geometry of the artifact. The image-based procedure was generated through the use of UAVs typology.

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ABSTRACT

The convent of Santa Maria da Ínsua, northern of Portugal, was founded in 1392 by the Observant Franciscans. The space has been studied mostly by Historians but an in-depth analysis of its physical evidences is missing. This paper seeks to fill in this gap, in order to contribute to the diffusion of this religious heritage site. This study is even more relevant in this historical moment because it is conducted exactly before the building rehabilitation. Digital photogrammetric surveys through UAVs provide a quick method to obtain a 3D textured mesh model for further studies, online visualization, preservation and sharing.

A 3D model for architectural analysis, using aerial photogrammetry, for the digital documentation of the convent of Santa Maria da Ínsua, on the northern border between Portugal and Spain

1. Introduction

Several scholars, mostly in the historical field, have deepened the diachronic evolution of the Franciscan community settled in the convent of Nossa Senhora da Ínsua (Figueiredo 2008)[1]. However, there is a lack of in-depth studies and documentation of the current physical evidences.

This paper aims to contribute to the knowledge and diffusion of this religious heritage site. This study is even more relevant because it has been conducted exactly before the built structure adaptation into a touristic accommodation. After the literature review, the identification and contact with the buildings' management entities, on-site visits allowed the digital documentation of the whole complex. A photographic and architectural survey of the buildings through SfM techniques, by using data coming mainly from UAVs, has been carried out. Specific constrains, due to the location on an uninhabited island, the climatic conditions and the time limitations, led to the definition of a specific workflow for the surveys activities. We first analysed the historical framework of the case study. After, we discuss the digital methodology for data collection. Finally, first outputs are displayed and discussed.

2. Historical Frameworks

The convent of Santa Maria da Ínsua was founded in 1392 by a group of Franciscan Observants, coming from the Spanish Galicia (Teixeira 2010; Rodrigues, Fontes and Andrade 2020). It originated by an oratory founded at that time by Frei Diogo Árias (Sousa 2016) on the site of a pagan temple previously dedicated to Saturn (Cepa 1980). Historical, social and economic factors led to a continuous expansion of the conventual structure, so that, in the mid-17th century it was surrounded by a fortress. Franciscans were forced to leave the convent in 1834, due to the Portuguese dissolution of the religious orders. The whole complex was managed by the Ministry of War until the last decade of that century, when it passed to the Navy Ministry. Despite the fortress and the convent have been classified as National Monument in 1910, important movable assets have been lost, most of all since the 1940's. The worsening situation led to the building's complete state of abandonment, still evident in the recent photographic survey. Since 2000, public access to the interior of the fort has been prohibited. In 2016, the fortress and the convent were included in the list of properties to be leased by the Portuguese state to private individuals, through the Revive program, with the aim of its conversion for touristic purposes. The selected project foresees the installation of a lodging establishment (equivalent to a four-star hotel). The adaptation work of the built construction is due to start soon. For this reason, the digital documentation is an opportunity to record the physical evidence state before these works.

3. Data collection

Architectural surveying is an evolving field in architecture that has changed significantly over the past decades due to technological advances in the area of 3D data acquisition. Today, several methods and tools are available for data acquisition, namely laser scanning, terrestrial and aerial photogrammetry. These tools make the detection process much more efficient and accurate, when compared with the traditional methodologies and allow the production of a

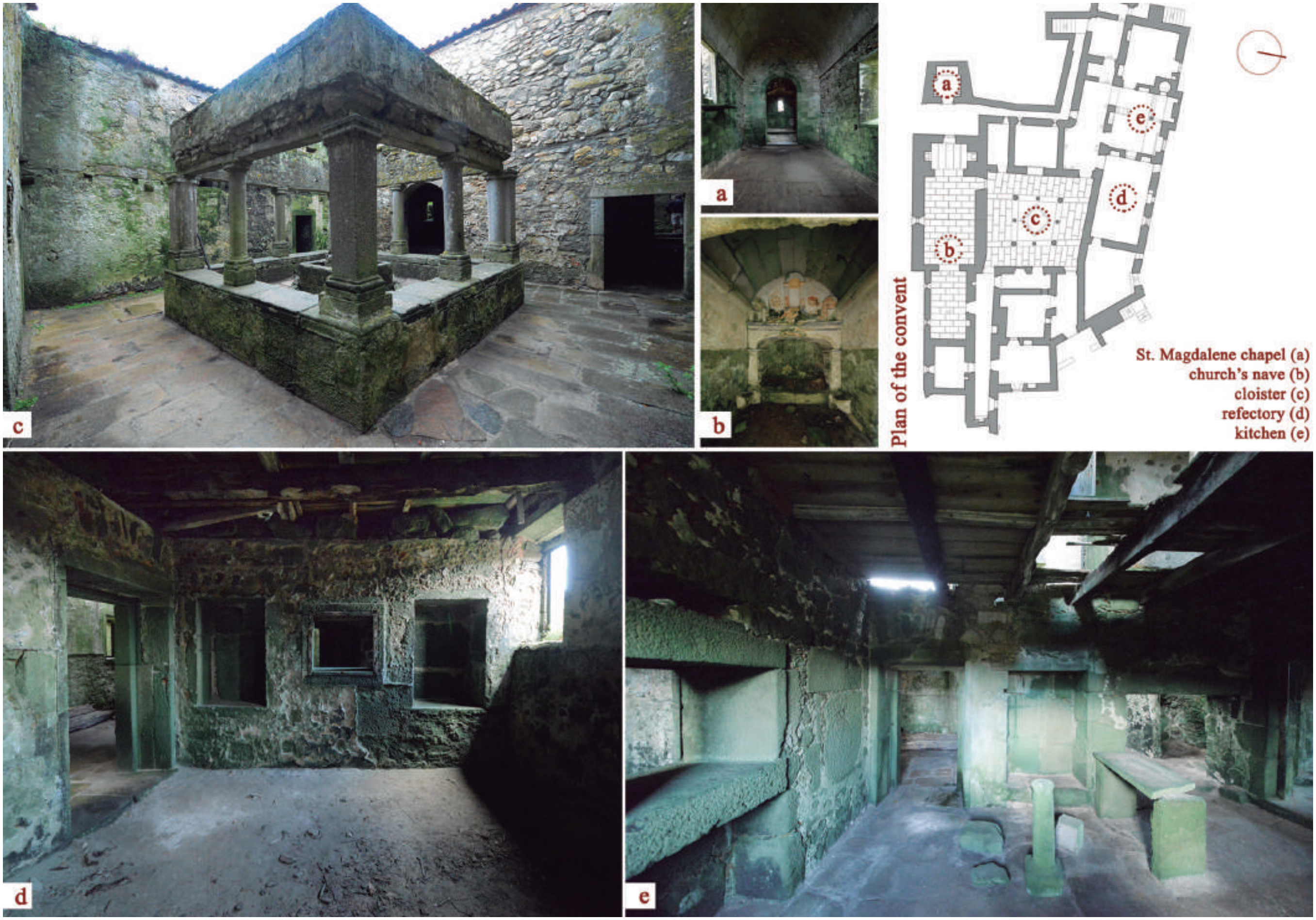

Figure 2. Photographic documentation: Saint Magdalene chapel (a), church's nave (b), cloister (c), refectory (d), kitchen (e). ©Rolando Volzone and Anastasia Cottini, 2021.

valuable three-dimensional database that can be used over time. Digital recording, documentation and preservation are required because our heritage (natural, cultural or mixed) suffers from attrition and ongoing wars, natural disasters, climate change and human neglect.

In particular, the environment and natural heritage received a lot of attention and benefits from recent advances in range sensors and imaging devices. In the last two decades the documentation of Cultural Heritage increased through terrestrial laser scanning techniques (Remondino and Campana 2014). Laser scanning, classified as a non-image-based documentation method, is effective over time as it offers acquisition of up to millions of points per second. However, the weakness of this non-image-based method stands in the low virtualization of edges, colors, and minor surface features, such as cracks, while the combined use of cameras and scanners offers complementary data for a rich and accurate view of objects. Implementing simplified software-hardware solutions that make the challenging task of data collection, data processing and model rendering

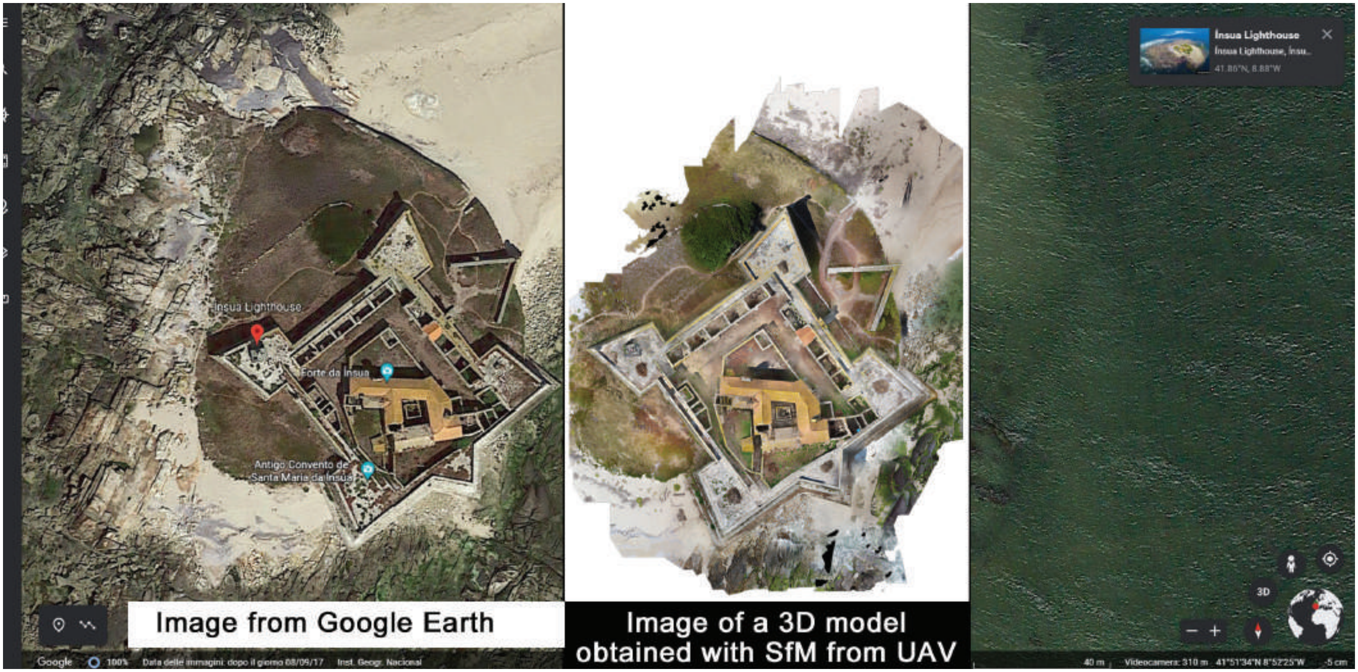

Figure 3. Aerial view of Santa Maria da Ínsua: picture by Google Maps (left), image obtained by processing pictures captured by drone (right). ©Pietro Becherini, 2022.

is a challenge that can be addressed with intelligent, can provide a large amount of accurate 3D data at various scales and resolutions, texture and georeferenced data, metadata and stereo visualization capabilities (Stylianidis and Remondino 2017). The value that the photogrammetric acquisition from drone has given to this work can be seen in the final product obtained, where each portion of the photographed structure is well defined both chromatically and physically thanks to the recording from GPS and the possibility of verification with the point cloud obtained by a laser scanner.

3.1 Historical Frameworks

Flight planning is an important step in completing a successful UAV flight mission and meeting the objectives and requirements of the mapping project. Different flight planning models can be applied depending on the activity and area of interest. For example, the flight plan for pinging the road map and power line is different from the ones required for mapping a ground area or tower.

In our case, a DJI Mini 2 was used which has a 12 MP camera (24mm lens), which can capture images with different photo modes, from single shot, to burst (3 frames), HDR, auto exposure, bracketing2 with different intervals, obtaining images of 4 dimensions: 4/3 - 4000 × 3000, 16/9 - 4000 × 2250. For the type of context, the burst of frames every 3/5 seconds allows to recover a good part of the totality of the photos acquired for this campaign, in the absence of a flight plan. The drone structure weighs less than 250g (dimensions of 245 × 290 × 55mm) and the battery life lasts about 30 minutes with a maximum operating ceiling above sea level of 4000m. Unlike previous models, hovering accuracy with a Vertical: ± 0.1m (with visual positioning), ± 0.5m (with GPS positioning) and Horizontal: ± 0.1m (with visual positioning), ± 1.5 m (with GPS positioning)

Figure 4. View from the Metashape program of the 3D model, the result of processing 1300 aerial photographs.

made it possible to obtain excellent photographs even with the annoying presence of the wind (the considerable presence of wind affected the battery life).
The GSD - Ground sample distance is another important parameter to be considered. In order to get a lower (better) GSD and a more accurate map, it is necessary to fly at a lower height than the camera's resolution and take more photos with higher resolution.
This means more time spent on a project due to longer flights and more data to process. In the case we analyzed, a maximum height of around 20 meters was set with respect to the data to be analyzed, of 1 cm instead of 3 cm; in this way an amount of data up to ten times was acquired and stored for the same covered area but with a much better detail.
Within this photogrammetric survey campaign, the evaluation of the weather conditions before each raising of the instrument was very important, because in addition to greater ease of management of the same, it is possible to make the most of the battery life, which otherwise, for the sole maintenance of the position, could undergo a drastic lowering. Flight plans were then defined for each type of front to be documented, in order not to have any

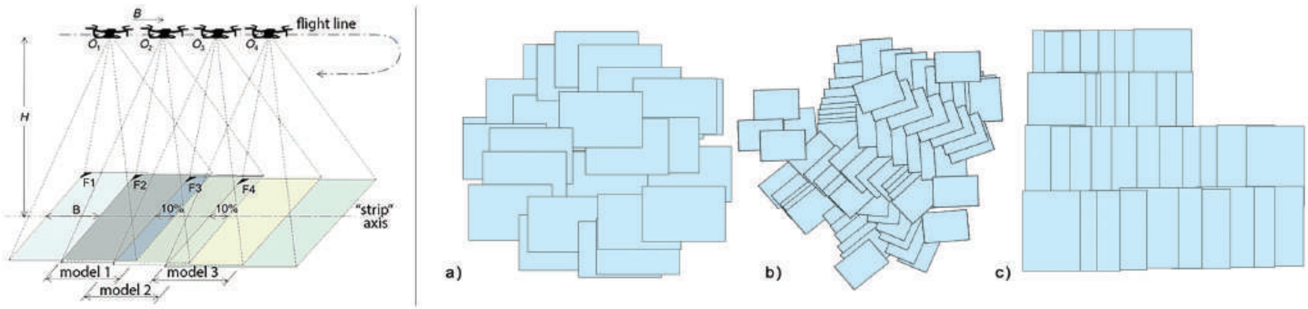

Figure 5. Verification, by entering the coordinates of the object of the aerial photogrammetric survey in the DSPace site, of any flight restrictions using UAV.

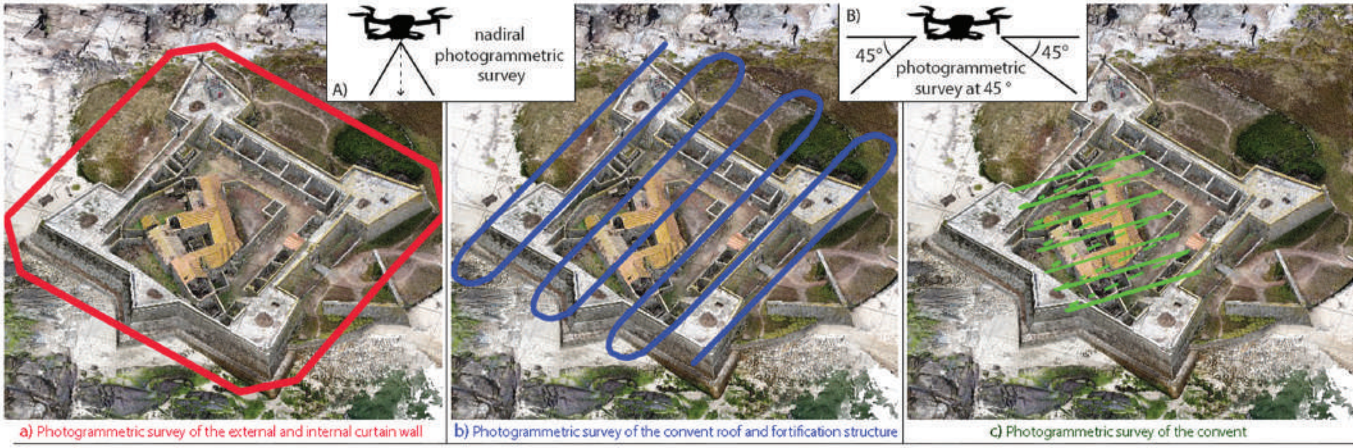

Figure 6. Methodology applied for the acquisition of the territory with a photogrammetric flight organized in rectilinear trajectories (a, b, c) with a nadiral and 45° (A, B) camera during which it is taken a certain number of frames called "streak".

lack in the post-production phase. The timetable was an additional value to be taken into consideration.

Avoiding shaded areas is important to obtain a color scheme of the structure common to all fronts. 1300 photographs were captured with planned routes and spiral or ellipsoidal shots, in order to cover specific architectural elements in more detail.

These geo-referenced images were used to define each quadrant of the grid created in the pre-acquisition phase, in order to cover the entire surface involved in the survey study.

3.2 Terrestrial Photogrammetry

In parallel with photogrammetric drone acquisitions, Nikon D610 digital camera photo sets with 24-120 mm lens were captured. A careful planning of work steps has been crucial to obtain photographic sequences that guarantee good results in data processing. The photographs must not have too sharp shadows and must be taken using appropriate parameters: low ISO, low focal ratio, short exposure time (Mosbrucker et al. 2017). Since the weather conditions were erratic and rapidly changing, we tried as much as possible to coordinate the photographic acquisitions from

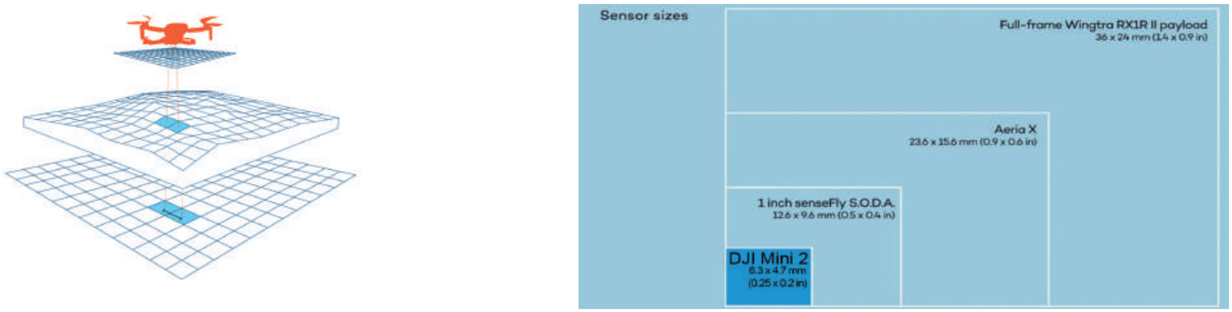

Figure 7. GSD is the amount of ground captured by the distance between the central point of two adjacent pixels. On the right, the size of a payload's sensor influences the quality of the pictures, especially those taken at lower altitude and at high speed. By comparing the real resolution of images with the same GSD, it is evident that a high-quality payload improves the final result.

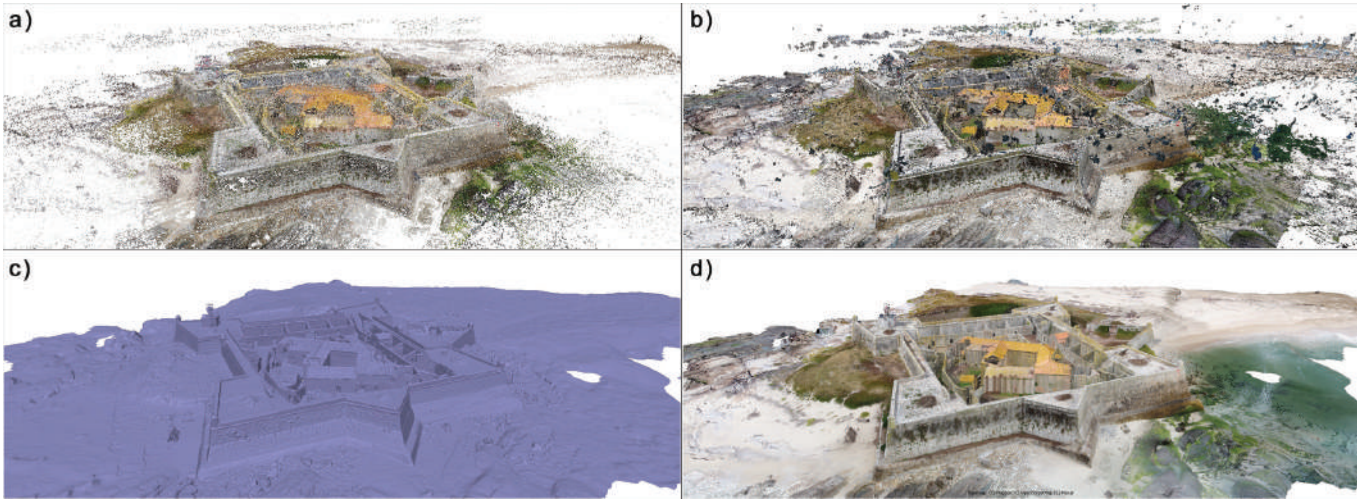

Figure 8. Modeling steps from aerial photographs processed in Agisoft Metashape. a) sparse cloud, b) dense cloud c) mesh, d) tex-tured model.

the ground with those aerials, in the hours of the day when the global lighting was sufficient and widespread. In this way, it was possible to acquire photographs that have similar characteristics in terms of exposure and color. The photographic acquisitions from the ground were concentrated inside the cloister of the convent, along the outer perimeter walls and inside the military accommodation along the perimeter of the fortress. The purpose was to integrate the data collected by drone to fill any gaps in acquisition. In the planning phase of the survey campaign the impossibility of flying with the drone at low altitudes was highlighted in order to avoid accidental collisions against the walls, also considering the presence of strong wind. The photographs from the ground are therefore particularly useful to obtain a greater definition of the areas that, from the point of view of the drone, are not very visible or hidden (Luhmann et al. 2020).

3.3 Laser-scanner survey

In addition to the photogrammetric survey, a campaign was carried out with laser-scanner instrumentation. The instrument used is a FARO Focus M70, a laser-scanner phase-based with integrated camera. The 215 laser acquisitions were concentrated in the internal and external spaces of the convent and the fortress, to obtain a metrically reliable data of the entire complex. The particular conformation of the buildings of the convent has allowed to acquire a rather complete point cloud, including the roofs of the buildings (when still intact) and the surrounding environmental context[2]. The conventual complex is located at a lower altitude than the walkways of the fortress walls, allowing the operator to position the laser-scanner instrument in order to easily acquire a data that has few gaps. The integrated camera of the instrument, moreover, has allowed to associate to the point-cloud a realistic color, which allows to appreciate the colors and textures of the walls.

4 Data elaboration and outputs

The data collected with the laser scanner were processed with Leica Cyclone software, to register together individual scans and obtain a complete point cloud, managed in a database and upgradable over time. The data collected with drone and digital camera were processed with Agisoft Metashape software, obtaining a 3D model of textured mesh. The model was subsequently scaled taking as a reference the point-cloud obtained

Figure 9. a) Perspective view of the point cloud of the fortress entrance, obtained from the SfM processing of 256 photos taken with a digital camera. On the right 3D, model obtained from 108 aerial photos (b – dense cloud, c – model 3D textured).

from laser-scanner, following operational methodologies already consolidated within the research team (Cioli, Lumini 2021). Mesh models are referenced based on the laser-scanner point-cloud, so that they have the same scale and orientation in space. Several well recognisable points are identified on the mesh model, to which are assigned "markers", whose coordinates are modified in order to be equal to those of the three homologous points belonging to the laser-scanner point-cloud. Mesh models are then combined into a single overall model.

The obtained three-dimensional elaborates, characterized by a high metric-morphological reliability, allow to carry out further analysis on the architectures, also with the support of the study of historical and archival sources. From the three-dimensional models, technical drawings, such as plants, elevations and sections, perspective views, axonometric splits, can be produced. These allow to study the represented architectures and provide metric and morphological information, including the materiality and chromatic appearance of the surfaces. This constitutes a valid support, for example, for the analyses concerning the distributive aspects of the architectural complexes, those relating to the decorative apparatus, the state of conservation of the wall surfaces and the evolutionary phases of the buildings. 3D models also offer different opportunities in terms of materials supporting accessibility. They can be processed in such a way that they are navigable, exploiting the applications of immersive reality both for touristic purposes and enhancement of the Cultural Heritage (Argyriou, et al. 2020, Häkkilä, et al. 2019) and educational purposes (Bekele, Champion 2019). They can also be 3D printed and used by visually impaired people (Volzone, et al. 2021).

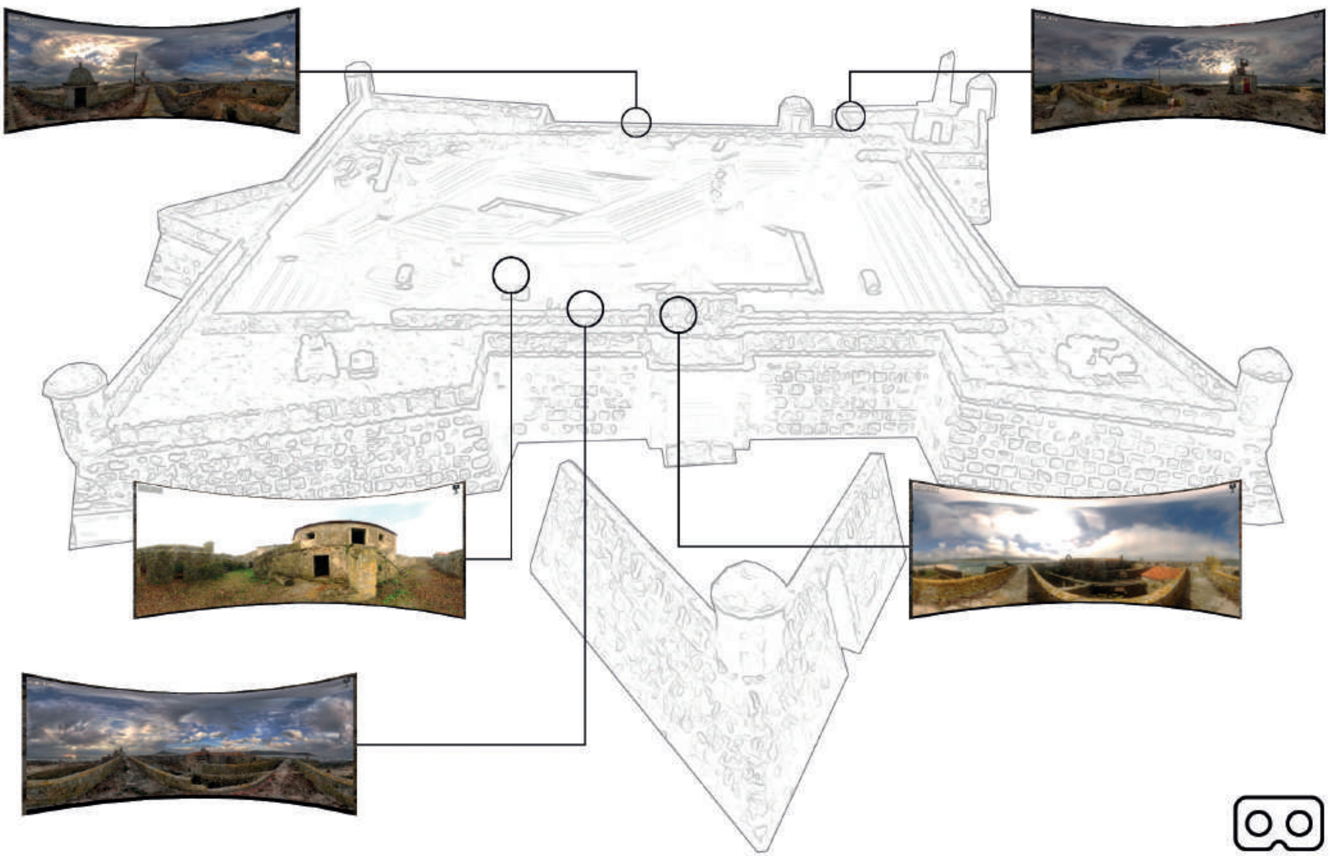

Figure 10. Virtual tour of the external and internal spaces of the conventual complex and fortress.

5. Discussion and conclusion

The singularity of the convent of Santa Maria da Ínsua, due to its strategic location – an islet in the Minho River at the Spanish border – and to its double function, with the coexistence of a religious building (the convent) and a military one (the fortress), makes this complex a unique case study. This is being delved deeper within the European project F-ATLAS, and integrates a cluster of convents founded in the same region (Alto Minho) and with origin in the same year (1392). The 3D survey operations enabled the creation of a digital documentation including 3D and 2D documentation. Future studies should focus on a typological comparison among these case studies, and with the others that are examined in Spain and Italy, belonging to the Franciscan Observance. Finally, once the survey campaign has been carried out exactly before the adaptation works of the space into a tourist accommodation, strategies of heritage communications will allow a universal and digital access to the conventual complex by local (or not) communities, even after its privatisation.

Notes

1 In the last years, Master's degree students have carried theses focusing on the valorization of the convent. See: Neto, J. L. G. S. 2019. "[Re]thinking the Fort of Ínsua. The meeting between the Sea, History and Belief". MSc thesis in Architecture. Coimbra: Faculdade de Ciências e Tecnologia da Universidade de Coimbra; Lima, S. M. M. N. 2015. "Intervenções de conservação e restauro do património edificado: o Forte da Ínsua". MSc thesis in Architecture and Urbanism. Porto: Universidade Fernando Pessoa; Loução, C. S. C. P. 2021. "O património conventual do concelho de Caminha e o seu percurso após a extinção das ordens religiosas, em 1834". MSc thesis in Heritage Studies. Universidade Aberta. In addition, results of a study carried out by students of University of Porto, have been presented in a book. See: Ferreira, Teresa Cunha, and Neto, Rui. 2019. Património na Paisagem. Santa Maria da Ínsua/ Heritage on the Landscape. Santa Maria da Ínsua. Guimarães, Portugal: EAUM/Lab 2PT/IPVC.

2 The laser-scanner instrument, having a range of about 70m, has produced a figure in which the rocks and the sandy beach surrounding the fortress walls are clearly visible. On the contrary, the surface of the water is not legible, since the laser is not able to correctly acquire the data of the reflective surfaces (https://shop.leica-geosystems.com/ca/it-IT/leica-blk/blog/video/scanning-dark-or-reflective-surfaces).

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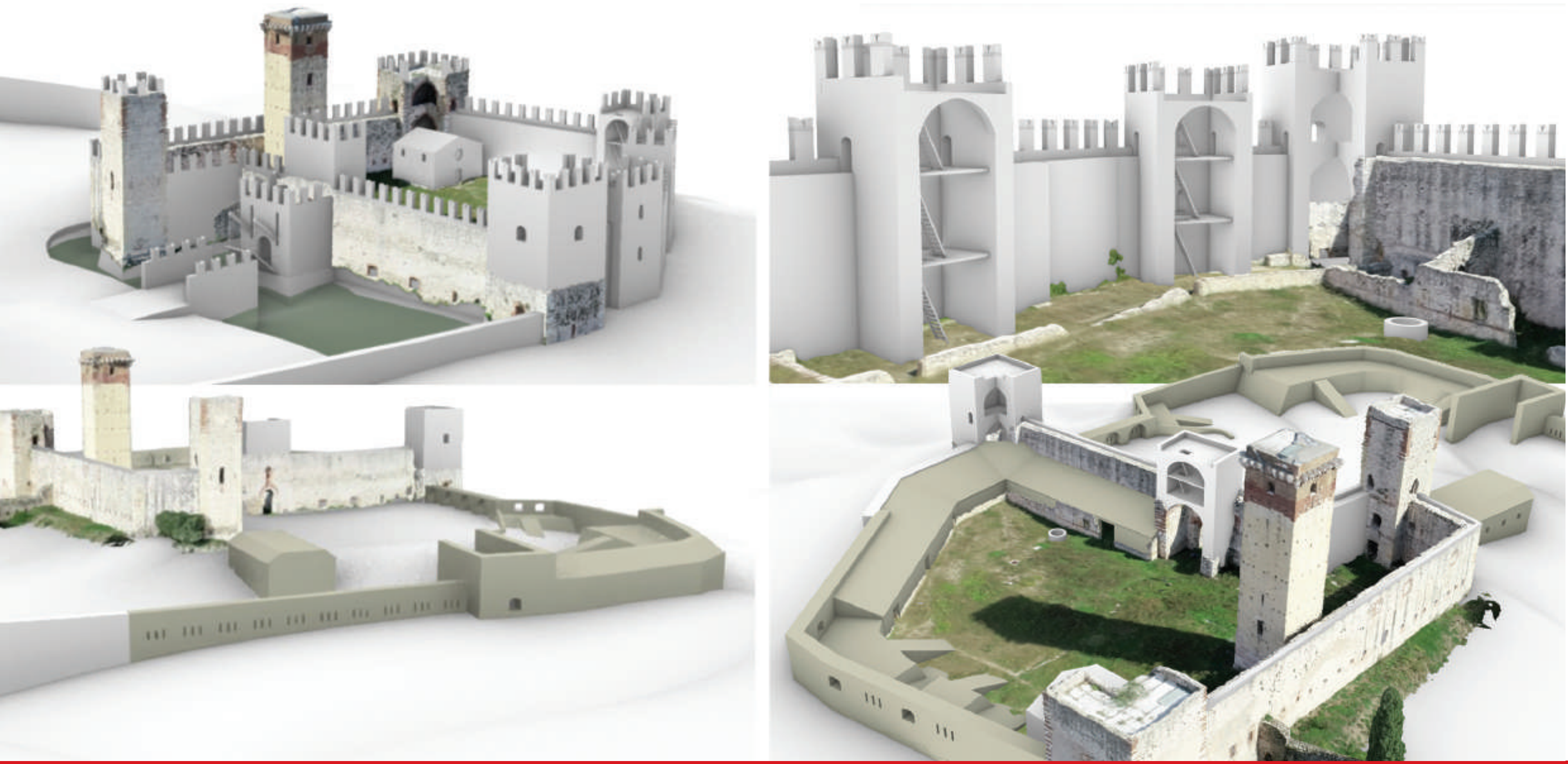

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ABSTRACT

The submitted paper deals in a research that concerns documentation systems for the Scaliger fortifications in the Verona area by using a case study: the Montorio Castle. The research aims to analyze the possibilities offered by drones for the creation of 3D models using frames exported from video footage. This activity creates a groundwork for the philological reconstruction of the military structures through its main construction phases. Accordingly, a possible development is to begin a process to enhance and preserve the historical knowledge of these fortifications through studying and describing them.

Videogrammetry for the virtual philological reconstruction of the Scaliger fortifications in the territory of Verona. The case study of Montorio Castle

1. Introduction

Fortification is an element that identifies the territory; its presence has always shaped and characterized the development of the surrounding space (Creighton, 2002). This connection between the fortress and the territory is clearly noticeable in Veneto. In this area, mainly in Verona province, there are many castles built between the thirteenth and fourteenth centuries during the Scaliger domination period. Part of those castles have reached the present day in an excellent state of conservation, such as Soave and Sirmione, others have come to us as ruins or partially modified, in such a way that the original conformation and its relation with the territory is no more easily understandable. For this reason, representing military architecture is a complicated process: it concerns understanding the territory that affects the characterization of the design of a particular defensive structure, but also documenting how much of these structures has been preserved. (Parrinello 2019). In order to do that, the research presented in this paper aims to analyze the possibilities offered by drones for the creation of 3D models using frames exported from video footage. The application of this method can help to start a process in order to enhance and preserve the historical knowledge of these fortifications. Various documentation activities on Scaliger castles have been promoted as a part of the collaboration agreement between the Department of Civil Engineering and Architecture of the University of Pavia and the Unesco Relations Office of Verona Municipality for the documentation of historical city walls. This actions aimed at the protection and enhancement of the fortified heritage in order to promote the strong cultural identity of the territory. Especially, the Montorio castle proved to be an excellent case study for test out of different steps of the research: from the documentation to the development of 3D models describing the different transformation phases the castle has gone through.

2. The history of the Montorio castle

Over the centuries the castle became strategically very important due to its privileged position in the surrounding area, and because of that has gone through several transformations. The territory on which the castle of Montorio stands is an area inhabited since ancient times. Thanks to numerous archaeological excavations begun in the 80s till nowadays, traces have emerged dating back to the Neolithic period (4000- 2200 BC) or the Copper Age (2400-1800 BC). The traces of the first castelliere date back to the VIII BC, when the ancient Venetians settled in the area where the Reti would have settle about a century later. Later on, was also proven the presence of the Cenomanian Gauls and the Romans (Alloro and Pasa, 2003). Anyway, the construction of the fortress on top of the ancient castelliere remains dates back to the beginning of the 10th century as a response to the frequent raids of the Hungarian populations (Simeoni, 1953). The current castle ruins date back no earlier than 1117, the year in which an earthquake seriously damaged the city of Verona. This event probably also has affected the Montorio castle. Infact, from the stratigraphic analysis on the walls it emerges that the current castle is dated after 1117 so the earthquake must have destroyed the old fortification on Montorio hill and due to that it was completely rebuilt after that event[1].

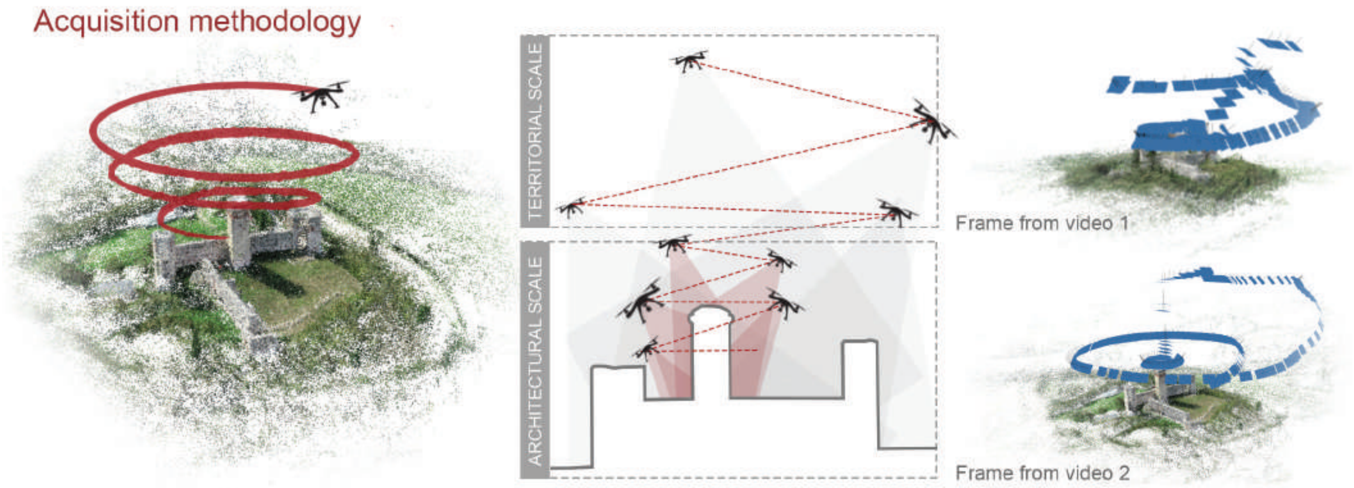

Figure 1. Flight-paths for drone's video registration and results from the frame allignment of the two video used. It is also noteworthy the camera position for each frame exported in the video sequence.

During the years of Federico Barbarossa's empire (1155-1190), the castle played a strategic role controlling a vast territory near the city of Verona and important communication routes. For this reason, Montorio has become the point of contention between the most powerful Veronese families, such as the Sambonifacio and the Crescenzi. When in 1262, Mastino della Scala was elected "Perpetual captain of the people of Verona", the castle passed under the Scaliger dominion. In 1313 when the castle was set on fire by the Paduans (in war with Cangrande Della Scala) it has been subsequently restructured. With the fall of the Della Scala family, the castle passed into the hands of the Visconti and later of the Venetians. In this period, the castle slowly loses importance with long and dusty periods of neglect[2] until the advent of the Austro-Hungarian Empire. Indeed, after defeating the Napoleonic army in 1814, the Austrians understood the strategic importance of the area of the Preafitta ridge and decided to convert the castle into a large defensive battery. During this period the castle underwent significant interventions, including the demolition of some towers and the removal of the crenelated wall. The documentation of these transformations have come to us thanks to several historical reports that described the castle[3].

3. UAV system: survey methodologies for the defensive system and data processing

The digitization of the fortified heritage through the creation of 3D databases is a process that requires preliminary assessments of the methodologies and an accurate selection of tools to best represent the objects of study. Furthermore, is critical to evaluate the timing, the morphology and the territorial extension of the data, especially the purposes that must be achieved (Parrinello et al. 2020). The trial on the castle of Montorio through video frame processing techniques taken with UAV equipment, was born with the idea of acquiring a great number of data covering large territorial portions for the digital representation of the fortified heritage through 3D models. Images captured for photogrammetric modeling can be taken with either a still camera or a moving camera. In this case study it was decided to use video sequences[4]. During the survey phase, two high-resolution videos (about four minutes each) were made with a DJI Phantom 4 Pro UAV[5]. The video shootings were carried out working on two different scales: a punctual one aimed at the most valuable elements of the castle such as the dungeon; and a territorial one that involved the castle, the

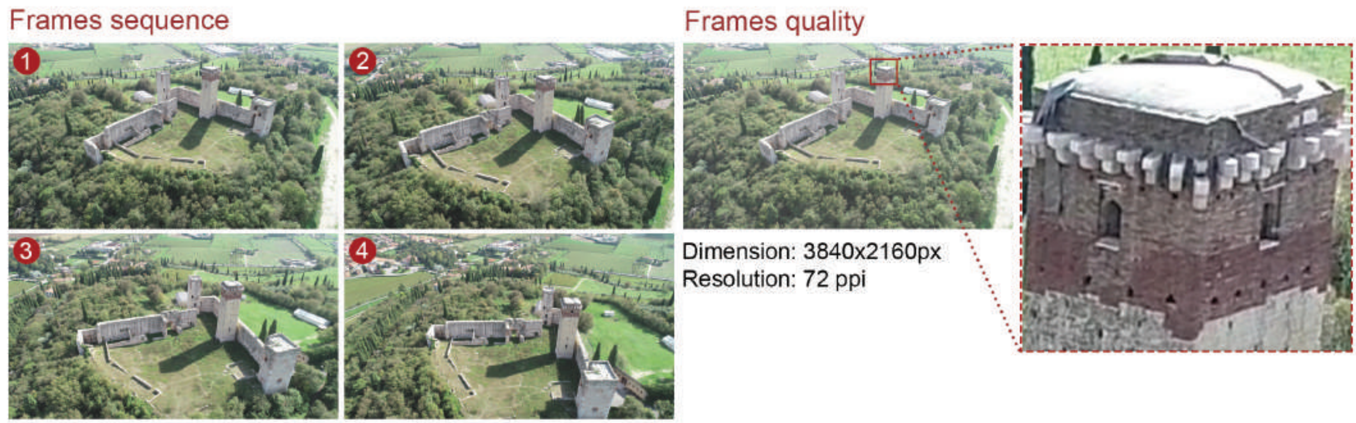

Figure 2. Frames sequence and quality.

bastia and a part of the surrounding space.
Unlike some case studies carried out on fortified elements[6] realized using SfM techniques through static images, where generally for each punctual element is planned radial flight-path while for the territorial elements a grid, in this case study both videos were made by performing a manual flight following a radial path with heights variations for both detail scales, architectural and territorial ones (Figure 1). During the post-production phase, the videos were processed by exporting each frame (VLC Media Player) in sequence, creating two distinct photographic datasets. As in the case of traditional close-range photogrammetry, processed from cameras, the frames were extrapolated sequentially trying to have sufficient overlap between them (Figure 2). The exported frame format is the same of the shot video, 4k quality, 3810x2160 pixel, with 96ppi resolution. For the first video, lasted 4 minutes and 44 seconds has been created a 182 frame dataset, while the second video, 4 minutes and 12 seconds, the dataset is 172 frame. For each video, a dataset containing the generated frames was created and imported into an image processing software (Agisoft Metashape), generating a sparse cloud (for each dataset) representing the result of the alignment

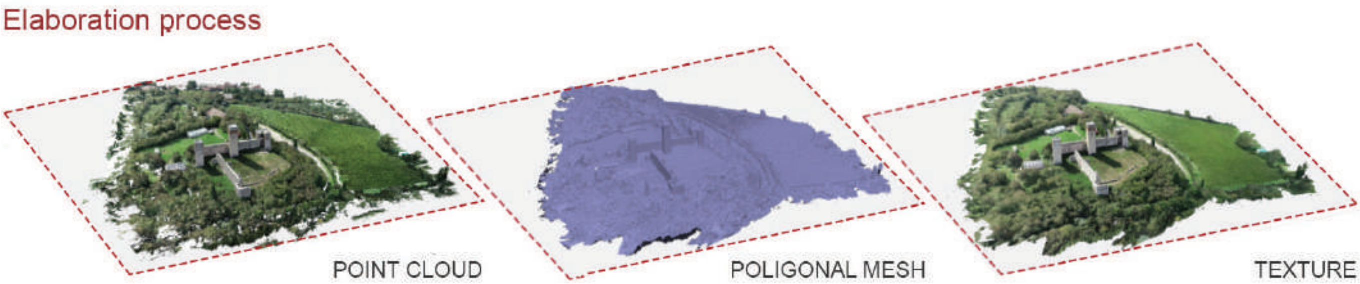

Figure 3. Following steps of photogrammetric elaboration (after alignment) and final texturized model.

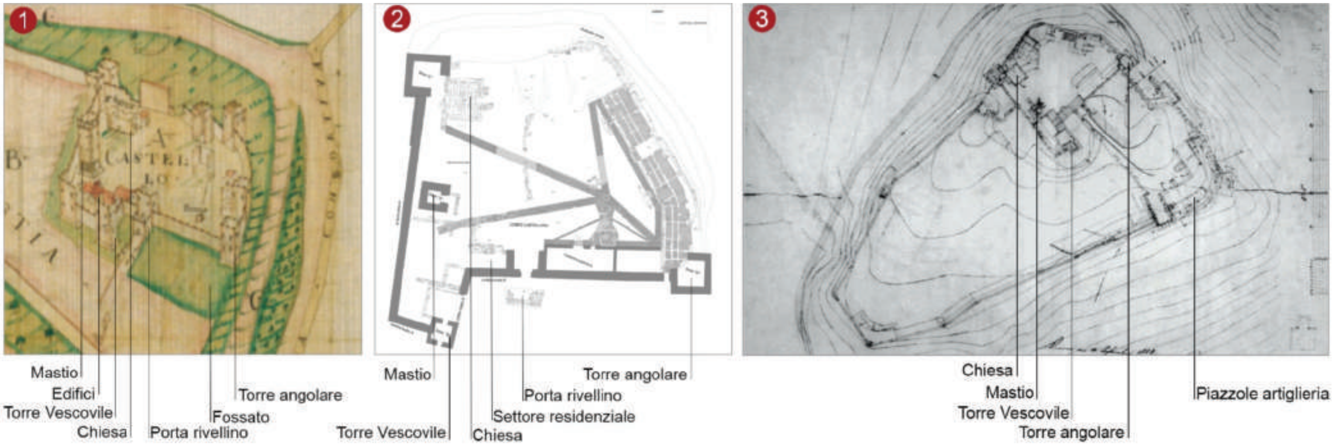

Figure 4. Representations of the castle: 1- Drawing made by Iseppo Cuman in 1663 (details); 2- Plan of archaeological excavations carried out in 2013; 3- Austrian survey dating back to 1859.

of the cameras. For the first dataset the generated sparse cloud contains 499,523 points, while the second dataset a sparse cloud of 477,729 points. Then, the two sparse clouds were aligned (automatic alignment by points) and joined, generating a unified cloud. The dense cloud was first processed and then elaborated into a polygonal mesh (19,821,151 polygons). Following this step the texture was generated, to emphasize the material characteristics (Fig.3). In the last phase, the model was scaled on the reference of the existing plan[7]. The final model has enough resolution for visualization purpose and virtual fruition.

4. Study of historical documentation for a process of philological reconstruction

The following philological reconstruction, carried out by consulting archival records provided by the Municipality of Verona, was structured based on the two main historical phases that changed the castle image. The two historical periods taken into consideration are the Scaliger period and the phase of Habsburg domination. During this later one, the castle has suffered several changes whit the aim to reconvert it into a defensive battery. In order to digitally reconstruct the elements that no longer exist, an important amount of broad spectrum information was used. In the development of the Scaliger phase, the historical drawings were essentials; among them was of the utmost importance the one created in 1663 by Iseppo di Cuman[8]. In his representation, it is possible to identify the presence of a moat in the south-eastern portion of the wall with a drawbridge that led to the entrance of the castle. Moreover, in the forepart of the currently existing portal there was a rivellino gate system of which it is still possible to see the foundations recovered following numerous archaeological excavations (Figure 4). Likewise for the portion of the north-eastern wall, no longer existing (as it was demolished and replaced by a series of embankments used as defensive spots during the nineteenth century), the archaeological evidences and the map of Cuman have allowed to reconstruct the perimeter layout of this portion of the boundary. On the city walls there were also towers that articulate the ring path. To find out in what number and in what position they were, numerous historical sources[9] were used, integrated with the representation of Cuman. Similar structures from the castles of Soave and Sirmione were taken as a model for the architectural characteristics of the towers (Calisi, Cianci 2018). For the philological reconstruction of the Habsburg period, various survey made on the castle by the Austrian Military Engineers were used, in particular one made

Figure 5. Modeling phases of the Scaliger reconstruction.

in 1859 [10] and one dated 1860 in which the detailed plan of the castle and the wall of the bastia is combined with a series of sections of the newly constructed defensive works. To support the cartographic information, photographs and historical memories were used too.

5. Digital reconstruction: operational process and results

Once generated the textured model, it was imported for the digital reconstruction of the castle within the mesh management software, Rhinoceros. For the reconstruction of the castle, in the texturized model, only the portion of the wall that currently exists was maintained as the modifications that took place over the centuries have also affected the conformation of the land in a conspicuous manner. In fact, in the reconstruction of the Scaliger period, the riverbed of the ditch was modeled, while in the Austrian reconstruction all the shooting ranges within the walls and in the north-eastern portion of the fortress were rebuilt. In the reconstruction of the medieval period, following the modeling of the terrain, the volumes of the towers and the missing perimeter of the wall were extruded. In the last phase, the elements inside the parade ground (such as the church and the houses, found in the 1664 drawing) were modeled[11] (Figure 5). The changes in the conformation of the fortification that occurred during the Asbrugic period were recreated in the second reconstruction, thanks to the inclusion of the 1859 relief within the software. After being scaled on the textured model, it was used as a reference for the extrusion of volumes. The result is two models that frame the historical moments of the fortress and in which it is possible to observe and analyze the changes that have occurred over the centuries.

To highlight the existing castle from the historical reconstruction, the model was treated and highlighted with chromatic differences to distinguish the existing (textured portion) and the reconstruction operation (Figure 6).

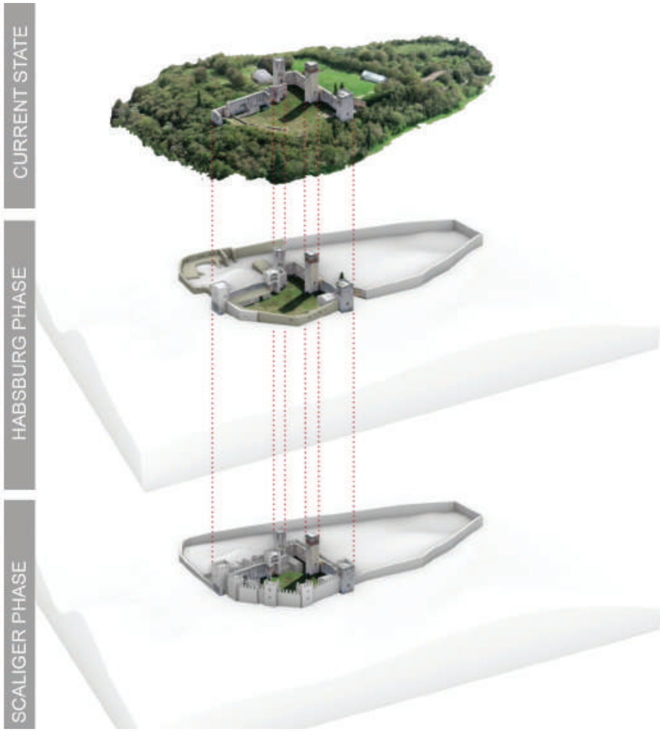

Figure 6. Reconstruction phases, results.

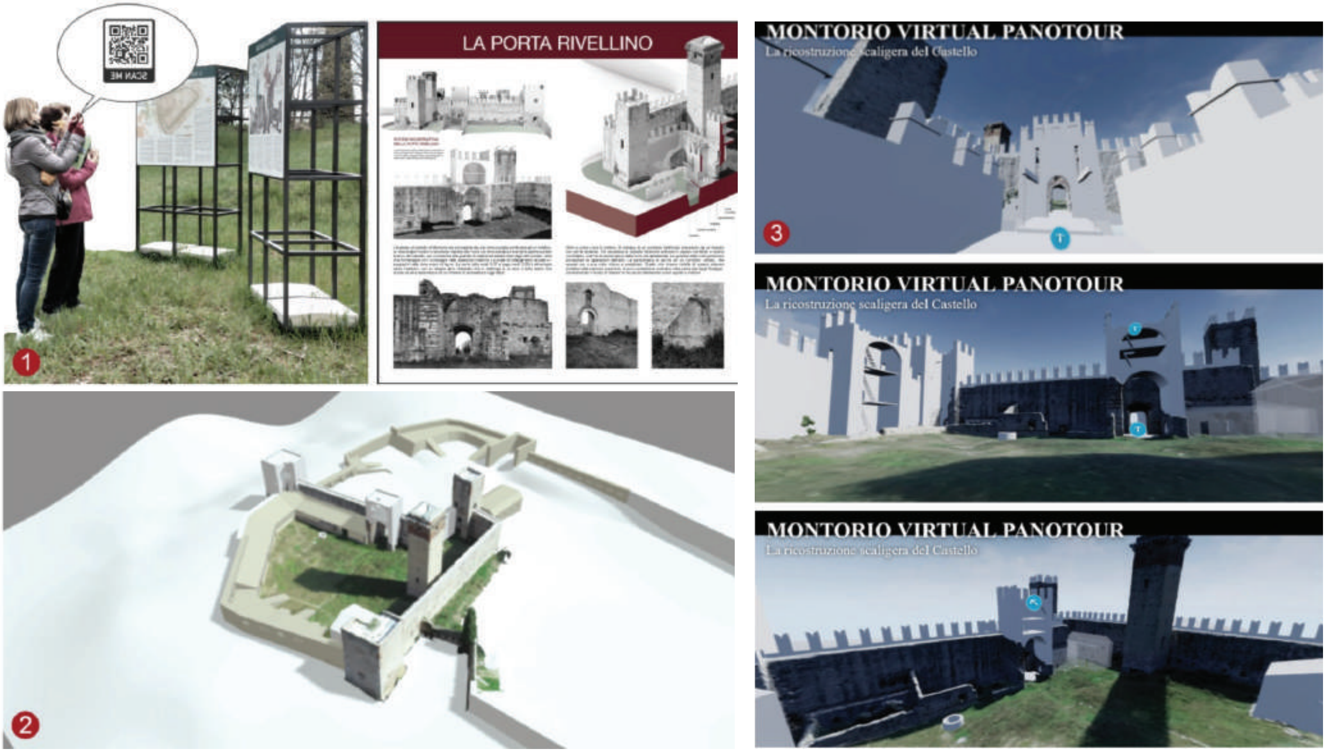

Figure 7. Fruition opportunities: 1 – Graphic reconstructions for exhibitions; 2 – Models available online; 3- Creation of virtual tours (panotour).

6. Conclusions

The 3D model developed can serve many purposes: its use can help to understand and study the Scaliger defensive systems and to comprehend the changes the castle has undergone over time. In a museological perspective, the potential of a 3D reconstruction can be exploited by the creation of virtual and augmented reality systems.

Within the framework of exposition, it can be viewed through digital devices scanning a QR Code printed on the exhibition panels (Figure 7). Otherwise, through the potential of 3D printing, it is possible to create a physical model to give the possibility of use to all age groups and people with disabilities. In this way, the municipality of Verona promoted an exhibition inside the Montorio Castle aiming to explain the cultural relations and historical events that have gone through these defensive systems. 3D models of the philological reconstructions were used in various ways: for the creation of 2D drawings explaining the architectural elements, for virtual tours and online models that can be used by scanning the QR code.

In conclusion the application of this type of methodology is successful for the creation of 3D models suitable for online use. Furthermore, the rapidity of acquisition allows it to be extended to a territorial study of the castles in order to better understand the role, as a defensive spots, that they have played over the centuries, especially during Della Scala government. Clearly an increasing interest in studying the castles from a territorial scale can lead to a broader understanding of it. The enhancement of the landscape and its stone architectures allow the creation of cultural paths that can favour tourism and the rediscovery of these architectures often forgotten by history.

Notes

1 L. Alloro, M. Pasa, 2003, p.43.

2 Ivi, p.58.

3 One of this description is provided by Carlo Belviglieri in Grande illustrazione del Lombardo-Veneto, 1859: "...bello e pittoresco fino a questi ultimi giorni né quali venne brutalmente mutilato dagli austriaci".

4 For more information about projects that used documentation methodology with video frames see: Croce V., Martínez-Espejo Zaragoza I. (2018).

5 Drone's characteristics: video resolution 4K/60fps, camera sensor: CMOS 1", pixel: 20M, focus: 8,8 mm/24 mm (format 35 mm) f/2.8 -f/11 autofocus. The video shooting quality is 4k, frame width 3810, frame height 2160, 29.97 fps.

6 To compare different SfM methodology applied to fortification documentation, see: Picchio F., Pettineo A. (2019); De Feo M. (2020); Liuzzo M. et al (2020); Versaci A. et al (2021).

7 The plan, attached in the archeological report and drawn after the excavation of 2013 realized by Thompson Simon - scavi e rilevamenti archeologici and kindly shared by the municipality Verona.

8 Drawing realized by Iseppo Cuman in 1663, taken from Alloro L., Pasa M. (2003). Il castello di Montorio. Analisi storica, socio-economica e architettonica, p. 69.

9 Among the historical sources need to be mentioned the one written by G. Orti Manara in 1824: "Esso... ha sette torri nel su recinto, ed una nel mezzo"; and the one date back to 1854 included in the poem Invito a Montorio: "L'attuale castello di Montorio [è] cinto da sette torri con una nel mezzo".

10 Habsburg survey date back to 1859, taken from Alloro L., Pasa M. (2003). Il castello di Montorio. Analisi storica, socio-economica e architettonica, p.79.

11 Luisi R., (1996), pp.42-45, the author describes the residential aspect inside the castle. Generally, the castle enclosure contained houses, stables, warehouses and vegetable gardens. In the case of Montorio, the representation of Cuman is confirmed by traces of buildings that emerged during the archaeological excavations.

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Keywords:
Archaeological rescue, Stratigraphic analysis, 3D GIS, "Santa Margherita" complex in Pavia.

ABSTRACT

The present research focuses on the experimentation of different data acquisition techniques and model restitution for the creation of information systems dedicated to the management of archaeological excavations. In detail, the research is applied to the "Santa Margherita" complex in Pavia where, following construction work, archaeological evidence emerged. Through surveys, conducted also with micro-drones, it was possible to obtain models that can be import into a GIS environment. The purpose of this research is to test the effectiveness and the quality reliability of 3D GIS models from SfM data acquired from UAVs.

Close-range potogrammetry for the production of models and 3D GIS platforms of archaeological rescue excavations

1. Introduction

Rescue archaeology is a relatively new term but whose concept has long been known: recovering archaeological information from sites that are threatened or actually about to be damaged or destroyed. The causes of destruction are sometimes due to nature, but more often they are due to human development on the territory (Carandini, 2010). In this perspective, rescue excavations place the archaeologist in an uncomfortable condition: site selection is determined by urban planning activity rather than the needs of archaeology. Moreover, immediately threatened sites may require drastically altered survey techniques rather than standard procedure, and excavation may take place under difficult, rushed, and even dangerous conditions (D'Andrea, 2008). As a result, the quality of the results may suffer: the data may be incomplete or even misrepresented, and since the site may be destroyed, this would result in the impossibility of further investigation to correct errors or clarify ambiguities.

Within this context the research is conducted on the case study of the "Santa Margherita" complex (Figure 1). Since August 2021, in fact, a series of 15 excavation essays have begun at the site of the former Santa Margherita Institute in Piazza Collegio Borromeo, Pavia, with two purposes: to be functional for engineering-structural determinations of the building (aiming at converting the complex into apartments) and useful for stratigraphic reading for the archaeological understanding of the site and its documentation. This demand, combined with the urgency of keeping memory of what was discovered, led the company "GEA archaeology," engaged in the preventive excavation activities on the site, to take advantage of the technical support of the Department of Civil Engineering and Architecture of the University of Pavia. In particular, the agreement defined the documentation strategies for the development of an archaeological excavation information system developed by researchers of the experimental laboratory Dada-LAB.

Figure 1. LEFT: a 1941 view of the portion of the building with the tower and oratory dedicated to St. Margaret. CENTER: the building overlooking the north side of the square. RIGHT: the inner courtyard with access to the wrought-iron "First Aid-Acceptance", in the background, the "Sacco" tower and that of the Lacchini palace.

Figure 2. LEFT: detail of the neighbourhood from "bird's eye" view of Pavia (around 1600); RIGHT: detail from Hollar's map (1662).

Significant archaeological evidences have emerged in the course of the excavation activities. In fact, some of the essays carried out, are placed in areas of already known or presumed archaeological potential. For this reason, the research activity is therefore aimed at documenting a chapter of Pavia's history that, faced with the task of construction activity, will be lost.

2. The case study: the Santa Margherita complex

The first settlement of the "Pio ricovero Santa Margherita" is the residence of the Pavia poet and jurist Catone Sacco. The house, in fact, is mentioned from 1458 in notarial documents and owes its current appearance to interventions made in 1571.

The period between 1571 and 1858 is reconstructed by Dr. Sergio Martini, as part of the 2010 Report on Archaeological Interventions for the benefit of the "Soprintendenza Archeologica Belle Arti e Paesaggio (SABAP) for the provinces of Como, Lecco, Monza-Brianza, Pavia, Sondrio, and Varese" under the direction of Dr. Sara Matilde Masseroli, and is deduced from available cartography.

In particular, from a "bird's eye" view of Pavia (1600) it is appreciable the building presumably referable originally to the "Sacco house" and the corner building having its origin in the tower of the same name, which then became "Pio ricovero Santa Margherita"; immediately south of this is appreciable another building having an east-west trend, hypothetically referable to the Santa Margherita oratory.

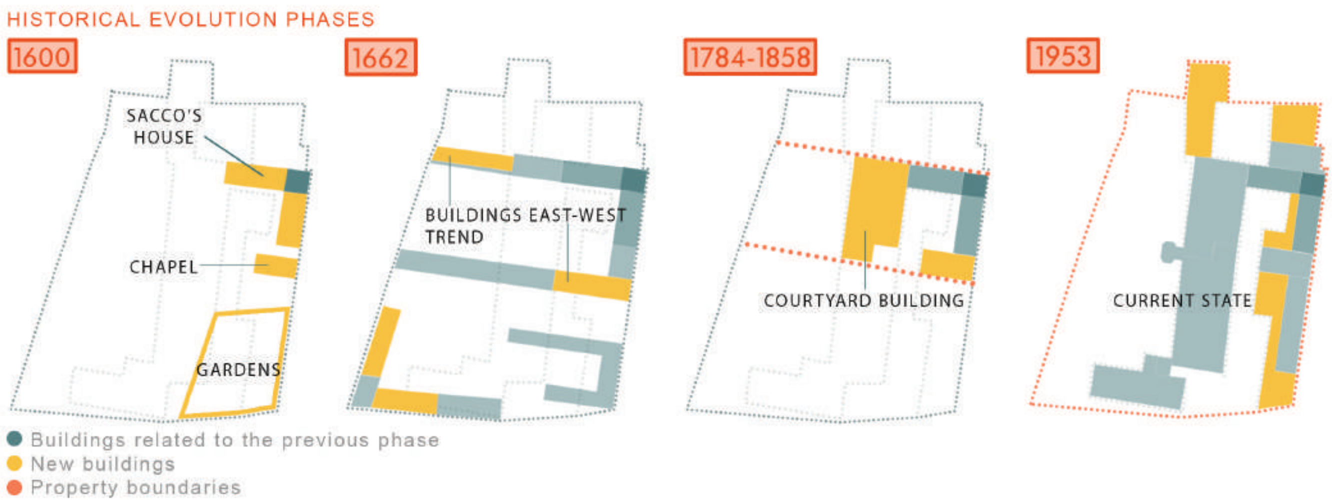

Figure 3. Some of the historical phases the site has gone through.

Figure 4. Some the archaeological evidence found in the site that are still in the dating process.

From an oblique view of 1659 and the Hollar's map of 1662, however, it is possible to observe how the original complex is enriched by a series of terraced buildings proceeding along the same course. These buildings were later actually identified during archaeological assistance activities.

The available cartography does not allow reconstructing the period between 1662 and 1784, when (after 118 years) the terraced buildings disappear and the Santa Margherita begins to take its final conformation, becoming a "courtyard" building.

From 1858 the property is named at the land register as "Luogo Pio delle Convertite," a reference to the mission of the Pia Casa del Soccorso as a shelter for repentant prostitutes. Between 1903 and 1912 two new buildings were built: the central one corresponds to the buildings in which structural evidence of archaeological interest was found to be of high density and which archaeologists have dated as certainly pre-1571. (Figure 3)

Given the archaeological evidence (Figure 4), preservation of the memory of the site has become critically important. In addition, because of the complexity and rapidity of archaeological intervention carried out in emergencies, it is necessary to define data management systems that are easy to apply, but at the same time offer not only a representation as faithful to reality as possible, but also allow for cataloguing and organization of information that can truly help the chronological and functional interpretation of the excavation.

Figure 5. From left to right: Extensive survey with CAM2 Laser scanner FOCUS; Broad survey with DJI MAVIC MINI 2; Detailed survey using Canon EOS 70D.

3. The documentation of rescue excavations

Standard techniques for archiving artifacts include technical drawing of plans and sections, compositional diagrams, and photographic surveys of stratigraphic units. These techniques are effective but have several limitations in that they are time-consuming, not only in situ, but also during post-production activities outside the excavation site, where the information may no longer be accessible.
The needs of Cultural Heritage preservation and the problems associated with emergency excavations have therefore led researchers to consider unconventional methods of excavation documentation and management: GIS systems and 3D modeling techniques (Roosevelt et al. 2015). The two approaches, employed individually, have their limitations in the archaeological field. GIS is the ideal tool for documentation and information storage because it integrates excavation site registration procedures, data management, and functional analysis; however, it lacks a faithful representation of the artifact and excavation area. 3D modeling, on the other hand, although more realistic and suitable even as a basis for virtual reconstruction, by not including any kind of information about the archaeologist's understanding and analysis, is useless and ineffective and aimed at pure entertainment (Dell'Unto, 2022).
3D integration in a GIS environment clearly can only work if the model is easily usable; therefore, a method needs to be developed to be as effective as possible from several point of view: in the actual representation of the artifact, in the management of information related to the object, in the graphical rendering of the relationships between objects, in the timing of modeling and data entry, and in the digital enjoyment of the system.

4. Methodology Acquisition

The investigation of this research is aimed at conducting an evaluation of aerial photogrammetry for excavation documentation from the perspectives of timing, restitution, data, and purpose. The goal is to understand, in the context of preventive archaeology, whether UAV systems are suitable tools for generating optimal models for subsequent 3D processing and GIS input, which software generates the most reliable model, and whether the use of drones allows the operator easier in situ documentation of the excavation area.
An integrated survey (Figure 5) was carried out during the documentation phase of the complex:

- Extensive survey using laser scanner;
- Broad survey of the excavation area by UAV;
- Detailed survey by photographic shooting from the ground for stratigraphic units.

Specifically, although both metrically supported by the laser survey, ground photogrammetry was used to document each subsequent excavation phase for the purpose of reconstructing the stratigraphic units; while aerial photogrammetry was used to have extensive textured data of the entire excavation area for GIS input.
The objective of this extensive UAV acquisition campaign on the area was to obtain a general model, with a good geometric resolution and a valid chromatic component, to which the individual models obtained from ground photogrammetry could be referenced.
The UAV used has been a DJI mavic mini, a drone that due to its characteristics of harmlessness, lightness and ease of use is configured as one of the preferred UAV tools for close-range detail photogrammetry.
The piloting was performed manually, flying over the excavation area at a constant height and trying to cover the surface with an "s" path, with a designed GSD of 4 cm/pixel. With the will to obtain a 3D model with a high quality texture component , a campaign was created with a uniform exposure of the area.
More than 400 photographic images were shoted, whose alignment on the SfM software was guaranteed by an overlap of about 70-80%.
The images were processed in two different SfM software: Metashape 8 (by Agisoft) and Reality Capture beta1.0 (by CapturingReality). The decision to carry out this dual processing for each dataset is aimed at testing the potential and limitations of the two software, in order to find the most suitable tool (in terms of result accuracy, ease of use, and processing speed) to handle the large amount

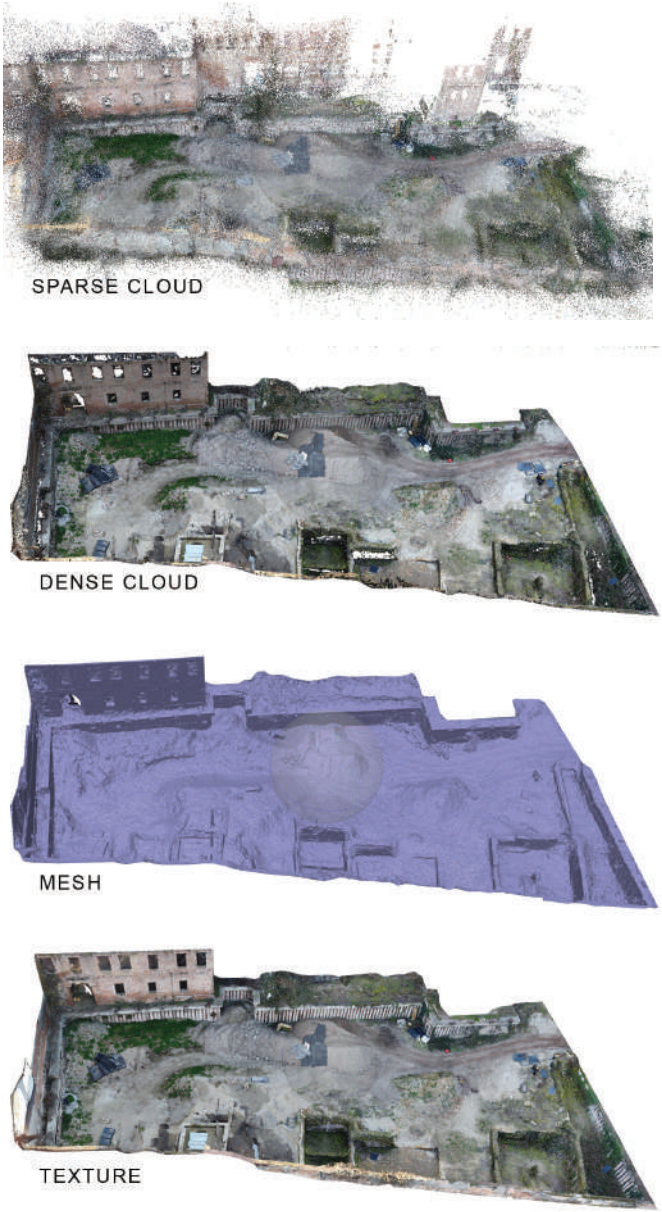

Figure 6. Data processing in Agisoft Metashape from point cloud (sparse and dense), to mesh model, till the textured model, ad the first level of detail for the development of GIS platform.

of data acquired in a archaeological excavation and create a sufficiently accurate model of the surveyed area.
The comparison was performed using a desktop computer with a 3.30 GHz i9-7900x CPU, NVIDIA Ge-Force GTX 1080 Ti graphics card and 64 GB RAM. The two points clouds obtained from this processing allowed us to make considerations about the pros and cons that characterize the workflows followed with the two software.
First, the collected dataset was processed in a single chunk within Metashape (Figure 6). During the automatic alignment phase, 422 images on 422 were aligned correctly. A sparse cloud of 2032919 points was then extracted. Once this phase was completed, the dense cloud of the entire archaeological site was obtained. It is composed of 57034286 points. Next, the polygonal mesh was processed. The result was a triangular mesh composed of 11406831 faces and 5724976 vertices. Finally, the texture was produced, with a resolution of 8192 x 8192.
At the same time, the same photo set was processed within RealityCapture(fig.8). By subjecting the frames to an initial alignment process for automatic calculation of their position and orientation in the scene, the polygonal mesh was then derived. Specifically, the software was able to automatically align 432 images on 438, resulting in a point cloud of about 1281565 points and a triangular mesh composed of 28990472 faces and 14539661 vertices. Again the texture was processed, with a resolution of 8192 x 8192.
At this point, it was possible to compare the results of the two workflows, identifying strengths and weaknesses (Figure 7). A first significant strength of RealityCapture concerns the processing phase, which took around 1 hour, while on Metashape it took more than 4 hours. RealityCapture also allows the dense cloud and mesh to be processed simultaneously, helping to make the workflow faster and easier. Reality Capture mesh has higher quality; this is proven by the number of polygons of the overall model, but detailed views also show that objects texture is better reconstructed.
Finally the two models, after being georeferenced within CloudCompare, then where exported in MeshLab.

METASHAPE			
	Tie points	Mesh	Texture
Settings	Accuracy: high Generic preselection	Quality: high Surface type: arbitrary (3D)	Mapping mode: generic Blending mode: mosaic
Results	2.032.919 points	11.406831 faces 5.724976 faces	Texture size/count: 8.192x8.192

REALITY CAPTURE			
	Tie points	Mesh	Texture
Settings	Max feature per mpx: 10.000	High model Detail decimation factor: 0,1	Texturing style: visibility based
Results	1.281.565 points	28.990.472 faces 14.539.661 faces	Texture size/count: 8.192x8.192

Figure 7. Comparison between the model from Metashape (left) and the one from Reality Capture (right).

Given the large number of polygons from which the photogrammetric model is composed, a series of decimations[1] were carried out in order to lighten the overall model and simplify management actions in GIS environment. MeshLab was the best choice in order to do that because (compared to other software as Blender, or MeshMixer) it allows polygon reduction without losing texture mapping.

Once decimated, M(a) and RC(c) models were imported into the GIS environment (Figure 8). ArcGIS Pro (by ESRI) was found to be the best software from the perspective of model management[2] as it retains the model location and texture once imported (.dae file). As can be seen from (Figure 9), the two models have a comparable mesh (in terms of numbers of polygons), however, the texture resolution of the model from Reality Capture is of greater detail. This metodology also showed that when dealing with such complex objects in a GIS environment (such as archaeological sites, which are characterized by highly

Figure 8. M(a) and RC(c) models overlapped and georeferenced in ArcGIS Pro.

Figure 9. Comparison between the final decimated models. On the left the model M(a) from Metashape, on the right the model RC(c) from Reality Capture.

irregular surfaces and extremely complex volumes), RealityCapture offer a much complete reconstruction and a must faster way of processing data.
Because of that, the combined use of UAV for data acquisition and Reality Capture for data elaboration, simplify and speed up the process and so it helps a lot especially when dealing with rescue excavations.

5. Conclusions:

The use of drones in the context of an emergency excavation, allows the documentation of sites that are difficult to access or in any case to reduce the operator's risk during the survey phase if there is a context (due to natural or anthropogenic causes) that presents critical issues related to safety.
The case studies examined the "Santa Margherita" complex in Pavia, where the high-resolution aerial imagery obtained from UAVs was imported into SfM photogrammetry software to create fast and automated generation of a 3D textured model.
Aerial photogrammetry allowed 3D reconstruction of the excavation context with a higher resolution and speed of restitution, which is therefore essential in the context of rescue archaeology. The high accuracy of the 3D model can be used to document and monitor changes over the excavation phases. (Figure 10).
In addition, the created 3D model was imported into GIS in order to produce a textured and metrically reliable base of the excavation area. Individual 3D models derived from close-range terrestrial photogrammetry were then superimposed on this base to document the stratigraphic units. This thus enabled the creation of a 3D database that not only allowed the realistic visualization of individual stratigraphic units (with their associated tabs), but also placed them in a realistic, textured context of the excavation area. This is of great importance from the perspective of logical and functional interpretation of the archaeological excavation, as it not only enables visualization of the relationships between the individual stratigraphic units, but also an understanding of how they relate to their surroundings.

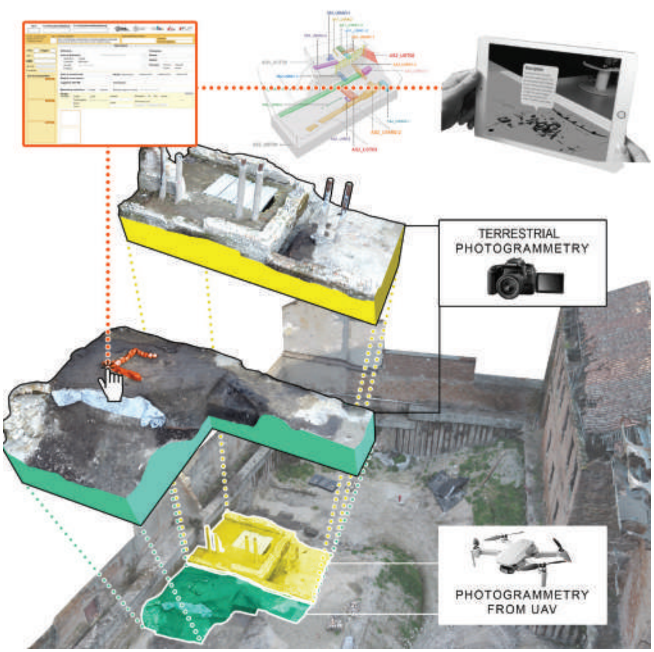

Figure 10. Close range acquisitions scheme for the analysis and stratigraphic representation of the archaeological rescue.

The result is thus a 3D GIS model that enables responsive visualization of large, high-resolution 3D models. The tiled model created is built on models obtained from photogrammetry from UAVs (suitably decimated), while "hierarchical tiles" of which the model consists of are taken from terrestrial photogrammetry.
This methodology made possible to increase, in a very sensitive way, productivity in the field, compared to traditional methods used in archaeology.
This paper also holds the potential to pave the way for furthering accurate, realistic, reliable, and relevant research in the nascent field of drone-based archaeological documentation.

Note

1 The original model from Metashape (5703415 polygons) was cleaned and was decimated by 1/10th of the original value (model M(a): 421538 polygons) resulting in a model with a bounded resolution of the textured surroundings (further decimation would have compromised the resolution of the model). The original model from Reality Capture (14495236 polygons), was cleaned and decimated first by 1/10 of the original value (model RC(a): 1331038 polygons) and then by an additional 1/10 (RC(b): 133103 polygons), but the model resolution was not optimal. Therefore, the RC(a) model was decimated by 1/50 (RC(c): 665519 polygons) obtaining a model comparable (in terms of number of polygons) with the M(a) model from Metashape.

2 A comparison was made with the ArcScene PRO software: in this case, the problem was related to the fact that once imported, the models did not keep the geographic position when replaced/integrated, also the model did not automatically keep the texture. Since the texture cannot be held, the number of polygons in the mesh has to be increased; this results in difficult model management.

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SfM Photogrammetry, Drones, Archaeology, Selinunte, Temple G.

ABSTRACT

In the past two decades UAV have been increasingly used for the survey of wide areas. The chosen case study, the huge heap of ruins of the Temple G in Selinunte, demands a higher accuracy than that usually accepted for wide areas survey; nonetheless, the morphology of the ruins makes laser scanning survey inadequate to the purpose of the analysis and interpretation. The proposed methodology integrates SfM photogrammetry from UAV and action camera's photos. A test on a specific area has evaluated the accuracy of photogrammetric survey through the comparison with laser scanning data.

Multi sensor photogrammetric techniques for the documentation of the ruins of Temple G in Selinunte

1. The case study

The Temple G of Selinunte is one of the greatest Doric temples of Sicily and Magna Grecia. It is one of the three temples (E, F, G) built outside the walled town, in a sacred area today named 'eastern hill' (Figure 1). The temple was never finished and it is therefore a precious subject for researches on construction techniques in the classical age. At the time when Selinunte was discovered, all temples were ruined to the ground, presumably after an undated earthquake. Laser scans taken 2009 with Leica ScanStation2 and Leica P20 scanners, addressed the documentation of the naos. These scans evidenced the difficulty to achieve a thorough documentation of the temple with laser scans taken from the ground: the size of the blocks and their messy layout made hard to safely place the device on the tripod; furthermore, most of surfaces were surveyed in unfavorable conditions, i.e. with a small angle of incidence of the laser ray, particularly relevant in elements with a cylindric or conic-like shape (drums). Another obstacle for the documentation was the vegetation that grew naturally in the interstices of the ruins and covered relevant parts of the architectural elements. In 2021 the opportunity for a new survey was provided by the administration of the Archeological Park of Selinunte, that operated an in-depth vegetation's removal, thus making visible many parts of the temple that had been occluded in the previous 20 years. In the years between 2009 and 2021 UAV were strongly developed and became an affordable tool for surveying. Aerial photogrammetry overcomes most of the problems that laser scanning survey had encountered in the previous surveying sessions. Nonetheless, aerial photos, even when taken with an oblique shooting axe, cannot document many parts of the blocks that face interstitial areas and can be documented only at a closer view from the ground. For the documentation of these areas and the integration with the general documentation of the ruins, a workflow, based on SfM photogrammetry restitution from images taken with an action camera has been tested.

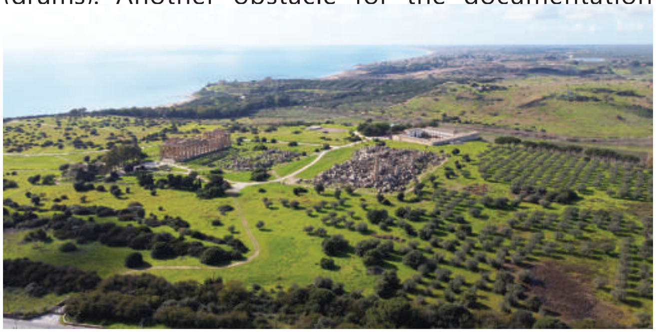

Figure 1. Aerial photo of the Eastern Hill in the Archaeological Park of Selinunte.

2. Related works

SfM photogrammetry is a well established technique for Cultural Heritage documentation; its accuracy is strongly related to the cameras, the lenses, the light conditions, the radiometric properties of surveyed surfaces; even if its potential is widely acknowledged, laser scanning survey is still today considered the reference for the verification of the accuracy of SfM photogrammetric survey, given that fewer variables can affect its accuracy. Many studies in the last decade focused the use of action cameras for the documentation of CH: Balletti et al. (Balletti 2014) focus the issue of camera calibration and correction of distortions, one of the most relevant issues when dealing with action cameras; further studies aim at testing the accuracy of SfM restitution from action cameras through the comparison with other surveying techniques: Calantropio et al. (Calantropio 2018) make a comparison with topographic survey; Fiorillo et al. (Fiorillo 2016) and Carraro et al. (Carraro 2019) compare action cameras with laser scanning survey. All the mentioned studies evidence the opportunity to perform specific verification to evaluate the usability of SfM restitution from action cameras images.

3. The proposed methodology

The first step of the surveying process was dedicated to design, place and measure a 482.1m long topographic polygonal that encompasses the area of the Temple. Eight vertexes were marked by topographic nails placed along the route for visitors that follows the perimeter of the Temple. A further vertex was placed in the area of the naos and was connected to the polygonal. The topographic survey was performed with a Topcon IS 101 total station (Figure 2); the closing error of the polygonal, ranging from 10 to 15 mm in East, North and Elevation coordinates, was compensated. The topographic polygonal allowed the measure of 10 rectangular targets fixed outside the Temple and of further temporary circular targets placed inside the area of the Temple in each surveying session. Targets were used for the external orientation of the SfM photogrammetric models.

The vastity of the area and the need for an accurate documentation demanded the execution of more surveying sessions; in order to set a reference system usable in different sessions, rectangular targets were built to be placed on site and stay still for a week or two. Steel sticks, used in the past to mark alignments for cadastral surveys, were used to support 40*40cm aluminum plates that were painted black and white. Steel bolts were customized to fix the plate to the stick and host the conic end of topographic mini prism stick (Figure 3). This homemade system allowed to keep the targets on place for the whole duration of the survey. At each surveying session some rectangular markers were measured to verify that they had not moved and further circular targets were placed inside the Temple and measured as well (Figure 4).
Photos have been taken with an Autel Evo II Pro drone, a 1.2 kg UAV mounting a camera with a 1" wide sensor having a 20mpx resolution, an adjustable aperture ranging from f 2.8 to f 11 and a maximum ISO equal to 12800.
One of the strengths of this device, almost similar in size and shape to DJI Mavic 2 Pro, is the software released by Autel itself, that allows to plan the mission and to control the process of photo acquisition.
For the documentation of the ruins of temple G the mission mode 'oblique' appeared to be the proper choice: when flying in this mode, the software draws 5 grids almost overlapped; the first grid controls the flight lines for the acquisition of nadiral images; the four additional grids are automatically extended outside the main grid to allow the acquisition of the surveying area

Figure 2. Topographic and laser scanning surveying sessions.

Figure 3. Rectangular targets fixed to the ground

with a tilted shooting axe; the tilt angle can be set by the operator; in this study oblique photos were taken with a 50° tilt. Oblique images allowed to document many important parts of the ruins that result occluded in nadir images. Further settings controlled the images overlap, that was set to 80% both for nadir and for oblique images (Figure 5).

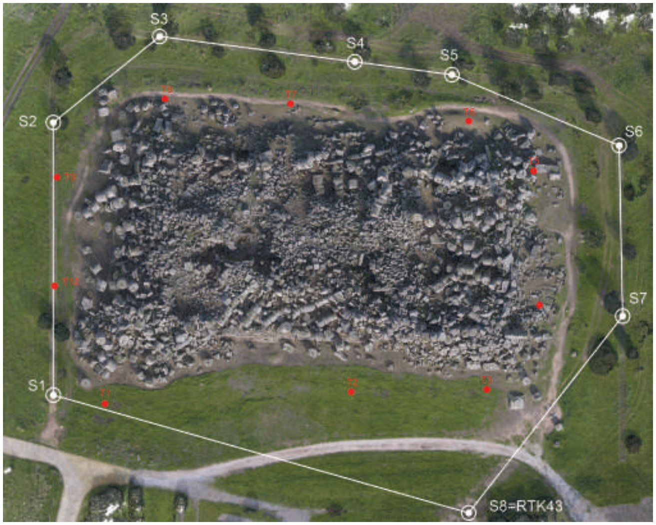

Figure 4. Top view of the point cloud, the topographic polygonal (white) and the rectangular markers (red).

Before starting the execution of missions, some flights were made to test the performance of the device and the effectiveness of the chosen mission parameters. The results of these test flights allowed to fix the following critical issues: i) the file format; ii) the exposure, ISO and the like; iii) the duration of the battery.

The photos taken in the first test flights were registered in the *.jpg file format and taken in automatic mode (exposition, aperture, white balance). The quality of these images resulted inadequate for the purposes of the research; further tests evidenced a great improvement of image quality when using the *.raw file format and manual settings for exposure, aperture, ISO and white balance.

One of the problems, due to the vastity of the area and to the needed detail for the reconstruction of the architectural ruined elements, was the choice of a low flight altitude, to allow an adequate detail of the pictured elements; lower altitudes imply a higher number of images and longer time for photo acquisition.

Another relevant issue in battery duration is the wind speed; Selinunte faces the Mediterranean sea and the region is almost windy at any season.

In test flights appeared that wind forced the UAV to a continuous correction and thus reduced the flight time, from 30 minutes to even 15 minutes.

Figure 5. The UAV used for the research and the mission planner interface

The first mission, dedicated to a general documentation of the ruins, was planned with a flight altitude of 25m for nadir images and 35m for oblique images; the UAV shot 1446 images. The mission needed 6 batteries; the UAV was equipped with 4 batteries and the time to charge one battery is almost 90'; the charge of the two additional batteries required 180'. The second session of the mission was therefore completed at a later time and the light condition of the site had changed in the meanwhile; this feature would become a critical issue in photogrammetric processing (Orientation, texturing). The resolution of images and the different lighting conditions suggested to use these photos for a general documentation.

For a more accurate documentation of geometry and texture new missions were planned dividing the area of the temple into 3 parts, so that the entire acquisition could be performed at a lower altitude (higher image detail) with the available 4 batteries.

The altitude of flight ranged from 15 to 18 meters for nadir and 20m for oblique images. The photos taken for the documentation of the three parts amount to 5605 (Figure 6).

The photogrammetric processing was developed with Agisoft Metashape; in the reference panel GPS data recorded by the UAV were cleared and topographic coordinates of markers were uploaded; in the calibration panel, the size of the sensor was typed. All images were aligned and the external orientation produced errors ranging from 6 to 9mm. The following step addressed the automatic extraction of point clouds and meshes. Mesh extraction was initially executed using Depth Maps as the source datum for calculation. Usually the mesh models generated from depth maps result more detailed than those extracted from dense point clouds, but a critical issue in depth maps are sharp edges; in this research the edge at the intersection between the conic surface of columns' drums and their flat top and bottom surfaces resulted swollen. The mesh extracted from the dense point cloud produced a less detailed documentation of surfaces but a more accurate representation of sharp edges (Figure 7).

Date	Number of flights	Number of images	Average flight height Nadiral photos (m AGL)	Average flight height Oblique photos (m AGL)	Focal lenght (mm)	GSD of Nadiral photos (cm/pixel)	Area Covered (mq)	Number of GCPs
18.12.2021	6	1446	25	35	10.57	0.57	15000	18
05.01.2022	6	1706	15	20	10.57	0.34	5025	9
15.01.2022	6	1885	15	20	10.57	0.34	4500	10
19.01.2022	6	2014	18	20	10.57	0.41	6700	13

Figure 6. Flight mission data resume.

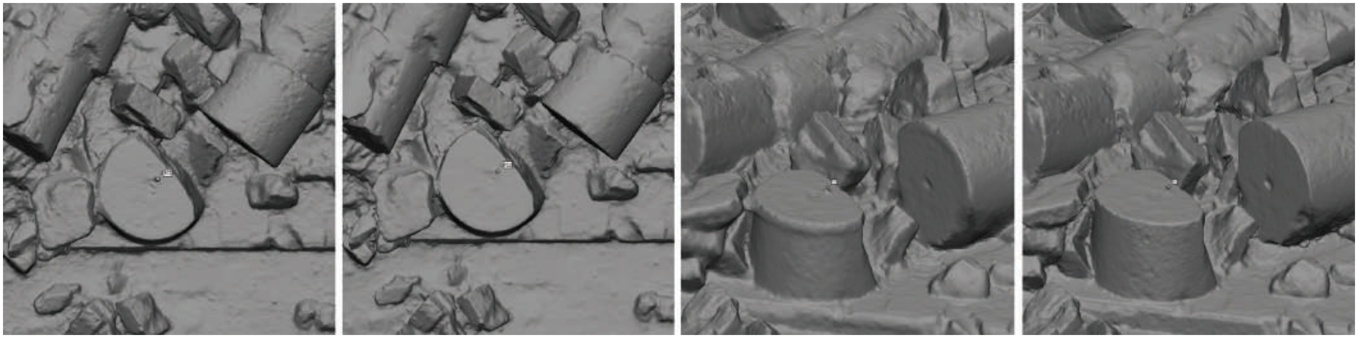

Figure 7. Meshes extraction from depth maps and dense cloud sources. From left to right: Top view of depth maps and dense cloud meshes; Perspective view of depth maps and dense cloud meshes.

The visual inspection of meshes and point clouds extracted with photogrammetric processes from UAV images evidenced a good overall and detailed documentation of the ruined architectural elements (Figure on the cover) but, at the same time, the presence of many occluded areas that could not be shot by the UAV; most of these areas are effectively inaccessible, but some recessed parts of the blocks are visible when moving on the ground. The survey of these parts would make the documentation more complete and accurate.

In most cases the survey of the occluded parts is difficult because they are visible from very recessed and narrow spots, that make the use of laser scanners inadequate or impossible. Laser scans of these recessed areas would furthermore imply complexities in the registration with other sources.

For the documentation of these areas the research experimented the use of photos extracted from footages taken with a 4K action camera Insta 360 One R mounting a wide angle lens (Figure 9). The test for the photogrammetric alignment of these photos has been developed as follows: i) the photos from the footage have been added to the chunk with the photogrammetric model of the test area; ii) an alignment process that kept the previous alignment unvaried has been performed to align UAV and Insta 360 photos.

The mesh model extracted from this chunk showed a good integration of the two sets of photos and a more complete documentation of the ruined block (Figure 10).

Before using this workflow for the documentation of the occluded areas of further ruined architectural elements, a test on an isolated and easily surveyable element has been developed in order to evaluate the reliability of the data extracted from photos taken with the action camera Insta 360 One R.

The element chosen for the experiment is a capital of one column of the eastern front, that is today isolated from the heap of ruined blocks, close to the south eastern corner of the Temple. The capital is still integer and is oriented upside down.

The surveying session was developed in three stages: i) laser scanning survey; ii) photo shooting with a mirrorless camera Sony Alpha 7R, with a 35mm lens and a resolution of 36.4 Mp; iii) footage shot with the Insta 360 One R; iv) photos taken with the UAV used in this study from an altitude of 10m from the ground.

In order to refer all surveyed data to the same coordinate system, some Leica targets were placed above and around the capital; the targets are mounted on a steel round basement and can be turned around a vertical and a horizontal axe. The rotation allowed to set the targets in a vertical position for the referencing of laser scans and of photos taken from the ground (Sony and Insta 360), and in a horizontal position for the referencing of photos taken with the UAV (Figure 11).

Laser scans were assumed as the reference for the evaluation of the accuracy of the other surveying techniques.

The test for the comparison of the point clouds extracted with the mentioned techniques was performed with Cloud Compare; the software is capable of measuring cloud-to-cloud, cloud-to-mesh and mesh-to-mesh

Figure 9. Photos of an occluded area facing a narrow interstice extracted from a footage taken with the action camera Insta 360 OneR.

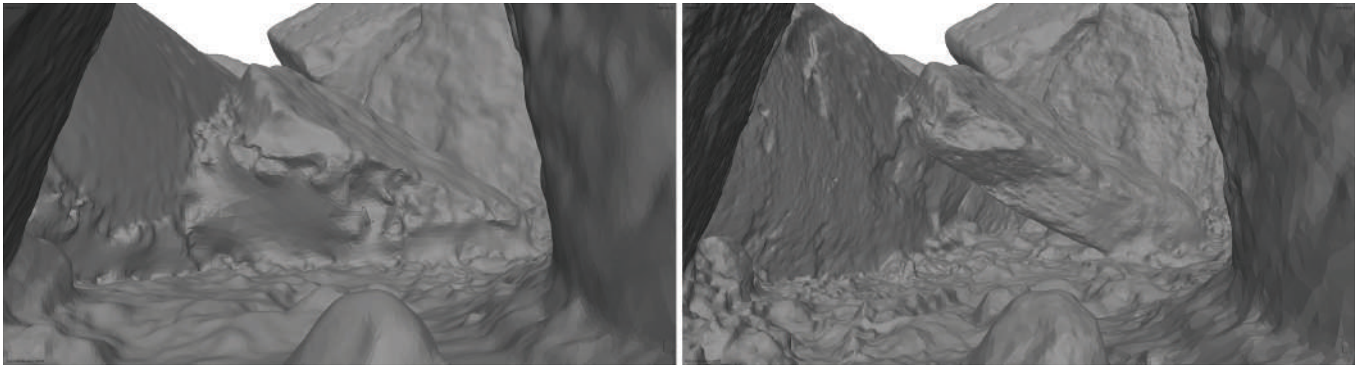

Figure 10. Mesh model of the ruined block before (left) and after (right) the integration of action camera photos.

distances, using an inner distance calculation tool (C2C) that is not customizable and performs only the calculation of absolute distances. A similar calculation can be performed with the M3C2 Cloud Compare's plugin, that allows a more robust and signed result.
M3C2 calculation has been applied to the multi sensor data taken for the survey of the capital of Temple G evidenced, assuming the laser scanning point cloud as the reference datum (Figure 12). The calculation was executed using the normal of the laser scanning point cloud generated by Recap; the value of the projection diameter has been set equal to 0.129m and the Maximum search length was set equal to 0.340m. The result of M3C2 calculation evidenced, as expected, that the best performance was given by the photos taken with the mirrorless camera, with a 0.005436 standard deviation and a profile showing that most points are not far from the mean value. Another visualization of the error has been created with a pie chart, that shows that the 80% of points have a distance from the laser scanning point cloud minor than 4mm. The results of comparison for the Insta 360 One R show a wider profile of the 0.006087 standard deviation and that the 64% of points has a distance lower than 4mm from the laser scanning point cloud. Finally, the histogram generated for the point cloud extracted from the photos taken with the UAV showed some critical issues, i.e. a bimodal profile, that suggests some interference in the acquisition process;

Figure 11 Capital at the SE corner of the Temple: laser scanning (left) and photogrammetric survey from photos taken by the UAV (middle) and the action camera (right).

the standard deviation results equal to 0.007480 and only the 35% of points has a distance minor than 4mm.

4. Conclusion

The research tested a workflow for the photogrammetric survey of a complex archaeological monument, a huge heap of ruined architectural elements that once made the Temple G of Selinunte. Tests on laser scanning evidenced that this technique is not effective for the purposes of an overall documentation. Photos taken with an UAV provided a good documentation of the ruined blocks, but many areas resulted undocumented; some of these areas have been shot with an action camera and the images have been successfully integrated with those taken with the UAV. A test for the evaluation of the accuracy of restitution from action camera images evidenced a good accuracy but, at the same time, some critical features in the restitution from the images taken with the UAV appeared. Further experiments will address the exam of these critical features using further UAVs on the same test area.

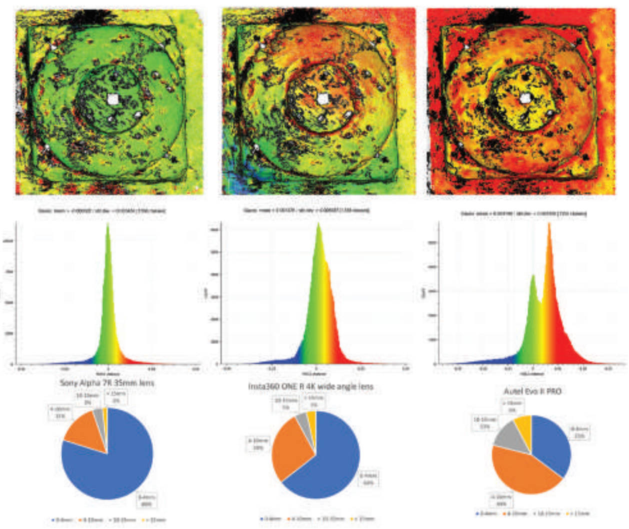

Figure 12. M3C2 distance calculation for the evaluation of the accuracy of photogrammetric point clouds. From left to right: photos taken with the mirrorless camera, with the action camera and with the UAV.

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UAV, Conservation, Valorization, CulturalHeritage, NewPerspectives.

ABSTRACT

UAV (Unmanned Aerial Vehicles) platforms are an extremely effective tool for small and large scale diagnostics and monitoring of Cultural Heritage and landscapes. However, these tools with their great potential have limitations on the operational level. The following contribution compares two different case studies with similar criticalities: the archaeological park of Tindari, in Sicily and the Montecatino complex, in the Lucca area. Both sites present problems related to the accessibility of the sites and to the application of traditional terrestrial survey techniques.

Conservation and enhancement of Cultural Heritage using UAVs. New perspectives for the preservation of some case studies

1. Introduction

Today's cultural dimension has been hit by a multitude of changes and transformations concerning the fruition of Cultural Heritage, also thanks to the increasingly central role played by technology in its many facets (UAV, Virtual Reality, video mapping, web, social networks, etc.). The issue of conservation and enhancement of heritage is in fact closely related to these processes of management and use of knowledge. In particular, for several years the technologies that led to the birth of unmanned aerial vehicles (UAV) have allowed the development of increasingly advanced and specific devices to meet the needs of a variety of areas, including cultural and landscape heritage. The diffusion of UAVs in the architectural and archaeological field is due to the numerous fields of application and advantages that these devices allow to obtain. The main advantages given by the use of lightweight UAV-type platforms can be applied in the initial phases related to the first approach to the asset; to the various study analyses, up to the aspects of publicizing the assets and monitoring over time; drones therefore can be used in the different processes that characterize the various phases of knowledge and enhancement of Cultural Heritage. Among these processes, UAVs can be enormously useful in the first steps of the study, for a rapid reconnaissance of the area in question, in order to assess the various criticalities and peculiarities. The purpose is to plan and manage in an optimal way the subsequent phases of analysis, thus realizing a careful planning of the operations to be carried out in the survey campaign.

They can also be used for the photogrammetric restitution that allows to generate, quickly and with reduced investment, the data necessary for the realization of metric drawings. These works can be used both as an instrument of knowledge and as a basis for the realization of multimedia products for the publicizing of the good itself (Figures 1, 2).

As a matter of fact, UAVs can be used for a strategy of promotion and communication of Cultural Heritage directed towards an offer that, following the traditional instruments of heritage dissemination, can meet the new needs of the public. Photographic and video recordings of cultural assets placed in their context that develop over areas of varying extensions, such as archaeological

Figure 1. Tindari Archaeological Park view.

Figure 2. Torre del Bargiglio view, a defensive element of the Lucca Republic.

sites or historical centers, can provide an appropriate tool that allows to bridge the gap between perception of reality and visual limitation of the context in which the final visitor is located. Another area in which it is possible to benefit from UAV platforms is the constant monitoring of Cultural Heritage, as it is possible to reach less accessible areas and verify the conditions without the risk of damage by man: a UAV is in fact a safe, modern, and of great versatility.
In the realities described below are summarized some of the results obtained through the application of UAV platforms. For both the Archaeological Park of Tindari and the Montecatino complex, these new technologies have made it possible to obtain better quality data in less time. In addition, they have made possible the verification and inspection of portions not accessible except through the use of lifting platforms. The UAV platforms have accompanied the process of knowledge of the artifacts during all phases of study; confirming themselves as a valuable support both for carrying out investigations on landscapes and archaeological ruins and for a constant monitoring of their state of conservation.

2. The ruin of Montecatino (LU)

The architectural documentation, both in general and related to restoration and enhancement projects, has always used two-dimensional systems such as maps, elevations, sections and plans to represent three-dimensional geometric data. In recent years, the habit and the need to produce digital documents, together with the opportunities and advantages in terms of time spent, possibility of processing the data, quality of the level of detail, have led to provide for the finalization of all documents in digitized form, making the digital survey solution superior to any technique adopted in the past (Verdiani 2016).
Through survey campaigns carried out through sessions with 3D Laser Scanner, total station and digital photogrammetry terrestrial and drone, it is possible to produce certain elaborations, correct from a metric point of view and accurate in the description of the state of conservation and any injuries (Figure 3).
Very often the sites to be surveyed are located in territories that are difficult to reach and are in such conditions as to make the survey by the operators unsafe or even unfit for use. This is the case of several ancient military architectures such as castles, towers and walls, which

Figure 3. Some of the equipment used to survey the sites.

were deliberately built in places potentially difficult to attack (Pecci 2020); today, the same characteristics make difficult the surveys, the restoration and the structural interventions. Some of the fortifications that were part of the territorial defensive system used by the Republic of Lucca can be traced back to this category of site.
Briefly introducing the defensive system of Lucca is useful to emphasize that Lucca, an urban center of Roman origin located in the north-west of Tuscany, was the capital of the small homonymous Republic for more than 400 years: it remained independent from 1369, when it freed itself from the yoke of neighboring Pisa, until 1799, when the French troops of Napoleon entered the city (Manselli 1983). The State, to maintain control over the territories, therefore decided to ensure proper protection. Architects, military engineers, and war experts designed the new layout to adequately defend the city from the new military siege techniques, which the previous medieval walls would not have been able to support (Martinelli, Puccinelli 1983). At the same time, the professionals who followed one another in the design of the new city walls were also responsible for the restoration and adaptation of the elements of territorial defense. The fulcrum of this whole system of sighting and signaling, inside the city, was the Tower of Palace (Bartoli 2011), at the top of which were installed fixed sights and telescopes aimed at the towers placed inside the territory and those along the borders of the Republic.
One of the elements of the signaling system can be found in the ruins of Montecatino. The homonymous hill located 15 km north of the city/capital, hosts on the summit plateau the remains of an ancient church and of a tower/bell tower used for the transmission of communications. Probably restructured in the 17th century, the tower could communicate with the Lucca Palace’s Tower, with Aquilea, with Brancoli and with the Bargiglio. The site of Montecatino presented several difficulties of survey due to the morphology of the places, the intrinsic architectural characteristics and above all the state of preservation. For the acquisition of data, the survey techniques mentioned above, 3D laser scanning and photogrammetry both from the ground and from the air, were used (Figures 4,5).
The use of the drone has first of all allowed to reduce the risks for the operator; the possibility of incurring dangers such as sudden landslides, landslips, falling ruins and problems related to an extremely steep slope have been strongly reduced.


Figure 4. Montecatino ruins points cloud.


Figure 5. Site aerial view.

At the same time the 3D model generated was fundamental for the analysis of the static nature of the site and to carry out the studies necessary for the realization of plans, sections, and elevations. On the latter, cracks and deterioration maps were developed, monitoring the site in a periodic and constant way. The UAV platforms have also been used for a communication and awareness campaign of the citizenship, which - as the European Landscape Convention of 2000 underlines - is an indispensable behaviour for a correct valorisation of Cultural Heritage and has a fundamental role in the practice of conservation; to put in place a publicity - according to the declination of 'public domain' - of the site. (Valenti 2012) – in every phase of the cognitive/conservative process, can in fact be fundamental, if we also consider the large amount of data easily available on the web, very often lacking an established historical-scientific interpretation (Figure 6).

During the planning phase of the photogrammetric survey campaign, it was decided to carry out different flights: the first one to realize a zenithal coverage and the second one for an oblique one, filming the artifacts at 360 degrees and taking photos at regular intervals. As for the UAV models used, two different ones have been employed: a DJI Mavic Air 2 that has more anti-collision sensors and that has allowed a design of the flight plan and a DJI MINI 2 more manageable for the shooting of the most critical parts that has required a pilot to fly by sight, at a constant distance from the monument, controlling the framing of the camera on the smartphone (Figure 7).

Figure 6. Montecatino ruins panoramic view.

This allowed the photos to be captured from different perspectives and heights to capture more detail. This acquisition mode allows the Structure from Motion software to create more accurate 3D models than using only aerial images taken at a fixed height and distance. The photos at this point were processed through the Agisoft Metashape photogrammetry program, creating 3D models with a high level of detail and precision. Subsequently of fundamental importance was the scaling of the 3D model, through the measurement of some certain points (elements of the artifacts, angles of structures, markers created specifically, etc.). Finally, from the 3D model made, it was possible the creation of final outputs such as orthophotos, DEM (Digital Elevation Model), manageable within GIS software and / or CAD, for the realization of the studies (Figure 8).

3. The Archaeological Park of Tindari (ME)

A multi-disciplinary approach is one of the fundamental prerequisites for safeguarding and preserving the built heritage. The involvement of new technologies represents an important support tool able to fit into the multiple needs and different levels of scale required by the historical building. The studies carried out on the Sicilian Archaeological Park of Tindari highlight the advantages and criticalities of including UAV (Unmanned Aerial Vehicle) platforms in the knowledge project of an archaeological site. The site, named after the ancient city of Tyndaris, extends over 27 hectares and is still uninvestigated in some areas (Figure 9). The cognitive and analytical process began with the morphometric survey of the site and its emergencies: the significant monumental building with the function of propylaeum, defined as the Basilica, the Greco-Roman theatre and

Figure 7. UAV during photogrammetry sessions.

Figure 8. Photogrammetric's restitution.

Figure 9. Archaeological area of Tindari view. Insula IV and the Basilica.

insula IV, the only excavated one of the many that made up the urban fabric of the ancient city of Tindari. The survey of the entire area was obtained through the integration of Laser Scanner instrumentation and a UAV platform, preceded by a topographical-urbanistic reading.

The UAV was of fundamental importance both in understanding and analyzing the area on a territorial and urban scale, and in analyzing and monitoring in detail the state of conservation of the individual artefacts. The total survey of the area was obtained through careful planning, combining aerophotogrammetric shots with punctual Laser Scanner scans (Figures 10, 11).

A Laser Scanner survey of the single artefacts (Basilica, theatre and insula IV) was carried out both to cover the areas not reachable by UAV and to obtain a better quality of the data of the areas of greatest interest.

The current state of the site, with some parts covered by trees, mainly *pinus pinster* and *olea europaea*, showed the limits of the UAV; in fact, it was necessary to compensate for this lack by acquiring the data using laser scanning and ground photogrammetry. On the contrary, for the apex portions of the Basilica, the use of the drone was fundamental, to reach the parts that could not be reached with the other instrumentation.

The data was then critically re-elaborated through a continuous comparison between the digital models obtained and a direct reading of the site.

The restitution of the metric-geometric data, the critical-descriptive architectural data and the structural data was followed by the analysis of the structural behaviour of the building, the identification of the material consistencies, the identification of the degradation and alteration pathologies and the stratigraphic analysis of the masonry. The latter analyses were carried out by means of a continuous comparison with archive material, which was fundamental to understand which portions had undergone previous restoration work. In addition to the thematic tables, three three-dimensional models of the entire area were created from the point cloud: the first depicts the current state of the site, the second and

Figure 10. Tindari Archaeological Park theatre's Point cloud.

Figure 11. Tindari Archaeological Park theatre's photogrammetric Point cloud.

third show, respectively, a hypothetical state prior to the anastylosis and a hypothetical reconstruction of what the site must have looked like in ancient times (Figure 12).

The critical reading of the complex through a careful study not only of the existing, but also of the archival and documentary sources, both published and unpublished, has made it possible to understand the critical aspects of the site and of the Basilica.

The latter, like most of the Archaeological Park, has been the subject of numerous excavations and anastylosis campaigns throughout the 20th century. The monumental building, we find today is the result of three anastyloses (Ghelfi 2020), the last of which was carried out by means of a special system of tensioned steel cables, passing through vertical perforations inside the wall face (Sorteni 2017).

Through the historical photographs found during the archival investigation, it was possible to hypothetically identify the position of the anchorage points of the steel cables in the apical portion of the facing.

The UAV platform made it possible to verify the actual positioning of these points and to analyze their state of conservation (Figure 13). This operation had not been carried out since the last restoration site was dismantled in the mid-1970s. Without the use of the UAV, monitoring

Figure 12. Tindari Archaeological Park Basilica's Point cloud.

would have required the erection of scaffolding or the use of cranes or lorries with lifting baskets, bearing in mind that access to the archaeological area could only have been by small vehicles due to the narrow access routes to the site. Furthermore, through the UAV platform it was possible to monitor the state of conservation of the asset with a constant time interval in order to verify the material deterioration in the unit of time.

5. Conclusion

The use of UAV platforms in the field of Cultural Heritage has opened new perspectives still under development: from the generation of three-dimensional models for the restitution of surveys and virtual fruition, to the monitoring of accessible sites. In both case studies, starting from the point clouds and from a critical reading of the site, parametric three-dimensional models of the artifacts have been developed, obtained from the laser-scanner data. The discretization of the various structural components in addition to improving the overall knowledge of the space, has also taken into account the new perspectives introduced by HBIM (Heritage Building Information Modeling) systems. These tools and methodologies, with their great application potential and proven versatility, however, require a thorough knowledge of data acquisition, management and interpretation techniques. The operator, as demonstrated also in the cases described here, must keep in mind several variables, which are closely related to each other and strongly affect the success of the scientific investigation. In conclusion, UAV platforms represent an important resource, and in some cases an indispensable tool for the Cultural Heritage sector.

Figure 13. View of the apical portion of the Basilica.

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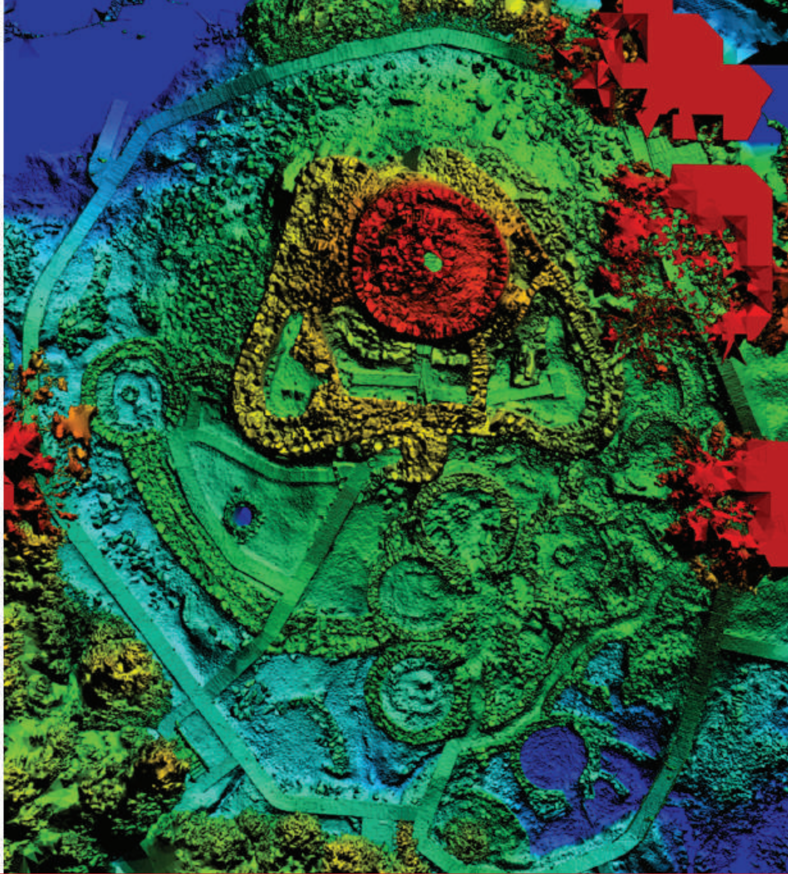

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Keywords:
Survey data Integration, Data Comparison, Image and Range Based Survey, Survey for Cultural Heritage, Software Performances.

ABSTRACT

This paper aims to evaluate the performance, in terms of accuracy and speed, of various commer-cial software (Reality Capture®, Agisoft Metashape® and 3DF Zephyr®) for the integration among image and range-based survey data. Datasets were collected in the Nuragic complex called "la Prisgiona" (Arzachena, SS, Italy), during a collaborative research project between CNR – ISPC and the Municipality of Arzachena, using aerial photogrammetry, topographic and TLS survey. Re-sults of comparative tests demonstrates that, when working on architectural scale survey, passive and active techniques are to be considered homologous in terms of accuracy and precision.

A 3D survey in archaeology. Comparison among software for image and range-based data integration

1. Introduction

Three-dimensional survey techniques are nowadays commonly used as part of Cultural Heritage professional and academic practice, aiming at documenting, understanding and preserving ancient civilizations historic and material legacy (Hassan et al. 2019). Archaeology, among the disciplines that deal with Cultural Heritage makes frequent use of geomatic technologies, to such an extent that this can no longer be considered a phenomenon but more of a consolidated practice (O' Driscoll 2018; Hoon Jo et al. 2019; Trillo et al. 2020). Digitization using image-based and/or range-based techniques applied on archaeological remains is commonly used for excavation records, conservations tasks and heritage management and communication. The massive use of these technologies in CH studies has been, in recent years, a frequent subject for publications aimed at identifying good practices, even if the scientific community has not yet agreed on a formalization for standardizable workflows and procedures. (Remondino et al. 2006; Bitelli et al. 2007; Hoon Jo et al. 2019; O' Driscoll 2018; Aragòna et al. 2017; Erenoglu et al. 2017; Apollonio et al. 2021).

One of the most stimulating aspects in this still open field is the integration between different measurement paradigms, in particular among range and image-based. (Rönnholm et al. 2007). In fact, both techniques have advantages and disadvantages, which are offset by the integration of the two technologies to achieve a more complete coverage of the surveyed area (Rönnholm et al. 2007; Russo et al 2014; Russo et al. 2015). The integration of image and range-based measurement data, considering the high effectiveness of the technique, has a well-established tradition of studies. Search addresses usually consider datasets acquired from TLS and close range or UAV-based images (Rönnholm et al. 2007), then focusing on data registration and, with various approaches, on range maps matching analysis, (Gonizzi et al. 2012; Russo et al. 2014) sometimes using SWOT analysis (Hassan et al. 2019).

This paper aims to analyze workflows within commercial software (Reality Capture® - RC -, Agisoft Metashape® - AM - and 3DF Zephyr® - 3DF -) to evaluate the effectiveness of these approaches for integrating datasets. In particular, a performance evaluation will be made in terms of speed, completeness and accuracy in the cameras positioning. The survey conducted at the *La Prisgiona* nuragic complex, located in *Arzachena* (SS), was used as a case study for this analysis. For dimensions, location and geometry it lends an excellent opportunity to evaluate different approaches and produced data quality.

2. Case study

The three-dimensional architectural survey of the Nuragic complex "*la Prisgiona*" was carried out whitin the agreement "*per un progetto di studio e di ricerca sulla Conoscenza e ricostruzione del paesaggio storico del territorio di Arzachena*". The Agreement was established in 2021 between the CNR ISPC and the Municipality of Arzachena (SS, Italy). The agreement's object is the

On the cover, Top view of "*La Prisgiona*" nuragic complex: Orthophoto (left) and DEM (right).

archaeological study and the digital three-dimensional reconstruction of the territory of the Municipality of Arzachena, the monuments documentation, from a metric, archaeometric and cultural point of view, and the anthropic study of the territory in antiquity. The first activities were carried out in collaboration with the municipality of Arzachena between July and September 2021 allowing to carry out a 3D survey of some archaeological sites including the "*la Prisgiona*". The archaeological site, a large Nuragic village built in a strategic position with a panoramic view of the surrounding area, dates back to the late bronze age and its architectures are the result of 3 different construction phases. (Antona 2012) The *nuraghe* is a *tholos* type construction, consisting of a central tower with a bastion incorporating two side towers. A curvilinear surrounding wall protects the *nuraghe*, enclosing a large courtyard occupied by a well. The village is outside the wall consisting of numerous circular huts and fences. Survey's aims were various, mostly: archaeological remains' accurate documentation and implementation of a digital replica for future public dissemination within 3D visualization systems. The data captured on the field were also exploited for research purposes in geomatics, in this article the result of the integration of image-based and range-based measurement data are presented here for the first time.

3. Data aquisition

Preliminary to 3D acquisition, a topographic survey has been performed with a Ruide R2 total station and a Geomax Zenith 20 system GNSS. Nineteen automatic detection targets (16 bit) have been measured stationing on 6 positions. This data has been used both in the photogrammetric process, to scale and adjust camera orientations, and in TLS survey for registration evaluation and to have homologous coordinates system among range maps from different technologies[1].

As for photogrammetric survey, a DJI mini 2 UAS has

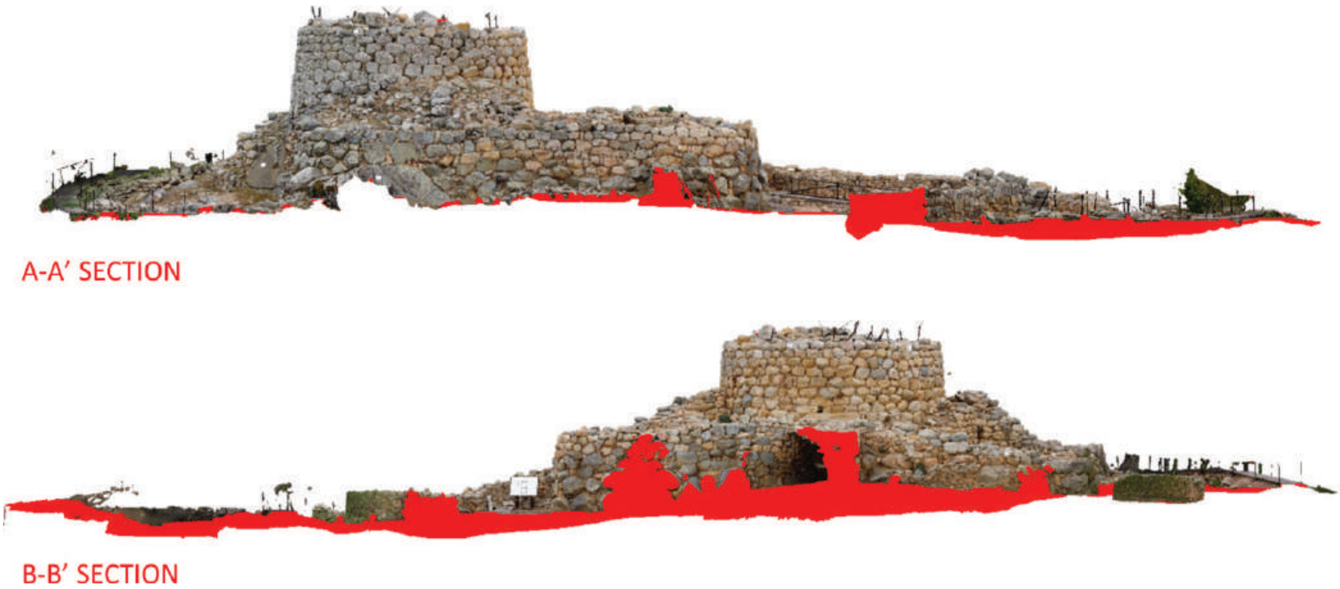

Figure 2. "*La Prisgiona*" nuragic complex: cross sections.

been used (1/2,3'' CMOS, 12 MP.), the images were taken operating a manual flight, surrounding the structure with circles at various distances (4 mm GSD). In order to have an adequate overlapping and resolution, 329 photos have been chosen and processed. After topographic and photogrammetric survey, fifty-seven scans were acquired with a Leica BLK 360[2], mounted on a tripod at different heights but never below 2m. Scan resolution was set to high. Point clouds were registered using C2C registration (RMS 3 mm). in Autodesk Recap®.

4. Data processing and comparison[3]

Photogrammetric set was processed in AM (High Accuracy) producing a dense cloud of 77 mil. points, in RC (normal detail[4]) generating a dense cloud of 28, and in 3DF (urban landscape), having a dense cloud of only 2. Alignment results after optimization showed, in all three software, a noticeable consistency in error estimation (+/- 1 cm).

TLS reference cloud was obtained using Autodesk Recap® through a C2C registration of fifty-seven structured scans. TLS cloud was later referenced in local coordinates and exported as structured data in.e57 format. The same format was chosen for exporting 3D products (dense cloud) from AM and 3DF, while for RC, the export format was.xyz, due to the impossibility to export in.e57.

4.1 Data integration

Integration among photogrammetric and TLS data, within the three tested software, is obtained by different technical approaches, more specifically: RC and AM have a camera alignment approach, even if AM allows a geometric alignment too, which could be useful for the integration of unstructured scans. 3DF on the other side does not make use of photos taken by the scanner while aligning TLS and photogrammetric sets, the procedure has then an approach purely based on range maps geometry registration.

In RC integration is based on synthetic images generated

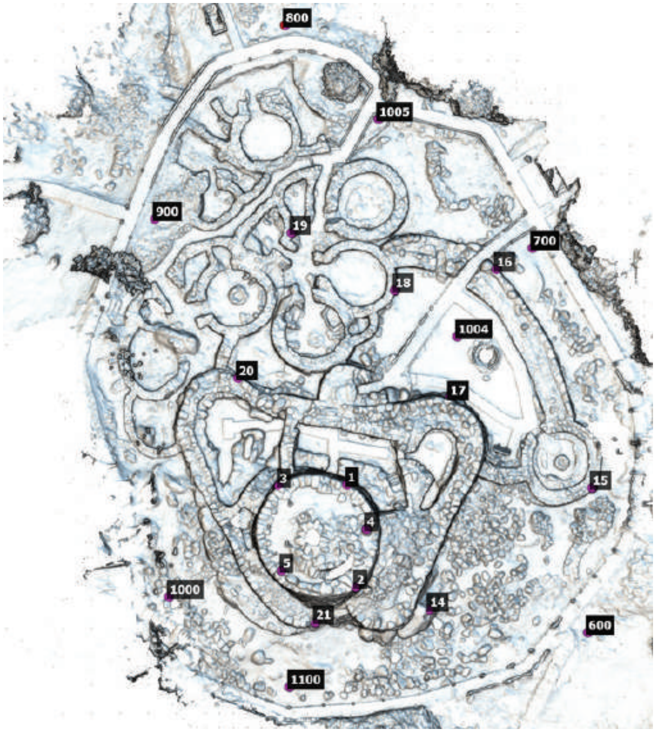

Figure 3. Topographic measures displayed over dense point cloud.

from the TLS registered point clouds using color or intensity. These spherical images, one for each standpoint, are converted into six.lsp files (Julin et al. 2019). The.lsp files are calibrated and oriented for each rotation, generating a cube that is externally positioned and orientated as the TLS standpoint (Luhmann et al. 2020). Photogrammetry image matching and orientation is based the on TLS synthetic images (Luhmann et al. 2020).

AM mainly uses spherical panoramas or TLS depth maps, when the instrument can't acquire spherical images, for the co-registration of TLS and photogrammetric data. Photogrammetric depth maps are merged with the TLS depth data during the dense cloud or mesh generation[5]. If TLS clouds are unstructured, the integration is obtained performing a self-calibrating bundle adjustment through GCPs that can be refined with an ICP between two clouds by the means of external software tools (Fiorillo et al. 2021).

In 3DF the integration among clouds is obtained by merging photogrammetric and TLS data that are always read by the software as "non structured". The integration of the two clouds is articulated in two steps: rough alignment, which can be done by a manual superposition or by corresponding homologous GCPs, and fine alignment, using ICP[6].

4.2 Comparison methodology

Comparison among dense clouds was performed between each photogrammetry-based set and TLS reference cloud. Before comparison, photogrammetric clouds have been finely registered with TLS reference using ICP in Cloud Compare with a consistent result for all sets (RMS 0.25). After fine registration, all clouds, including TLS, were decimated with a maximum density of 5 mm to have a homologous resolution for all data. After this preparatory step a cloud comparison has been performed in Cloud Compare using C2C distance.

In order to specifically analyze deviation among areas shared by image and range-based survey, a first data filtering was carried out eliminating shadow cones area non-shared among TLS measurements and photogrammetric survey (Figure 4). Following this filtering, it has been observed that the average deviation between the photogrammetric clouds and the laser measurements is in a range between 0 and 3 cm. A first comparison was performed by setting the maximum deviation between the two clouds to 1m. The result for the three photogrammetry-derived clouds is close to 6 cm on the whole model. A consistent error in all three models derives from the upper part of the structure: this error is intrinsic to the model, since with TLS this portion of the structure was not correctly detected, given its morphology. To better understand the value of the error and where it lies within the model, the range of the deviation between the two clouds has been reduced performing a filtering of maximum deviation of 4cm to avoid TLS shadow cones.

4.3 Comparison outcome

Figure 5 shows in false colors the deviations among the clouds. Through the calculations performed it is noted that the mean and standard deviations do not exceed 2 cm. Major differences, excluding TLS shadow cones, are located on vertical surfaces.

5. Conclusions

A first observation is the substantial consistency of the deviation between all photogrammetric clouds and TLS reference with an average difference between 0 and 2 cm. The greatest deviation can be observed on vertical elements, especially on those described through images

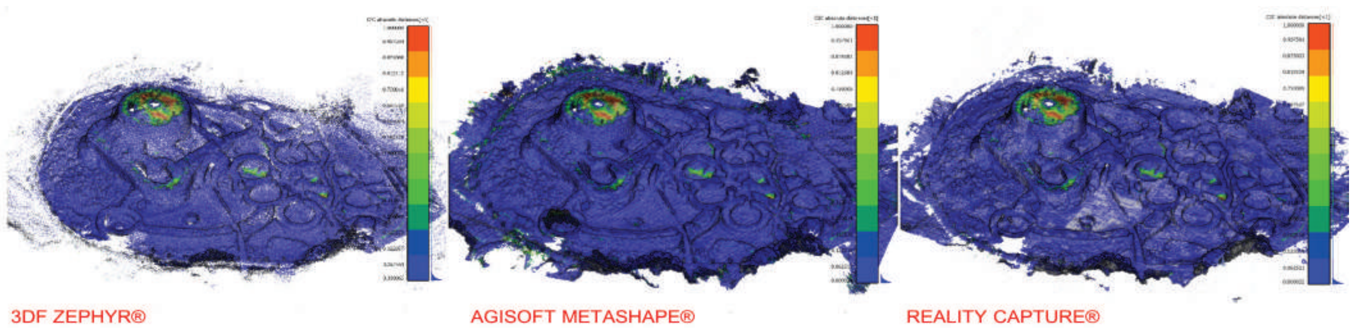

Figure 4. Comparison evidencing photogrammetric cloud distance on TLS shadow cones.

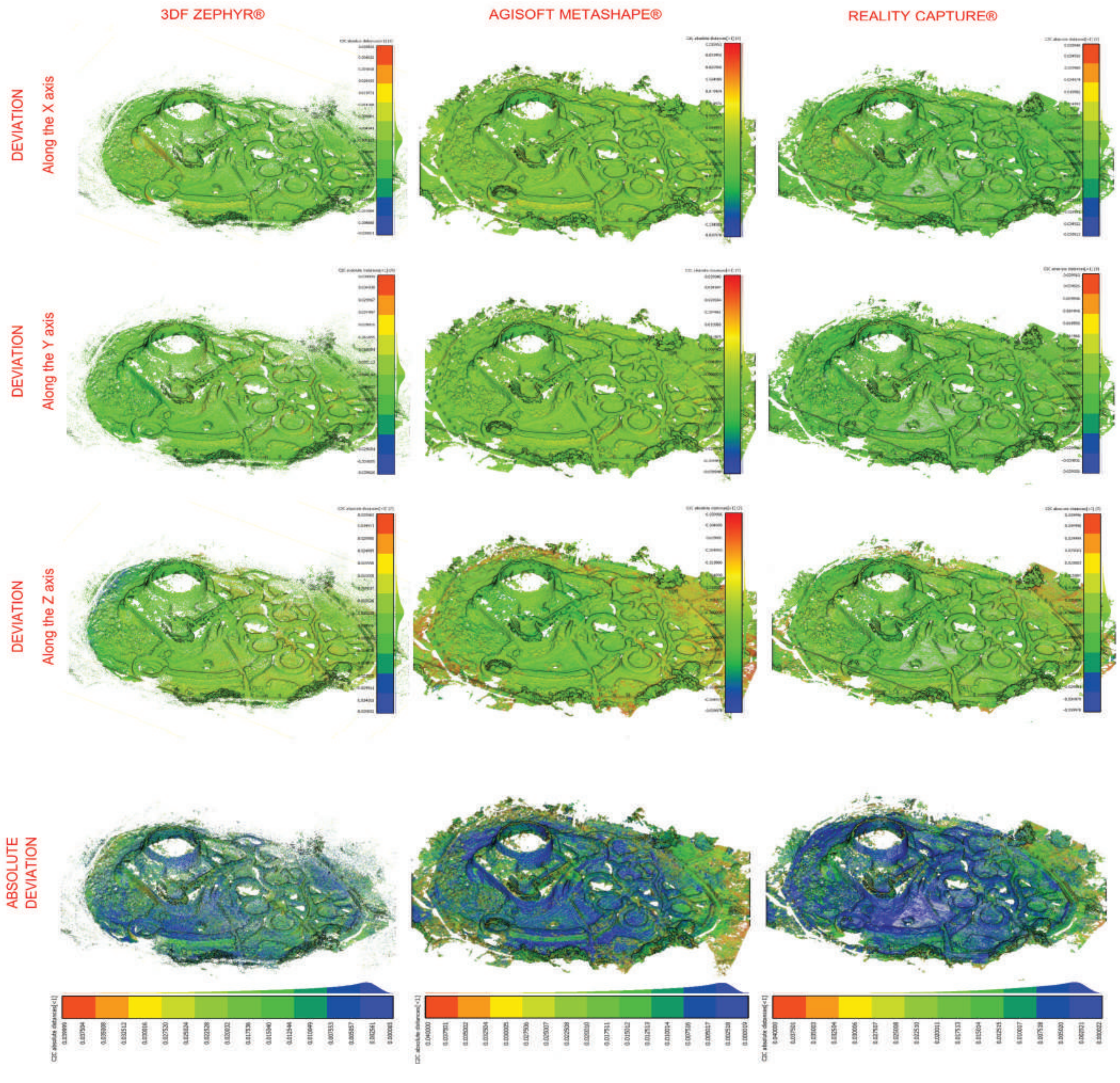

Figure 5. Comparison evidencing deviation.

taken with strong inclination, probably due to hard normal estimation and more difficult camera location.

As for software performance, from a 3D product generation point of view, the most evident difference is found in the 3DF dense cloud, characterized by a much lower density. As for processing time the best performance, considering both alignment and dense cloud generation, has been provided by RC (47 min.), followed by 3DF (74 min.) and AM (91 min.).

When taking into account data management, it is possible to observe a greater elasticity of AM, capable of implementing both structured and unstructured clouds, even if in a less linear solution for dataset management and with a longer processing time. The use of unstructured laser data in 3DF allows the use of a wide range of measurement data while saving storage space, considering the lower weight that unstructured data have compared to structured ones. However, pure geometric alignment can be not as smooth as the ones exploiting images taken from the scanner.

As for RC performance, despite the need to use structured, the ease of the process of registering data from both active and passive sensors using images taken from the scanner, is definitely worth consideration.

Moreover, it is necessary to add the rapidity of the overall processing for both three-dimensional data, through the out of core approach, and the two-dimensional one, a quality partially shared with 3DF.

In conclusion it is difficult, if not wrong, to identify a single solution as the best. The choice can be made only after considering the type of data available. The major advantage of the integration of data from active sensors with image-based techniques can be found on the one hand in the integration of any lack of data determined by the acquisition geometry in the photogrammetric survey and on the other in the integration of shadow cones characterizing TLS survey.

For architectural scale survey, this comparison verified that passive and active techniques are to be considered homologous in terms of accuracy and precision.

Acknowledgements

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Notes

1 More specifically, for the mean of data comparison, local coordinates were preferred.

2 Range 0.6 m - 60 m, max measurement speed 360.000 points/second, HDR integrated camera, field of view 300° on vertical - 360° on horizontal, ranging error 6mm @ 10m.

3 All processes and comparisons have been performed with the same graphic workstation equipped with: In-tel i9 9900k, RTX 3080ti, RAM 128 GB.

4 RC reconstruction process only results in a surface, not a dense cloud. The cloud compared is therefore made of vertices and not of points. That aspect might therefore affect the results of the comparison. https://agisoft.freshdesk.com/support/solutions/articles/31000159101-terrestrial-laser-scanning-data-processing

5 http://3dflow.net/zephyr-doc/3DF%20Zephyr%20Manual%206.0% 20English.pdf

6 Allowing only rotation and translation not scaling.

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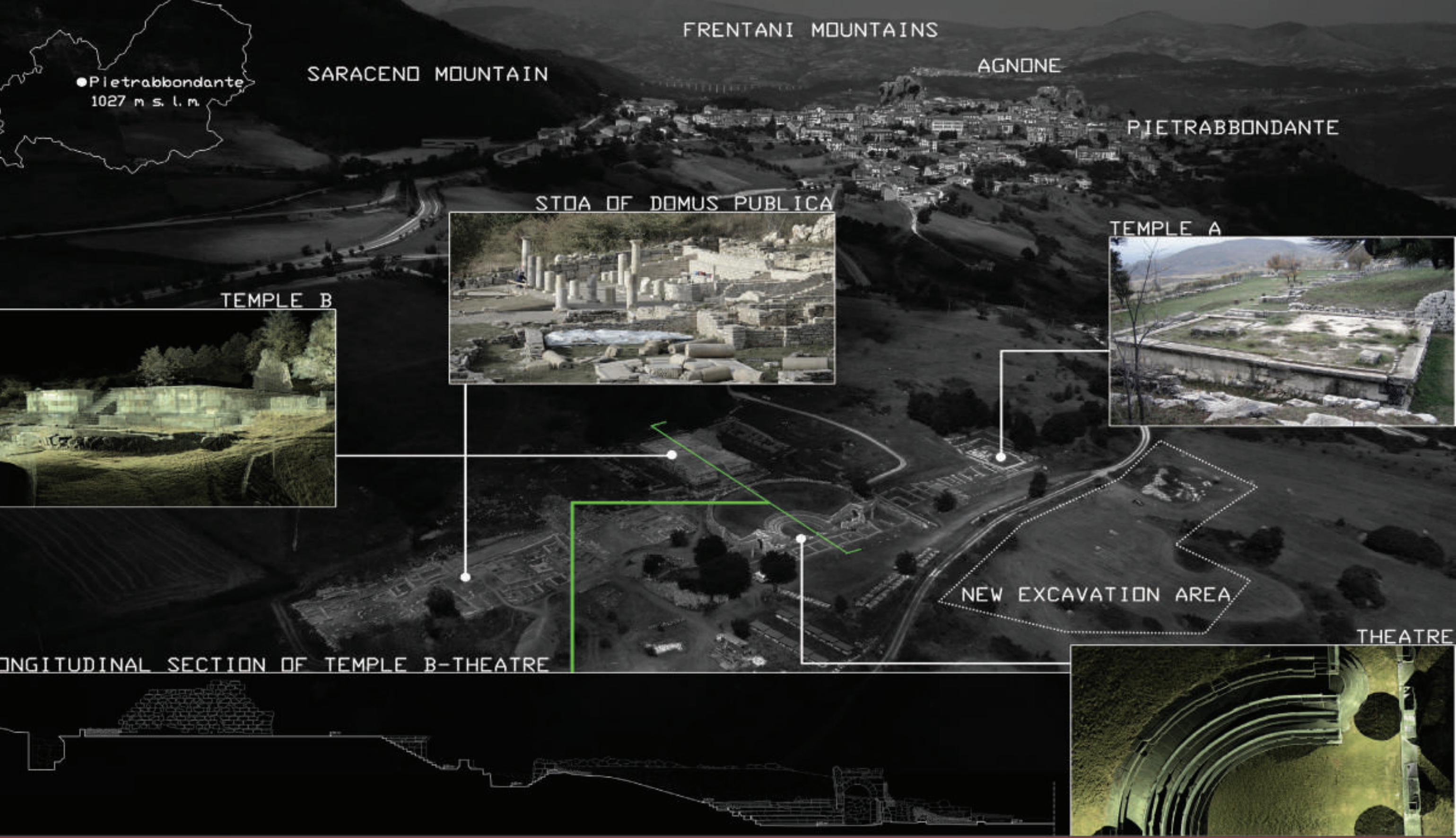

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Aerial photogrammetry, UAS, Pietrabbondante, Archaeological survey, Italic Sanctuary.

ABSTRACT

The paper displays the results of the research project aimed at survey, historical knowledge, and archaeological documentation of the Italic Sanctuary of Pietrabbondante. Due to its monumentality, this site is the most important place of worship in *Samnium*. An extensive use of digital photogrammetry by drone alongside the topographic instruments like GNSS receivers, provided a complete survey of the best known and ancient part of the Italic Sanctuary, the minor temple, the *tabernae* and the *domus publica*. The use of drone photogrammetry can today be considered among the faster procedures for detecting spaces and architectural objects. These latest acquisitions made it possible to integrate the knowledge of the archaeological site by adding new elements to a previous survey campaign using the laser scanner and generating an integrated and complete point cloud.

Experience of integrated survey by drone for archaeological sites. Documentation, study, and enhancement of the Italic Sanctuary of Pietrabbondante

1. Introduction

Archeology today shows an increasing interest in the formation of three-dimensional information systems capable of progressively replacing the traditional two-dimensional representations (Gaiani et al., 2010). One of the reasons can be identified in the fact that archaeological sites often offer only few fragments of the architecture of the past and for this reason the reconstruction of their original consistency becomes a difficult task, in which the technologies of representation and communication are essential.

The first step towards modeling implies in this case the collection of a whole series of data and information characterized by different levels of objective reliability: surveys, metric and geometric analyzes, photographic documentation, historical studies and suggestions collected during the visit (Bianchini et al., 2014).

The need to collect metric data of the artifacts, to allow dimensional analyzes, and make accessible, on a large scale and remotely, access to Cultural Heritage, together with the ease and cost-effectiveness of finding specialized instrumentation and software, have made digital photo-grammetry one of the most important survey methodologies in the archaeological field.

The creation of three-dimensional metric models managed on a computer makes it possible to investigate the manufact and make it "shareable" with users both for virtual visits and for dissemination in the promotional field. In the field of Cultural Heritage, photography was always very important in the documentation of artefacts and the archiving of data.

Especially for architectural studies or in the archaeological field, the application of digital photogrammetry to aerial images has had relevance. From this point of view, the possibility of having high-resolution cameras mounted on drones has favored their use for the documentation, survey, and monitoring of the historical, architectural, and archaeological heritage. In fact, the SfM methodology allows the automatic orientation of digital images, also taken from video, and therefore the generation of point clouds and 3D models from these (Brusaporci et al., 2020).

The combination of these two methods of massive data acquisition, laser scanner and digital photogrammetry, often allows to overcome the limitations that the same technologies present: terrestrial laser scanner clouds often have gaps due to shadow areas, for example, lintels and overhangs, while drones allow shooting from until now inaccessible points; however, there is still greater precision and certainty in the measurements offered by the laser scanner.

Figure 1. General view of the archaeological site.

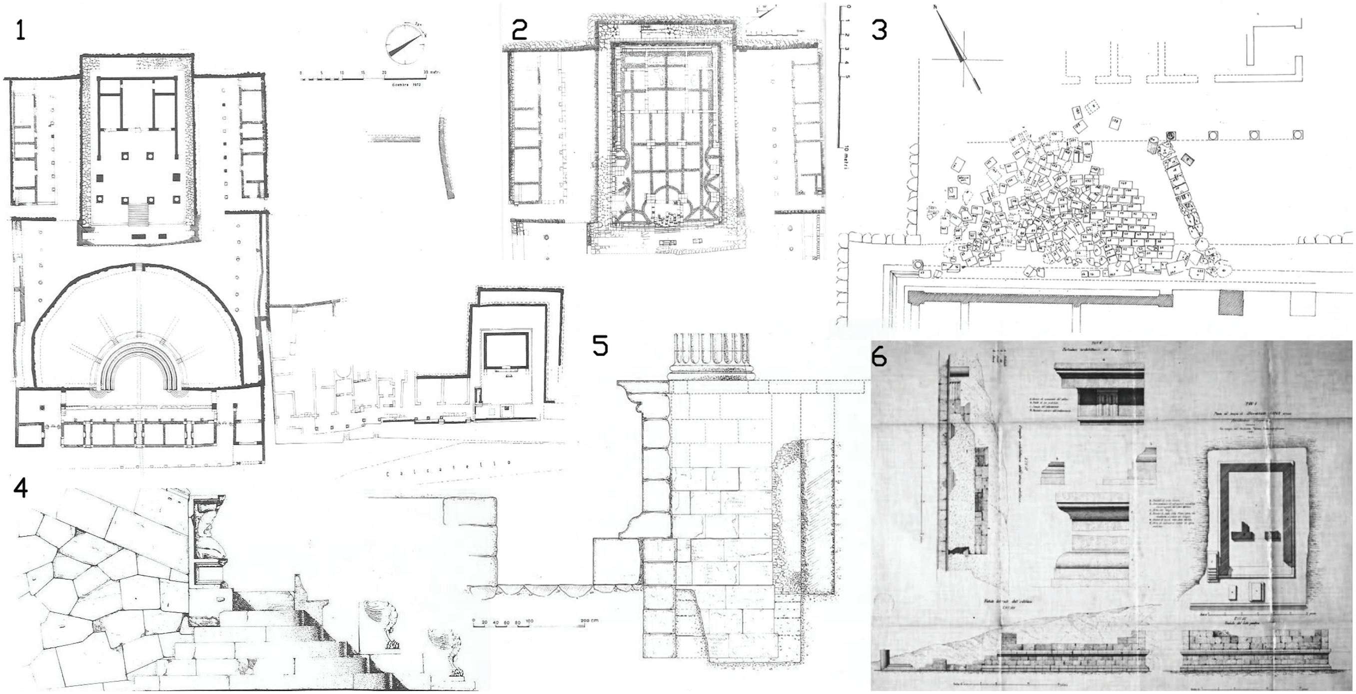

Figure 2. Graphic documentation of the Sanctuary: 1-2-3-4-5, B. Di Marco, Plan of the sanctuary, of the temple B, collapsed wall of the cell temple B, analemmata of the left of the theater, podium of the temple B, 1967-70 ca; 6, U. Ricci, drawings of temple A during the Bourbon excavations, tavv. I-V, 1858.

In addition, it is possible, even after a long time, to integrate the data acquired on the area allowing a new recording of the clouds produced by one and the other methodology. The results can be multiple, from two-dimensional analyzes and outputs, to 3D mesh modeling or HBIM; more generally, the three-dimensional models, through their visualization, are useful in telling the story of the artefact and therefore in the enhancement of the Cultural Heritage (Brusaporci et al. 2017). The research presented here stems from the possibility of updating and completing the data of a pre-entry survey on a topographic and laser scanner basis using aerial drone photogrammetry.Unmanned aerial vehicles have proven highly valuable in the fields of archaeology and Cultural Heritage, as they provide a non-invasive, time and cost-efficient way to document Cultural Heritage (Campana et Remondino, 2014).

2. The archaeological context

The Italic Sanctuary of Pietrabbondante, in the province of Isernia, preserves the most important monumental witnesses of the Samnite religion of ancient Molise. The sacred area extends over an area of over seven hectares, on the slope of Monte Saraceno, at 968 m above sea level and in a dominant position of Sannio (Figure 1). Excavations began in the mid-nineteenth century with the discovery of temple A and the exploration of the theater and were resumed in 1959 with the discovery of the main temple (temple B) (La Regina 1978). Subsequent investigations made it possible to identify other buildings and to better understand the characters and function of the entire monumental complex. In the first half of the 2nd century BC Temple A and two chapels to its left are erected: between the final decades of the 2nd and the beginning of the 1st century BC a unitary project is conceived which will also include the area previously occupied by the Ionian Temple destroyed by the Carthaginians, namely the Temple - Theater complex and the *domus publica*, a representative structure intended to house priests, ambassadors, and members of power politics. This is the moment of greatest splendor and richness of the sanctuary in which, alongside the purely sacred function, the public and political role coexists and emerges (La Regina, 2014). The clash between Rome and the Italic populations during the social war will see the interruption of the projects started and, starting from the first century BC, the sanctuary will gradually lose its religious and political importance, maintaining productive functions and local worship. After about half a century, with the coming to power of Augustus, the land that included the sanctuary was assigned to the Socelli family. The minor sacred buildings will continue to attract the faithful while the main ones fall into neglect and the *domus publica* is transformed into a private home. After the third century, very poor life forms are documented on the site up to the fifth century AD, when the pagan temples still active are destroyed in compliance with imperial edicts.

3. A century of investigations

The graphic documentation produced of the archaeological site of Pietrabbondante begins with the archaeological excavations conducted by the Bourbon Government between 1857-58 and 1871-72. These investigations, by the architect Ulisse Ricci, documented both the plan of the hitherto excavated area of the theater in its entirety and of temple A, with significant architectural details (Figure 2). In 1959 the excavations were resumed by Valerio Cianfarani and Adriano La Regina, and the cavea of the theater was restored by Italo Gismondi. A rich graphic production was produced during the excavations of the 60s by the designer Benito di Marco on the main temple. There are also numerous drawings of the same during the 70s, which update and integrate the plans of the structures in the state of discovery or propose the restitution of their risers enriched by clay decorative apparatus (Strazzulla, Di Marco 1971). Until 2011 topographic instrumental surveys were carried out by the surveyors of the Archaeological Superintendence of Molise. Many graphic outputs in 1:50 scale and detail were produced manually by archaeology

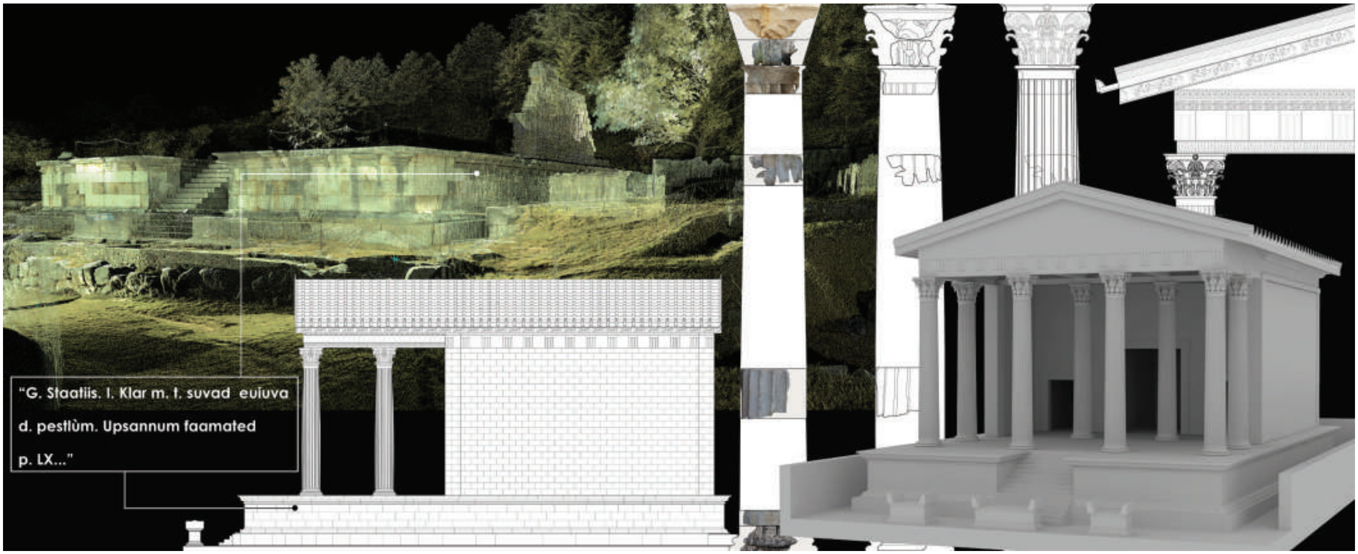

Figure 3. Survey and three-dimensional reconstruction of the main temple of the Italic Sanctuary.

Figure 4. Shooting, positioning of the targets and view of the cameras in temple A and *tabernae*.

students during the excavation campaigns conducted by INASA since 2006. A first laser scanner survey was made in 2013 by the architect Roberto di Re and in 2015 dates to the last aerial photograph of the archaeological area, made by Gianfranco De Benedictis, to document what has been brought to light so far.

4. The first survey and the new acquisition campaign

During the first acquisition campaign, conducted in June 2016, an integrated survey of the theatre-temple complex was carried out, combining different methods and detection tools: long range 3D laser scanner (Leica C10), Image – based modeling and direct survey. The point clouds generated by the 17 stations automatically recorded using the scanner in topographic mode, have become the numerical reference model for the orientation and resizing of those generated for terrestrial SfM of the porticoed areas of the main temple. The processing of these data was preparatory to the 2D representations in 1:100 scale of planimetry, raised of the podium of the temple and the theater and longitudinal sections. The objective of the research of the time was the execution of an accurate survey of the monumental complex dating back to the II BC. and the cataloguing of the finds belonging to the major temple to draw up a probable reconstructive hypothesis of this building, able to improve the overall knowledge of the monument[1] (Figure 3).

Six years after the first survey and following the authorization by the Regional Directorate of Molise Museums, it was decided to integrate the survey of the excavated archaeological area, acquiring the minor temple,

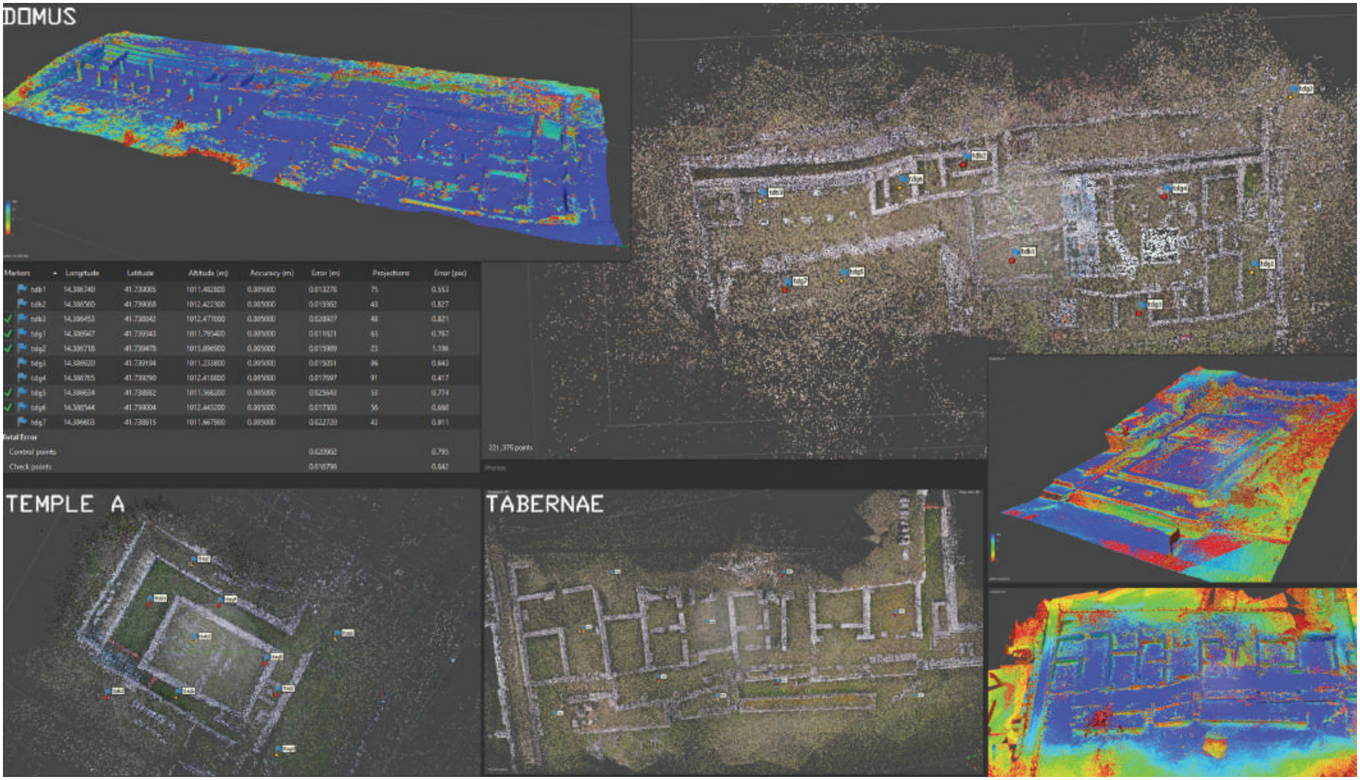

Figure 5. Sparse point cloud, insertion of target's coordinates and cloud confidence of the domus, temple A and tabernae.

the *tabernae* and the *domus publica* (still not open to the public). For this new acquisition campaign, the choice of the survey methodology fell on aerial photogrammetry from drone, accompanied by a topographic GNSS receiver for the georeferencing of point clouds and an error control on photogrammetry measurements. The reasons that led to the choice of this methodology were: the reduced acquisition times, considering the extension of the area to be detected, and the desire to test its limits and potential compared to acquisitions from terrestrial scanners.

Photogrammetric shooting was conducted over three days in February 2022. The aerial photogrammetric survey was carried out using a DJI Mavic 2 Pro quadcopter, which has an unladen weight of 0.907 kg and a flight range of about 31 minutes at a constant speed of 25 km / h. The navigation of the aircraft can be managed manually by a qualified operator using a remote control up to 5 km away or in automatic mode with a pre-established route for waypoints, thanks to the GNSS / IMU system mounted on board the drone. The drone used is equipped with the Hasselblad L1D-20c camera, with a 1-inch CMOS sensor, a fixed focal length of 28 mm and a maximum resolution of 20 megapixels. The camera is mounted on the aircraft by means of a gimbal that allows both stabilization on the 3 axes and the control of the inclination by the operator during the flight. The first operational phase consisted in the study of the survey area and in the subsequent planning of the flight plan in compliance with the flight limitations imposed by ENAV (National Agency for Flight Assistance) through the analysis of the site cartography and the available orthophotos and the consultation of

Figure 6. Textured mesh models and orthomosaics of temple A, tabernae and domus publica.

the *d-flight* portal. The areas under investigation shall have the following dimensions:
The archaeological site has no flight restrictions except

Structure	Area (mq)	Perimeter (m)
Domus publica	2'867	236
Tabernae	1'505	162
Tempio A	1'073	132

Table 1. Detected Site Extensions Table

for temple A area, on which drone flight operations are allowed up to a maximum height of 45 m above ground level (AGL).
In this phase of planning the activities, double mesh flight plans were established using the free PIX4Dcapture application and the distribution of the targets to be positioned on the ground was decided, pursuing a homogeneous and regular coverage of the area to be detected.
For the acquisition campaign, the flight mission included flights at two different altitudes and camera inclinations: Given the 4k resolution and the excellent stabilization offered by the drone's camera, it was decided to shoot video with a frame rate of 24fps, to obtain video material to be used also for information and promotional purposes of the archaeological site detected.

AGL medium (m)	Camera inclination	GSD (cm/px)
15	45°	0.38
25	30°	0.64

Table 2. Flight Settings Table

The flight operations were preceded by the usual and indispensable pre-flight checklist activities, to which was added the manual setting of the correct exposure values, white balance, ISO, shutter speed, aperture and focus to obtain images with homogeneous characteristics despite the different scenes framed. The flight mode was conducted both in manual mode, entrusted entirely to the capacity of the operator with remote control, and in automatic mode through a preset route (Figure 4). Prior to the flight, 10 targets of 50x50 cm in size were positioned on the ground to be used as points for the georeferencing of the frames. The survey of the targets was carried out by means of GNSS survey in RTK mode using a Leica Viva GS15 GNSS receiver with an accuracy of about 1.8 cm in flat and 2.5 cm in altitude. The elaboration of the GNSS survey data was carried out using Leica Geo Office software with UTM-WGS84 reference system.

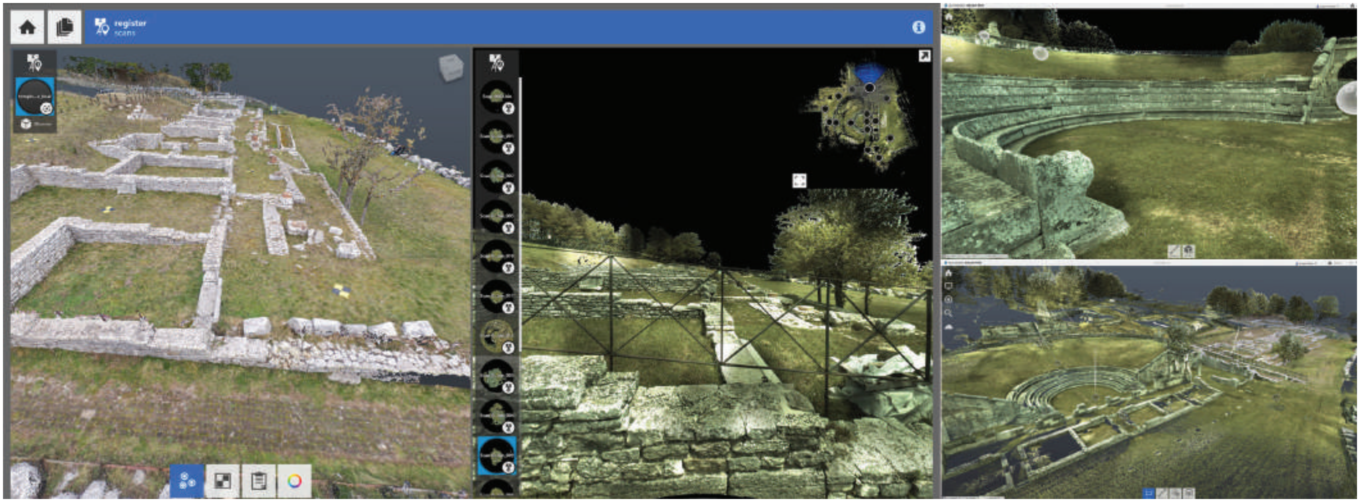

Figure 7. Cloud to cloud alignment and recording of temple theater and temple and tabernae point clouds in Autodesk Recap Pro 2022.

Structure	N° shots
Domus publica	197
Tabernae	377
Tempio A	275

Table 3. Shooting table

5. Data Processing

Once the dataset was put in the system and archived, it was decided to create three-dimensional reconstructive models of the situation through the SfM procedures of each of the new areas acquired. Therefore, the frames of the *domus publica*, temple A and *tabernae* were processed separately within the Agisoft Metashape software.

The process involved the preparation of chunk for different photographic sets, the evaluation of the quality and selection of individual frames and the generation of the scattered point cloud from these. Subsequently, the targets within the photographic set were identified and the corresponding markers were inserted. At the end of this operation, the coordinates recorded by GNSS receiver were imported for each marker and the markers to be used as check and control points were diversified. This operation made it possible to estimate an error in terms of accuracy of the output of about 1.6 cm for all three structures. The dense point cloud, the mesh model and the textured model of each artifact were then progressively obtained. A confidence filter was applied to the dense point cloud to obtain a clean and as accurate point cloud as possible for mesh generation. For all the models, an orthomosaic in planimetry vision and some detailed shots of the model were also generated (Figures 5, 6). For temple A and the *tabernae*, since they are adjacent structures, we also proceeded to align and merge the chunks containing the two clouds of dense points respectively, in order to also have a united model. The second phase of data processing concerned the possibility of integrating the survey of the newly acquired structures in aerial photogrammetric mode with the previous survey, made inside the sanctuary, of the theater-temple complex; the latter as already mentioned acquired six years earlier in laser scanner mode supported by a topographic survey. Having no more traces of the cornerstones fixed in the first survey phase, it was decided to work a posteriori, for overlapping of homologous points between the laser scanner cloud and the photogrammetry clouds, and on the GNSS topographic survey of some remarkable points of the structure of the main temple and the theater built during the last acquisitions. The dense point clouds of the *domus*, temple A and *tabernae*

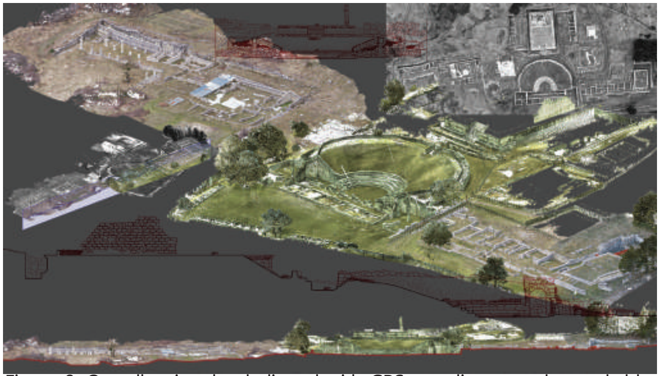

Figure 8. Overall point cloud aligned with GPS coordinates and remarkable sections.

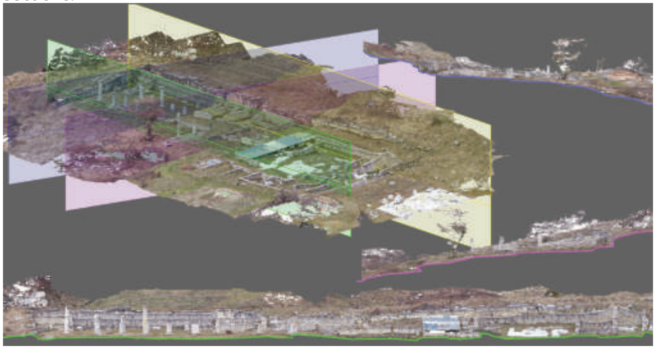

Figure 9. Longitudinal transverse archaeological sections of the *Domus publica*.

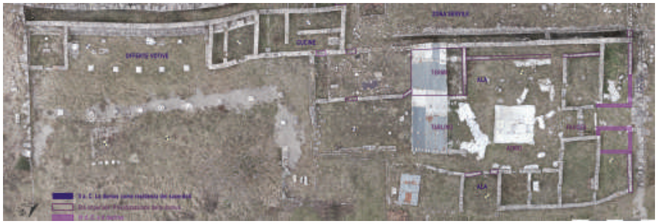

Figure 10. Planimetry with the main building phases of the *Domus publica*.

Figure 11. Visualization of the navigable textured model of the *Domus publica* in Visual Media Service.

were exported from Agisoft Metashape software in.e57 format and later imported into Autodesk Recap Pro 2022. Once the new scans and the old survey of the temple theater, consisting of 17 scans, were indexed, a cloud-to-cloud manual alignment of the recognizable remarkable points of the archaeological structures was made (Figure7), thus obtaining an overall point cloud of the theater-major temple area, *tabernae* and temple A. Since the *domus* is in an area secluded from the main nucleus of the sanctuary, and since this is an unrestored structure and therefore not open to the public, it was not possible to find overlapping areas to be able to align it with the rest of the archaeological structures. In this case we then proceeded to the alignment, being able to count on the georeferencing of the two-point clouds remained separate in the UTM-WGS84 coordinate system, thanks to the GNSS topographic points on the targets of the new survey and on recognizable points of the archaeological structures of the theater-temple. The work of georeferencing the clouds has made it possible to obtain a recorded point cloud complete with all the main and known archaeological structures of the Italic Sanctuary. Through the import of the same in Autodesk Autocad 2022 it was possible to dissect the cloud to obtain a general plan, elevations, and sections of the structures (Figure 8).

6. Results and Conclusions

The database obtained lends itself well to any type of analysis for the documentation and communication of the investigated site. In this phase we focused on the documentation and dissemination of the survey and knowledge of the *domus publica*. Located south of the temple theater complex, the domus is unique not only in the Samnite landscape but throughout the peninsula. It looks like a large atrium house with *impluvium, tablino and alae,* differing from the classic scheme of the Roman-Italic residence for the presence of a portico with two naves for votive offerings. It was probably built in the second half of II BC together with temple B and its activity reached the earthquake of 346 AD. During this period the *domus* underwent numerous restorations with planimetric changes. From the historical and bibliographic research, on the publications of the latest excavation news, the three main building phases have been identified, which have been visualized on the archaeological plan (Figures 9, 10). Moreover, since the latter, brought to light in 2004, has not yet been opened to the public, it was thought of a dissemination project through the sharing, through the Visual Media Service platform, of the three-dimensional textured model. This model can then be navigated and provides general information on building structures and facies (Figure 11). The next developments will concern, as already proposed for the major temple in 2016, the three-dimensional modeling, in this case within the Autodesk Revit BIM authoring platform, of the reconstructive hypothesis of temple A, supported by the cataloguing, already in progress, of the finds found and the architectural remains preserved at the site's deposits. It is also hoped to complete the acquisition of the archaeological site through aerial photogrammetry, also for the last excavated structures. The important experience conducted and the 2D and 3D restitution, starting from the acquisition of images, have allowed the production of an updated documentation of the site, the carrying out of various analyzes, as well as the evaluation in positive terms of the acquisition of data from drone for the survey of archaeological areas. The case study showed the goodness of current technologies for archaeological surveys using drones, which have allowed an accurate restitution so far outlined. The results that today we can achieve thanks to the acquisition of images, structured by topographic surveys and low-cost acquisition operations, are truly formidable and constitute the future of expeditious surveys.

Notes

Following the graphic restitution, some considerations were undertaken regarding the units of measurement used in the realization of the complex and geometric constructive and stylistic analysis on the theater. In this regard, see Potestà, G. (2019).

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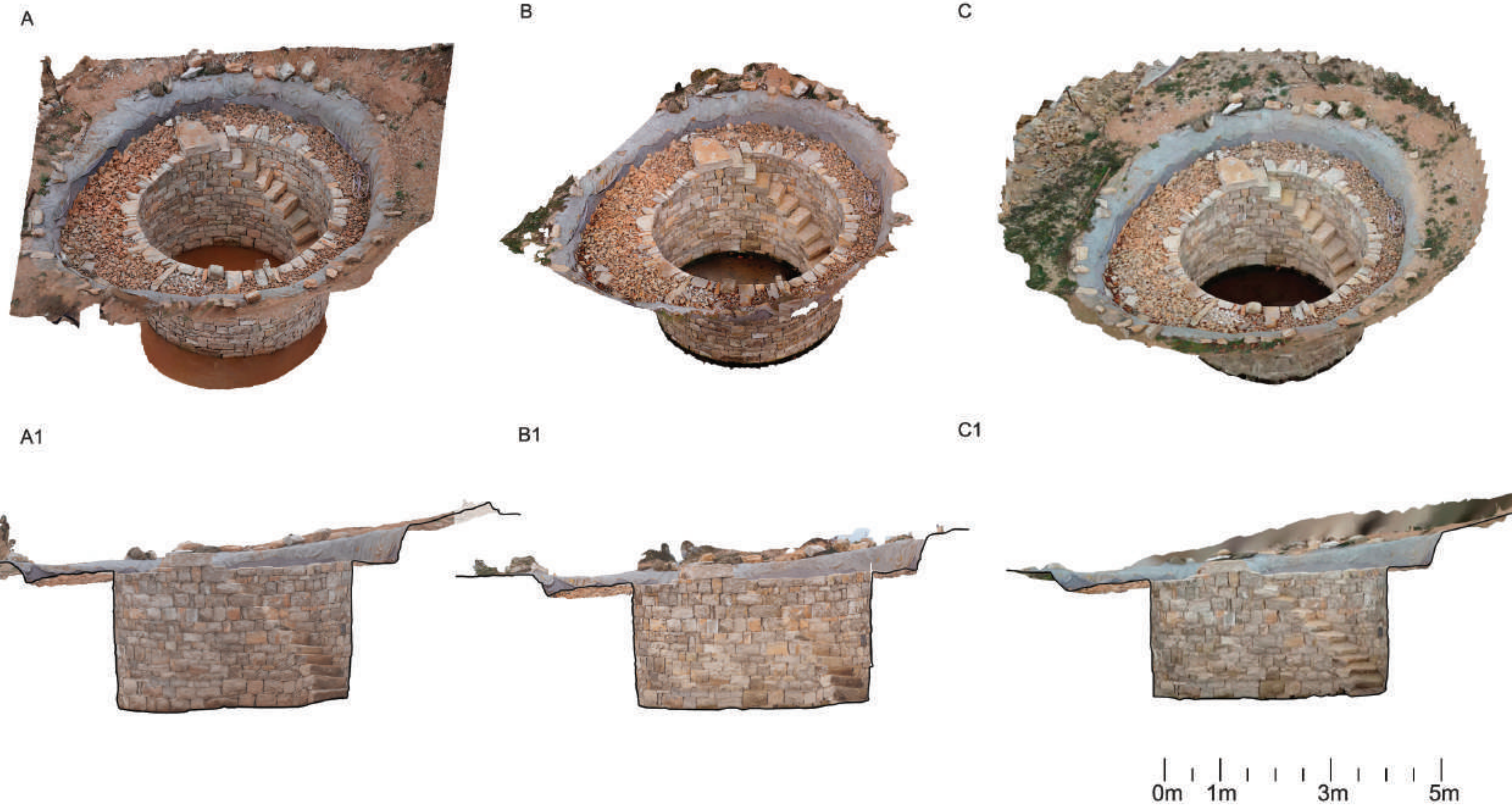

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ABSTRACT

The aim of this research is to determine which surveying process among different methods allows to obtain precise, fast and complete results. The applied research methodology is based on a comparison between different methods of photogrammetric survey: the traditional method using a camera, manual photographs of a drone flight and the extraction of frames from an automatic drone flight. This will allow verifying the accuracy, post-processing and timing of the different processes used, thus obtaining the different advantages and disadvantages of each of them.

Photogrammetric comparison between different drone survey methodologies: dry stone as a case study

1. Introduction

This research aims to determine which of the different photogrammetric recording methods allows obtaining complete, precise and fast results, taking into account the context in which the constructions are located. The study case can be extrapolated to other types of isolated constructions and with difficult access conditions. Photogrammetric recording by drone allows the study, conservation, development and dissemination of framed vernacular heritage.

1.1. Heritage and technology

The use of Remotely Piloted Aircraft System (RPAS) or drone was intended to be used as a remotely directed apparatus and for military use. Nevertheless, a device like this took very little time to change its use and be marketed to perform other tasks (Fernández Díaz 2018). The use of drones presents a very suitable complement for the results obtained in researching fields, reducing time (Sancho Gómez-Zurdo et al. 2021) and necessary resources (Marta et al. 2018).

The comparison of the state of the elements at the structural level, to have a virtual representation of a building in an accessible and rigorous way to leave a record at a temporal level and to generate material for scientific and architectural dissemination (Fernández Díaz 2018). There are studies (Tacca Qquelca 2015), that have used total stations and drones to proceed with their comparison regarding versatility, economic costs, time and personnel involved. Others (Cu et al. 2020), compare various tools but oriented to topographic use.

1.2. Dry stone constructions

Dry stone construction has been studied in the Iberian Peninsula since the 20th century (Sola Morales i Rubió 2008; Torres Balbás 1933). The main studies have been carried out over the last years (García, Zaragozá 2000; Tarragó 2006). This construction technique uses the remains of stone from farmland. However, there are common characteristics: the use of a single material and stability based on the balance between elements under their own weight. It is a technique declared in 2018 by UNESCO Intangible Cultural Heritage of Humanity (United Nations Educational Scientific and Cultural Organization 2018).

Several studies have been carried out on the vernacular architecture application of massive data capture tools (Restuccia et al. 2012; Rossi, Massimo 2013). Specifically, digital photogrammetry has been used to analyse constructions (Chen et al. 2017; Mineo et al. 2019). Some studies have been carried out to allow standardizing and simplifying the point cloud throughout a construction (Todisco et al. 2017; Vegas López-Manzanares et al. 2010).

1.3. Study case

The construction chosen to develop this study is a raft in charge of storing rainwater built using the dry stone construction technique. This construction is located in the municipality of *La Fatarella* (Tarragona - Spain) (Figure 1). It is an isolated, buried and helical-shaped construction. It has dimensions of 2.73 meters deep and 4.30 meters in diameter.

Figure 1. Location of the study case.

2. Methodology

2.1. Analysis methodology

The methodology is based on a comparison between different photogrammetric survey methods: the traditional method using a camera manually, manual photographs of a drone flight and the extraction of frames from an automatic drone flight (Figure 2). This will allow to verify the precision, processing and timing of the different processes used, thus obtaining the different advantages and disadvantages of each of them. Once the process has been validated, a comparison can be made between the results obtained.

To assess the timing between the different methods, the times used to perform the survey and the post-processing are recorded, in order to establish a comparison. In the generation of the photogrammetry of the three models, the Agisoft Metashape 1.6.4 software is used, on which the photographs are dumped and all the processing steps are carried out. To verify the integrity and precision of the different models, the basic data of each photogrammetry is compared, such as the number of points obtained, the quality of the model and the quality of the orthomosaic texture. This allows us to determine which model is the most accurate of the three survey methodologies, in order to compare two other models with this one.

In order to scale and compare the three models in the same coordinate system, three control points are used, located in the three corners that delimit the last upper rung of the ladder. The results will indicate the error for the support points, the calibration comparison between cameras, as well as the calibration coefficients and correlation matrices.

The comparison methodology used in the models is based on two-dimensional and 3D studies from the point cloud. The Cyclone 3DR software is used to perform this analysis. In the case of the 2D study, horizontal and vertical sections of each model are made to allow them to be compared with each other, seeing the possible deformations and imperfections of the models through the differential areas. Four vertical radial sections are compared with the geometric centre of the most precise model and with a separation between them of 45º. In the horizontal direction, a comparison section is made at half height of the raft.

In the 3D study, two types of comparisons are made on the models. The first allows us to analyse the models

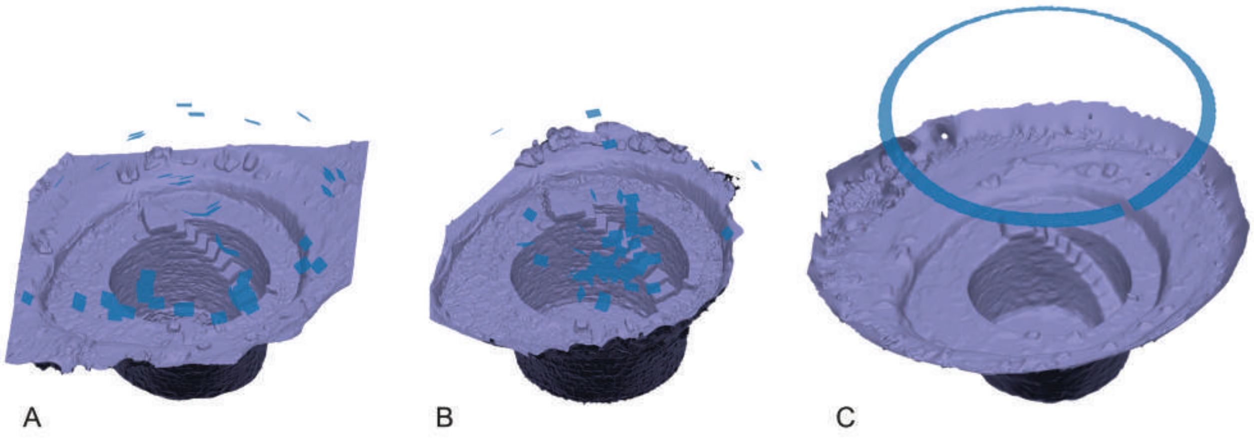


Figure 2. 3D models obtained. A - using manually a camera. B - manual photographs from a drone flight. C - from the extraction of frames from an automatic flight with drone.

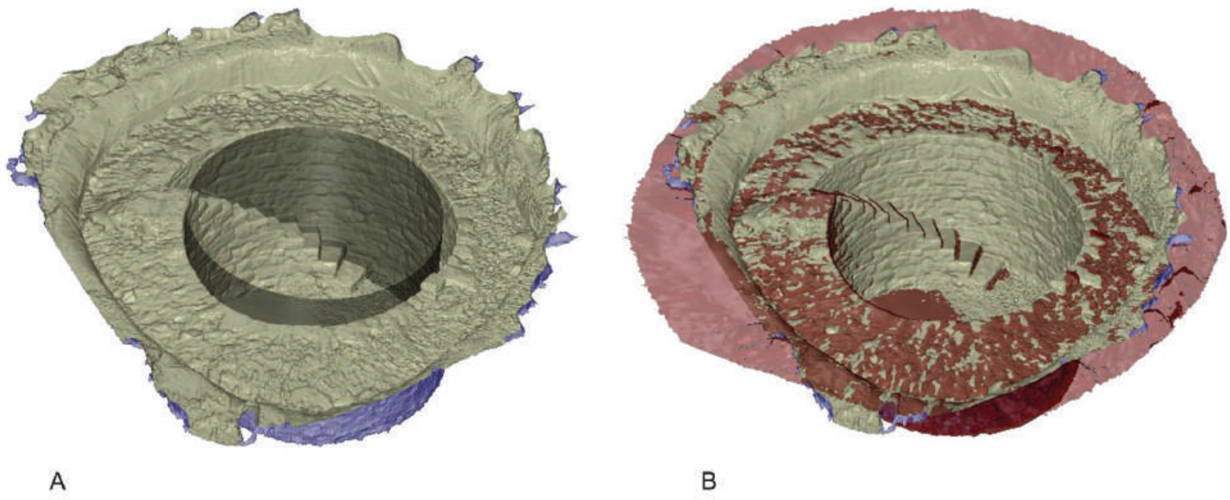


Figure 3. A – Comparison between the model and the cylinder that best suits. B – Comparison be-tween the models.

with a primitive form of comparison, in this case the cylinder that best approximates the perimeter of the pool, obtaining the formal differences of the model (Figure 3A). The second part consists of a comparison between the point clouds of the models under the same coordinate system, through control points (Figure 3B). This allows to obtain a gradient of discrepancies to know which method provides more errors or discrepancies.

2.2. Survey methodology

The data collection is carried out in a single campaign of one day to avoid possible differences caused by the passage of time. A NIKON D7000 camera with a TAMROM LD XR DI AF 15-50mm 67 a16 lens is used for the survey with manual photographs, and the average distance or flight altitude at which the photographs are taken is 5.75m, with a focal length of 16mm.

The DJI Mavic Mini 2 model is used for data collection with a drone, with the FC7303 camera model and characteristics of the 1/2.3" CMOS sensor, with 12 megapixels; a 24mm format FOV 83º lens, with an aperture f/ 2.8 and a shutter speed of 4-1/8000s Photographs were taken at 4:3 image size and video resolution at FHD (1920×1080 at 60 fps).The flight altitude of the photographs is 3.32m, with a focal length of 4.49mm.

In the third method, an automatic circular flight is carried out as an orbit around the raft with a duration of 15 seconds. The obtaining of frames per second is fixed at 7 since the higher the frames, the longer the post-processing analysis time, with a very low difference between photographs, which caused errors in the detection of common points in the photogrammetry post-processing. For this reason, it has been verified that a good range for the analysis of a photogrammetry is between 5 and 10 frames per second. The flight altitude of the frames in this case is 7.13m.

3. Results

3.1. Results of the survey and precision of the method

With the results obtained of the surveying (Table 1) and post processing, it can be seen how the photogrammetry obtained with more precision and photographic detail is that of model B, while the one with less detail is that of C. It is curious to observe that, although models A and B have a similar number of photographs, the times of drone photography model B give shorter post-processing times, the first being a total of 3 hours 29 minutes 36 seconds and the second a total of 2 hours 1 minute 36 seconds. This may be due to the fact that model A has more points of passage between photographs, generating a longer processing time. Even so, the model B is still more accurate with fewer link points between photos. The representation of the 3D textured models (Figure 4) allows us to observe the precision of the model and the quality of the ortho mosaic specified in (Table 1).

From the reports obtained from each survey, it can be seen that in general the three models obtain a very high overlap between images (>9 in most cases) (Figure 5). In the case of the residual plots, the largest error is distributed circularly and at the extremes in model B,

	Method A: Manual Photography	Method B: Drone Photography	Method C: Automated Flight and Frames
SURVEYING			
Photographs (n)	95	98	100
Surveying time	15'	5'	0,15''
POST PROCESSING			
Photo Orientation			
Coordinate system	WGS 84 (EPSG::4326)		
Number of link cloud points (n)	59,865	80,738	22,152
Reprojection error (pix)	1.127	1.203	0.863
Average multiplicity of waypoints (n)	5.888	4.728	7.284
Orientation time	4' 45"	3' 54"	2' 53"
Depth maps (n)	96	98	100
Map processing time	1h18'	48' 36"	20' 35"
Total orientation time	1h 22' 45"	52' 30"	23' 28"
Dense Point Cloud			
Total number of points (n)	3,906,287	7,984,768	374,003
Map obtaining time	1h 18'	48' 36"	20' 35"
Cloud generation time	23' 2"	6' 18"	3' 10"
Total processing time	1h 41' 2"	54' 54"	23' 45"
Modeling			
Number of faces	260,412	1,596,935	180,000
Number of vertexs	131,799	800,995	90,405
Reconstruction time	2' 36"	5' 39"	16"
Texture size (pix)	4,096		
Texturing time	6' 4"	6' 19"	1'58"
Total time	8' 40"	11' 58"	2' 14"
Orthomosaics			
Pixel size (mm)	1.570	0.966	5.01
Processing time	2' 36"	2' 14"	31"

Table 1. Comparison of the parameters between the different surveys.

while in A and C they are more dispersed. It is observed how model B is the most calibrated model. Regarding the control points, the model with the least errors (measured in microns) is B (with an interval of ±0.8 microns), while the one that shows more dispersions is A (±0.3mm). In the QC point ECM tables, it is reflected that the total error between points for model A is 4.87mm, 0.76 microns for model B, and 0.496mm for model C, concluding that in terms of precision the model B with drone photography is the most accurate. These first results allow us to choose model B of drone photography as the most accurate model in terms of surveying and precision. For this reason, the comparisons of models A and C with this one are established in this way and seeing how much the results differ.

3.2. Comparison results

3.2.1. 2D comparison

Firstly, using the Cyclone 3DR program, the horizontal sections made at ½ of the interior height of the model have been compared, establishing the section of model B as a common shared element (Figure 6). The comparison of the sections between models A and B has allowed us to observe that the percentage of coincidence between the meshes with a pre-established interval between ±0.01 is 14.60%. The comparison of the sections between models C and B has allowed us to observe that the percentage of coincidence between the meshes with a pre-established interval between ±0.01 is 28.20%. According to the metric standards used in the construction of the area, the unit of 2.0 centimetres has been established as a comparative measure between the meshes (Fullana 1999; Mallafrè et al. 2019). A comparison has been established between the differential areas of the sections of the 3D models (Table 3). The comparison of the sections between the models A and B has allowed us to observe that the average of the differential areas obtained has been 0.42 m^2. The comparison of the sections between the C and B models has allowed us to observe that the average of the differential areas obtained has been 0.56 m^2.

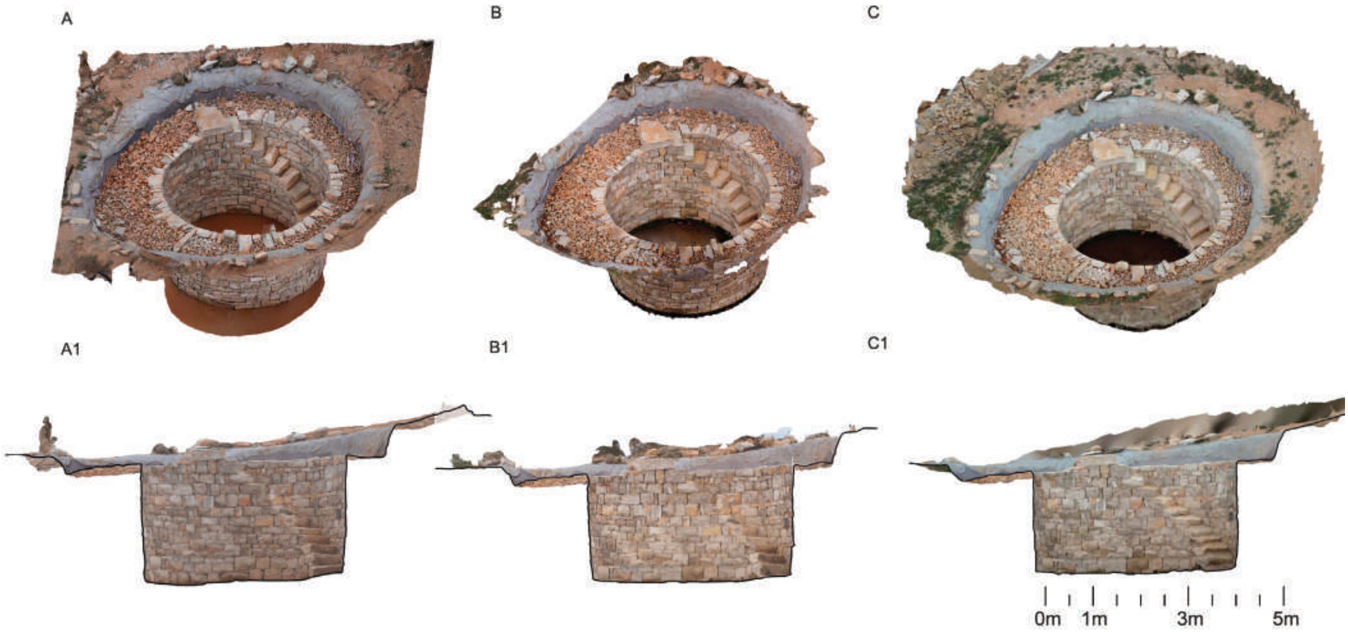


Figure 4. On the cover: Textured 3D models and sections obtained. A – Manual Photo. B – Drone photo. C – Drone and frames.

3.2.2. 3D comparison

The 3D models have been compared with the perfect cylinder obtained by matching the mesh of model B (Figure 7). The perfect cylinder and the comparison is made using the Cyclone 3DR program. The comparison between the models and the cylinder that best approximates has allowed us to observe that the percentage of coincidence with an interval between ±0.088 for model A is 21.5%, both with an interval between ±0.098 for model B is 32.1%, and with an interval between ±0.099 per model C is 20.4%.

3D models A and C have been compared with model B (Figure 8). The comparison between these models has allowed us to observe that the percentage of coincidence with an interval between ±0.02 for model A is 39.59%, with an interval between ±0.02 for model C it is 42.66%, and with an interval between ±0.099 for model C it is 20.4%.

4. Discussion

As it has been observed in the results of the survey, the most precise and detailed model is model B. For this reason, in the comparison results in 2D and 3D it has been taken as a reference. In the two-dimensional comparison of sections, it is shown that the model with the fewest discrepancies is model C, although with a 28.1% coincidence. It can be seen how the photogrammetry appears distorted towards the outside in the second quadrant. In the same way, in the comparison of the differential areas, the method that best approximates is also model C. This is because, although model C is less precise than model A, it maintains a better coincidence due to the fact that it is of a smoother mesh, without taking into account the irregularities due to the construction material. These two models are also based on the drone methodology, so their approach is more similar.

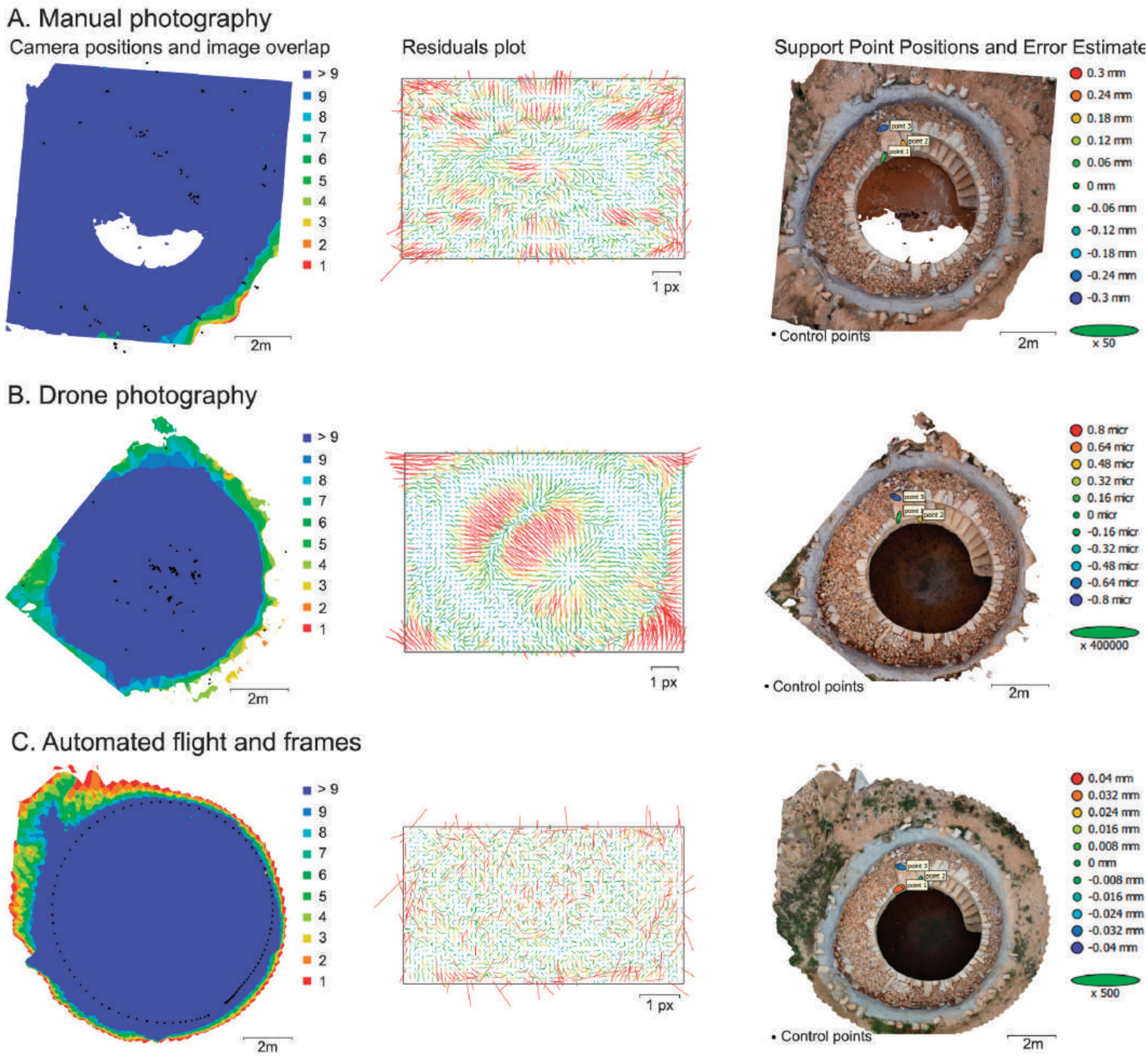


Figure 5. Comparative processing data.

A. Manual photography

Calibration coefficients and correlation matrix

	Valor	Error	F	Cx	Cy	K1	K2	K3	P1	P2
F	2839.27	0.12	1.00	0.01	-0.16	-0.08	0.25	-0.22	0.01	-0.11
Cx	1.89907	0.12		1.00	0.01	-0.00	0.01	-0.01	0.94	-0.04
Cy	23.8745	0.11			1.00	-0.03	-0.00	-0.00	-0.02	0.86
K1	-0.0624788	0.00011				1.00	-0.94	0.88	-0.01	0.03
K2	0.0649439	0.00032					1.00	-0.98	0.01	-0.04
K3	-0.0263287	0.0003						1.00	-0.01	0.03
P1	0.0022559	1.3e-005							1.00	-0.06
P2	0.000422231	1.1e-005								1.00

QC Point ECM

N	Error X (mm)	Error Y (mm)	Error Z (mm)	Error XY (mm)	Total (mm)
3	2.61763	4.10149	0.196255	4.86562	4.86958

B. Drone photography

	Valor	Error	F	Cx	Cy	K1	K2	K3	P1	P2
F	3018.03	0.071	1.00	-0.01	-0.66	-0.14	0.23	-0.21	0.01	-0.69
Cx	-0.462259	0.081		1.00	0.05	0.00	-0.00	0.00	0.95	0.04
Cy	10.4605	0.17			1.00	-0.10	0.03	-0.03	0.04	0.98
K1	0.00473429	8.4e-05				1.00	-0.96	0.91	0.00	-0.10
K2	-0.0202797	0.0003					1.00	-0.98	0.00	0.03
K3	0.0140871	0.00032						1.00	-0.00	-0.02
P1	-0.000224134	7.8e-06							1.00	0.03
P2	0.000248486	1.4e-05								1.00

QC Point ECM

N	Error X (micr)	Error Y (micr)	Error Z (micr)	Error XY (micr)	Total (micr)
3	0.274433	0.497821	0.499242	0.568453	0.756559

C. Automated flight and frames

	Valor	Error	F	Cx	Cy	K1	K2	K3	P1	P2
F	1395.47	2.8	1.00	-0.81	-0.99	0.25	-0.24	0.28	-0.37	0.10
Cx	-41.1726	0.25		1.00	0.81	-0.21	0.18	-0.22	0.76	0.14
Cy	70.2711	1.5			1.00	-0.33	0.27	-0.30	0.41	-0.03
K1	0.0117853	0.00065				1.00	-0.90	0.84	-0.17	-0.08
K2	-0.0483752	0.0021					1.00	-0.98	0.02	0.04
K3	0.0443721	0.0023						1.00	-0.05	-0.02
P1	-0.0102592	4.5e-05							1.00	0.10
P2	-0.000817523	8.1e-05								1.00

QC Point ECM

N	Error X (mm)	Error Y (mm)	Error Z (mm)	Error XY (mm)	Total (mm)
3	0.374274	0.324358	0.0263726	0.495267	0.495969

Table 2. Comparison between calibration coefficients and error in QC points.

In the 3D study, with the comparison with respect to the best cylinder, the model B with the greatest coincidence is highlighted, followed by model A.
This indicates that the most accurate model in a 3D manner is model B. In the comparison between meshes, it returns to observe how model C better approximates the mesh of model B, as they are similar methodologies as just explained, although in some points it shows more discrepancies than model A.
The results are parameterized (Figure 9) and it can be concluded that the method that provides the best results in relation to time/precision/detail is method B of drone flight and photography.
Regarding the results, establishing common comparison criteria, it is observed that the mesh that best approximates the perfect cylinder is the one corresponding to model B (Figure 10). In this way it can be verified that the geometric approximation to the primitive form depends on the methodology used in the survey and that it interferes with the results obtained.

5. Conclusions

The research has made it possible to provide objective data in terms of time, detail and precision of the three chosen photogrammetric survey methods.
It has been possible to demonstrate how the use of drones for photogrammetric surveys provides greater detail and precision than manual methods, also reducing post-processing times.
The survey through photos taken with gift are a very useful tool for dry stone constructions located in places of difficult access.
However, automated flights do not provide as reliable and precise results compared to drone photography methods, although they do provide general models with low processing times.
This can be useful for getting low detail models quickly, but for detailed models manual flight and photography is recommended.

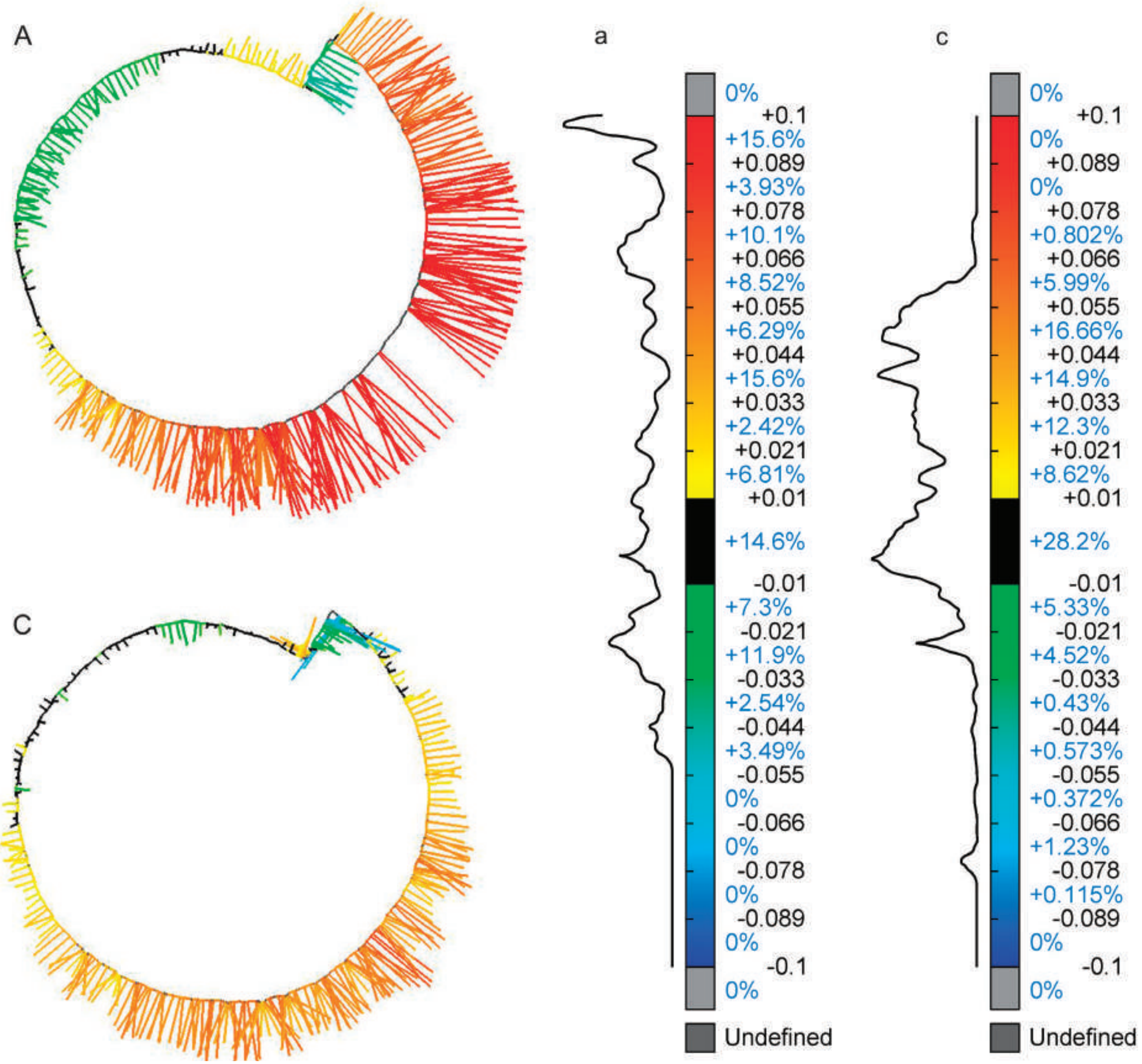


Figure 6. Differences between horizontal sections.

Comparison	Section 1	Section 2	Section 3	Section 4
Model A and B	0,2065	0,519	0,3885	0,5753
Model C and B	0,7391	0,5498	0,5884	0,3487

Table 3. Differential areas between methods.

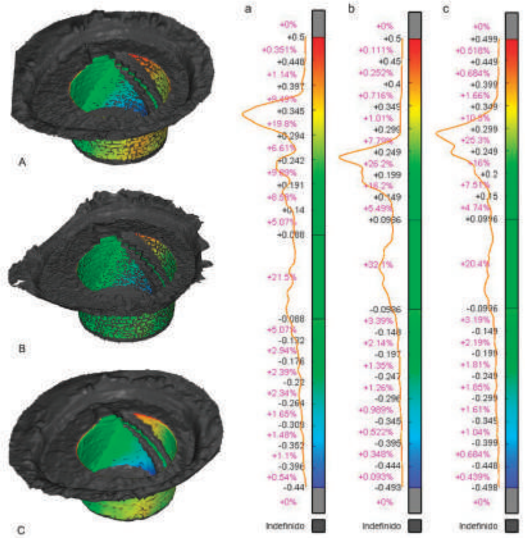


Figure 7. Comparison between the mesh and the best cylinder.

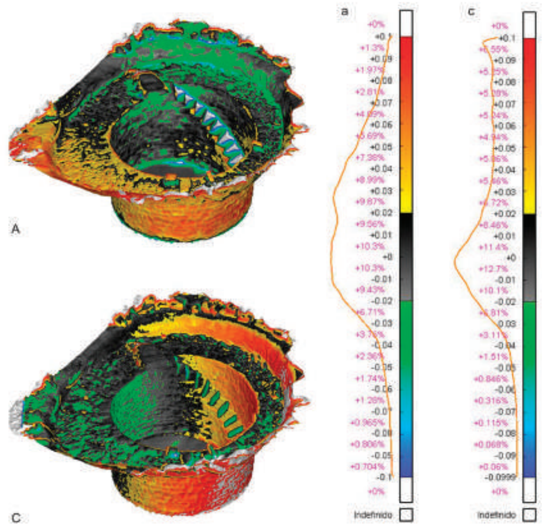


Figure 8. Comparison between the 3D models.

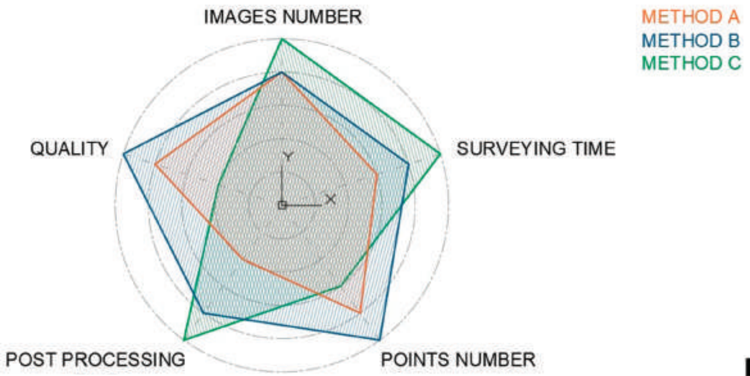
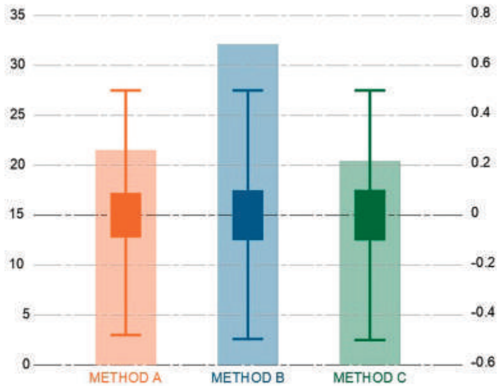


Figure 9. Comparative between the results obtained.



Comparison	Percentage of points	Higher Rank	Maximum	Minimum	Lower Rank
Method A	21,5	0,5	0,088	-0,088	-0,44
Method B	32,1	0,5	0,0986	-0,0986	-0,493
Method C	20,4	0,499	0,0996	-0,0996	-0,498

Figure 10. Comparison between the meshes and the best cylinder.

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Cultural Heritage, Virtual reconstruction, Drone, Geo-referenced, Historical landscapes.

ABSTRACT

Wars have influenced the modification of the territory and today we can see it through its scars on the landscape. The objective of the research is the analysis of military architecture and its relationship with the territory in the Battle of Jarama, one of the clashes of the Spanish Civil War.
With UAV systems we can locate and georeference the architectural elements distributed in the landscape and create a 3D of the area to establish a hypothesis of its construction. The generated 3D models can be used as tools for heritage restoration and tourism development through virtual tours.

Scars in the landscape: photogrammetry and analysis of the trenches of the Spanish Civil War

1. Introduction

The landscape that surrounds us today is the result of a series of modifications made by the action of nature and human. Through them we can learn about the history of our territories and better understand the evolution of our society. One of the human actions that has had the greatest influence on the modification of the landscape over the centuries have been wars.

This transformation of the landscape increased exponentially throughout the 20th century due to the technological development that took place in the military industry. As a result, the different constructions, weapons and means of transport used since the First World War have had a greater impact on the environment, both urban and rural, than in previous eras.

The war conflicts in which the European continent was immersed in the first half of the 20th century can be seen today through the scars that are preserved in the landscape. Many of these scars are formed by the remains of military architecture that have defined and modified the territory and we can see today.

In the case of the Spanish Civil War (1936 - 1939), the impact of emergency military architecture on the landscape is still present in many areas of the Spanish geography. For this reason, the case study focuses on the analysis of military architecture and the modification of the landscape in the Battle of Jarama, one of the clashes of the Spanish Civil War. This battle took place in the southeast of the province of Madrid, in February 1937, and remains of defensive architectural elements and trenches connecting different points of the territory are still preserved today.

Thanks to the introduction of new information and communication technologies (ICT), such as unmanned aerial vehicle (UAV) systems, we can carry out an analysis and subsequent dissemination of military historical and architectural heritage, which is often difficult to access, and we can also produce documentation that helps to enhance its value and conservation.

2. The Battle of Jarama and Counterattack Post No. 8

Nowadays we can learn about the conflict, the military architecture and the way of life at the time, thanks to the descriptions made by some great international authors, such as Ernest Hemingway, who through his articles as a correspondent for NANA (North American Newspapers Alliance) narrated part of what happened at Jarama (Roldán, 2014). The Battle of Jarama was one of the most tragic conflicts of the Spanish Civil War. The battle took place in February 1937, with cold weather and heavy casualties for both armies. As Hemingway describes in his articles, the frontline landscape was filled with olive groves, adding to the difficulty and harshness of the fighting on the ground (Hemingway, 1989). After the battle, the front was stabilised and remained militarily active until the end of the Civil War in 1939, and for almost two years various fortifications, trenches and roads were built in the area that are still preserved today. One of these fortified complexes from this period is located in the area of Casas Altas, in the

Figure 1. Photograph of the Casas Altas trenches.

Madrid municipality of Morata de Tajuña. This defensive post is located on the slope of a small hill from which the army of the Spanish Republic could control the Vega of the River Tajuña, the entrance to the town of Morata and the road in the area towards Valencia, the city where the Republican Government had moved. The enclave studied is made up of two lines of trenches built at different levels. On the upper level, a communication trench was established with zigzag-shaped gun positions, while in the trench located on the lower level, different defensive fortifications were built, such as shelters, machinegun nests and squad posts.

3. Methodology and objectives

Due to the territorial scale of the defensive elements built in the landscape of "Casas Altas" and the difficulty of access to the area, different methodologies have been applied to develop the research, with the intention of carrying out a virtual reconstruction of the architectural elements and the territory.

Through ICT we can use different technologies for the virtual reconstruction and comprehensive treatment of historical landscapes (Tzanelli, 2013). In this case, historical research (Labrador, 2018) has been combined with the use of new technologies through georeferenced augmented reality (Castaño, 2018) provided by UAV systems.

The study was carried out taking into account the following points:

- The analysis of the configuration of the heritage spaces to identify the elements and limits of the studied area by means of archaeological methods;
- The description of the architectural and natural elements found on the basis of the analysis of the historical remains of the environment and also taking into account the transformation of the landscape as a result of the conflicts;
- The interpretation of the territory and the heritage elements through 3D models, also applying the data obtained from the historical research to analyse their current state and improve the conservation of the heritage.

Based on these points, the aim is to develop a methodological system based on historical research, georeferencing and augmented reality to visualise, analyse and interpret the heritage elements.

In the case of the remains of the Battle of Jarama, the methodology allows a better understanding of the environment and the existing elements for their cataloguing, recovery and participation of end users, whether for scientific or tourist uses. The following techniques were used to achieve this objective:

- The analysis of remains of defensive architecture from the wars of the first half of the 20th century for the knowledge of different constructive typologies used;
- The preparation of 2D and 3D cartographic documentation to analyse the configuration and presence of the defensive elements in the landscape;
- The generation of a 3D model using photogrammetry and UAV systems to visualise the elements in a virtual environment according to their current state.

As a result of the methodology used, different visit itineraries can be created through new technologies to make different areas accessible and favour the transmission of cultural and landscape heritage.

Results and research process

4. Results and research process

After establishing the objectives and methodology to be used, firstly, a study of the territory and the defensive elements that were built during the Battle of Jarama was carried out. At the same time, we studied military fortifications that were built in different parts of Europe during the two World Wars and in postwar periods, such as the 750,000 bunkers built in Albania during the Cold War (Stefa, 2012) and mainly the military construction manuals that were published during the Spanish Civil War and which were used by the soldiers fighting at the front to build their own defences.

These manuals described, in a pedagogical way, the construction of different fortifications and provided information on materials, dimensions and the relationship of the elements with the terrain through floor plans and sections (Capdevila, 1938). The campaign manuals allow us to know the construction prototype, but due to the conditions of the battles, the construction materials available and the construction knowledge of the soldiers, the defensive elements could have important variations.

For this reason, the analysis of the defences of the surrounding area is essential, as the means available were similar. In this case, six kilometres away from the area of study, we found a machine gun nest, in a good state of preservation, and with similar characteristics to one of the defensive elements of Counterattack Post No. 8.

After the historical analysis and the analysis of the military elements of the environment, the process of digitalisation

Figure 3. Photograph of the gun nest in Morata de Tajuña.

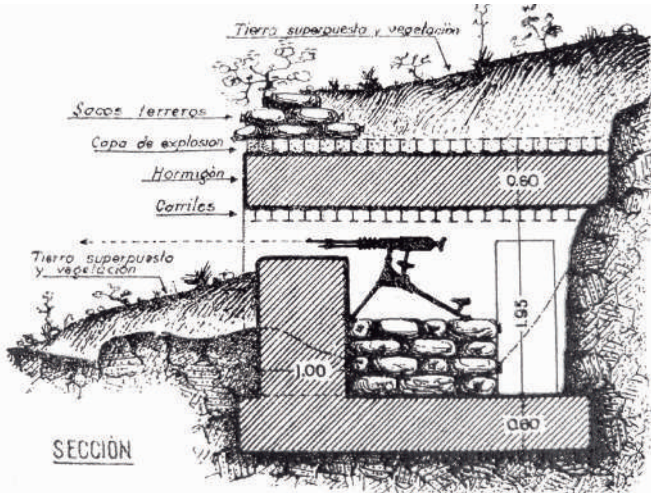

Figure 2. Machine gun nest according to the Field Fortification Manual (Capdevila, 1938).

Figure 4. Topographic plan of Counterattack post No. 8.

of the area of study was carried out for its subsequent virtual reconstruction. As part of this process, a first approach was made by means of a photographic analysis of the elements for their identification and a topographic survey to determine both the elevations, through the contour lines of the terrain, and the exact location of the defensive constructions. The second step carried out in the field was the use of UAV systems. Through an initial drone flight, photographs were taken of the defensive complex to get a better perception of its dimensions and its insertion in the landscape and to get a better idea of the state of the defensive elements, which were difficult to access due to the slopes of the terrain. After the initial flight, a second drone flight was carried out with the established route patterns to obtain a photographic set of the entire study area. With this action it was possible to carry out the photogrammetry of the defensive complex and to georeference the different constructions within the area of study. Through this second drone flight and the photogrammetry, a 3D digital survey of counterattack post no. 8 was obtained. Through the cloud of points generated by the photogrammetry and the 3D mesh, the depth of the military constructions that were not accessible, such as the different shelters and trenches, whose height could not be known by means of the first topographic survey, could be known in a concrete way. From this 3D model

Figure 5. Aerial photograph of Counterattack post No. 8.

it was possible to generate videos with interactive tours through the trenches and fortifications that reflect the current state and allow the user to better understand both the elements and the orography of the terrain.

The initial topographic survey, together with the 3D model obtained after the photogrammetry carried out by the UAV system, made it possible to obtain sections of the terrain and the representation of the defensive elements within them. In these sections, the levels and the current state of the visible elements were represented, together with the underground elements that had to be analysed manually. With this method, technical sections were generated, by line, combined with the textures of the constructions extracted from the photogrammetry.

After the preparation of the sections with the current state of Counterattack Post No. 8 and on the basis of the previous analyses of the fortification manuals and the constructions in the surrounding area, a hypothesis of the original state of one of the most important elements of the defensive complex, the machine gun nest, was carried out. This element is located at the low level of the line of trenches and similar models appear in the fortification manuals of the period. Its construction is based on reinforced concrete and cement mortar for the interior finish. At present, and as shown in the section, it lacks a roof due to an explosion, as large remains of reinforced concrete are preserved around it. Using the historical planimetries, the defensive element located 6 kilometres away and the remains of the roof, a section was drawn up with the same orientation as the previous one with the morphological hypothesis of the fortification with the intention of finding out its initial state. Once the hypothesis of the current element in the terrain section had been made, a three-dimensional reconstruction was made from the 3D generated with the photogrammetry carried out after the drone flight.

In this way, the machine gun nest was reconstructed according to previous experience, showing its current appearance and its original appearance, which was inserted into the terrain.

This 3D reconstruction added depth to the representation by reflecting the colours of the landscape and the textures of the building materials. The reconstructions carried out, both in section and in three dimensions, provide greater knowledge of the integration of the construction elements in the landscape, their dimensions, their materials, their current state and their original state. In this way, these images can be used as a basis for different projects of knowledge, recovery and conservation of the defensive complex and its surroundings.

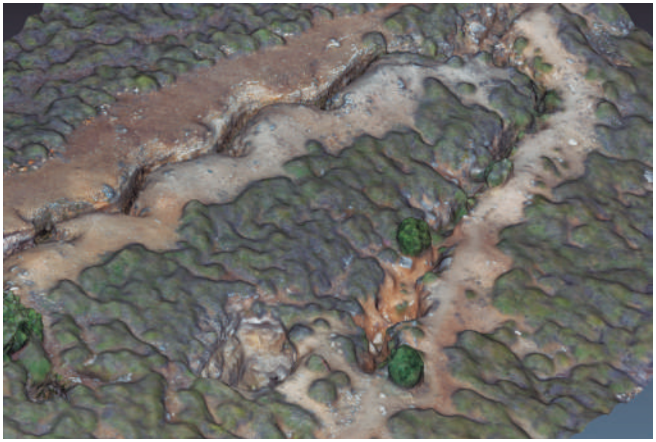

Figure 6. 3D image obtained from the photogrammetry of the study area.

Figure 7. Video capture of the tour through 3D.

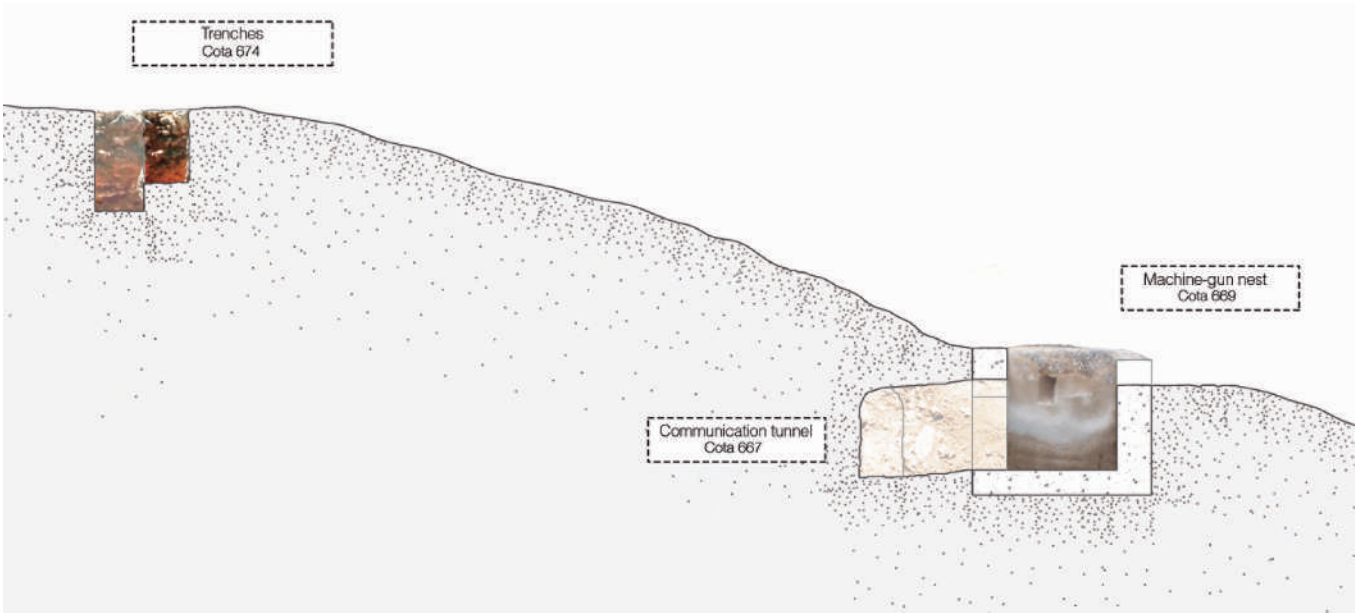

Figure 8. Section of the terrain by the machine gun nest of Counterattack Point No. 8.

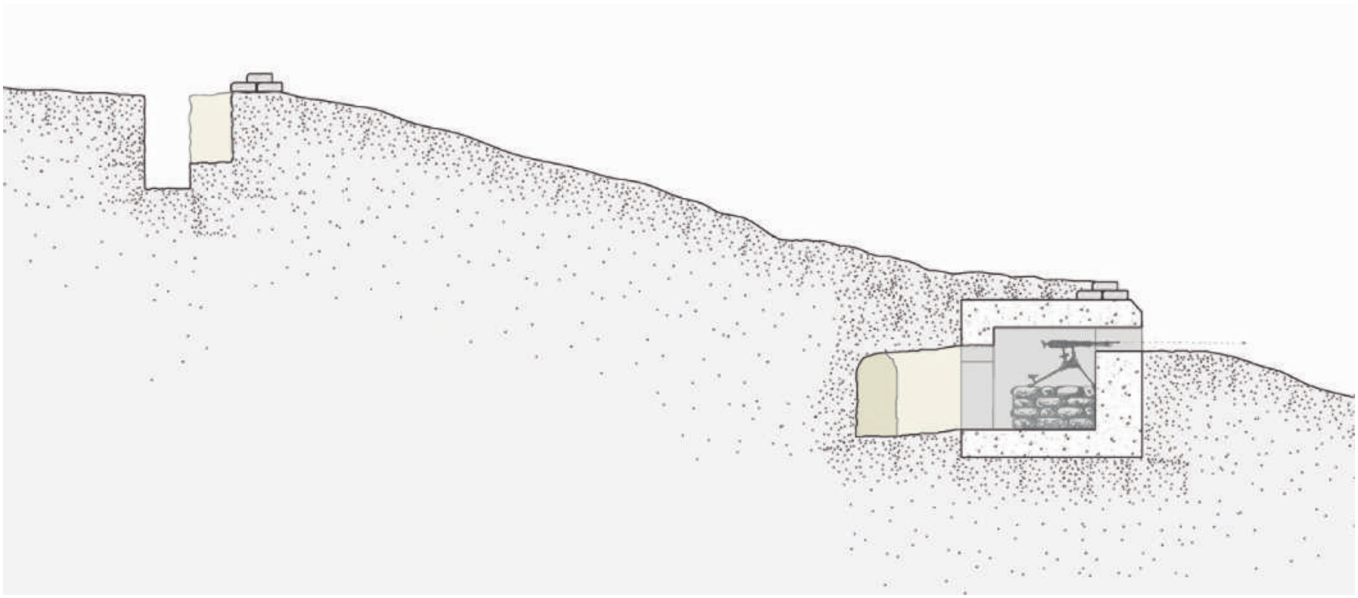

Figure 9. Hypothesis of the section of the terrain by the machine gun nest of Counterattack Point No. 8.

Figure 10. Section and hypothesis in 3D of the machine gun nest of Counterattack Point No. 8.

4. Conclusions

Through the methodology used based on UAV systems, together with other techniques, it has been possible to gain an indepth knowledge of the study area and to analyse in detail the different defensive elements that were difficult to access. The difficulty of access, together with the lack of existing information on the constructions of the Spanish Civil War and the elimination of many of them after the war, have allowed us to reflect on the usefulness and progress that UAV systems represent for the recognition of the terrain and historical heritage. This study has not only shown us the constructions and the relationship of the defensive elements with the terrain, but it also shows us the way of building and living in difficult times. The 3D models and simulations generated through the established methodology can be used in two ways as a result of the study carried out.

On the one hand, the recreations can serve as a basis for the recovery and restoration of the architectural heritage of the complex and other similar defensive elements found in other Spanish Civil War landscapes, and on the other hand, they can be used for the development of rural tourism in the area through both virtual and face-to-face visits to the military landscape.

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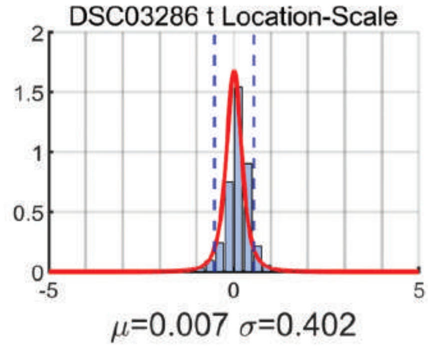

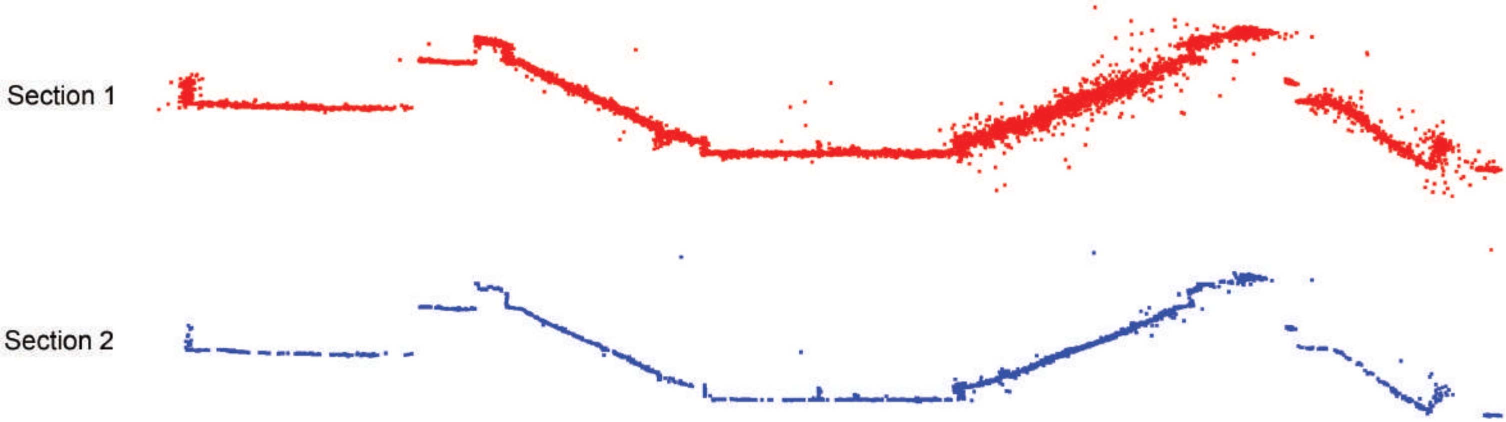

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Photogrammetry, Archaeology, Accuracy, Point cloud, Reprojection errors.

ABSTRACT

In this paper, we present a method developed in order to increase the accuracy of the sparse point cloud (made of Tie Points) created from images acquired from UAVs (Unmanned Aerial Vehicles). In a first step, after having aligned the images, the probability distribution of reprojection errors on each single image is statistically analyzed, then masks are automatically created to remove image regions characterized by reprojection error values outside the chosen confidence interval. The re-sults are promising, and highlight the usefulness of using input data preparation techniques to in-crease the accuracy of the output 3D model.

Automatic point cloud editing from UAV aerial images: applications in archaeology and Cultural Heritage

1. Introduction

Photogrammetry has been more popular in recent decades for creating 3D digital models in various applications (Mancini et al. 2021). It is now feasible to build accurate models of broad regions at extremely cheap prices because of the advancement of computer vision algorithms and novel processing techniques, as well as the rapid evolution of optical sensors, which were earlier known to be weak spots of the approach (Li et al. 2021). In addition, UAVs (Unmanned Aerial Vehicles) have been progressively employed for various photogrammetric applications since the 2000s (Zahari et al. 2021). High-resolution modelling of the earth's surface for geomorphological study, precision farming, disaster management in the aftermath, and inspection of viaducts and bridges for infrastructural applications are just a few examples.

Because of the technique's high degree of adaptability and capacity to create 3D models and graphical output of the surveyed item rapidly and correctly (Barba et al. 2019), it has seen significant advancement in the field of cultural and archaeological heritage conservation (Themistocleous 2020).

Therefore, unlike traditional photogrammetric techniques, which require the use of a calibrated camera or photogrammetric camera, SfM (Structure from Motion) algorithms allow the automated computation of the calibration parameters (self-calibration) of cameras using only homologous point correspondences between different images, the cameras installed on UAVs in most heritage documentation applications are usually commercial non-calibrated cameras (Fraser 2013).

The picture acquisition and setup processes are the most difficult of the entire procedure for developing an accurate model. To eliminate shadow areas in the model and increase the success of matching and following image alignment, UAVs should be able to gather nadiral and oblique pictures at close range with very high percentages of overlap between them. Furthermore, combining nadir and oblique images is critical for improving form definition, surface continuity, and a better description of sub-vertical walls (Pádua et al. 2018), in addition to assisting the self-calibration process (Fraser 2013).

On the other hand, a poor model's correctness might devalue the data's high resolution and, as a result, the objects created from the ensuing 3D model.

The sparse point cloud, which is made up entirely of Tie Points (TP), serves as the foundation for the whole 3D model. Low-quality TPs should be removed since their existence impacts the future phases' outcomes, including recalculating the orientation parameters and creating the thick cloud that results. Our objective is to remove TPs from photos directly to optimize and enhance the homologous point matching process. It is accomplished by creating masks that obviate the need to discover Key Points (KPs) in parts of the picture when a reprojection mistake.

Tests were carried out on the two most relevant and best-preserved Roman Amphitheaters located in the Campania region: (i) the Amphitheatre of Pompeii and (ii) the Amphitheatre of Avella. For both case studies,

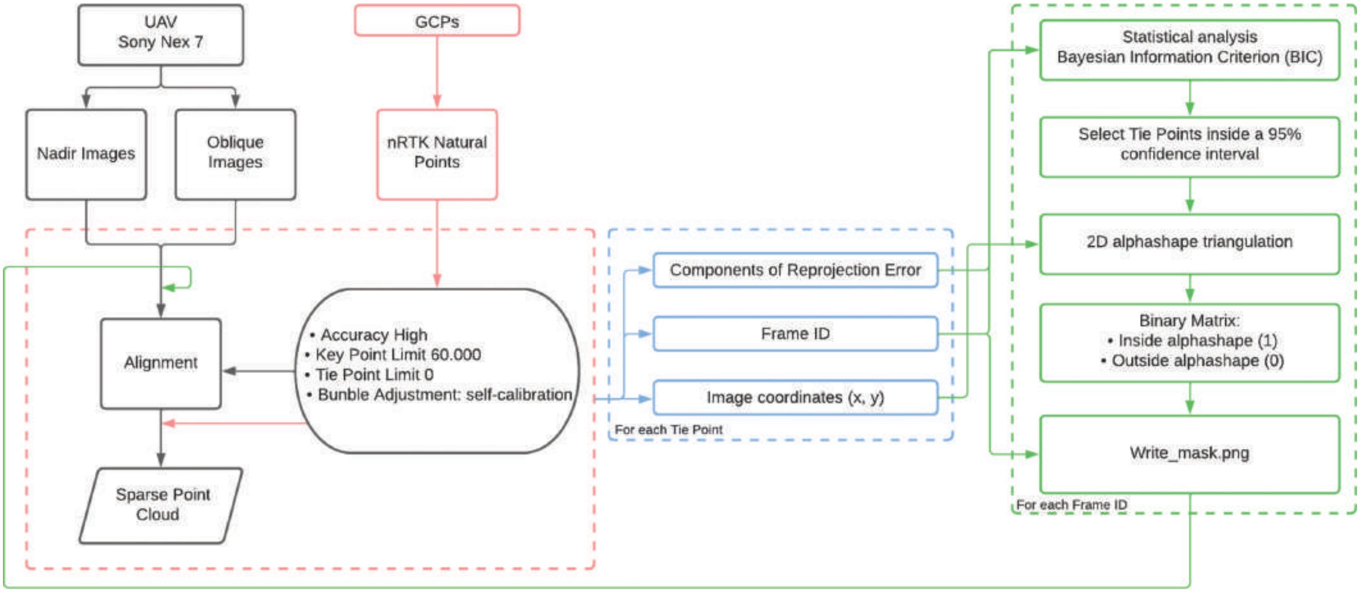

Figure 1. Research methodology workflow.

the frames were acquired with an assembled hexacopter equipped with a 24-megapixel Sony Nex 7 camera which integrates a APS-C sensor (resolution of 6000 × 4000 pixels, image sensor of 23.5 × 15.6 mm, pixel size of 3.96 μm) fitted with a fixed Sony E-Mount lens (16 mm focal length, Field of View - FOV 83°). For the Amphitheatre of Pompeii, a total of 496 frames were acquired, 301 nadiral frames with the automatic flight plan and 195 frames with manual flight and oblique camera (45° to the horizontal position). As for the Amphitheatre of Avella, a total of 626 photograms were acquired, of which 435 with the automatic flight plan and nadir camera and 191 photograms with manual flight and oblique camera. The software Metashape by Agisoft was used to process the photogrammetric data.

2. Methods

The images were processed in Agisoft Metashape (ver. 1.5.1). In addition, a few Python scripts have been written and performed within the program (Agisoft 2021) to extract particular processing outputs that are not available by default, such as reprojection errors. The reprojection error εi is a geometric error corresponding to the image distance between a projected and measured point (Fraser 2013). It is used to determine how closely a 3D point estimate approximates the real projection of the point.

Various methods have also been designed and implemented in MATLAB for statistical analysis and mask generation.

The following are the significant steps in the Metashape image processing process:

- Bundle adjustment with the self-calibration technique for estimating internal orientation parameters.
- Identifying the KPs on each image, where KP refers to an “interesting” point on a 2D image; it’s usually a spot that stands out against the backdrop or has an interesting texture.
- Estimation of relative orientation parameters to generate a sparse “low density” point cloud.

- Find homologous points in photos by automatically detecting and matching TPs.
- Computation of the pixel coordinates of the TP picture on each of the photos that include it.

Although Metashape outputs the numerical value of the error, a Python script was written to extract the magnitude and direction of the reprojection error ε_i, as well as its components ε_x and ε_y on the picture plane, for each TP. The output of Python scripts is stored in text files.

For each TP, the following information is provided: (i) the picture IDs that include that TP, (ii) the components of the reprojection error on each image, and (iii) the TP's associated image coordinates on each image.

To run the following analysis, the text file is imported into MATLAB and using the Bayesian Information Criterion (BIC) (Neath et al. 2012), a criterion for picking the best model from a finite number of models was used to find the probability distribution that best suited the reprojection errors. The method for selecting models is based on probabilistic statistical tests that seek to assess the model's performance on the training dataset and its complexity. This method has the advantage of not requiring a hold-out test set, but it has the disadvantage of not accounting for model uncertainty, which may result in picking too basic models. When comparing two estimated models, the one with the lowest BIC value is favored.

The related TP is regarded to be deleted if the value of any two components of the reprojection error exceeds a specific threshold (outside the 95 percent confidence range). From tests carried out in previous works the t Location-Scale distribution is the predominant distribution in the analysis of the reprojection error. This distribution is useful for modeling data distributions with heavier tails (more prone to outliers) than the normal distribution. It approaches the normal distribution as ν approaches infinity and smaller values of ν yield heavier tails. The probability density function (pdf) of the t location-scale distribution is:

$$\frac{\Gamma\left(\frac{\nu+1}{2}\right)}{\sigma\sqrt{\nu\pi}\,\Gamma\left(\frac{\nu}{2}\right)}\left[\frac{\nu+\left(\frac{x-\mu}{\nu}\right)^2}{\nu}\right]^{-\left(\frac{\nu+1}{2}\right)}$$

Where Γ (•) is the gamma function, μ is the location parameter, σ is the scale parameter, and ν is the shape parameter. Masks are generated automatically to filter out regions where TPs must be eliminated. The mask is a binary image with only one channel and values of 0 or 1. When it comes to showing images, one is white, and zero is black. The masks have the same size and resolution as the input pictures, with the value 0 denoting the masked image region. To eliminate the pixel effect, the masks are produced using 2D Alpha Shape triangulation with the picture coordinates of the TPs on each image (Gardiner et al. 2018). The Alpha Shape triangulation creates a bounding area or volume that envelops a set of 2D points. It is possible to manipulate the object to tighten or loosen the fit around the points to create a nonconvex region. And add or remove points or suppress holes or regions. After creating a shape object, MATLAB allows performing geometric queries. For example, determine if a point is inside the shape or find the number of regions that make up the shape. Also, calculate useful quantities like area, perimeter, surface area, or volume, and plot the shape for visual inspection. Within the Alpha Shapes, all of the image's pixels will be replaced with white pixels, while the remaining pixels will be replaced with black pixels (Edelsbrunner et al., 1983). In addition, the approach is designed to employ sparse matrices to avoid overflow concerns; this allows a complete matrix to be converted into sparse form by squeezing out any zero entries. The whole alignment procedure was then repeated in Metashape, applying the masks that had previously been constructed to the KPs to re-estimate the pictures' exterior orientation parameters. The alignment process is enhanced by masking the KPs with high reprojection error, resulting in a more accurate and low-noise point cloud. Figure 1 illustrates the research methodology workflow.

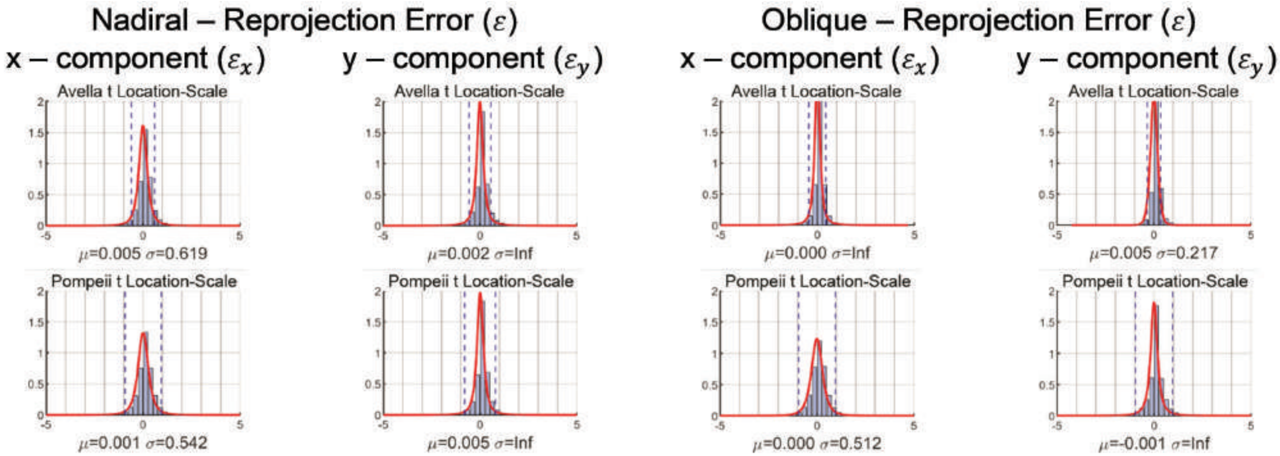

Figure 2. Probability distribution (confidence interval 95%) that best fits the components of the reprojection error.

3. Results

The t Location-Scale is the probability distribution that best matches the reprojection errors for practically all pictures in Avella and Pompeii projects (Figure 2).

The main results of the automated mask creation procedure (Figure 3) for two different sample photos (one nadiral and the other oblique) in the two projects. The “good” TPs, i.e., those with the reprojection error within the confidence interval boundaries, are shown by the green pixels (Figure 3, a).

When looking at the nadiral picture in Figure 3 (a), one can see that the green pixels correspond to areas free of vegetation and stable. Figure 3(c) shows the binary masks generated automatically from the alphashape interpolation illustrated in Figure 3(b).

The green pixels in the oblique image highlight the building, but the sky and foliage are erased. This is true for all of the studied photos for which masks were created (1122 in total). The sparse clouds created with the masks’ utilization have removed 47 percent of TPs for both datasets. This aspect demonstrates that using the masks generated according to the described methodology improves geometric congruence even when the reprojection errors are numerically very close to those of the original model (without mask); this was to be expected because filtering based on the reprojection error does not provide significant noise reduction benefits (Barba et al. 2019).

4. Conclusions

The proposed method enables the automatic generation of masks on the images to eliminate those Tie Points with unacceptable reprojection error. The results are encouraging.

The study of the probability distribution of the reprojection errors using the BIC criterion and a 95% confidence interval allowed to identify the values of the reprojection error components.

The results show that the masks created improve image alignment by aiding the Scale Invariant Feature Transform (SIFT) method in identifying homologous positions in different images and significantly reducing processing time.

The cloud of Tie Points after the application of the masks is significantly less noisy than the one obtained with standard methods, allows the creation of a more accurate model able to describe the general geometry of the historical structures.

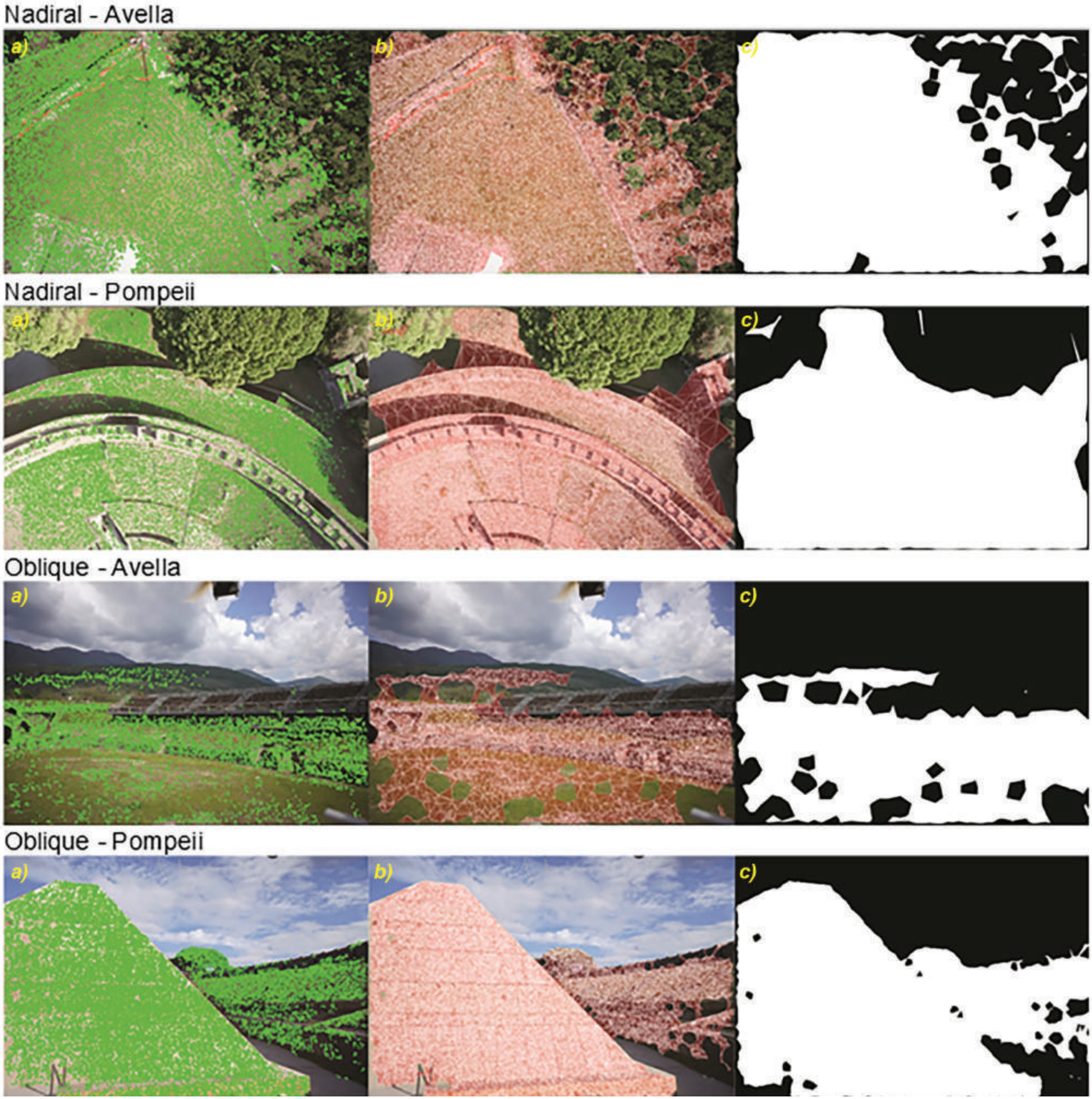

Figure 3. a): Identification on the image of the TP inside the confidence interval (green pixels); b): Alpha Shape triangulation (transparent red); c): Binary mask.

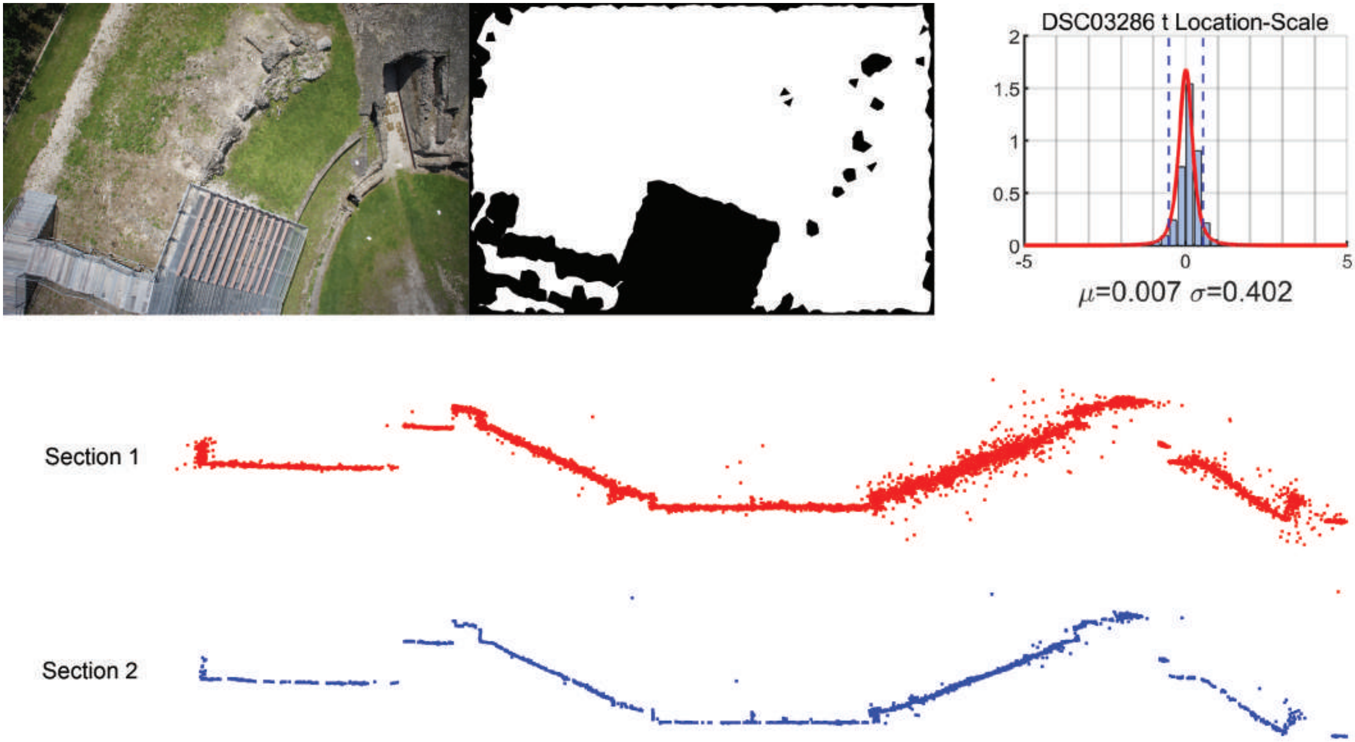

Figure 4. On the cover: Comparison betwee point cloud slices before (Section 1) and after (Section 2) the application of the masks.

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ABSTRACT

The research presents the analysis of an archaeological cultural site: the cenotaph of Palinuro. The contribution is developed on two tracks, firstly, the investigation of indirect sources aimed at understanding what the monument represented in the iconography of the Cilento landscape; furthermore, the site analysis artifact in the contemporaneity using drone technology for the process of photogrammetry. The objective is to focus attention on an interesting item of the Cultural Heritage, little studied and known, to engage a process of dissemination and enhancement carried out by new technologies.

Drone flight as a knowledge tool for Cultural Heritage

1. The role of digital technologies in the approach to knowledge for restoration

The significance of the protection and enhancement of Cultural Heritage is one of the subjects at the center of the Italian and European cultural debate for several decades. Our territory is rich in sites of historical, artistic, and architectural interest. For many years the interest in the protection and enhancement of tangible and intangible Cultural Heritage is focused on the best ways to transmit it to future generations and on how to make these resources easier to be known and accessible. For this reason, Cultural Heritage must be conceived as a resource to be reintegrated into the dynamism of contemporary society. Nowadays it is necessary to deal with the multiple modes of communication of the actual community, characterized by the digital age.

As evidenced by the main commitments both at the local and global governmental level (COM(2018) 267 final), which have focused on the role of digital transition, to be set up in a system to enhance the potential of innovation in favor of the different needs and perspectives related to knowledge, fruition, and enhancement of Cultural Heritage. *«In terms of European strategic lines, Cultural Heritage and digitization are two of the main areas of action that transversally empower the social, economic and international relations of the "New European Agenda for Culture 2018", which assigns full relevance to the Digital4Culture strategy»* (Puma 2020).

The development of new technologies, whose potential and multiple fields of application are getting more consolidated, in the study, in knowledge and promotion of Cultural Heritage allows more sophisticated analysis of the architecture.

These innovations, which are becoming more accessible from an economic point of view, have also opened scenarios regarding the diffusion of advanced digital approaches, aimed at the knowledge of the heritage, but also at its valorization thanks to the sharing on digital platforms. This approach helps to establish a dialogue with the younger generations, accustomed to multimedia devices, in order to stimulate their curiosity, interest and create a mechanism of awareness of Cultural Heritage.

2. The case study: the Cenotaph of Palinuro and his history

The object of this study is the Cenotaph of Palinuro. The site is located at the top of a southern promontory of the coastal strip of the village of Pisciotta, in the National Park of Cilento, Vallo di Diano, and Alburni. The Cenotaph appears in the state of an archaeological ruin strongly degraded because of the continuous exposure to atmospheric agents. The first acknowledgment of this site as an object of notable historical interest occurred in 1930 by the Sovrintendenza ai Beni Culturali of Salerno, which on that date placed a metal seal on the top of the archaeological ruin (Mautone 2003). Later, at the beginning of 2018, this protection has been consolidated by a decree of the Regional Secretariat for Campania of the Ministry of Heritage and Cultural Activities and Tourism, which recognizes the Cenotaph as an item of

Figure 1. *Atlante Marittimo delle Due Sicilie*, plate V, A. Rizzi-Zannoni, 1792.

Figure 2. On the cover: *Cénotaphe de Palinurus*, W.Gmelin, gravure, 1819.

particularly relevant archaeological interest (D.S.R. n°385 del 30/01/2018).
From the historical point of view the Cenotaph of Palinuro appears in literature for the first time at the end of the XVIII century in the work of Giuseppe Antonini entitled *"La Lucania, I discorsi"* (Antonini 1795). The author approaches the site's descriptive process, deepening the most relevant aspects. He outlines the position of the artifact concerning the geographical references of the time. This geographical referencing is absolutely accurate and finds a faithful comparison on the coeval Atlante Marittimo delle Due Sicilie by Rizzi Zannoni (Figure 1).
Similarly precise appears the description of the Cenotaph of Palinuro made by Antonini regarding the geometric dimensional assets as well as concerning the state of conservation of the building in the late eighteenth century period (Antonini 1795). The geometrically detailed exposition makes the features of the Cenotaph intuitable and highlights the simple dimensional ratios that constitute its essential rule. The annotations concerning the state of conservation of the work punctually identify the static criticalities linked to the collapse of the southern wall and of the relative access vain; at the same time, these annotations identify the elements of great value that had been transferred up to that time, such as the fragment of plaster of the inner minor vault, which at the end of the 18th century still presented traces of pictorial decoration. The representation made in literature of the overall state of the object in relation to that period is further corroborated by the drawing made a few years later by Franz Ludwig Catel and further developed in an engraving by Wilhem Friederich Gmeiln and released in Europe in the first quarter of the nineteenth century (Figure 2).
The dating of the structure is uncertain, the report attached to the decree of the regional secretariat for Campania presumes a plausible collocation of the construction period of the Cenotaph to the first century BC.
Finally, the ethno-anthropological examination carried out by Antonini in his excursus on the Cenotaph defines and identifies in the epic mythology the reasons that induced the local populations to erect the celebratory funerary monument object of this research (Antonini 1795).
The analysis of the current state of the object reduces the scale to an archaeological ruin of which it is possible to recognize the square planimetric structure of approximately 6.70 m emerging from the ground level for a height in its maximum development of

3.00 m. The ruin has walls composed of stone blocks ranging in size from 15 to 20 cm, the mortar courses are severely eroded, to the point of compromising the coherence of the components of the wall. The upper part of the archaeological site is largely colonized by low Mediterranean vegetation. Fragments of the southwestern and north-western cornerstones emerge from the vegetation. In a central position, it is possible to detect, in a fragment of the wall not attacked by the vegetation, the circular metal seal placed by the superintendence in 1930 which is mentioned at the beginning of the paragraph.

3. Methodological approach

The methodological approach adopted for the acquisition of data related to the site subject of this study is driven by the need to investigate the archaeological find in its geometric and material consistency without carrying out actions that could be potentially dangerous for the archaeological heritage. For this purpose, is particularly appropriate the process of an indirect photogrammetric survey operated through the acquisition of images by a support UAV then processed through the use of a specific software "Structure from motion" for data

Figure 3. The cenotaph of Palinuro. Part of the data set for the aerophotogrammetry.

processing to obtain a sparse point cloud, dense point cloud, mesh model and finally a mesh model with texture. The absolute lack of contact between the detector and the object allows firstly the absence of risks related to the damage of the artifact (Parrinello et al. 2020). Secondly, this mode of inspection allows operating the preliminary actions of knowledge of the site without exposing the operator to the risk of close contact with architectures of which is not possible to know the level of structural stability or whose access is made complex by prohibitive orographic conditions of the context. Photogrammetric data acquisition was conducted using a Dji Mavic mini 2 drone. The device is equipped with a 12 Mpixel photographic sensor measuring 6.3 x 4.7 mm with characteristics of 4mm focal distance, 24 mm focal length, and 83° FOV visual angle. The sensor is assembled on a three-axis stabilization gimbal system and has an operating angle that allows camera rotation from -90° to +20°. The use of a UAV system belonging to the C0 category is related to several reasons of technological order, authorization, and affordability. Concerning the technological evolution, the device considered today of the entry-level class is equipped with a photographic system of comparable performance to the equipment of professional imaging drones available on the market in 2020 (Dji Phantom 4). The homologation class C0 provided for drones with a take-off weight of less than 0,250 kg allows a considerable simplification of all authorization procedures for the realization of low altitude VLOS missions. The third parameter used for the choice of this type of equipment is the high degree of accessibility both in economic and operational terms. This aspect considerably increases the range of users who can have access to the technology and use it for the collection of preliminary data that are not intended to replace the most advanced professional acquisitions but that are a fundamental element for the development and expansion of the database of knowledge of objects of great historical, artistic, architectural and archaeological value that are scarcely known or even unknown to the scientific community and the protection authorities.

The acquisition process, about the small size of the object of study, has involved the realization of several revolutions at different altitudes around the item (Figure 3). The first revolution was made by a cycle of shots made with angle 0 of rotation of the sensor for the acquisition of images orthogonal to the vertical plane at an altitude of 1.50 m from the base of the object equal to 39.50 m above sea level. The subsequent rotations around the object have used an increasing angle of shooting realizing complete series with an inclination of -20° (altitude 4,00 m), -45° (altitude 6,80 m), and -60° (altitude 8,70 m), finally, the acquisition process was concluded through the realization of shots with an inclination angle of -90° orthogonal to the horizontal plane to achieve a series of images that capture the artifact from the zenithal point of view starting from close shots in a 4x4 grid (altitude 10.60 m) subsequently reduced in relation to the growth of the capture altitude up to a single shot at an altitude of 33.70 m.
The processing phase of the data acquired through the survey campaign has generated a sparse point cloud composed of 34100 points subsequently thickened up to 4991000 points in the development of the dense cloud. The consequent model composed of 1351000 polygonal meshes is metrically compatible with the dimensional references acquired during the survey campaign. It has been therefore possible, as the last phase of reconstruction structure from motion, to apply the texture to the mesh model generated by the photogrammetric process, in order to provide to the model a material connotation (Figure 4).

4. The drone and new technologies, as a tool for knowledge, enhancement, and heritage conservation

The architectural survey is certainly the base for the geometric and morphological knowledge of the architectural heritage. Every project of architectural restoration begins with a process of systematic analysis, thorough, as the result of an interdisciplinary approach, aimed at a meticulous acquisition of knowledge of the object of study (Campi et al. 2018). An initial phase of direct awareness of the object is followed and accompanied by careful bibliographic and iconographic research, the so-called indirect sources. The survey of the artifact is among the first fundamental cognitive acts, followed by a series of studies necessary and useful to the diagnosis of the phenomena of degradation and instability: through in-depth surveys of materials and degradation.

The use of drone and aerophotogrammetric process allows a global knowledge and analysis of the architectural artifact or archaeological rests, permitting the overflight and the shooting of images from above. The development of orthomosaics is useful to obtain different information of qualitative, as well as quantitative type, to analyze and identify the phenomena of degradation. These allow the realization of knowledge elaborations of the archaeological heritage at a scale of representation of 1:50. The detail obtainable from the elaboration of zenith orthophotos and photo plans related to the four elevations of the artifact allow expanding the degree of knowledge of the object through the production of materic representations and

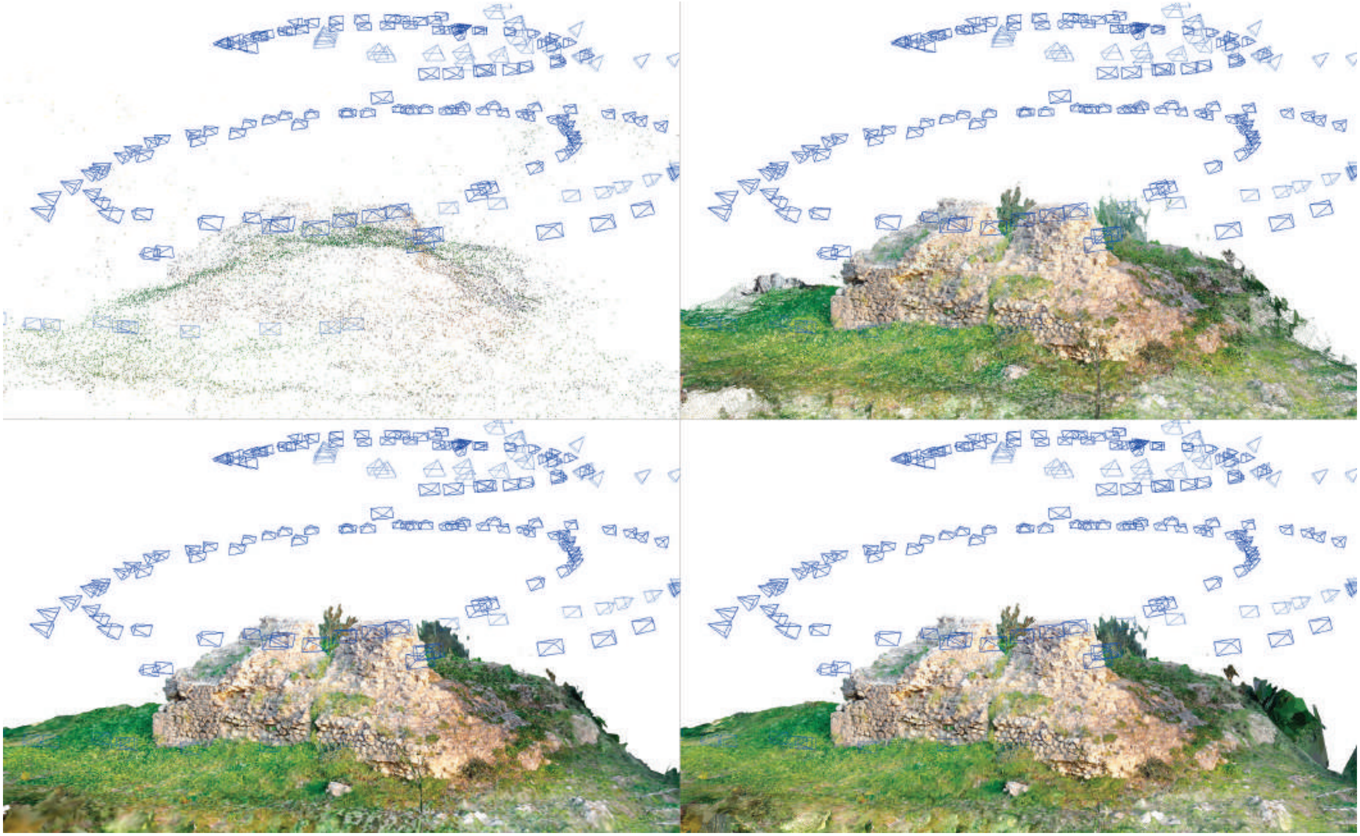

Figure 4. The cenotaph of Palinuro. The phases of the aerial photogrammetric process. From the left above: sparse point clouds, dense point clouds; From the left below: mesh model, textured mesh model.

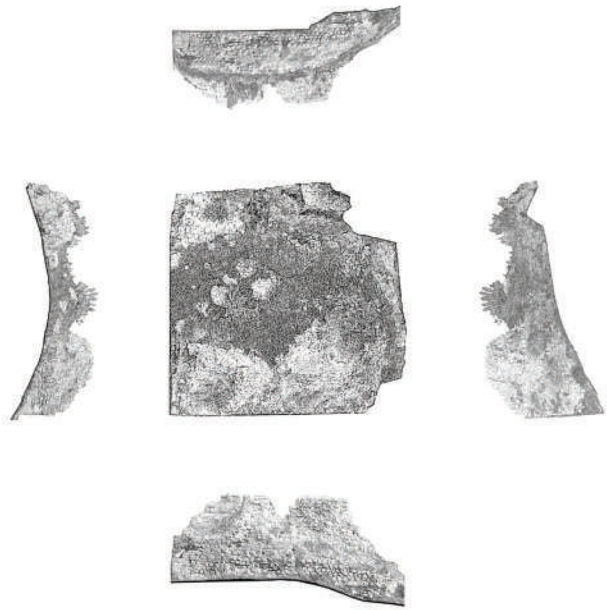

Figure 5. The cenotaph of Palinuro. Materic graphic restitution.

subsequent analysis related to the state of degradation. The three-dimensional model, useful to study the morphological conformation, in the archaeological field represents a possibility of considerable interest, especially for the non-invasiveness of the inspective action. A necessary study, not only to understand the complexity of the object but also for the definition of the restoration project, whether purely conservative or aimed at reconstructing the functional structure of the object. This technology, in addition to offering an important instrumental contribution, for knowledge and diagnostic investigations, represents an extraordinary possibility regarding the diffusion of heritage through digital reconstructions.
The post-pandemic scenario has accelerated a global process of transformation and digital innovation, forcing the entry into the average citizen's daily life of several technologically advanced processes, just think of the widespread use of calls and smart working.

In this perspective, the research intends, in a second phase, to capitalize on the use of virtual platforms where it is possible to upload and make accessible, even if only virtually, the object of study. The aim is to focus attention on a part of the abandoned and forgotten heritage of high historical, artistic, and cultural value.

5. Conclusion

This research aims to reflect on the great importance of digitization tools, not exclusively related to the survey but finalized to the knowledge and investigation of the heritage. *«The appearance of the documentation becomes even more important when the policy of conservation concerns both the physical object that the immaterial memory of the historical, artistic and cultural artifact that maintains and forward in time»* (Bertocci, Parrinello 2015).
The first outcome of the research concerns the efficacy of the use of entry level technology for photogrammetric processes, not as a substitute for the more advanced technologies used by the scientific community, but as a useful tool to amplify the process of knowledge of the large number of heritage sites still poorly studied spread on the territory. The long-term objective of this type of research is related to the possibility of creating a database of open access knowledge able to make the data available and expand as much as possible the awareness of the architectural and archaeological heritage. The objective is to draw attention to a scarcely known and analyzed site, which is an element of great importance in the iconographic construction of the Cilento coastal landscape, that has been the object of important representations as illustrated above.
An anthropic element placed at the top of a hill, in strong synergy with the coastal landscape, which has now lost its identity character of a fundamental element. Its study and digitization want to be the first step to establish a process of knowledge aimed at the preservation and promotion of the heritage. The innovative nature of the methodological approach lies in the possibility of analyzing categories of similar

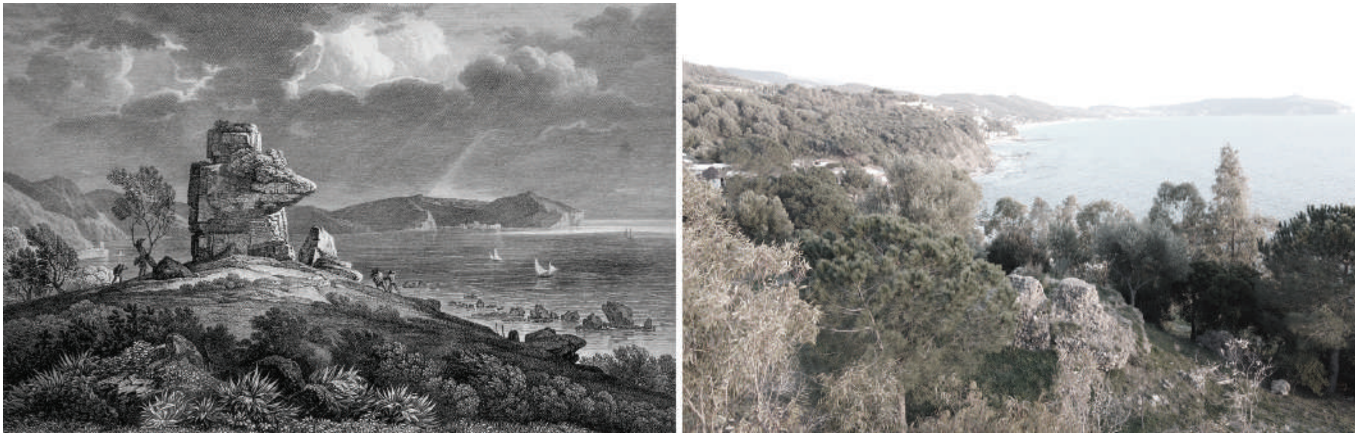

Figure 6. The cenotaph of Palinuro. Comparision between iconography and contemporaneity. On the left: Cénotaphe de Palinurus, W.Gmelin, gravure, 1819. On the right: view of the cenotaph and his en-vironmental landscape from a similar viewpoint identified through the drone flight.

objects, implementing the lack of knowledge, and starting virtuous mechanisms of enhancement and protection of Cultural Heritage. The Italian territory for its characteristics of dense historical stratification combines richly known territories described and analyzed with areas that for reasons of inaccessibility remain unknown or forgotten.

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Keywords:
UAV, Drones, Cultural Heritage, Accessibility.

ABSTRACT

Using drones in the architecture field is very useful in terms of the dissemination of Cultural Heritage and a fundamental tool in order to reach universal accessibility in it. Thanks to the use of drones and advanced photogrammetry softwareswe can make known our Cultural Heritage through interactive 3D models, virtual reality VR and augmented reality AR of these models and, even, mockups. This way, we can achieve that our Cultural Heritage, considered like one of our gratest attractions, reaches to all the society without limitations.

Drones in architecture research:
methodological application of the use of drones for the accessible intervention in a roman house in the Alcazaba of Mérida (Spain)

1. Introduction

As we know, the use of drones has been consolidated in many areas such us the cinematographic industry, events broadcast or, even, fiscal control. However, the use of drones it is not yet consolidated in other many areas, like architecture, topography and Cultural Heritage, that, apart from providing really good results, it approaches this new technology to the majority of the society whom actually uses of drones become too distant. Futhermore, we can't forget how useful could be this technology for the study, the reconstruction, the recreation and the maintenance of the discovered archeological remains of our countries (Parinello, Picchio, 2019, p. 1).

Therefore, the fundamental goal of the applications of drons in the architecture field is those which pretends reach universal accessibility all around our cultural and architectural heritage in addition to favour its dissemination. For it, we follow a process based on the use of drones (Rueda Márquez de la Plata, Cruz Franco, Cruz Franco, Gibello Bravo, 2021, p.11,12) like an innovative and useful method for taking datum and a correct process of these datum through an advanced photogrametric software. In this contribution, we are going to apply this methodology (Rodríguez Sanchez, 2021, p.30-39) n the roman remains of a house located inside the Alcazaba of Mérida and the importance of the use of drones in the accessibility interventions proposed of this kind of heritage. This contribution is based on a previous research about the roman remains of the Alcazaba de Mérida. (Gómez Bernal, E., 2021, p.36-42).

2. Methodology

Next, we are going to carry out the methodology based on the taking datum with dron (Templin, Popielarczyk, 2020, p.8) and the processing of the images obtained applied to the roman house od the Alcazaba of Mérida (Parinello, Picchio, De Marco, Dell'Amico, 2019 p. 4). The first step of this method is based on the historic, constructive and evolutionary analysis of the roman remains mentioned as the base of the study and de developement of the photogrammetric survey (Cruz Franco, Rueda Márquez de la Plata, Cruz Franco, Ramos Rubio, 2017, p.4). The contruction solutions that the romans used to built its houses, the transformations of these techniques and, even, the facings and coverings they used must be studied (Figure 1).

Figure 1. Constructive solutions of the roman house of the Alcazaba of Extremadura.

To understand the followed methodology first, we must be clear about photogrammetry concept. Photogrammetry is an accurate method to get three-dimensional (3D) *datum* from two-dimensional(2D) information compile through the taking of photographs. This method is totally employed in 3D reconstruction, renovation, analysis and maintenance of cultural and architectural heritage as digitalization of the seek information about it (Parinello S., Picchio F. 2019, p. 3,4). Thus, photogrammetry, using cameras or, in this case, drones, create models that reproduce the state of the heritage generating a new information system (Parinello Picchio, Dell'Amico, De Marco, 2019, p. 19,21).

The previously mentioned method consists on the following steps:

2.1.Select the working area

First of all,it is necessary to select the archeological remains, the architectural heritage or just a part of it in which we are going to apply this procedure.

As a continuation, we have to establish an order for the taking photos considering the drone access conditions and limits refered to the place where we are. Finally, we have to consider the weather. In order to get better results we have to avoid strong shadows so, if we can, the taking datum should be done during cloudly days.

In this case, the selected zone is the roman house located inside the Alcazaba of Mérida that, due to this house is located outdoors, it hasn't got any space limitations for the taking datum with the drone.

2.2. Taking datum

In second place, we proceed to take photos with the drone. It is important that each time we have to take datum, we have to use the same drone due to all the images have to be taken with the same focal distance and it is characteristic of the dron. In this case, the ultralight drone DJI MAVIC MINI has been used for the taking datum (Figure 2).

Besides, one of the most important parts with regard to obtain good results is the positioning of the necessary targets to orient the images that the program is not able to orient automatically and to connect parts of a large model to obtain a good result without distortions (Figure 3).

These targets are numbered and they must be always placed where they were pointed in the first taking datum in order to get a good result from the fusion of the different models.

When we are working on architectural and Cultural Heritage, the positioning of targets could be difficult because, in most cases, we find large areas of remains

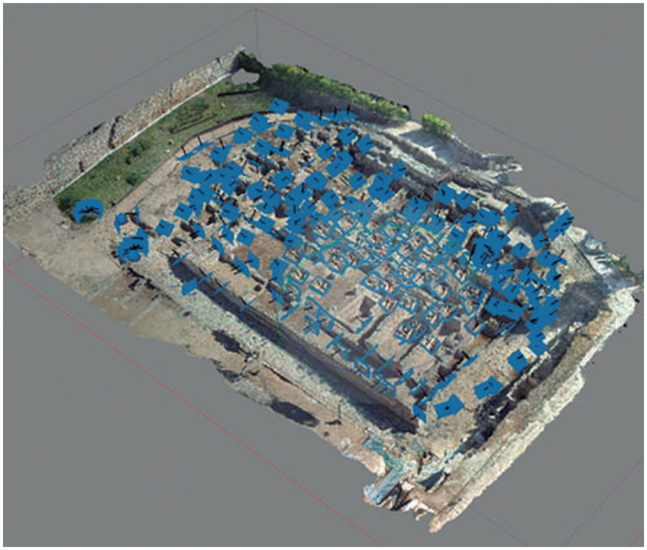

Figure 2. Taking *datum*.

Figure 3. Positioning of targets.

to which we cannot access due to the protection of the specific heritage or because of the security risk that it entail.

With regard to the take of photos, the optimal methodology to get better results is those which is based on overlap images trying that the targets appear in as many images as is posible to help the photogrametric software to relate them.

In addition, to avoid holes in our final 3d model, it is necessary that a same zone of the heritage which photogrammetric survey we are carrying out appears in different images with differents points of view. Thus, this procedure cannot be improvised, we must previously establish an order to organize the job, optimizing the time duration of the batteries and making easier the process of the images to the software.

2.3. Generating point clouds and triangle nets as the final process of photogrammetry

When we have taken datum, we use the processing images software called *Agisoft Metashape*. Inside this software, the first step consist of charging the images taken with the dron (Parinello, 2020, p. 4,5).

Then, we orient the images prepared to be process. The drone receives a GPS signal which let orient them directly according to the coordinate system that the drone use for the taking datum. The majority of images will be oriented automatically, nevertheless others won't be pointed and we have to point them in a manual way. From the oriented images we get a dispersed point cloud which must be convert on a dense point cloud which let us see the shape of the part of the heritage we are studying. It let us filter by confidence removing those which "*make noise*" in the final result (De Marco, 2022, p.4).

This dense point cloud give us the following results:

- A planar Digital Elevation Model (DEM) which permit us seeing the current slope in the studied heritage;
- A triangle mesh that join the points of the point cloud. Applying a texture to this net, we obtain a 3D model which must be scale 1:1 to get really useful

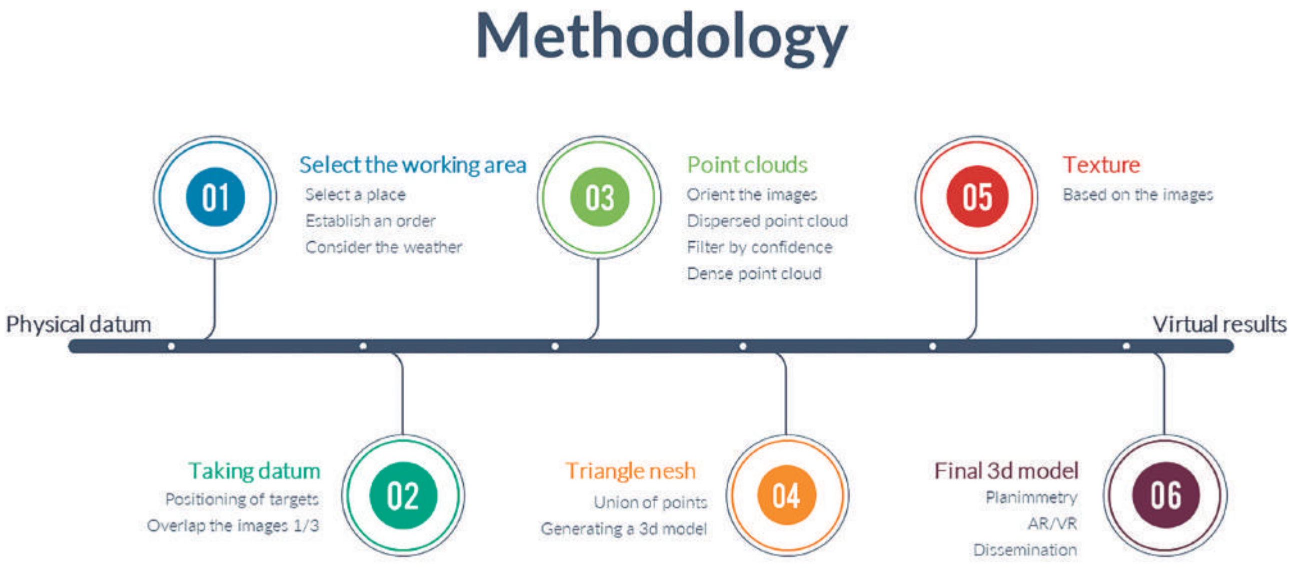

Figure 4. Workflow diagram.

results to the society. Futhermore, we can create ortophotos from XY and YZ planes that give us sections to promote a quite approximately view of the measures of Cultural Heritage.

This procedure (Figure 4) give us really good results keeping its low cost in mind. It is an affordable, quick and simple procedure that anypeople can carry out with some basic notions about the managment of the drones. Photogrammetry with drones permit obtain accurate measurements, however, the precision of this method could be improve through other more accurate survey tools like a Terrestrian Laser Scaner (TLS).

3. Intervention

Actually, people can access to the mentioned roman remains throug a platform that join the general zone of the Alcazaba and the roman road or through a platform that penetrate into the remains (Figure 5). However, there isn't an accesible itinerary for people with reduced movility. What is more, nowadays, anypeople can come into the roman house, so everybody get a non realistic view of these remains.

For it, the proposal intervention was based on creating a serie of platforms and ramps that allow everypeople get into the roman house giving a realistic view of the roman life in this house in addition to allow people with reduced movility access to this roman remains, considering that, actually, it is impossible for them.

On the other hand, the connection between the west roman road and the south roman road must be kept to allow the movement of visitors through them, so the planned intervention must be carried out in accordance with this issue (Figure 6).

Firstly, from the 3D model we obtain planimetry based on which we get real measurements of those places that we cannot access in person. Then, we generate sections through precise photogrammetric cuts of the model (Cruz Franco, Rueda Márquez de la Plata, Cruz Franco, 2020, p.9) in order to understand the architectural configuration of the heritage and study the characteristics, measurements and volumetry of it.

Combining the contour lines provided by the DEM and the information obtained from the sections, we get the altimetric heights required to plan the proposed accessibility intervention (Figure 7).

Figure 5. Existing access to the roman road and existing platform that penetrate into the remains.

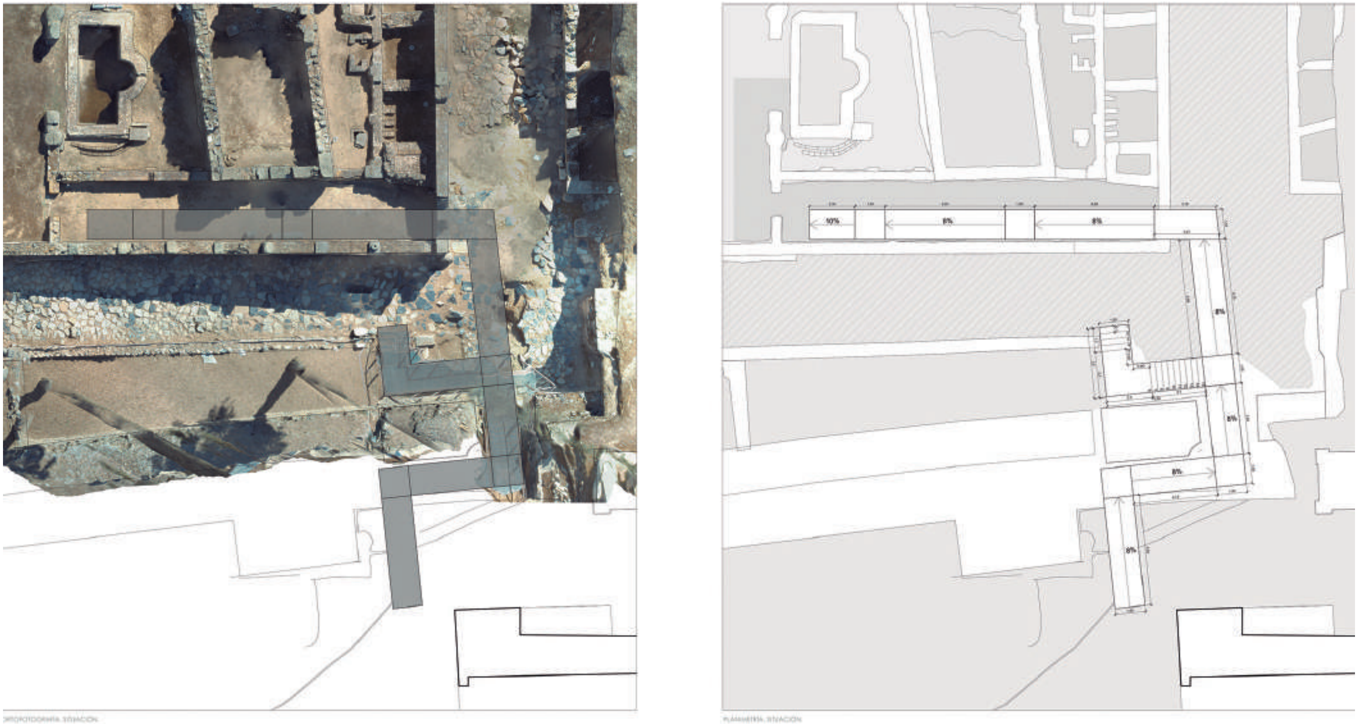

Figure 6. Intervention based on platforms and ramps.

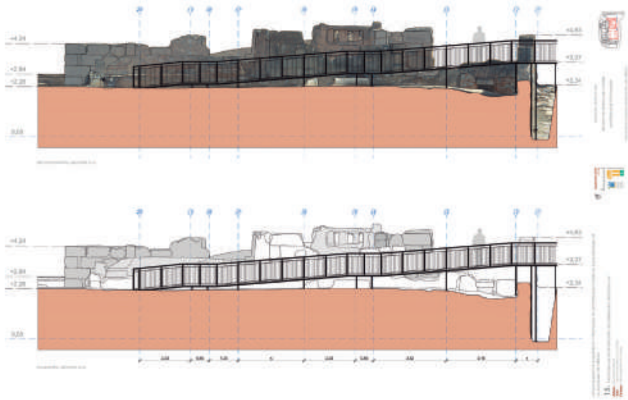

Figure 7. Planimmetry. Sections with the accessibility proposal.

In this case, the proposal is based on the execution of a platform that connects the Alcazaba with the interior of the roman house and the west road.

From these altimetric heights, we know the slope to overcome both at the beginning of the ramp and at the platform that crosses the passage over the wall until reaching the interior of the Roman house. Based on it and on the route selected for the development of the platform, we calc the slopes, taking into account compliance with the spanish accessibility regulations (Figure 8). Thanks to this step we could outline the access to the interior of the roman house and maintain the access to the roman road.

In addition, to carry out the proposed intervention, it is necessary to design and calculate a structure in order to support the mentioned platform and to make

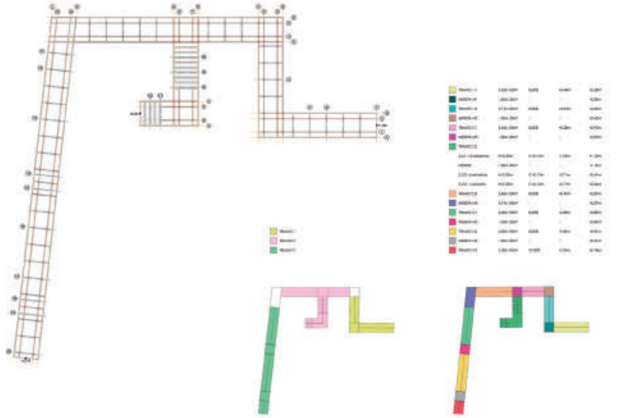

Figure 8. Planimmetry. Slopes calc for the accessibility proposal.

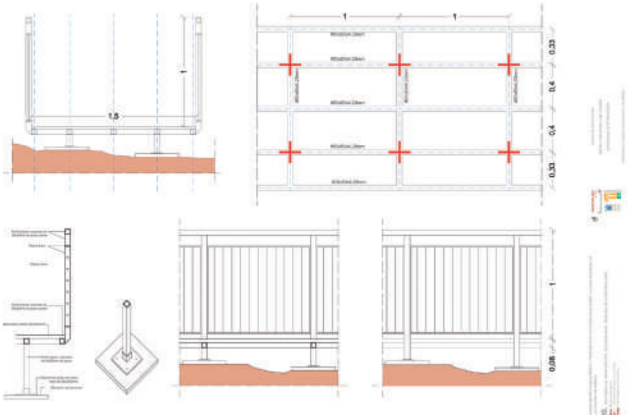

Figure 9. Construction solutions and the structure support.

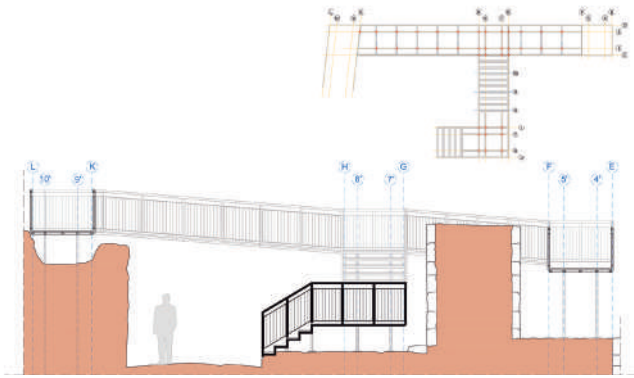

Figure 10. Plans to execute the accessibility proposal.

possible its construction. In this calculation, the main consideration to keep in mind is considering that we are working in an intervention on roman remains considered as Cultural Heritage so we can't execute foundations and the calculated structure must be supported by the existing substrate (Figure 9).
When we have completed these steps, we proceed to generate planimetry to permit the execution of this accessibility proposal (Figure 10) and a 3D model of the planned intervention supported on the 3D model generated with a drone.
For the final step we get 3D renders of the intervention throug softwares like *Lumion* which let me obtain videos and photographs (Figures 11 and 12) that simulate the implementation of this intervetion on real life.

4. Results

Besides the possibility to carry out an accessibility intervention, we obtain other interesting results from the photogrammetry methodology (Zhihua Xu et all., 2014, p.5).
By one hand, from the images taken with the dron, we get a group of photograps which we can employ in the informative panels that normally are located near the Cultural Heritage as an explanation and a way to orient the visitor. Futhermore, there are online platforms like Sketchfab where we can upload the 3D model with notes generating interactive models (Ramos Sánchez, 2021, p.119). On the other hand, thanks to the described procedure and online platforms we can take our heritage everywhere (Monterroso-Checa et all, 2020, p.12,13) accessing, even, to those corners which anybody can access by another way. What's more, people with reduced mobility could access to those points like any other person without these limitations. This accessibility is achieved through the new technologies that offer us novel results that some years ago were unbelievable. These results are virtual reality (VR) and augmented reality (AR). Both of them let us visiting from home the roman remains of the Alcazaba of Mérida getting over the accessibility limitations that could prevents it.

Using virtual reality glasses and the 3d model uploaded to the online platform, we could see, explore and move (Obradović et all, 2020, p.14) around the heritage we have been working about. This technology transform a 3D model into an interactive experience and it become the future of museum resources (Barrado-Timón, Hidalgo-Giralt, 2020). We can't forget that universal accessibility doesn't mean just a physical concept. A full accessibility involves also a sensorial and a cognitive concept. About sensorial accessibility, mockups can be generate to assist the understanding of the heritage and to allow a those people with sensorial issues enjoy and undestrand the heritage as well as any other person. On the other hand, about cognitive accessibility, 3D models uploaded to Sketchfab favour the understanding of the heritage through the notes that appear with the model (Figure 13). Just when our heritage would been accesible to everypeople we could talk about the required universal accessibility that we are looking for our Cultural Heritage.

Figure 11. View of render.

5. Conclusion

In conclusion, thanks to the advance of the technology, to the use of the drones in some areas in which its use it is not consolidated yet and whose consolidation supose a great profit for all the community, to the advance of the photogrammetric softwares, to the use of online platforms which show our heritage around the world, to the implementation of the heritage through mockups and, finally, to the mix between the photgrammety process and the digitalization of the information, we can reach a biggest dissemination of the Cultural Heritage and the universal accessibility to them.

Figure 12. View of render.

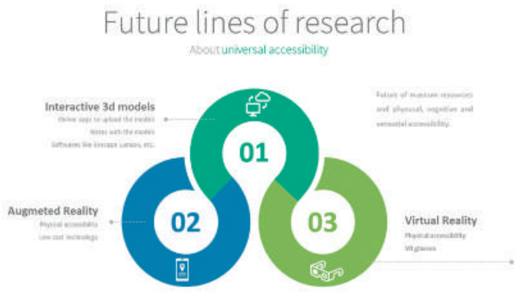

Figure 13. Diagram about the evolution of the research about universal accessibility.

As demonstrated, it has been possible to project a one hundred percent accessible entrance to a venue that until now had no accessibility thanks to the help and photogrammetric precision that the use of drones has given us in a complex project in terms of its development. and its elevation and level changes.

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UAS, HBIM, SLAM, SfM.

ABSTRACT

Uncrewed Aerial Systems (UAS) are nowadays a consolidated technique for the 3D metric documentation of Built Heritage. Nevertheless, a complete survey of complex heritage assets still requires the integration of different techniques, using a multisensor and multiscale approach. The research presented in this contribution relates a documentation experience achieved on a complex heritage asset, from multisensor data acquisition, through data processing and validation to the phase of 3D modeling and HBIM creation.

UAS photogrammetry and SLAM for the HBIM model of the Montanaro Belltower

1. Introduction and case study

The documentation of Built Heritage is a complex task that requires to be carefully planned and executed (Letellier, 2015; Patias, 2007; Remondino & Stylianidis, 2016). The developments of Uncrewed Aerial Systems (UAS) over the last decade allowed to speed up and simplify the overall documentation process in different fields of applications and specifically also in the one of Built Heritage. A rich scientific literature is available regarding the different approaches that can be adopted with these platforms and the operative guidelines for implementing data acquisition and processing (e.g., Adami et al., 2019; Chiabrando et al., 2017; Nex & Remondino, 2014; Remondino et al., 2012; Russo et al., 2018). Nevertheless, a complete survey of complex heritage assets still requires the integration of different techniques, using a multisensor and multiscale approach (Achille et al., 2018; Georgopoulos, 2018; Remondino & Stylianidis, 2016).

Furthermore, while the acquisition and processing phases are generally managed with consolidated strategies, the phase of 3D models generation and data interpretation still presents some major challenges. This aspect is particularly evident in Heritage Building Information Modeling (HBIM) workflows where the data collected and processed need to be further interpreted, validated, modeled, and enriched (e.g., Banfi, 2020; Brumana et al., 2013; Yang et al., 2020). This phase presents a series of challenges that need to be faced, new solutions that need to be researched, and new approaches yet to be validated and studied.

The research presented in this paper relates a comprehensive and thorough experience completed on a complex heritage asset: the Santa Marta Belltower designed by Bernardo Antonio Vittone between 1769-1772 A.C. for the municipality of Montanaro (Figure 1), a little town close to Torino (Northwest of Italy). This asset was designed and built together with other structures with which it forms a unique heritage palimpsest. The belltower is indeed the fulcrum of the architectural composition, while the other structures are: the town hall, the brotherhood of S. Marta, and the parish church. This project represents the integration between the secular community and the sacred space in the XVIII century municipality of Montanaro (Battaglio, 2000) and was carefully designed by the architect (Figure 2). The belltower is approximately 48 m high; it becomes slender in the progression toward the top and has a peculiar internal spiral stairway made of stone. Considering that this asset should be part of a new requalification project in the next years, a complete metric documentation of the tower and the surroundings was necessary.

2. Data acquisition, processing, and validation

A detailed 3D model of the belltower was completed combining different techniques: in particular UAS photogrammetry was used for the exterior part of the belltower while Simultaneous Localization And Mapping (SLAM) based solutions were adopted for the

On the cover: aerial view (from south) of the Santa Marta Belltower and the buildings around.

interior. All the different acquisitions were referred to the same coordinate system thanks to a set of ground control points measured with traditional topographic techniques (Global Navigation Satellite System -GNSS and Total Station surveys) that were used also for evaluating the accuracy of the different processing approaches. The final products of the documentation project were requested to meet the nominal map scale accuracy of 1:100 (precision under 0.02 m with an accuracy of 0.04 m). The topographic network was constituted of a total number of 8 vertices (five in the square facing the tower and three in some intermediate floor in the indoor). All the vertices were measured by mean of Total Station and, moreover, two of the vertices outside the belltower were measured with GNSS static technique, to georeference the network with respect to WGS84 Datum (UTM Zone 32N coordinates). Secondly, UAS acquisitions were performed to achieve a complete 3D reconstruction of the exterior part of the belltower. The UAS deployed in the field was a DJI Phantom 4 Pro[1] and, considering the urban conformation of the area and the proximity of other buildings it was decided to perform manual flights, to guarantee a better control of the platform during the operation. Images were acquired starting from the ground to the upper limit of the tower and to ensure the desired Ground Sample Distance (GSD) of 3 mm, a mean distance of 5 meters was maintained between sensor and object. For each façade both nadiral and oblique images (with respect to the façade average plane) were acquired for a total number of 543 images (Figure 3). This acquisition solution was preferred to the Point of Interest (PoI) flight scheme for two main reasons: i) to avoid flying over the nearby building and ii) to guarantee a lower acquisition distance from the tower with a consequent lower GSD and higher detail. To document the interior part of the tower a rangebased approach was used exploiting the SLAM algorithm

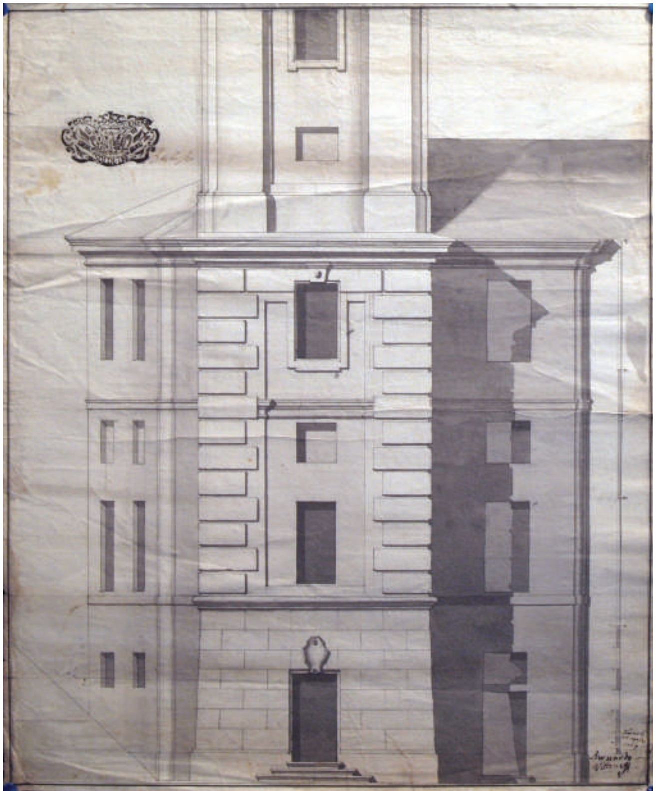

Figure 2. An example of the drawings (Historical Archive of Montanaro) carried out by B. A. Vittone: the main façade (1769-1772).

Figure 3. UAS acquisition scheme (left) and examples of acquired images (right).

within the ZEB Revo RT[2]. This approach is sustained by a recently new technology that however has proved to be suitable also for heritage documentation under certain conditions (Barba et al., 2021; Chiabrando et al., 2018; Malinverni et al., 2018; Sammartano & Spanò, 2018). During fieldwork, the operative and wellknown procedures for acquiring data with this system were followed (Riisgaard & Blas, 2004), and specifically, closedloop acquisitions were achieved. The acquisition with the Zeb Revo RT started and ended outside the belltower entrance and the operator reached the higher accessible area inside the belltower, a total number of four scans was acquired. The acquisitions with TLS were not conceived to cover all the volume of the belltower, and thus only few scans were achieved to serve as ground reference. A Faro Focus3D X 330 TLS was used for data acquisition and a total of eighteen scans were acquired covering part of the exterior of the tower and part of the indoor areas. The processing and the final products derived from the acquisitions were metrically and geometrically validated following two approaches: the use of Ground Control Points (GCPs) and Check Points (CPs) and the comparison with a Terrestrial Laser Scanner (TLS) dataset that can be considered a more consolidated technique and can thus be used as a ground reference.

Both artificial papercoded targets and natural features were used as GCPs and CPs and were measured by mean of a Total Station in the interior and exterior part of the belltower. The points measured on the exterior were mainly used for the UAS data processing and validation, while the ones in the interior were crucial to ensure a reliable connection between indoor and outdoor and to control the interior acquisitions. In the exterior part, it was possible to measure 67 points while 32 were measured in the interior. Concerning data processing, it was decided to follow consolidated strategies for all the different acquired data. Images acquired during the photogrammetric flights were processed in a commercial solution (Agisoft Metashape) exploiting the standard pipeline: from image matching, via the Bundle Block Adjustment (BBA), metric validation through GCPs and CPs (Table 1), point cloud densification, and generation of added value products such as Digital Surface Models (DSM) and orthophotos. Due to the high number of

Table 1. Main processing results of the photogrammetric processing.

Images	N° GCPs	3D RMSe GCPs (m)	N° CPs	3D RMSe CPs (m)	GSD (m)
543	27	0.009	8	0.008	0.003

Figure 4. Example of the quality of the 3D models generated by the UAS photogrammetric processing on a portion of the belltower.

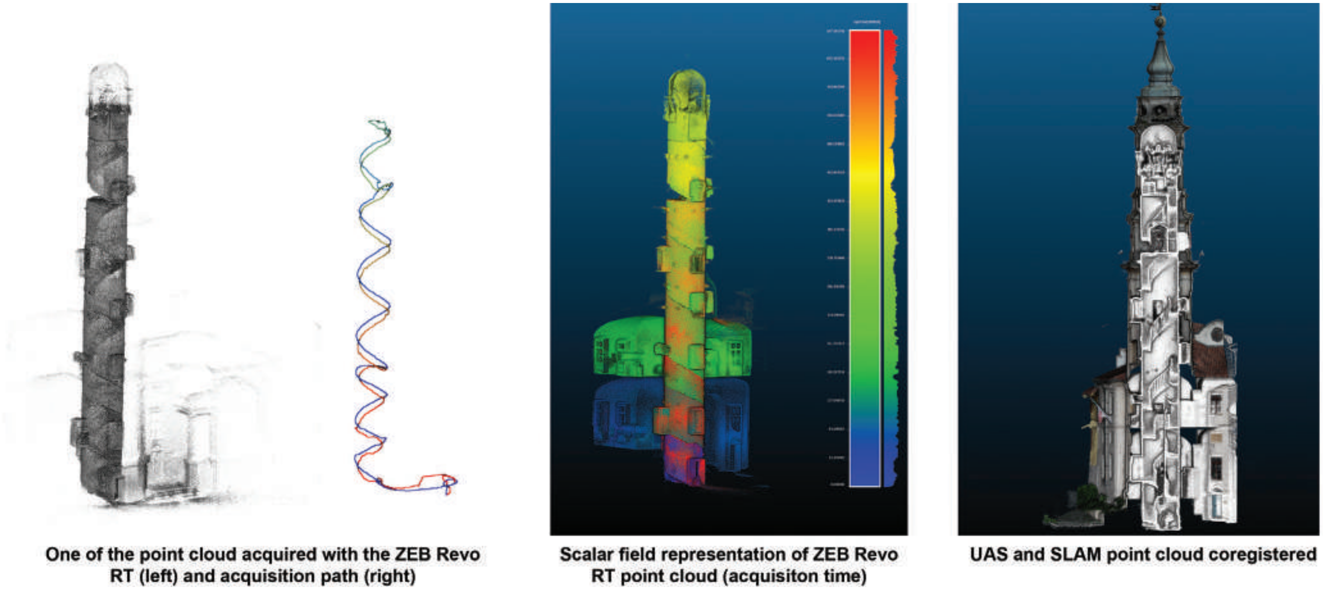

Figure 5. Workflow of the on the field survey (left), schema of the GNSS network and the position of the ground marker used for the photogrammetric UAV processing (center)). Topographic measurements total station (right).

images and the reduced sensorobject distance, it was possible to generate a high detailed 3D model, as shown in Figure 4. The TLS dataset was processed using its dedicated solution: the Faro SCENE software and two different approaches were followed for the outdoor and indoor dataset. The outdoor scans were firstly registered using an Iterative Closest Points (ICP) algorithm and then georeferenced using the ground control points measured during the fieldwork. For the indoor dataset, the control points were used for both the registration and georeferencing phase, due to the different and more complex geometry of the scan positions influenced by the environmental constraints. The accuracy of the targetbased registration was 1 cm for the outdoor dataset and 0.5 cm for the indoor dataset. The first step of the ZEB Revo RT processing (Figure 5) foresees an optimization of the acquired point cloud thanks to the SLAM-based algorithms and is then followed by a registration of the SLAM point cloud in the same reference system of the other acquisitions. The first step is performed in GeoSLAM hub and the operator's possibility of processing customization is quite limited.

In the second step inside GeoSLAM hub, the different point clouds are roughly aligned and then registered by the software via the "merge" function. During this second step the SLAM scans were then coregistered with the TLS dataset using an ICP registration in the open-source solution CloudCompare[3]. The RMSE (Root mean square error) resulted from this operation was approximately around 4 cm. A more detailed description of the acquisition and processing phases can be found in (Teppati Losè, Chiabrando, & Tonolo, 2021; Teppati Losè, Chiabrando, Novelli, et al., 2021) while more information about some tests connected to Spherical Photogrammetry approaches completed using the belltower as test sites can be found in (Teppati Losè, Chiabrando, & Tonolo, 2021).

3. From point clouds to HBIM

Two main products were generated starting from the point cloud derived from the metric survey: traditional 2D drawings and a first HBIM model. The creation of an HBIM "as-built" model represents a further step of the documentation project of the belltower.

As is well known, the use of this type of data (point clouds) in the BIM software solutions is still not fully implemented and different challenges need to be addressed when adopting this approach, especially when dealing with a complex architectural object.

Different solutions were tested in the BIM software used (Autodesk Revit), both using built-in tools and external plugins or software.

The first approach tested for the creation of the HBIM model consisted in a more consolidated solution, that started with the import of the point cloud in the Autodesk Revit software and the subdivision of the belltower in different main portions. For each of the eight portions created a series of sections was then extracted to serve as the geometrical base for the creation of the main volumes constituting the belltower. Thereafter, the sections were manually vectorialized and served as core elements to create the main volumes of the belltower (Figure 6). After this first phase of modeling, each face of the new volumes created was converted into wall elements, and information derived from the joint use of indoor and outdoor data was applied (e.g., thickness, stratigraphy, etc.). Concluded this initial modelling phase, it was necessary to refine the details of the belltower (decorative elements, windows, niches, etc.) that needed to be individually modeled exploiting different tools provided by Revit (e.g. cutting geometry using solids) and using as reference the different point clouds. It was particularly challenging to model the molding and the decorative bands for which three different strategies were tested: i) sweeping a 2D profile along a path, ii)using AutoCAD and Rhinoceros to create more complex NURBS and, iii) increasing the number of sections on the element to be modeled (Figure 7).

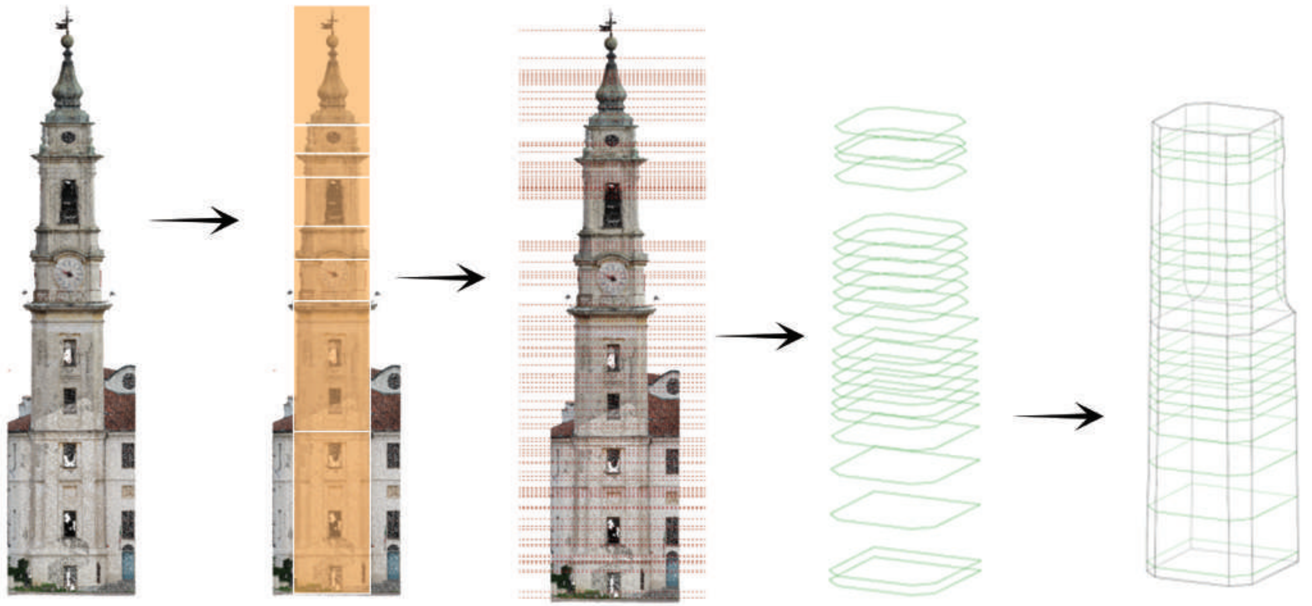

Figure 6. Standard approach from point cloud to solid geometry.

Furthermore, considering that some decorative elements are repeated on the four facades it was possible to create specific families inside Revit and to customize all the related parameters.
A final step of this process was connected with the enrichment of the HBIM models with a series of information. Data derived from historical sources and in situ inspections concerning the wall stratigraphy and materials were added to the model. Moreover, extracts of the orthoimages of each facade were connected as image parameters where it was necessary to underline specific features such as state of decay, missing elements, etc. The generated HBIM model was finally validated using an M2C (Model to Cloud) analysis thanks to the plugin FARO As-Built for Revit; results from this analysis are reported in Figure 8. It needs to be reported that the plugin failed to analyze the portions modeled inside Rhinoceros and thus further analyses are needed on these elements. The image reports the analyses conducted using the point clouds as a ground

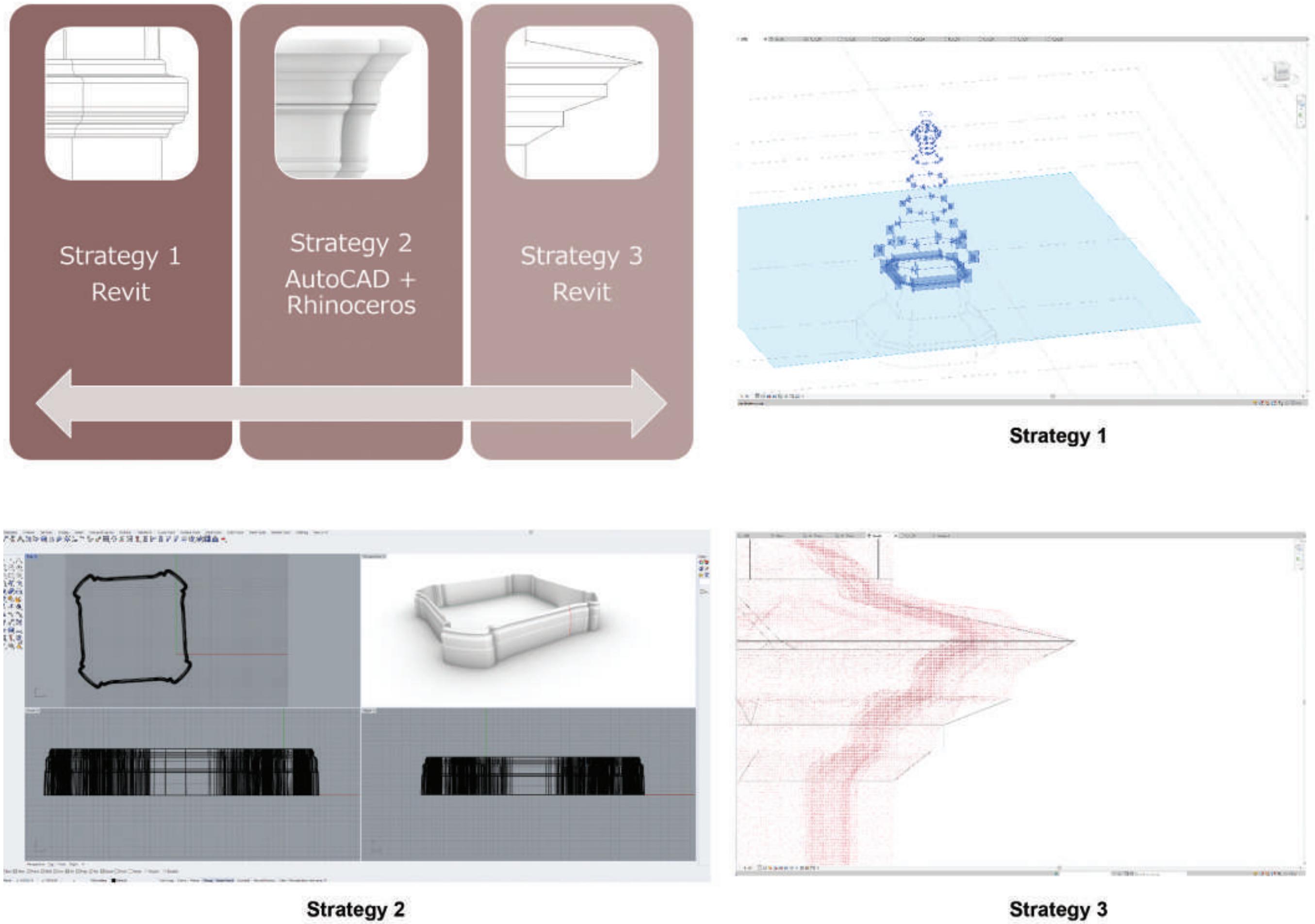

Figure 7. Example of the different modeling approaches tested.

reference and shows the deviation of the HBIM model. As is possible to notice results can be considered satisfying, especially for a complex asset like the Santa Marta Belltower and are in a range of few centimeters. Results are under 2 cm in areas constituted from the more simple geometries of the belltower, while a bigger deviation can be observed in the more complex parts where the modelling phase was more challenging (mainly in the higher moldings of the structure).

4. Conclusion and further perspectives

The documentation project of the Santa Marta Belltower allowed tailoring several issues connected with the different phases of the documentation work,

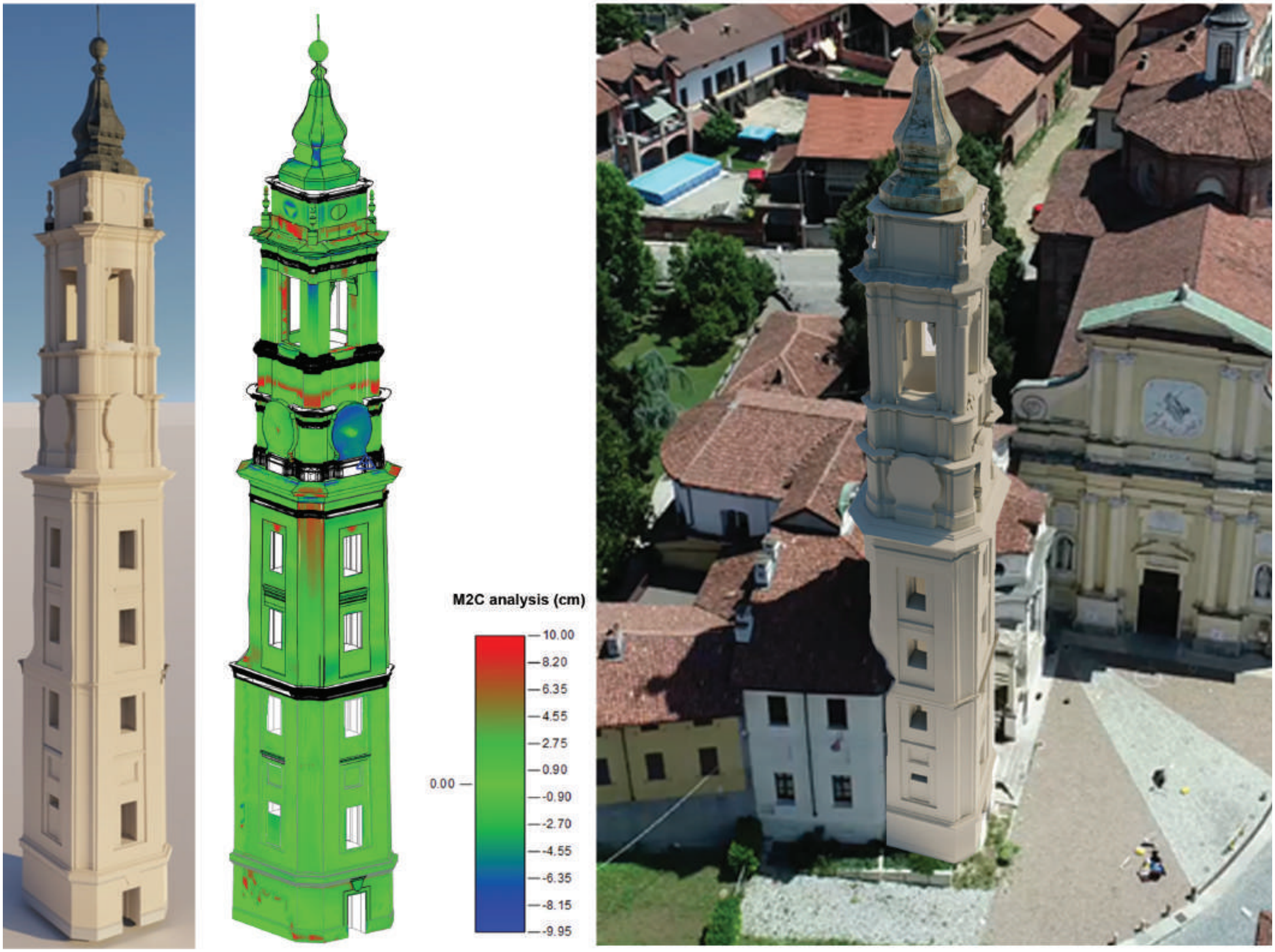

Figure 8. The final HBIM model and the results of the M2C analysis.

exploiting all the survey pipeline from survey design, via data acquisition, processing and validation, to the generation of addedvalue products including the HBIM model. In this contribution, the focus was on the modelling phase. After data acquisition and processing, for the creation of an as-built parametric model. It is clear from the experience conducted and from the result presented that, despite the advancement of the last years, this phase is still the most time-consuming and the one that requires a high effort from the involved operators. Automatization is still missing, or at least is at its initial phase of development, and the use of point clouds in the modelling requires expertise and experience. Different strategies have been tested for the management of survey products in the phase of 3D modelling, both inside the Revit software, both using external solutions or ad hoc plugins. Nevertheless, every strategy has its own pros and cons and needs to be selected mainly considering the characteristics of the asset. This is particularly evident when dealing with Built Heritage which lacks the possibility of standardization and still requires the research of new solutions for enhancing this phase of work. A contribution in this sense can be provided by the recent development of AI (Artificial Intelligence) approaches applied to Cultural Heritage, which is a hot research topic continuously evolving.

Notes

1 https://www.dji.com/uk/phantom-4-pro/info#specs

2 https://geoslam.com/solutions/zeb-revo-rt/

3 https://www.cloudcompare.org/

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ABSTRACT

This contribution presents the study carried out on the Tower of Belem, a UNESCO World Heritage Site since 1983. The events of recent years have focused attention on the importance of the "digital projection" of Cultural Heritage and the various forms of archiving and dissemination of information associated with it. The aim of the research was to document the heritage, creating a database of three-dimensional models for possible conservation, maintenance and enhancement of one of the jewels of the Portuguese capital

Methodologies for the protection of the Portuguese architectural heritage

1. Introduction

Cultural Heritage can be defined as a living memory of Digitisation, facilitated by recent technological innovations, is an essential action to make it accessible, allowing the information associated with it to be stored for knowledge of the places, thus contributing to its conservation, enhancement and use.

The digital survey responds to the request of international organisations regarding the need for documentation in a precise, detailed and timely manner. It provides not only a scientific basis for study and research (TorresMartínez et al. 2016) but also a tool for the design of heritage conservation strategies. As it is known, in the cognitive process triggered by the survey, drones are representing a tool capable of acquiring extremely advantageous information by increasing the pace and speed of the related data acquisition activities. The use of such instrumentation is therefore to be considered a resource for achieving increasingly high performance objectives and producing widespread knowledge for the benefit of all. (Parrinello, 2020)

This contribution presents the results of the study conducted on the Tower of Belem, recognised as a UNESCO World Heritage Site in 1983, together with the nearby Monastero dos Jerónimos, for its high historical and symbolic value. In 1755, the Portuguese capital was hit by a major earthquake, followed by a tsunami that destroyed much of the architectural heritage located near the coast. Given the location of the Tower and the possibility of a similar catastrophic event occurring again, the aim of the survey was therefore to carefully document the state of conservation of the building, providing a digital source of graphic and iconographic data for possible reconstruction work on one of the jewels of Lisbon and Portugal in the event of a disaster.

2. Historical notes on the Belem Tower

The Tower of Belém is a 16th-century fortification located in Lisbon along the northern bank of the Tagus River, serving as both a fortress and a ceremonial gateway to the city by combining the originality of a Gothic watchtower with a modern, pentagonal, well-armed bastion.

Built during the height of the Portuguese Renaissance at the behest of King Manuel I, the architectural artefact was an addition to the network of structures for the military defence of the river mouth formed by the towers of S. Sebastião da Caparica and Santo António in Cascais. This allowed crossfire between the two banks, preventing enemy ships from entering the capital, which had become one of the world's commercial centres after the Great Discoveries. There is some speculation that the Tower, built in the middle of the Tagus, now stands adjacent to the coast after an earthquake struck the city in 1755, redirecting the course of the river. The Portuguese Ministry of Culture and the Institute for Architectural Heritage have ascertained that the fortress was built on a basaltic rock outcrop, belonging to the Lisbon-Mafra geomorphological volcanic complex, close to the shore (Figure 1). Progressive urban development, extending towards the coast, gradually integrated the Tower into the coastline. The project, presented by the military architect Francisco de Arruda, who envisaged the use of a local white-beige limestone in the Lisbon area, was completed in 1519 and took the name Castelo de São Vicente de Belém, in honour of the patron saint of the Portuguese city. A drawbridge, decorated with plant motifs and armillary spheres, surmounted by the royal coat of arms and flanked by small columns (Figure 2), gives access to the bastion, which consists of two parts: a 30-metre high quadrangular tower and an irregular hexagonal bastion with elongated flanks jutting out into the river to the south.

The former is considered one of the main works of the Manueline late Gothic Portuguese style. This is evident from the crosses of the Order of Christ, the armillary spheres and the twisted rope, clear symbols of the organic Manueline style of nautical inspiration. On four levels, the structure houses a cistern with a ribbed vault on the ground floor and on the first floor the Sala do Governador, connected by corridors to the watchtowers located in the northeast and northwest corners. A spiral staircase leads to the second and third floors, which respectively house the Sala dos Reis, a loggia with a seven-arched portico overlooking the river, and the Sala das Audiências. The last level,

Figure 1. The Belem Tower in Lisbon, north-west view. (Guerriero Fabiana 2021)

recognisable from the outside by a terrace with shields of the Order of Christ, houses a chapel with cross vaults and niches, emblematic of the Manueline style, supported by sculpted corbels. This room differs from the others, which have hollow concrete slabs on the roof. The whole structure is crowned by a terrace with pyramidal battlements enclosed by four turrets, from which it is possible to admire the monumental river area of Lisbon. The lower part of the bastion, the casemate, has openings for 17 cannons and embrasures that offer a view of the river, while the upper part, decorated with rounded shields, has lookout posts at strategic points. The latter, topped by domes with ridges, unusual in European architecture, and decorative elements, are characterised by corbels with zoomorphic ornaments (Figure 3). From the base of the bastion, two arcades open onto the main cloister to the north and south, while six broken arcades extend along the eastern and western parts, interspersed with square pillars.

The open cloister above the casemate, although decorative, was designed to disperse cannon smoke. The upper level was instead used for light calibre infantry. This diversification underlines a new development in military architecture as the Tower of Belem represents the first Portuguese fortification with a twotier gun emplacement.

Figure 2,3. On left: The Belem Tower in Lisbon. levatoire bridge (Guerriero F. 2021); on right: the Belem Tower in Lisbon, watchtower. (Guerriero F. 2021)

3. Research tools and technologies

The continuous evolution of surveying tools and techniques highlights how the use of these methods represents an added value capable of speeding up times and improving the accuracy of the work (Luigini, 2007).

As is well known, there are various methods available to produce three-dimensional models, including photogrammetry, which is widely used in the field as it enables dynamic and accurate information to be obtained from photographs by transforming two-dimensional information into three-dimensional information (Ceconello, 2003). The decision to use an image-based method was considered suitable for the documentation of the artefact under examination, taking into account both the lighting conditions and the purpose of the survey: to conduct a correct reading of the architectural object by applying the rules of scientific rigour, to return a comprehensive and objectively valid three-dimensional image and to develop support documents for projects for the protection, enhancement and promotion of the UNESCO heritage through the use of a non-invasive technique. The dimensions and geometry of the object to be surveyed required the use of different instruments, with two types of photography: one on the ground using a digital camera and one at altitude using a DJI Mavic Mini 2 four-wheel drone. The latter weighs 249 g and features a camera, integrated into the gimbal to maximise image stability during movement,

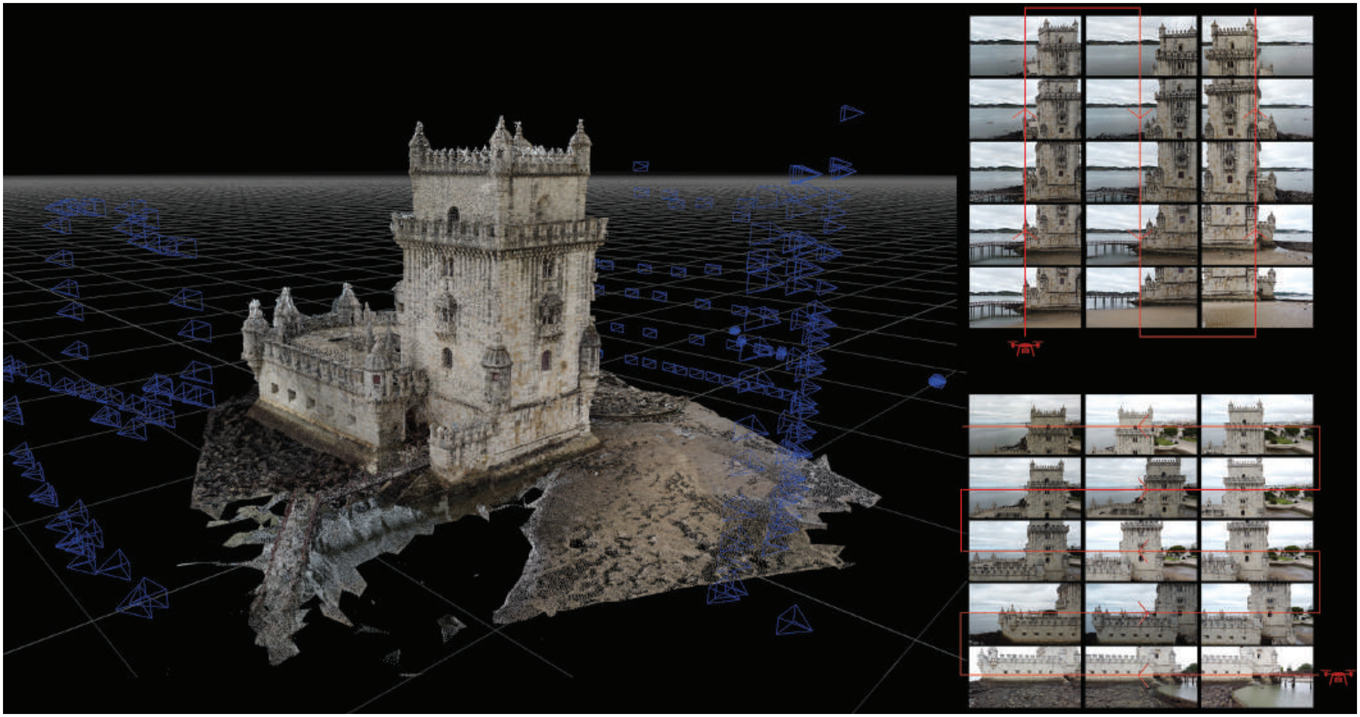

Figure 4. The Belem Tower in Lisbon. Perspective view of the dense point cloud, obtained through the process of aerial photogrammetry and identification of the acquisition points (left). Flight plan of the drone (right). (Guerriero Fabiana, 2021)

with a 12 MPixel sensor, wide-angle 4 mm focal length lens and 83° FOV (Field of View).
The sets of drone photographs were taken in several flights following a grid idealized vertically and horizontally divided into modules: shots were taken in manual mode along each axis of the aforementioned grid by varying the altitude and axis of rotation of the camera, without changing the distance from the object to be acquired (Fraser, Al-Ajlouni, 2006). The convergence of the axes thus ensured the coverage of the surfaces of the architectural apparatus, constituting a valid informative support both from a metric and qualitative point of view (Figure 4). The photographic data, approximately 400 taken with UAV instrumentation and 250 acquired by camera, were initially subdivided according to the fronts and environments in which they were taken in order to diversify the development of the 3D models and optimise the management phase.

Figure 5. The Belem Tower in Lisbon. View of the main elevation of the dense point cloud and tex-tured mesh obtained through the photogrammetry process. (Guerriero Fabiana, 2021)

The photographs, imported into a specific 3D photo modelling software, were then processed following a workflow based on four phases: Align Photos, Build Dense Cloud, Build Mesh and Build Texture (Barba S., 2020). During the first part of the process an algorithm, evaluating the internal parameters of the camera (focal length, position of the main point, radial and tangential distortions) as well as the camera positions for each shot, produced a dense cloud. In the next step, by reprojecting a larger number of pixels for each aligned camera, the Dense Cloud was created, which is fundamental for the subsequent processing of a three-dimensional high-poly model. Finally, according to a texture mapping algorithm, the 3D mesh was textured. This last process, operates, as far as the result obtained is concerned, generating a uniform image, without over or under zones, of the portrayed object capable of returning a very realistic perception (Figure 5) (Kairienè L., 2020). Of particular importance was the use of the UAV instrumentation able to observe the Tower from new points of view and to take frames that the digital camera had not been able to acquire, such as the entire roof and the upper part of the elevations (Figure 6). The joint use of the two instruments strengthened the calculation and processing of the dense point cloud, avoiding local deformations by the software.

The acquired frames, besides guaranteeing a considerable metric precision of the result, verified through fundamental measurements identified in situ, allowed the reconstruction of a complete three-dimensional photograph of the Tower of Belem capable of providing colorimetric and material information derived from the photographic acquisitions (Benedetti, Gaiani, Remondino, 2010). The three-dimensional models elaborated by the SfM photogrammetric survey give the possibility to explore the peculiar object of study and have also allowed the extrapolation of orthophotoplans in CAD software on the basis of which traditional two-dimensional multi-scale drawings have been elaborated, such as plans, elevations and sections, rich in descriptive details.

The outputs of this cognitive process, in addition to deepening the graphic and theoretical study of one of the symbols of the urban landscape of the monumental river area of Lisbon, are therefore a tool capable of facilitating the interpretation of historical dynamics as well as the design of strategies for the protection of this Cultural Heritage.

4. Conclusions

The Tower of Belém, one of the most remarkable monuments in Lisbon and Portugal, is a testament to the transitional nature of military architecture, with defence features from the Middle Ages and the modern Renaissance. A symbol of power and a jewel of architecture from the reign of King Manuel I, it is a landmark of Portuguese identity. The study, using interactive software for graphic restitution, digital representation, image-based techniques and 3D modelling, shows how the technological revolution has opened up horizons for the visualisation of Cultural Heritage by providing multimedia tools that make it possible for a wider public to enjoy the heritage (Svalduz, 2013).

The aim of the research was to carefully document the state of conservation of the property, through a consolidated survey process, constituting not only an iconographic database but also an archive of three-dimensional performing models of one of the nation's most famous cultural attractions of architectural interest, proposing possible interventions for the enhancement. The innovation will be in terms of: documentation -with the generation of engineering plans-, visualization -all the information about the monument would now be shown in a 3D virtual space-, and diffusion, through the creation of online material that will allow generalized virtual visits. This multidisciplinary and technological vision of heritage protection aims to be the digital key tool in current efforts to conserve, study and promote Cultural Heritage.

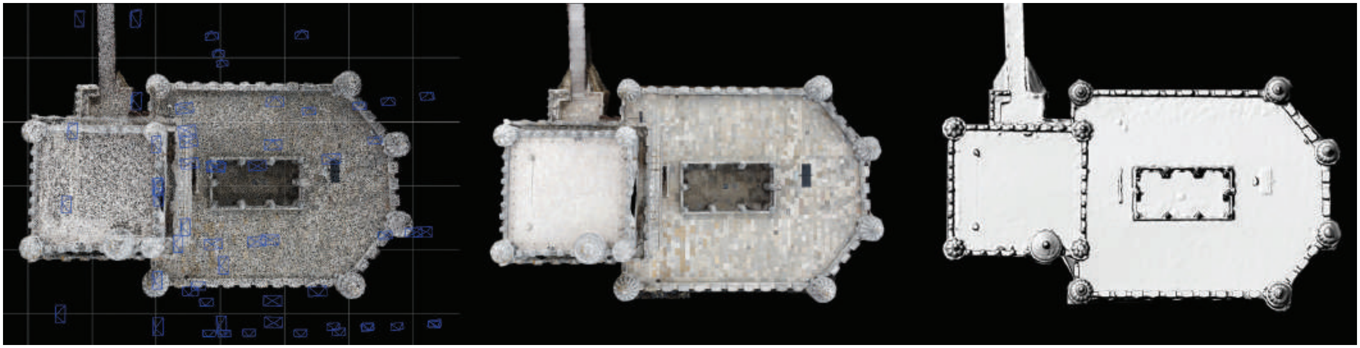

Figure 6. The Belem Tower in Lisbon. View of the dense point cloud coverage (left), the textured mesh (centre) and the three-dimensional model (right). (Guerriero F. 2021)

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ABSTRACT

The depopulation of small villages impacts built heritage conservation. A fast, low-cost and imple-mentable survey methodology, that combines lightweight UAV with target-less approach photogram-metry and traditional techniques, has been employed in the village of San Giovanni Lipioni (Italy) to measure several buildings units (51) of surrounding aggregates with the same point cloud. The out-comes are (i) synthetic factsheets that collect geometric, typological, and state of conservation data to outline the most suitable refurbishment interventions; (ii) the drafting of a "Restoration Manual".

UAV PHOTOGRAMMETRIC SURVEY AS A FAST AND LOW-COST TOOL TO FOSTER THE CONSERVATION OF SMALL VILLAGES. THE CASE STUDY OF SAN GIOVANNI LIPIONI

1. INTRODUCTION

Over the last decades, the depopulation of small villages has become a significant phenomenon in the rural areas of many European countries, causing social, economic, and demographic repercus-sions (Pulpón 2020). Consequently, not only the tangible and intangible local culture is directly threatened, but also the identity connected to traditional construction characteristics (Engelbrekts-son 2009).

In 2007, the number of people living in urban areas had surpassed the rural population, and, in 2050, more than 68% of the world population will live in cities (United Nations 2019). In Italy, marginal areas' progressive abandonment was followed by the definition of the National Strategy for Inner Areas (SNAI) and the approval of legislative measures to face this issue using specific funds and financial resources. The SNAI identified 72 inner areas, characterised by a lack of services and extremely rich in natural and Cultural Heritage, and two main objectives: (i) enhancing the natural and Cultural Heritage and (ii) improving and adapting primary services (mobility, schools, health) (Strategia Aree Interne 2020). Priority actions are needed to fight the loss of cultural identity as intangible heritage (Postiglione, Lupo 2006). However, the large amount of funds allocated does not meet concrete actions, so often bottom-up initiatives coordinated by local inhabitants foster directly rehabilitation projects. In this perspective, the collaboration was born between the Social Promotion Association APS "Nessuno Escluso" and the research unit of the Department of Architecture of the University of Bologna for the revitalisation of San Giovanni Lipioni.

The village is located in the province of Chieti, in the valley of river Trigno, near the border between Abruzzo and Molise, and it is included in the inner area "Basso Sangro Trigno". From 1971 to now-adays, it has recorded a demographic decrease of over 70% (ISTAT 2011), mainly due to the development of large industrial activities (automotive and food) along the coast, which have encour-aged people to move closer to their place of work. It currently has 152 residents with an average age of 72 years, divided into the following age groups: 2% 0-15 years; 3.3% 15-30 years; 39.7% 30-67 years; 55% over 67 years (APS "Nessuno Escluso" 2020).

The village is characterised by the historic centre and some expansions in a north-south direction along the main street. It is almost exclusively residential: there is a bar, a pharmacy, a doctor's surgery and a small retailer. This condition inevitably affects the built fabric: only about 15% of the dwellings are permanently inhabited, 57% are occasionally occupied, particularly in the summer

Figure 1. Photography of San Giovanni Lipioni. (Source: Authors' photography)

pe-riod, while 28% are currently unused (APS "Nessuno Escluso" 2020). These few data highlight the urgent need to safeguard the village and its territory to prevent its complete abandonment. The strategy elaborated and presented in this paper is addressed to the existing heritage and the urban areas; it aims at promoting the development of a tourist-residential reality thanks to the reconversion of the building units and the enhancement of the village peculiarities through the identification of significant pedestrian routes across the village.

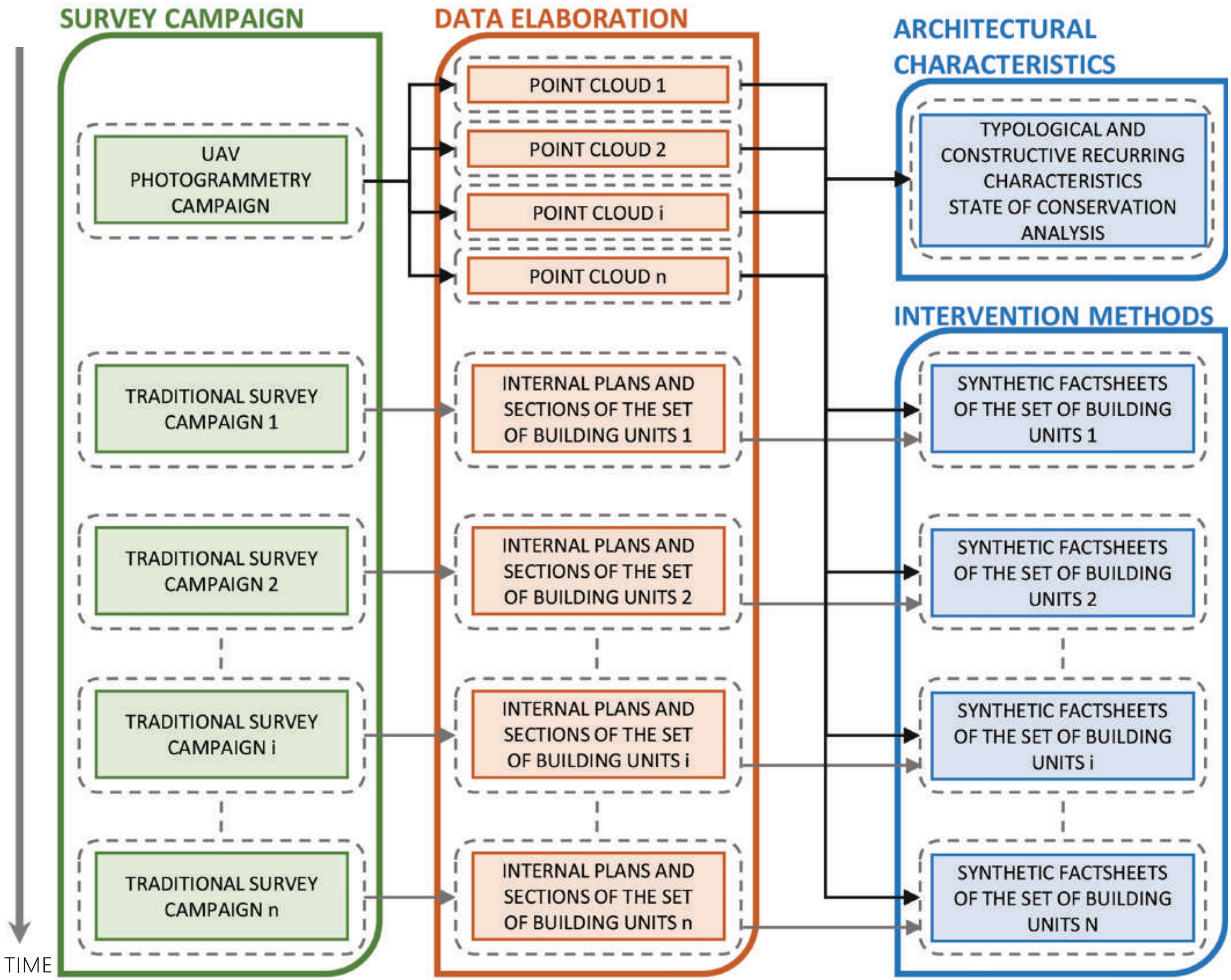

Figure 2. Methodology workflow. (Source: Authors' graphic elaboration)

2. Methodology

Located on a ridge of 545m.a.s.l., the historic centre of San Giovanni Lipioni presents typological, architectural, and construction recurring elements of small Italian villages of the inner areas in the southern-central regions (Bonafiglia 2015). Highly compact aggregates with complex volumes gen-erate an intricated grid of narrow and steep streets with rare widenings. The property of housing units is very fragmented and the cadastral and cartographic documentation is rarely available in digital form and may present lacks in the update. This condition contributes to not having a clear overall image of the village that instead need to be analysed and evaluated with a holistic perspective that merges urban and building scale (Cucari 2019).
In recent years, obtaining technically and economically optimised digital-survey workflows has gained even more attention, especially for small rural contexts (Federman 2017).

Figure 3. Upper row: Streets of San Giovanni Lipioni during the photogrammetric campaign; Lower row: photographs of residential buildings of the historical centre. (Source: Authors' photographs)

Figure 4. Mesh models of the historic centre. The analysed building units are highlighted and indi-cated with an alpha-numerical code in which the letter specifies the aggregate while the number defines units studied inside. (Source: Authors' graphic elaboration).

The morphology of the villages, the closeness of aggregates, and the shape of roofs could generate lacks in the TLS point cloud which then needs to bridge the gap with UAV photogrammetry, thus increasing the level of complexity and costs of the survey (Chiabrando 2016). Besides, despite the small size of these villages, it would still be too large to employ these techniques widespread on large portions of the historic centre and would not solve the problems concerned with the fragmentation of properties. Consequently, the digital survey could present holes in point clouds that would not be possible to overcome with future campaigns for a rural municipality due to the specific skills and instruments needed to employ TLS or photogrammetry. Starting from these considerations, the paper describes a fast, low-cost, and implementable workflow of UAV photogrammetry (Figure 2). This method has been employed on 51 abandoned building units to achieve a broad and solid knowledge of the local construction techniques and architectural characteristics. The use of lightweight UAVs, suitable for moving between the narrow streets, and the target-less approach consent to discard expensive sur-vey tools minimising the campaign cost and reducing the time significantly. This workflow employs only the EXIF position data recorded by the camera associated with the GPS of the drone

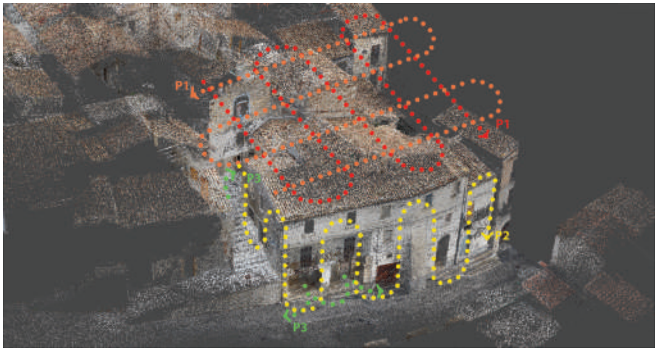

Figure 5. Sparse point cloud of Aggregate F. The first path (P1) was made with nadiral shots; pic-tures taken along facades constitute the second (P2); while the third path was carried out to survey the portico and the widening in the back street. (Source: Authors' graphic elaboration).

(not RTK), keeping a limited relative error in geometries and a remarkable grade of precision about buildings characteristics, proper for 1:50 scale representation (Massafra 2021).

At the same time, accurate topographic data in terms of absolute external orientation, calibration and deformation that could be solved by using GCP measured with GNSS receivers or total stations is unnecessary for the re-search outcomes. Consequently, a target-less approach was preferred.

Figure 6. Processing of Unit N1, from left to right: Sparse point cloud; Dense point cloud; 3D mesh model. (Source: Authors' graphic elaboration).

In this methodology, the internal surveys are done with traditional techniques and can be implemented progressively when building owners allow access to their units. Therefore, digital tools are not necessary considering that plans, sections and façades are already surveyed.

3. The collection and Processing of Data

The data collection has been carried on in two different campaigns; the first had a longer duration of about six days with two teams working in parallel, one on photogrammetry and the other on the photographic and traditional survey of internal (Figure 3). The second campaign took place in two working days to survey the internal of some building units where photogrammetry was already made. Regarding photogrammetry, a reasonable error with Ground Sampling Distance of approx. 3,00-6,00mm/pix on a horizontal plane allowed employing a cheap DJI Mavic Mini with the following char-acteristics: open category UAV of C0-class identification label (MTOM < 250 g), 1/2.3" CMOS sensor with 12 M.P. effective pixels, images of 4000 x 2250 pixels. The urban context is characterised by dwellings of modest size, generally two-story-high, embedded in highly compact aggregates, with a very fragmented property of housing units. Consequently, fol-lowing the standard photogrammetry guidelines for each unit would have been a long and complex process. For this reason, large portions of the historic centre were incorporated within the same point cloud in order to detect several building units belonging to surrounding aggregates (Figure 4). From an operational point of view, three trajectory types were employed as shown in Figure 5: the first is made with nadiral shots to the roofs and the context, using a two directions grid path at an average flight height of 20-25m that consent to survey the dimensional relationship between the constructions; the second is taken employing a similar path parallel to the front and along the side of aggregates with particular attention providing information about the state of conservation; the third is applied in cases of specific elements needing specific movement to overcome an obstacle or conformation between buildings. During the flights, the overlap between two consecutive pictures has been kept at least 65-70% longitudinally on the same row and 40-50% transversally between two contiguous lines. The photogrammetric models were subsequently built in Agisoft Metashape® 1.6.5, employing four large point clouds for the thirty building units in the historic centre and stand-alone or smaller models for those outsides.

Figure 7. Redrawn of plans merging orthophotos and traditional survey, from left to right: orthophotos of aggregate R, redrawn of unit R1 and R2. From up to down: from roof to basement plan. (Source: Authors' graphic elaboration).

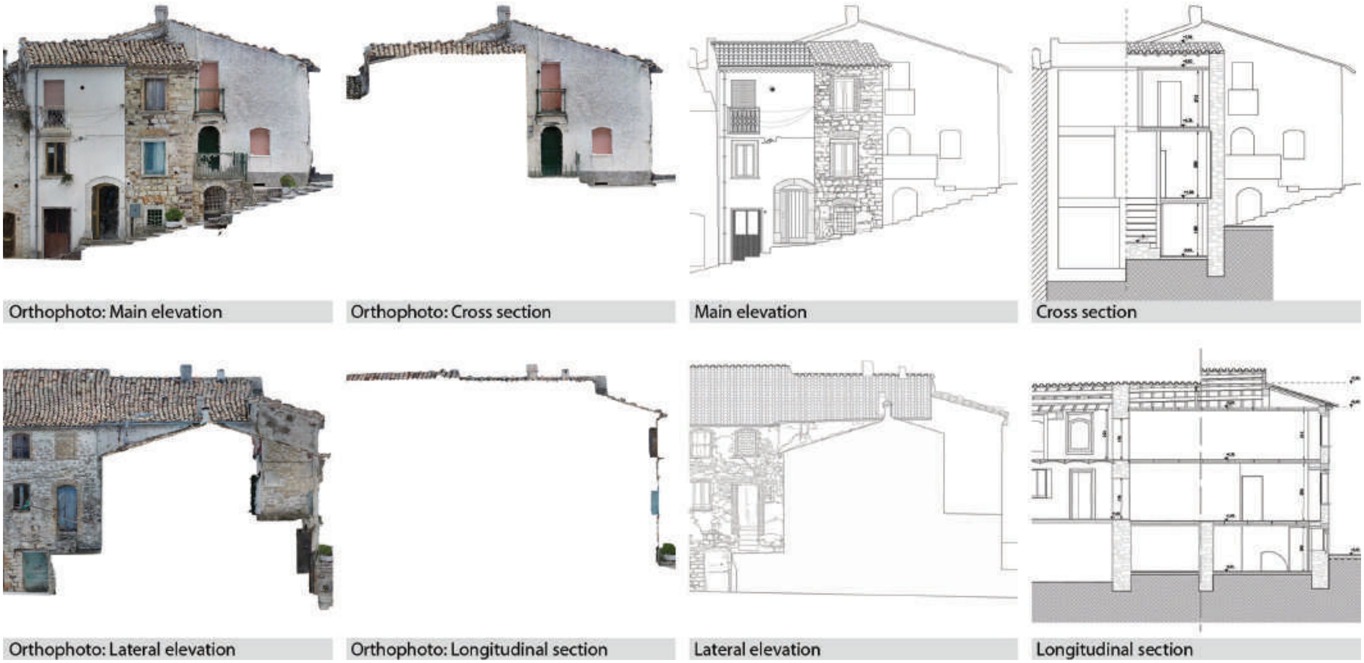

Figure 8. Redrawn of elevations and sections merging orthophotos and traditional survey, from left to right in the upper row: orthophotos of main façade and cross-section of aggregate R, redrawing of same documents. From left to right in the lower row: orthophotos of lateral elevation and longitudi-nal-section of aggregate R, redrawing of each document. (Source: Authors' graphic elaboration)

The processing phase has followed standard workflow parameters (Figure 6): high accuracy in the alignment of a varying number between the 560-1460 photos in the large mod-els, using generic preselection, reference preselection, key point limit of 40,000 and tie point limit of 10,000; medium quality building dense point clouds with medium quality and mild filtering mode in-depth maps generation. Afterwards, in order to create high-quality orthophotos, dense point clouds have been cleaned from unnecessary points or not necessary geometries as vegetation or traffic signals.

Finally, 3D mesh and texturised models were generated employing medium quality param-eters to obtain a reasonable faces number without reducing the orthophotos quality. Finally, high-resolution orthophotos were extracted to investigate different aspects: the horizontal orthophotos of plans or roofs and the vertical orthophotos of sections provide the outer-edge outlines that guarantee the accurate geometric data on which merge the traditional internal survey; the ver-tical orthophotos of façades offer detailed texturised images useful for the crack pattern, deterioration and different construction phases analysis. The collected data were elaborated and redrawn on a scale of 1:50 (Figure 7 and 8), merging the photogrammetrical survey with the traditional one.

In this representation scale, a graphical/reading error of 0,5mm corresponds to 2.5cm, therefore the survey can be considered reliable for the realisation of synthetic factsheets that collect the geometric, typological, and state of conservation data to outline the most suitable interventions for a functional refurbishment.

Figure 9. Above, 2 frames of a second-seismic shock (November 2016) and 2 frames of a flight after the debris removal (April 2018) (by M. Canciani). Below, volumetric model of the post-seismic situation (April 2018) (by M. D'Angelico).

4. Results

The drawings and outcomes of analysis on the 51 building units have been collected in synthetic factsheets using Microsoft Excel. A deliberately simple form facilitates understanding for people with-out a technical background, easily identifying the structural issues and the related solutions. The evaluation sheets are organised into sections, each of them containing specific information:

- Location data – the building unit is catalogued with an alphanumeric code providing the ad-dress and geographical coordinates;
- General information – this section summarises the main unit data like the typology, the num-ber of floors, the construction period and the current use;
- Geometric data – including drawings (plans, elevations, sections) - the number and type of rooms are identified, including data concerning the surfaces (DPR 1142/1949);
- Construction and conservation state characteristics of walls and horizontal structures - an alphanumeric code classifies the types of structure and information about dimension and conservation state. The Masonry Quality Index (MQI) is evaluated for vertical structures and construction weakness for horizontal ones;
- Risk and the state of damage assessment – the vulnerabilities are identified, as well as the presence of damage and which structural component is involved;
- Summary of recommended types of structural, energy and conservation interventions on plants, vertical or horizontal structures and roof;
- Detailed list of most suitable intervention types that link the structural, conservation of finishes and energy weaknesses with the solutions proposed in the previous point. These factsheets have been further summarised in a graphic poster form containing only the essen-tial information to analyse characteristics and issues of the various building units, which an example follows in Figure 9. The overall analysis has produced three synthetic schedules concerning the structural solutions, the finishes elements, decorative and functional components (Figure 10).

This cataloguing highlighted construction characters of San Giovanni Lipioni, recurring in many other villages of the Abruzzo Region (Ranellucci 2004). From a structural point of view, there is a preva-lence of irregular stone masonry (73.1%) with steel floors (67.2%), wooden roofs (67.9 %), brick-vaulted stairs (48%). The main decorative elements are brick or stone portals (24.6% and 14.8%); the eaves are built with the traditional technique of “Romanella” in which two rows of “Pianella” bricks and one of imbrexs (35.7%) or only two-row of imbrexs (21.4%) are used to make the overhang; balconies characterise about one-third of the facades, while traditional ovens or fireplaces the two-thirds of inner spaces. As regards the finishing elements, façades appear in masonry or are plastered in a similar frequency both on the outside (55.3% and 44.7%) that inside (57.9% and 42.1%), win-dows are mainly in wood (63.4%) while traditional terracotta tiles constitute the 25.3% of the floors finishing. All this information is collected to produce a “Restoration Manual” of the built heritage of San Giovanni Lipioni, inspired by the rich tradition of Italian manuals as an example the Restoration Manual of Città di Castello (Giovanetti 2000). The primary purpose of this kind of book is to collect, catalogue and graphically represent the local construction techniques to disseminate and provide guidelines to safeguard the traditional characters of built heritage.

5. Conclusions

The paper describes a fast, low-cost, and implementable methodology of surveys, consisting of the combined use of photogrammetry and traditional techniques that allowed identifying the uniformity in the construction and architectural characters of the built heritage of San Giovanni Lipioni, through the cataloguing of about 50 building units. Therefore, synthetic factsheets suggest the most suitable types of intervention to preserve the original traditional characters of the built heritage. Furthermore, the mapping and analysis of historic buildings allow achieving a broad and solid knowledge,

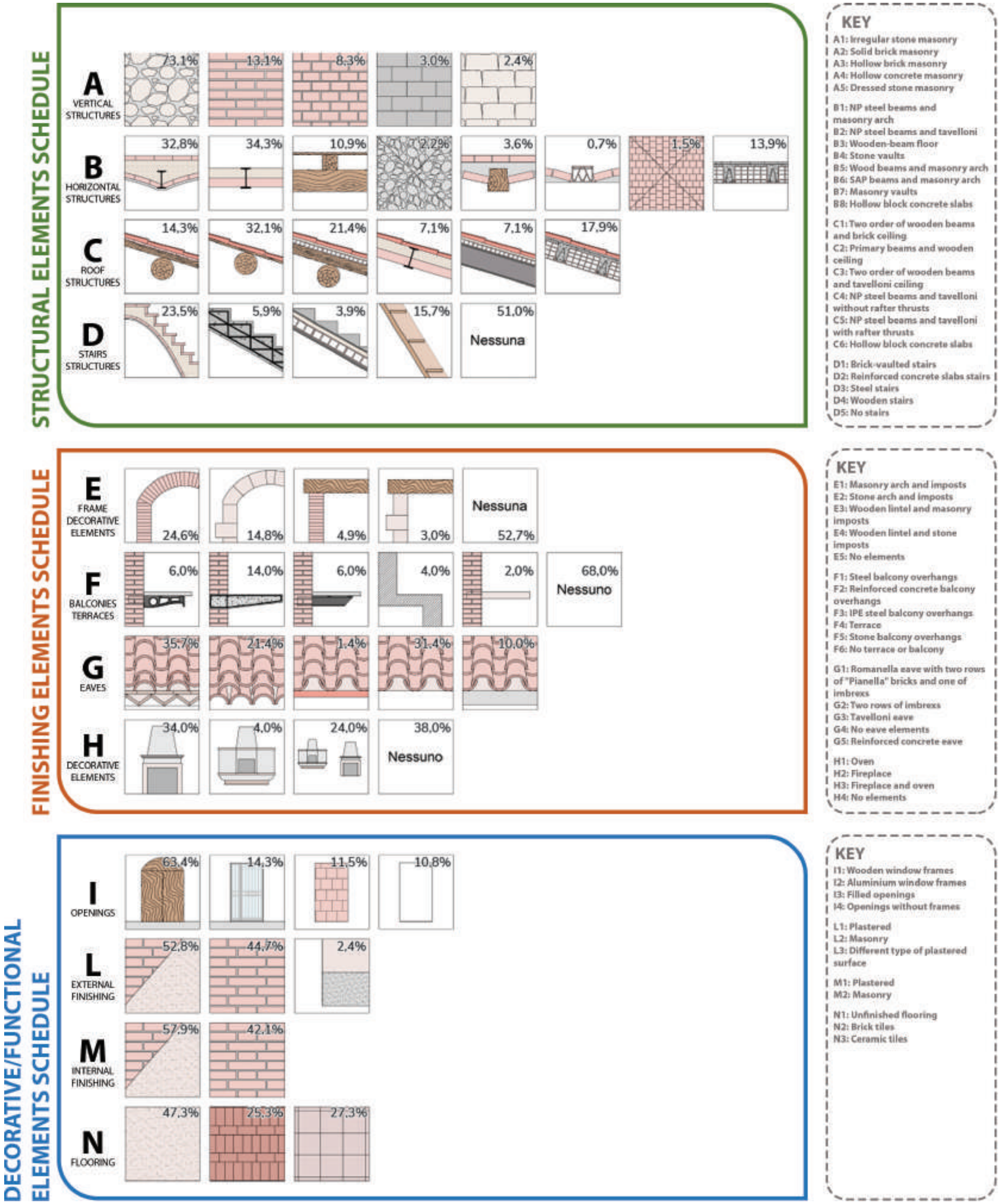

Figure 10. Structural, finishing and decorative/functional elements schedule. (Source: Authors' graphic elaboration).

that will define a wide enhancement program of the territory of San Giovanni Lipioni, through the creation of natural and cultural trails for hiking or cycling that involve the closer municipalities in a tourism net-work offering the product "nature-active holiday". Indeed, an untouched and untransformed land-scape represents a precious value for rural areas (Tempesta 2010), highlighting the need to pre-serve and enhance the natural environment and Cultural Heritage. These achievements are also at the centre of the current municipal and regional strategies for developing the Basso-Trigno area in the Abruzzo Region (Regione Abruzzo 2017).

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Indoor Droning, Survey, Structure from Motion, Cultural Heritage Documentation.

ABSTRACT
The paper presents the experience of surveying of the Renaissance Church of Madonna della Pietà near the village of Calascio (L'Aquila, Italy) employing a SfM (Structure from motion) technique. Using a light drone has been possible to operate at different scales, from the elaboration of a DTM of the site, to a precise 3D model of ornaments inside the church. A comparison is also presented between the results obtainable with drone photos and those taken from the ground. Finally, some considerations are presented about indoor droning, in relation to the maneuvering possibilities and the expected results.

Experience of indoor droning for Cultural Heritage documentation

1. Introduction

The diffusion of multirotor drones that are lighter, easier to handle and cheaper allows their use inside the buildings to document, survey and analyze indoor spaces, architectural details, statues, bas-reliefs, etc. This kind of drones, manually driven, give to the user the opportunity to freely move in the real surrounding space and environment, see and take pictures. In this way drones offer the opportunity of multiple direct observations, making easy operations that in the past could have been carried out with the use of telescopic rods, scaffolding, platforms, or balloons for photogrammetry. In a sense, it is a kind of aerial photogrammetry at the architectural or manufact scale. The paper presents the experience of surveying of the Renaissance Church of Madonna della Pietà near the village of Calascio located 1440 meters above sea level on the Gran Sasso Mountain, in a completely natural environment, and just 200 meters far from the famous fortress of Rocca Calascio.

The site can only be reached on foot, along a path of 500 m which has a difference in height of about 60 m. This clearly makes it awkward to use heavy or bulky tools.

The use of a light drone made it possible to document and survey the building at very different scales, starting from the outside, from the territorial context, and arriving at the details of the interior decoration. By integrating the data obtained from the photogrammetry with those deriving from the direct survey, it was therefore possible to carry out a complete survey of the architecture and a satisfactory documentation of the entire area.

2. The case of study: the Church of the Madonna della Pietà

The Church of the Madonna della Pietà is located in the municipality of Calascio, in the province of L’Aquila, within the borders of the Gran Sasso and Monti della Laga National Park, in the district called “Terre della Baronia”. The latter follows the territories that historically were part of the “Barony of Carapelle” and is made up by the municipalities of: Barisciano, S. Stefano di Sessanio, Castelvecchio Calvisio, Carapelle Calvisio, Castel del Monte and Calascio. The whole area was involved in the transhumance on the Tratturo Magno route, which connected L’Aquila with Foggia[1,2]. Calascio develops along the side of a mountain on whose summit the village of Rocca Calascio is perched at 1465m asl. La Rocca is the highest fortress in the entire Appennine chain and in southern Italy, considered by National Geographic to be one of the most beautiful castles in the world[3]. The Church of the Madonna della Pietà is located in an isolated position, along a path just outside the village in the direction of the Rocca. The place is extremely suggestive, since it is the last settlement before the Campo Imperatore plateau in the Gran Sasso massif (Figures 1, 2). The Church was built in the XVI century, as a sign of thanks for the victory obtained by the local inhabitants over a band of brigands who, crossing over from the Papal State, had headed from Campo Imperatore into the territory of the barony of Carapelle controlled by the family Piccolomini. The church is characterized by a mannerist language and a central octagonal layout. The side of the octagon

Figure 1. The main facade of the octagonal church of Madonna della Pietà; on the right the volume of the sacristy, in the background the Gran Sasso massif, with its highest peak, the Corno Grande, 2912 m asl.

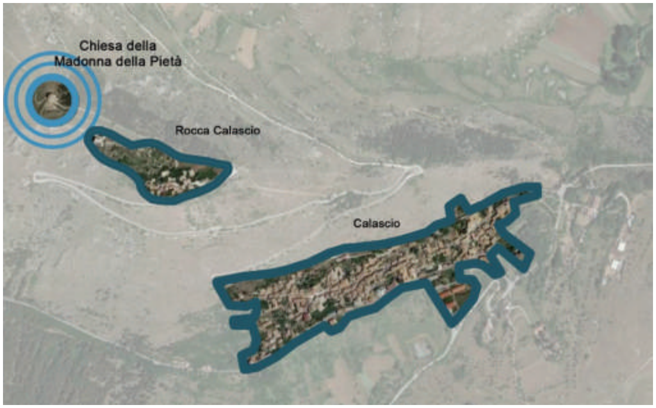

Figure 2. The spatial planimetric relationship between the village of Calascio, the borgo of Rocca Calascio with the castle and the church of Madonna della Pietà.

measures 5.64 m externally, the maximum width of the room is 11.84 m, the internal surface is 115 m^2; the height of the main facade from the ground to the cornice is 10.94 m, the top height of the lantern from the floor is 17.60 m. There are some examples of churches with these characteristics in Abruzzo: the closest is the church of the Madonna della Consolazione in Picenze, also built in the 16th century and just 13 km away in the direction of the city of L'Aquila. Other examples are the churches of S. Maria di Tricalle in Chieti, S. Maria della Misericordia in Ancarano and S. Flaviano in Giulianova. It is in fact probable that these architectures are the result of a common cultural line. With the exception of S. Flaviano in Giulianova, these churches share, in addition to the octagonal layout and similar dimensions, the devotional character and the location on the edge or outside the inhabited areas [4,5,6]. The building adapts to the rocky morphology of the place through a stone basement from which angles rise, also in stone that frame the walls. The main facade has a rich portal with a tympanum surmounted by a large window with a sumptuous decoration. A series of niches completes the design of the facade, together with two windows called "pectorals" that allow passers-by, originally mainly shepherds, to see inside. The central hall is marked by tuscan pilasters and is covered by a wedged dome with a top lantern. Of the various wooden altars that was to house the church, only the major one is partially preserved. However, the altar of St. Michael stands out, made of stucco and masonry, which presents a rich system of frames and columns, the statues in the first order of St. John the Baptist, St. Michael and another Saint, (probably St. Peter of Alexandria patron saint of Siena, a sign of the influence of Piccolomini family), of the Eternal Father among two Angels and two cherubs in the second order, again surmounted by two cherubs resting on the highest frame. On the right side there is the sacristy, a simple volume with a rectangular base placed next to the volume of the church which has only a pavilion vault on the ground floor and a single pitched roof (Figures 3, 4, 5).

3. The survey

The survey campaign took place in a single day, with one flight outside and one inside. Due to the strong wind (the site is very exposed to winds as it is very close to the crest of the ridge on which the fortress stands), in order to remain in safe conditions, the maximum altitude reached did not exceed 60 m. In any case, given the rather small size of the building, the extent of the photographic shots was considered satisfactory. The drone used (DJI Mini 2) does not allow automatic flight mode. For this reason, the flight was conducted exclusively in manual mode. After

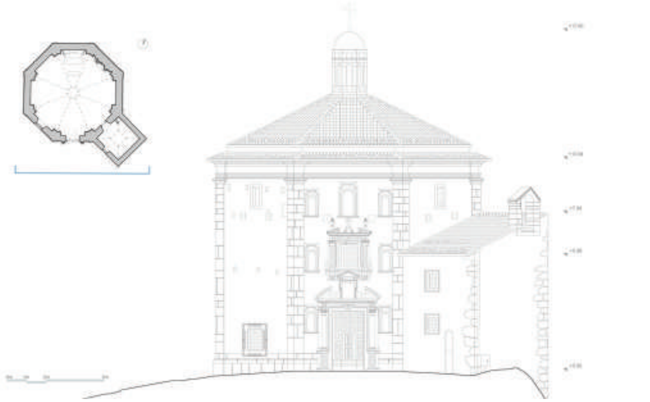

Figure 3. Elevation of the main facade of Madonna della Pietà. Top left the ground floor plan. Drawing by Luca Cetra.

Figure 4. Cross section of the Church. On the left, in projection, the altar of St. Michel. Drawing by Luca Cetra.

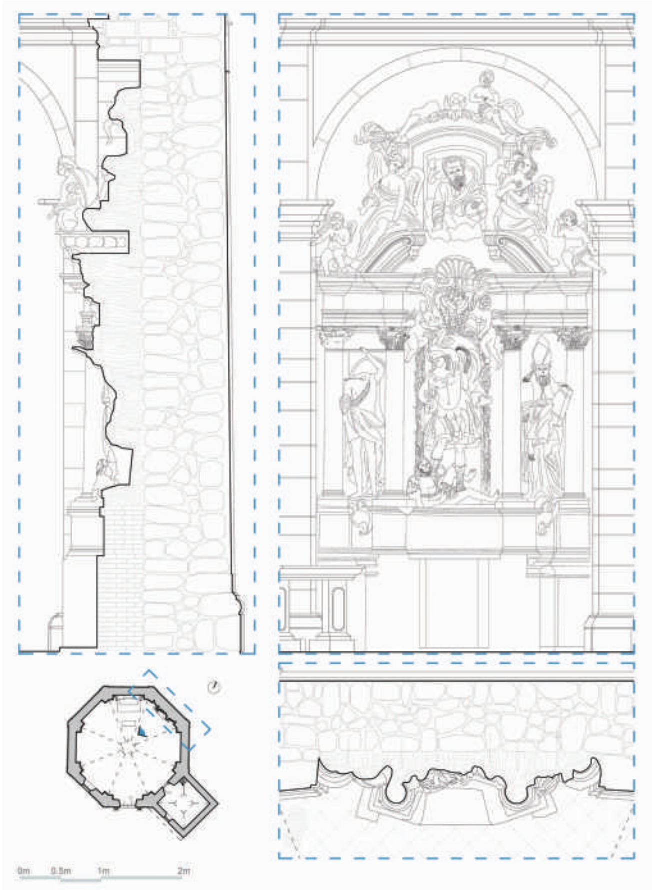

Figure 5. Detail in elevation, horizontal and vertical sections of the altar of St. Michel. Drawing by Luca Cetra.

completing the flight outside, the flight inside the building was carried out. The size of the room is such that it does not involve particular difficulties in maneuvering. Attention was focused on the altar of St. Michael, since the rest of the room, essentially bare, did not require such detailed data acquisition. It was therefore considered appropriate to limit the use of the drone to documentation from high points of view of the more complex decorative element, and to use a reflex camera and ground viewpoints for the rest of the environment. In addition to these activities mainly aimed at the use of SfM technology, a direct survey of the plan and of the section was carried out, in particular by trilateration. This indeed redundant measurement was carried out in order to be able to compare the results of the photogrammetric process and a more traditional process, so as to be able to evaluate the accuracy of the entire process. In summary, 130 drone photographs were taken (56 external, 74 internal) in two flights for a total of 24 minutes of flight. 293 photographs were also taken with a reflex camera (Canon EOS 1200 D) of which 226 were internal (including 78 dedicated to the altar of St. Michael) and 67 external (Figure 6).

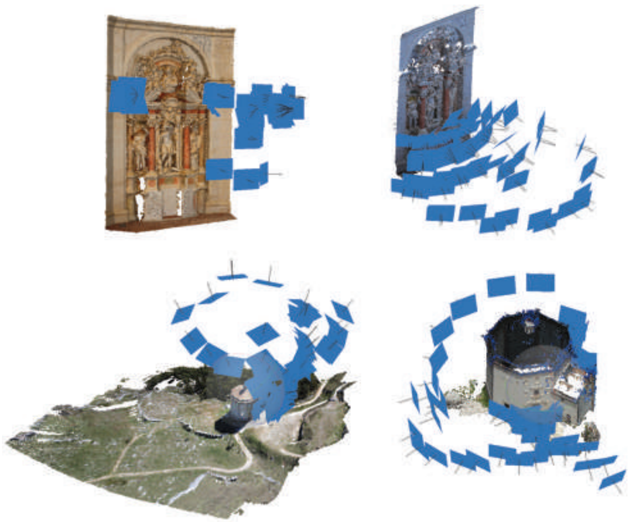

Figure 6. The four different datasets employed, clockwise from top left: “Inside_drone”, “Inside_ground”, “Outside_ground” and “Outside_drone".

Dataset/Chunk	
Outside_drone	56 drone photos of the exterior
Outside_ground	67 photos from the ground of the exterior
Inside_drone	74 drone photos of the altar of St. Michael
Inside_ground	78 photos from the ground of the altar of St. Michael

Dataset/Chunk	Sparse Cloud points	Sparse Cloud points after filtering	percentage reduction of the filter	Dense Cloud points	3D model faces
Outside_drone	157.421	93.952	40.3%	4.662.086	-
Outside_ground	140.660	61.288	56.4%	40.537.225	-
Inside_drone	45.317	16.160	64.3%	4.824.328	964.861
Inside_ground	172.331	46.360	73.1%	15.171.769	311.022

4. Elaboration process and comparison between datasets

The software used for processing was AgSoft Metashape. Given the desire to make a series of comparisons between the various results that could be obtained, the following datasets were used:

For each dataset, the first two steps of the workflow provided by the software were performed: Allign Photo, Build Dense cloud. The sparse clouds obtained after the first step were filtered using the gradual selection tool on the following parameters (Reprojection error 0.25; Reconstruction uncertainty 25.0; Projection accurancy 5.0). In the following table the numerical data of these elaborations have been collected.

We can see how the number of sparse cloud points obtained from the drone datasets is lower than the one obtained from the photos taken from the ground, but the smaller reduction following the application of the filter, indicates a greater confidence of the former and a consequent higher quality. Another relevant consideration is that the “Outside_drone” dataset concerns a much larger area than the “Outside_ground” dataset. So, the most fitting comparison is that between “Inside_drone” and “Inside ground” concerning both the same physic area, the altar of St. Michael. The difference in the number of points between sparse clouds increases sharply in dense clouds, where it reaches an order of magnitude. This gap is probably due to the different sizes of the images (4000x2250px vs 3456x5184px). However, the model of the “Inside_drone” dataset is more defined than the “Inside_ground” dataset, with a 1: 3 ratio in the number of faces since the excessive size of the dense cloud of the “Inside_ground” dataset required a more impactful decimation.

In addition to the quantitative aspect, we can proceed with a qualitative analysis of the dense clouds obtained. Comparing the Chunks “Outside_drone” vs “Outside_ground” we can see that “Outside_ground” completely lacks coverage and the reconstruction of the lantern is partial and unreliable. On the other hand, in Outside_drone the quality of the reconstruction in the shaded part is progressively poorer. This is due to the strong contrast between light and shadow.

Probably this inconvenience could have been avoided or reduced by paying more attention in the phase of taking the exposure values or acquiring the photographs in.raw format. Obviously there is also the substantial difference: the "Outside_drone" dataset allows to reconstruct a much larger spatial scope and allows, even without the use of GCP (Ground controlled points), the creation of a DTM (Figure 7). Turning to the comparison between the models of the altar of St. Michael, it is evident the presence of holes in the one obtained from the "Inside_ground" dataset and a better definition, especially of the upper parts in the other (Figure 8).

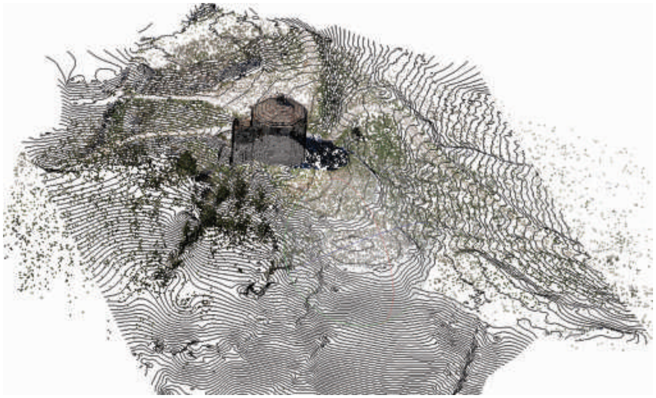

Figure 7. View of the spare cloud of dataset "Outside_drone" with overlapped the level curves resulting from the processing of the DTM.

Figure 8. Comparison between the models deriving from the "Inside_drone" (left) and "Inside_ground" (right) datasets. In the upper part of the models the definition it's sensibly different.

6. Outputs of the process

The results of the elaborations were used to derive a series of drawings and models employed as base in order to conduct detailed analyzes for the knowledge of the building. In addition to the DTM, used to build a representation with level curves of the area, 2D drawings of plans, elevations and sections were made, used as a basis for the survey of macroscopic surface degradation. Finally, 3D models were made of both the exterior and the altar of St. Michael. As mentioned in the introduction, the municipality of Calascio is very small and has limited resources, and this does not allow the church to be kept open, precluding its accessibility. The models obtained were uploaded to the SketchFab.com platform. In this way, the models are accessible both remotely and in situ by scanning a QR code on the information panel in front of the church (Figures 9, 10, 11, 12).

7. Conclusions

The described experience highlights a number of strengths of the surveying technique for SfM with the use of the drone, both inside and outside. The first notable aspect is that all the field work was carried out with two flights lasting a total of 24 minutes and a single battery charge. Bringing the drone to the site did not require any particular effort and was easier than any other type of ground instrumentation such as a laser scanner, with respect to which similar or better results were obtained in some respects. The internal use of the drone makes the dataset to be processed even more complete and extends the scope of the information that can be collected and the products that can be made, including 3D models of appreciable quality. Ultimately, the described one turns out to be a method of appreciable efficiency and versatility, which, as the experience described demonstrates, easily adapts to very different needs with great savings in time and effort.

Figure 9. View of the model deriving from the “Outside_drone” dataset

Figure 10. Plan development of external elevations obtained from the processing of point clouds. Each side it’s identified by a letter referred to the diagram in plan.

Figure 11. Overlap between the models obtained by SfM and the 2D drawings that have been obtained, relating to the altar of St. Michael, the cross section and the plan. The elaboration is by Luca Cetra.

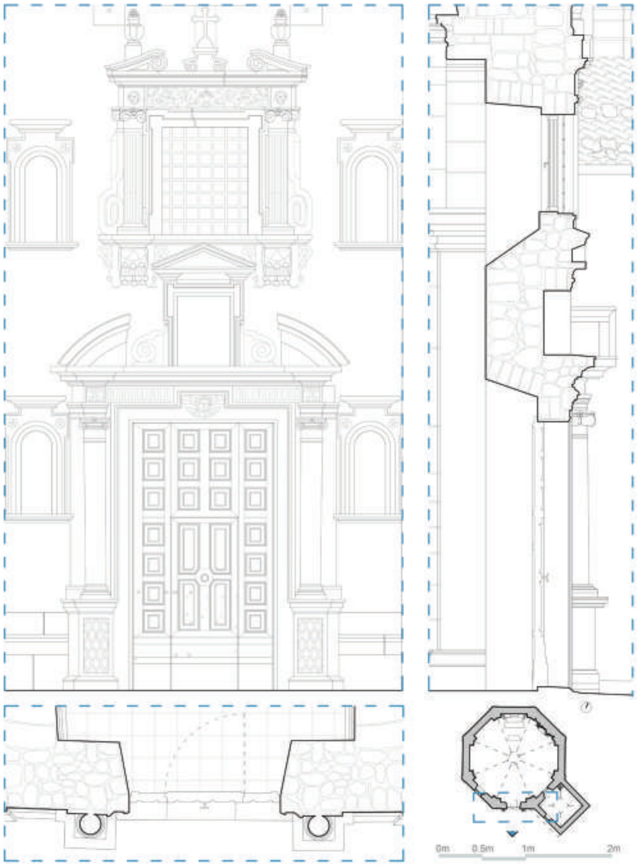

Figure 12. Detail in elevation, horizontal and vertical sections of the main facade. Drawing bt Luca Cetra.

A final consideration on indoor dronig: in the case study, the internal environment did not present particular problems for flight maneuvers, as it did not present internal obstacles and was rather large in size.
In the experience gained by the operators, we can say that the main problems that arise in narrower environments are not so much about the difficulty of maneuvering: the absence of strong air currents and the opportunity to constantly maintain visual contact with the vehicle allow you to operate generally in safe conditions.

The problem is rather the distance from the object to be photographed. In fact, when this is less than 3-4 m, the width of the shot is considerably reduced and consequently strong problems arise during the processing phase within the software, compromising the results. Finally, we want to underline how the documentation material produced at each step constitute a value both for the documentation of the heritage and for its communication and dissemination and, therefore, it can be considered that starting from the campaign on site, the investigation process generates the production and progressive growth of contents that have their own testimonial and communicative value (Figure 13).

Notes

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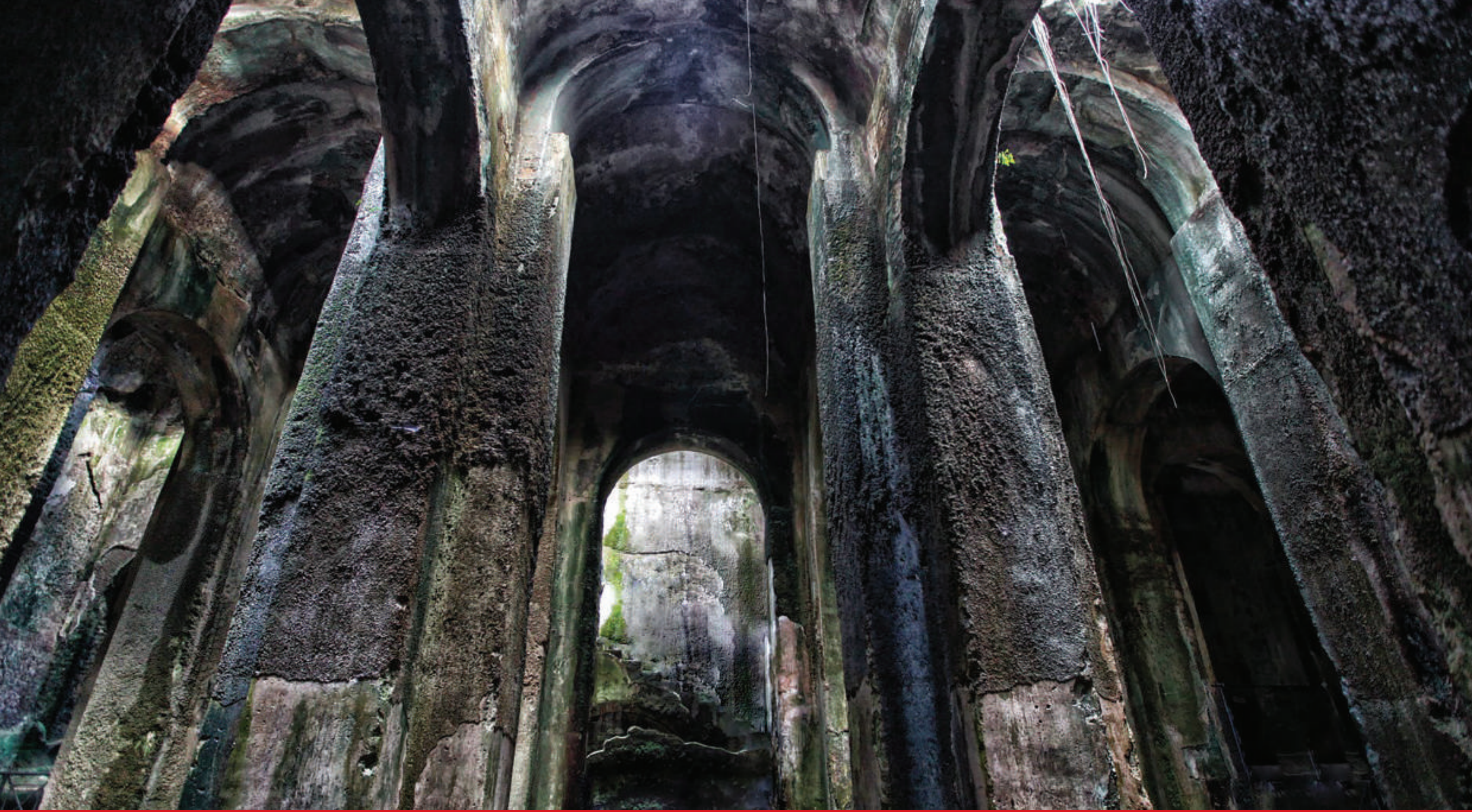

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Keywords:
Integrated survey, Archaeology, UAV, TLS, Thermal imaging.

ABSTRACT

The aim of the present research is to test an integrated framework between the data obtained from the Unmanned Aerial Vehicle (UAV), a handheld thermographic camera (Infrared thermography) and the Terrestrial Laser Scanner (TLS).

Piscina Mirabilis, in the city of Naples, becomes the benchmark to generate a comprehensive database, including a clear geometrical definition of the thermal variations of the wall surfaces by texturing the IR images directly on the RGB mesh surfaces. To measure the performance of mapping, the present research compared the quality of information by using 3D processing algorithms to optimise final the result.

Multi-source data framework: integrated survey for 3D texture mapping on archaeological sites

1. Introduction

1.1. Literature review: 3D thermal mapping and UAV in the Cultural Heritage field

Infrared thermography (IRT) is a widely used non-destructive method for energy audits.
However, considerable research indicates that the performance of thermography is influenced by the method of data acquisition (Hou et al., 2019).
The use of IRT images is playing an important role because heat loss from buildings can be easily detected and visualized by thermal cameras. In fact, for detailed inspections of small areas, terrestrial images can be taken manually, while for surveys of larger areas mounting IR cameras on an unmanned aerial vehicle (UAV) is an alternative option. Terrestrial image acquisition methods can provide detailed information on the smallest areas (Lin et al., 2018).
Unmanned aerial vehicles (UAVs) have been successfully employed to perform RGB photogrammetry to reduce the time and complexity of data collection.
But the data collected by an infrared thermal camera and an optical camera differ from each other in terms of the level of resolution: the data collected by the optical camera are considered to have a higher resolution.
On the other hand, the infrared thermal camera usually has a lower display resolution, is more likely to be influenced by environmental conditions and is limited by the distance between the camera and the objects (Mayer et al., 2021). Thermal texture mapping, which maps thermal images onto existing 3D geometric data, allows thermal images to be spatially referenced and thermal patterns to be accurately interpreted.
Due to large image overlaps, each face of a building model often corresponds to several thermal images.
Researchers are exploring different thermal texture mapping approaches focusing on the automation of texture selection: (Wang, 2008) combined object incident angle and visibility analysis to select textures from oblique images.
To differentiate components' semantic information (semantic segmentation) and to delineate each distinct object (instance segmentation), many computer vision algorithms - especially deep learning approaches - have been developed, such as Mask R-CNN (He, et al., 2020), the YOLO family (Wong et al., 2019), and the DeepLabfamily (Chen, et al., 2018). Finally, Chizhova and Korovin (Chizhova et al., 2017) improved the geometric matching accuracy of their model-to-image registration method by taking uncertainties of the 3D building model and image features into consideration.
Therefore, thermal radiant characteristics are taken into consideration. To measure the performance of texture mapping, this research compared the quality of images generated from a 3D point cloud model constructed by UAV and TLS acquired data with images acquired directly from a handheld thermal camera.
The comparisons were based on quality and efficiency in the data acquisition phase, and different factors' influences.
The following sections will present the goals and case of study, materials, research methods, discussion of the results and final conclusions.

1.2. Aims of the proposal and case of study

The present work seeks to determine a workflow to map the IR images with TLS and UAV data.

For this reason, it was considered necessary to integrate different techniques and sources of information in order to optimise the results and reduce the margin of error.

The main issue is that thermal camera resolution is not as high as the optical camera's resolution resulting in a lower quality 3D model generated by photogrammetry mapping.

The benchmark of the experimentation is the Piscina Mirabilis (Figure 1), the final reservoir of the "Serino aqueduct" in the city of Naples. (De Feo, 2007).

The aqueduct filled several points in the Campi Flegrei area to finally reach the end of the path: the Piscina Mirabilis.

This building is a gigantic water reservoir of 72 m long and 27 m wide with a height of 15 m., which operated through a series of gates that opened and closed along with the vaults in the central nave; the water was lifted by hydraulic machines over the opening terrace of the covered cistern. (De Feo, 2010)

Forty-eight pillars, presented in four rows supporting the barrel vaults, divide the space into five main naves on the long sides and thirteen secondary naves on the short sides, giving it the majestic appearance of a cathedral, hence its name, "The cathedral of water".

Today, the building is in a visible state of degradation and the creation of an integrative database could be considered a solution to manage the monitoring and restoration activities.

Based on these assumptions the subsequent sections of the manuscript are specifically aimed at proving the research procedure adopted.

Figure 1. Internal view of the Piscina Mirabilis in the current state. Source: Fondo Ambiente Italiano, Piscina Mirabilis, https://fondoambiente.it/luoghi/piscina-mirabilis.

2. MATERIALS

2.1. FARO Focus 3D X330

Faro Focus 3D X330 is a stationary laser scanner with integrated digital color camera.
The range-based modelling method employs techniques based on active sensors, using laser scanners that emit electromagnetic signals recorded by a sensor in order to derive a distance (range) measurement.
This solution guarantees an accuracy of +-2 mm in a range of 0.6 m up to 130 m.

2.2. DJI Phantom 4

The UAV has an approximate weight of 1.4 kg Its camera is equipped with a 12 MP Sony Exmor sensor and a wide-angle lens with a 4 mm focal length and FOV (Field of View) of 94°.
With a flight autonomy of almost 30 minutes the drone can fly at a maximum speed of 70 km/h.
The camera is integrated in a gimbal to maximize the stability of the images during the movements, being able to acquire videos in 4K definition.

2.3. Flir E40bx

This Thermal Camera has a 160x120-pixel resolution providing thermal images that clearly display building conditions.
The advanced MSX imaging feature adds even more texture and detail to these images, allowing quicker fault location.
With a low thermal sensitivity capable of detecting temperature differences as low as 0.045°C, the FLIR E40bx enables users to accurately diagnose anomalies.
The camera is in fact equipped with two separate optical systems for acquiring the thermal image and the corresponding image in real colors.

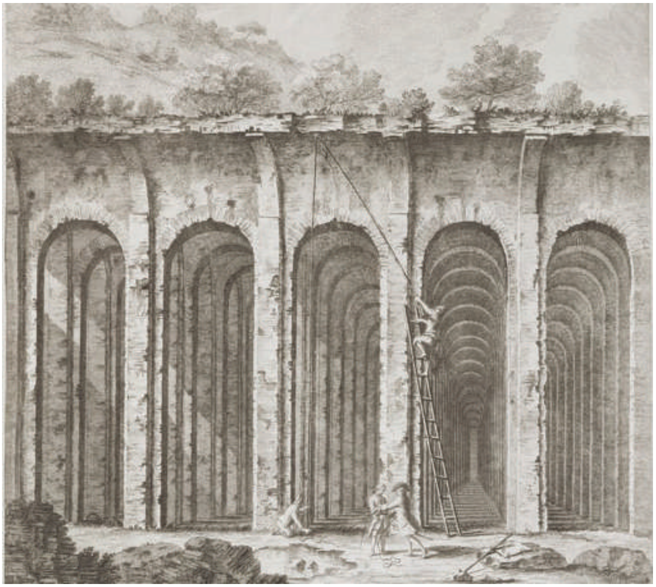

Figure 2. Design of a vertical section. Source: Avanzi della Antichita esistenti a Pozzuoli, Cuma, e Baia by Paulo Antonio Paoli, by Giovanni Volpato (1735-1803).

3. RESEARCH METHODS

3.1. Survey design and data collection

3.1.1. TLS

A survey design should first define TLS station locations to ensure complete coverage of the object at the required spatial resolution.
Considering the main dimensions of the interior space of the Piscina Mirabilis (on the horizontal plane the maximum extensions are 72 m x 25 m, and the internal height is 15 m) (Figure 2) with a total of 48 columns distributed in 4 rows of 12 columns, the instrument was set to have a resolution of 6 mm in 10 m. Basically, in order to avoid areas of occlusion generated by the number of pillars, as a general criterion, it was decided to make one scan for each bay. In the outside, the resolution was changed to 10 mm in 10 m, placing the

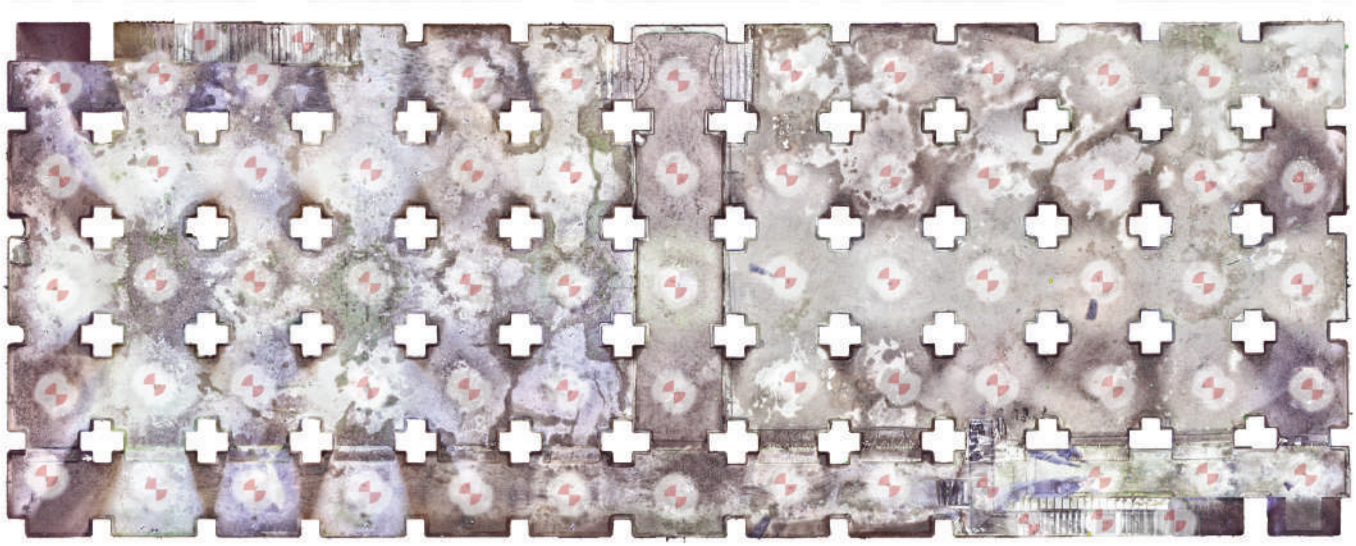

Figure 3. Floor plan extracted from the point cloud processed, with the interior TLS stations.

stations on the external street with a distance of 5 m. defined by the spacing between columns.

Finally, In the entrance sector, it was necessary to make 3 stations that allowed linking the data acquired on the inside and outside of the building.

With a total of 75 internal scans and 17 external scans, the TLS acquisition campaign has taken almost 10 hours, with a single-scan time of approximately 6 minutes and 30 seconds (Figure 3).

3.1.2.UAV

Due to the high elevation of Piscina Mirabilis (15 m), it was necessary to integrate the data acquired with the laser scanner. The geometrical acquisition of the upper vaults was not optimal because the insufficient illumination inside the environment did not allow an optimal acquisition of the color deducible from the projection of the panoramic image obtained with the laser scanner camera. Therefore, it was decided to merge the data using aerial photogrammetry, which, although less precise than the techniques based on active sensors, allows to control the parameters related to the exposure and the position of the shooting point. Considering that the study site to be treated is located at the underground level, it was already anticipated to carry out a manual flight because it would be impossible to connect the UAV to the GPS network. Consequently, the study area was reduced to the vaults adjacent to the side walls of the Piscina Mirabilis (Figure 4) in order to merge the information with infrared data to be acquired.

For the acquisition of the internal frames, two types of manual flights were designed: a first one for the acquisition of nadir photogrammetric images and a second one, with the optical axis tilted about 45°, to survey any shadow cones.

As expected, the quality of the data taken was not optimal since the drone presented stabilisation problems due to the missing connection to the GPS network and it was not able to fly at the expected height.

A total of 180 images were taken at 90°, while 235 images were taken at 45°, with a grand total of 415

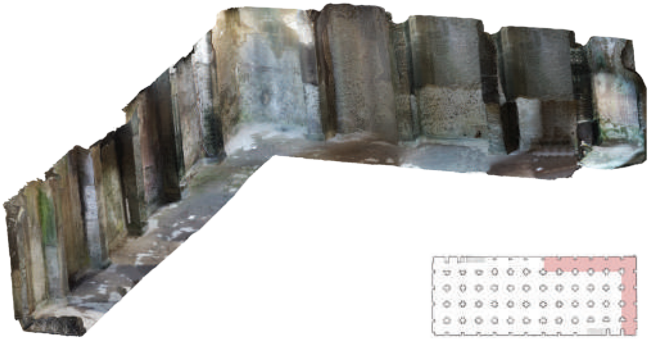

Figure 4. Axonometric view as a result of the photogrammetric process, with the study area highlighted in color.

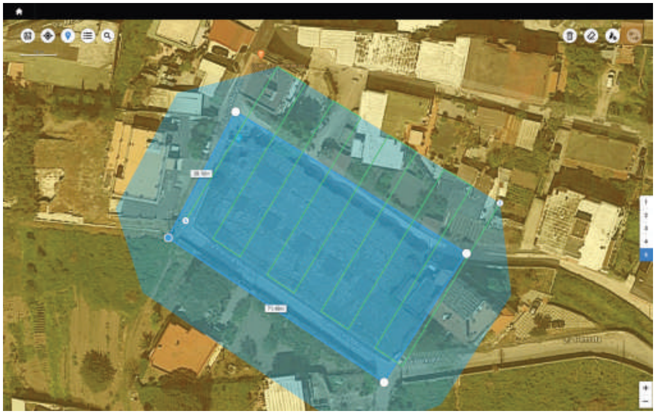

Figure 5. Oblique flight mission setup in DJI Terra software.

internal images and an overlapping of 80% in the first case and 70% in the second case. On the other hand, for the external data acquisition, the instrumentation worked correctly, allowing the loading of the flight plan previously designed in the DJI Terra software (Figure 5).
Another two flights missions are programmed: a first nadir flight and a second oblique flight, both having an image overlap of 70% as well as sidelap of 70% in a total area of 2550 m^2 approximately.
In the nadir flight, 74 images were acquired for the first grid, at a flight route distance of 353 meters and a flight time of 4 min and 35 s. After that, an oblique flight with the camera tilted at 45° on the horizontal plan, was carried out acquiring 143 photos in 5 minutes and 26 seconds.

3.2. Infrared thermography

In order to obtain a comprehensive representation of the anomalies present in the Piscina Mirabilis, thermographic data have been acquired through relevant instruments that have to investigate the reflective and emissive response of the surface examined in different bands of the integrated spectrum, providing auxiliary instructions compared to traditional methods.
The goal, as mentioned before, is to incorporate the differences in temperature obtained with the infrared camera.
For this reason, it was decided to continue working with the lateral zone of the monument, which presented a greater amount of masonry mass and therefore, a greater level of degradation to analyze.
A total of 182 images with a 160x120-pixel resolution were taken inside the building (Figure 6), obtaining as a result the IR and its corresponding RGB image.
Since this is a largely underground area, the temperature of the lateral walls varies between 5 and 9 degrees Celsius (41 and 48.2 Fahrenheit), increasing proportionally according to the amount of wall mass or the proximity to the outside, where the temperature is higher. However, despite the proximity of the user to the object of study (2 m), it was not possible to reproduce the degradation pathologies with an optimal level of detail.

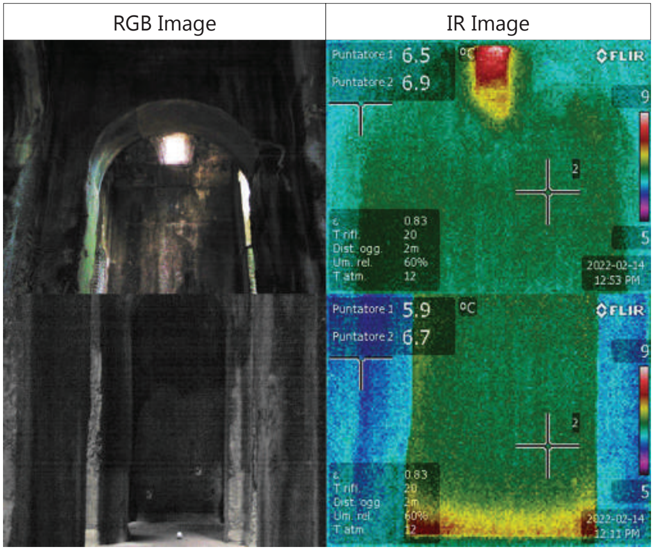

Figure 6. Comparison between the RGB image and the corresponding IR image, where the temperature is higher on the side walls.

3.3 Data processing: point cloud registration

3.3.1 TLS scan registration

These data were, indispensable to align the photogrammetric data. The clouds are characterized by a high degree of overlap (60%) and for this reason are registered employing a global bundle adjustment procedure, accomplished after a top view-based and cloud-to-cloud preregistration (Figure 7).

Given the set of scans, the algorithm searches for all the possible connections between the pairs of point clouds with overlap.

For each connection, a pairwise ICP is performed and the best matching point pairs between the two scans are saved. A final non-linear minimization is run only among these matching point pairs of all the connections. The global registration error of these point pairs is minimized, having as unknown variables the scan poses (Barba et al., 2021).

The RMSE on the registration is about 1,2 mm and the maximum value is 2,2 mm.

3.3.2 UAV orthoimages registration

Agisoft Metashape software was used for the photogrammetric data processing phase. Initially, all frames were grouped into a single chunk. Due to the similar geometrical characteristics of the building, it was necessary to add makers as control points for an easier recognition of homologous points in the different images.

The operations performed by the software are based on Structure from Motion (SfM) using algorithms such as SIFT (Scale-invariant feature transform) and SURF (Speeded Up Robust Features) that extract the significant points or tie points, homologues in different frames and identify the internal and external orientation parameters (Lowe, 2004).

With the data calculated by triangulation, the software created a first sparse point cloud. In the next step, Dense Image Matching (DSM) algorithms build a Triangulated Irregular Network (TIN) and a B-Rep (Boundary Representation) model is obtained.

Finally, it was possible to combine the photogrammetric data with that obtained by the laser scanner resulting in an integrated point cloud of the exterior and interior of the Piscina Mirabilis.

3.4 Data analysis: 3D texture mapping

To calculate the differences and errors between merged two images (IR and RGB), two mathematical approaches were used being Mean Squared Error (MSE) and Structural Similarity Measure (SSM). Shown in equation (1) and equation (2) (Hou et al., 2019).

$$MSE = \frac{1}{mn} \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} \left[I(i,j) - K(i,j) \right]^2 \qquad (1)$$

$$SSIM = \frac{\left(2\mu_x \mu_y + c_1\right)\left(2\sigma_{xy} + c_2\right)}{\left(\mu_x^2 + \mu_y^2 + c1\right)\left(\sigma_x^2 + \sigma_y^2 + c_2\right)} \qquad (2)$$

Figure 7. Partial cross-section showing the central part of the Piscina Mirabilis, as a result of TLS data processing in FARO Scene software.

MSE checks difference of every two relative pixels in two images. It squares these differences, sums them up and divide the sum of squares by the total number of pixels in the images. An MSE of value 0 indicates that two pictures are perfectly identical. The greater the value of MSE is, the more errors rendered pictures create. On the other hand, SSIM method can perceive changes in small sub-samples, whereas MSE estimates the perceived errors in the entire images. In equation two, (x, y) indicates the $N \times N$ sub-window in each image, and SSIM can be calculated on various windows of an image. The SSIM value can range between -1 and 1, where 1 represents perfect identicality. With the basis on these assumptions, in the present research the criterion of comparison was to calculate the differences and errors between RGB and IR images in 2 different scenarios presented in Table 1: First, with images taken at 90 degrees and second with images at 45 degrees. Different factors were tested: Flight grid, angle in the UAV flight pattern, overlap of images, number of aligned images, distance of the camera from the object under study and finally the height of the IR camera held by the user.

4. Results and discussion

Two comparison cases were tested, as presented in Table 1. In scenario 1, the flight was developed with the UAV camera angle at 90° with respect to the side walls (Figure 8). The image on the left presents the IR image and the picture on the right shows the RGB data as a result of integrated point cloud reconstruction.

To test the color rendering performance and structure similarity performance in the texture mapping process, the MSE and SSIM values are calculated (Fig 9.). Mapping process in images of a model with a flight camera angle of 90° (scenario 1) was better than rendering images of a model with a flight camera angle of 45° in terms of capturing color information, since scenario 1 had a lower MSE score. The MSE value in scenario 2 was

Scenario Number	Flight Grid	Camera Angle	Image Overlap	Number of aligned images	Mean Reprojection Error [pixels]	IR Camera Distance	IR Camera Height
Scenario 1	Complete Grid	90°	80%	180 of 180	0.198	2 m	1.7 m
Scenario 2	Complete Grid	45°	70%	213 of 235	0.203	4 m	1.7 m

Table 1. Summary of different factors to be tested in both cases.

5.25941 which can be considered an outlier, since the MSE values varied from 0 to 1.
Factors influencing the higher MSE value for scenario 2 is the distance and different angulation between the image taken by the UAV and that taken with the handheld thermal camera, obviously determined by the height of the user. Also, although the number of photos was higher, the overlap between images was lower than in scenario 2: because of this, Metashape software was not able to align all the images and therefore they were not processed.

5. Conclusions

Thermography has been introduced in a number of research fields, most notably, it has been used to capture the energy loss of a single building. However, creating a 3D thermal model with high resolution for asset restoration remains a challenge in terms of efficiency and performance.
Regarding the UAV flight, a camera angle of 90 degrees could capture more details on the internal walls or exterior flat roof system, while a camera flight angle of 45 degrees is more suitable for capturing details of the internal vaulted system, which presents a complex geometry.
In terms of image overlap, a larger number of thermal images could introduce more potential outliers. In addition, the quality of the images taken must be taken into account. Using a handheld camera, where the

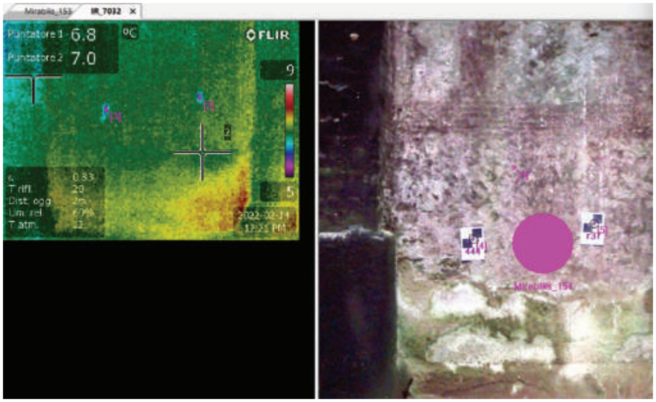

Figure 8. Comparison both images (IR and RGB) in the case 1.

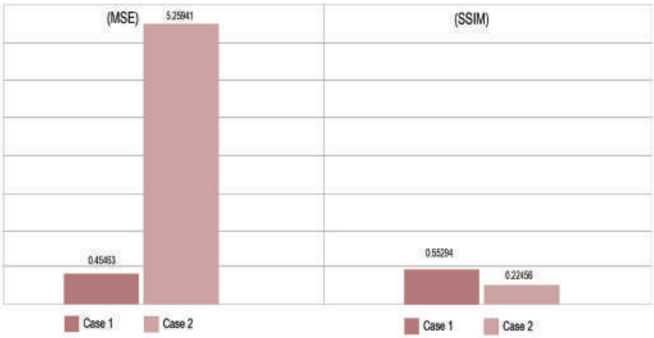

Figure 9. Statistics of MSE, and SSIM for both scenarios.

images are taken by the user, it is impossible to achieve a match between the angles of the images acquired by the UAV. If both RGB and IR images can be captured from the same angles and altitudes, a detailed 3D model can be created using high resolution RGB images, and then thermal textures can be projected onto the 3D model achieving a higher final accuracy.

Future prospects include the acquisition of data using UAVs with a thermal camera included to eliminate the problem of the angle difference between photos, which is a main factor influencing the efficiency and performance of 3D thermal mapping. In addition, it is also expected to face the problem of stabilization of the drone in areas without GPS signal, thus being able to optimize the data processing phase by applying automatic processing algorithms.

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Keywords:
Underwater photogrammetry, UUV, Low-cost sensors, Aerial photogrammetry, UAV.

ABSTRACT

The paper presents the first results of a research on the use of unconventional and/or low-cost sensors installed on or integrated with underwater vehicles (UUV) for the photogrammetric survey of underwater historical sites.
The experimentation was conducted on the case study of the Roman harbour of Minturno, whose digital model was obtained by integrating the survey of the underwater ruins with the aerial photogrammetric model of the emerged structures.

Evaluation of unconventional sensors for the photogrammetric survey of underwater historical sites

1. Introduction

Underwater photogrammetry is increasingly being used to study and monitor the three-dimensional characteristics of the marine world, investigated to satisfy the research interests of several fields: environmental monitoring, marine habitat study, archaeology, infrastructure inspection, etc. (Wright et al. 2020; Marre et al. 2019).

The field is still at an exploratory stage where the focus, especially in more recent years, is on the design of underwater vehicles with a high level of automation, capable of assisting and in some contexts replacing professional underwater surveyors for faster documentation of larger and more complex survey areas (McCarthy et al. 2019).

This implies, on the one hand, high costs for instruments that will have to be equipped with particularly high-performance optical and acoustic sensors (Mogstad et al. 2020); on the other hand, meticulous processes for estimating the accuracy and precision of the employed sensors that require, in addition, adequate data fusion techniques (Nocerino et al. 2021; Menna et al. 2019).

Having clarified the reference context, the research therefore focused on the use of unconventional and/or low-cost sensors installed on or applied to underwater vehicles (UUVs) for photogrammetric surveys of underwater historical sites. The aim of the study is to verify the use of these instruments, which stand out for being more accessible in terms of cost and portability, and possibly validate their use for the knowledge and documentation of ancient, submerged ruins through digital photogrammetry processes.

2. Case study

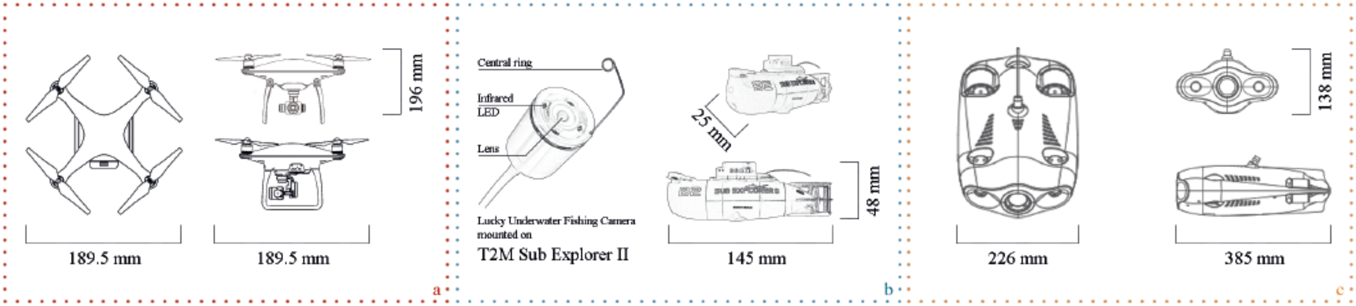
The research was carried out on the case study of the Roman harbour of *Minturno*, the outcome of the remodelling in the 1930s of the structures of a swimming pool for fish farming in an ancient private villa.

The residence is traditionally attributed to the wealthy *eques Formianus* Mamurra, a knight from Formia who lived in the Republican age, from whom it takes its name. It is a very ancient work in relation to the maritime constructions of the Gulf of Gaeta, built around 50 B.C. and therefore datable to the first style, with walls in *opus incertum*[1] and significant wall and floor decorations

The complex has learned from the architectural experience of the Hellenistic period: the building is adapted to the natural conformation of the site.

Small modifications to the coastline were only recorded in more recent centuries, as will be discussed below.

The villa is of considerable size: it is divided into several rooms arranged on three levels that rise from the sea along a wide promontory dominated by a large octagonal monument. From the highest point of the building, more than 100 metres above sea level, it is possible to reach the intermediate level, which consists of some residential rooms, two large water basins, the *Cisterna Grande* and the *Cisterna delle Trentasei Colonne*, and a large, vaulted ramp, known as the *Grotta della Janara*. The latter served as a link with the structures located near the sea, the lowest level of the residence; here are porticoes and rooms decorated with parietal coverings and refined floors, as well as one or more thermal structures.



DJI Phantom4		Lucky Camera		Chasing Gladius mini	
Weight	1.38 kg	Weight	0.93 kg	Weight	1.38 kg
True focal lenght	30.00 mm	Visible Camera angle	185°	True focal lenght	4.00 mm
Sensor width	36.00 mm	Screen width	9.00 cm	CMOS	Sony 1/2.3 inch
Sensor height	20.25 mm	Screen height	14.00 cm	Aperture	F3.0
Sensor horizontal resolution	4000 pix	Sensor horizontal resolution	400 pix	Sensor horizontal resolution	4000 pix
Sensor vertical resolution	2250 pix	Sensor vertical resolution	272 pix	Sensor vertical resolution	3000 pix

Figure 1. Main technical specifications of the sensors employed.

Finally, two bays used as fish-farming pools border the property: to the west the estuary of the Rio Santa Croce and to the east the so-called Roman harbour. The latter, as already mentioned, is now quite badly modified due to interventions carried out in the last century by the Marquis Carlo Afan de Rivera (Ciccone 1990). Owner of a large property on the promontory of Gianola, the noble landowner ordered the conversion of the large fish-pool into a landing place for his own boats and those of his guests. The basin was dredged, and powerful stone piers were built above the perimeter walls of the pool, complete with mushroom-shaped bollards for mooring and side ladders. A further wall was built ex-novo to protect the outside of the western part of the harbour and numerous ancient elements belonging to the inner walls of the fish-pool were removed by the action of the dredger. The complex is undoubtedly of significant importance as an exceptional testimony to the construction tradition of maritime villas along the coasts of ancient Italy. For this reason, the residence has been the focus of attention in recent years with projects of documentation, restoration and recovery aimed at both its emerging architecture and its submerged ruins[2].

3. Survey methodology

To create a 3D model of the entire area of interest in both its emerged architecture and underwater remains, an integrated methodology of reality-based techniques was chosen: (i) aerial photogrammetric survey to obtain a complete environmental point cloud; (ii) underwater photogrammetric survey to acquire information on the underwater structures by testing different sensors.

3.1 Aerial surveying

An initial collection of morpho-metric data on the emerged structures of the harbour was carried out using a DJI Phantom4 quadricopter (Figure 1a).
In relation to the conformation of the site and the extremely natural context, two flight missions with

waypoint navigation mode were planned to cover the entire area of interest. The images were captured with inclined-axis and nadiral shots, at a flight altitude of 10 metres. Then, they were integrated with manual flight recordings, thus recovering spatial information at different levels of depth and detail. A total of 472 frames were acquired for the port area, with an average overlap of about 60%. The lighting conditions, which were highly variable during the acquisitions, required a planning phase of the photographic survey to avoid shadow zones and overexposed areas in the acquired images, bypassing as much as possible a radiometric correction of the data in the pre-processing phase.

3.2 Underwater surveying

Two different sensors were used to survey the underwater structures: (i) an underwater fishing camera, the Lucky Underwater Fishing Camera, mounted on a small radio-controlled hobby submarine, the T2M Sub Explorer II (Figure 1b); (ii) a prosumer category underwater drone with an integrated camera, the Chasing Gladius Mini (Figure 1c). These sensors are diversified mainly by the cost of the instrumentation and the primary field of application, and it was decided to use them in the research to test their reliability and suitability for underwater photogrammetry applications. In this sector, in fact, the instruments traditionally employed are professional reflex cameras, used by professional divers, or extremely expensive but refined UUVs from the point of view of the optics involved. In this study, the two sensors were used to take a high number of photos, organising the data collection activity in two steps.

In a first step, photographs were taken of a chessboard above and below water to calibrate each lens in both conditions (see next paragraph).

Subsequently, stills of both the underwater structures and the emerged ruins were recorded to compare the geometric and colorimetric results obtained with the results recorded with the UAV optics. Specifically, this phase was conducted in two distinct moments. Using the fishing camera, the portions of the wall facing the shore of the inlet were surveyed, where the depth of the

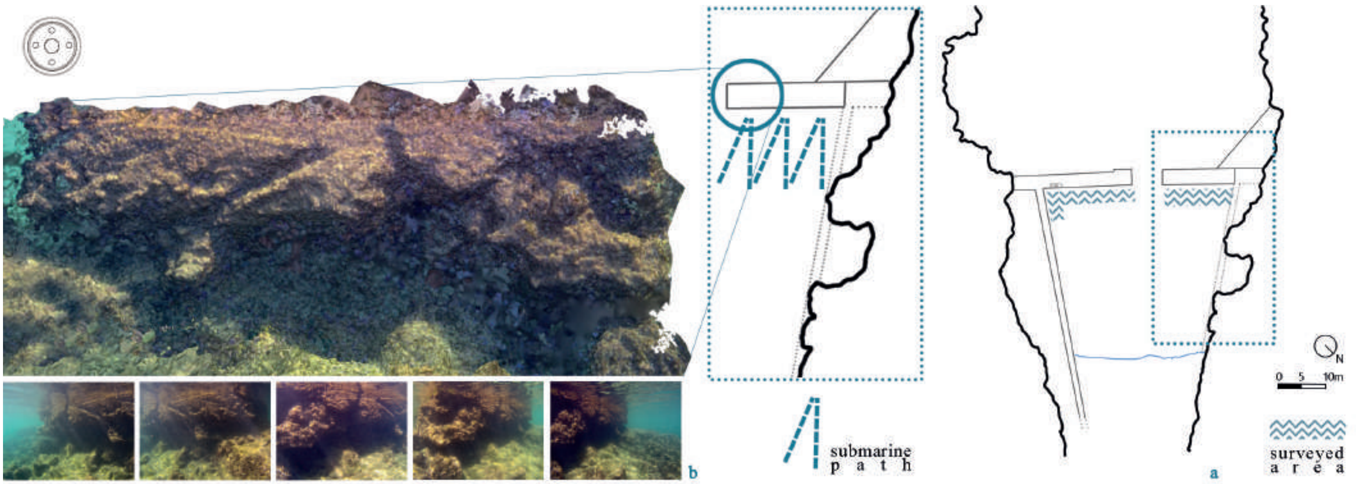


Figure 2. Underwater survey performed by the Lucky fishing camera.

remains, around 60 cm, was more compatible with the instrumentation used (Figure 2a). The small submarine used to transport the chamber does not allow great depths to be reached.

The use of the UUV, which can reach depths of up to 100 metres, is different: the Gladius was used to capture both the walls surrounding the basin, with particular attention paid to the surfaces facing the roadstead (Figure 3a), which preserves the original bathymetry of 7 metres at its deepest points.

Since the UUV used has propellers and thrusters that allow only some of the typical motions of a boat[3], the data acquisition was conducted according to a "comb-shape" trajectory. To overcome the impossibility of performing drift translations along the y axis, the drone was piloted following translations "forward and backward" (range of distance from the wall: min 0.30 cm; max 1.50 m) and rotations "left and right" (rotation angle: about 10°) allowed the recording of the required colour-metric information (Figure 3b).

4. Data processing and results

4.1 UAV photogrammetry

For the orientation of the photogrammetric datasets, only images with the highest quality parameters, estimated on the basis of focus sharpness, were used.

In line with the standard photogrammetric pipeline, the datasets were triangulated in well-known SfM application with the bundle-block adjustment algorithm. Subsequently, the homologous points, extracted from the calculation of the internal and external orientation parameters, were used to produce with dense image matching algorithms a textured polygonal model (Figure 4), an update of a previous survey (Iovane 2017).

4.2 UUV photogrammetry

As expected, the underwater images required more careful processing, managed by varying the processing parameters and working in separate groups, to obtain congruent photogrammetric clouds for both sensors

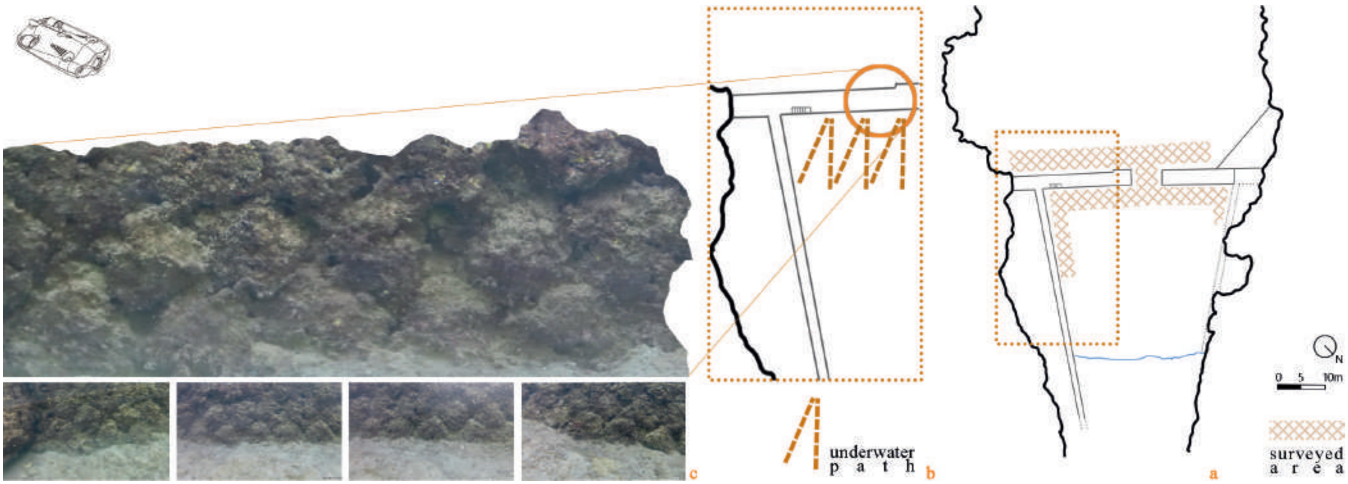


Figure 3. Underwater survey performed by the UUV Chasing Gladius.

(Figures .2b-3c), due to the inconsistent lighting conditions and the change in refractive index. Particularly interesting, for example, was the lens flare recorded in some shots of the Gladius pertaining to the wall block of the short side of the eastern pier (although captured at a depth of 0.70 cm - 1 m but backlit) and therefore excluded from the point cloud reconstruction process (Figure 5a). Since it was not possible to use targets during the acquisition phase that would allow the definition of a specific metric scale for the underwater parts, the model was scaled up using as reference some measurements taken directly from some of the most accessible stone blocks.

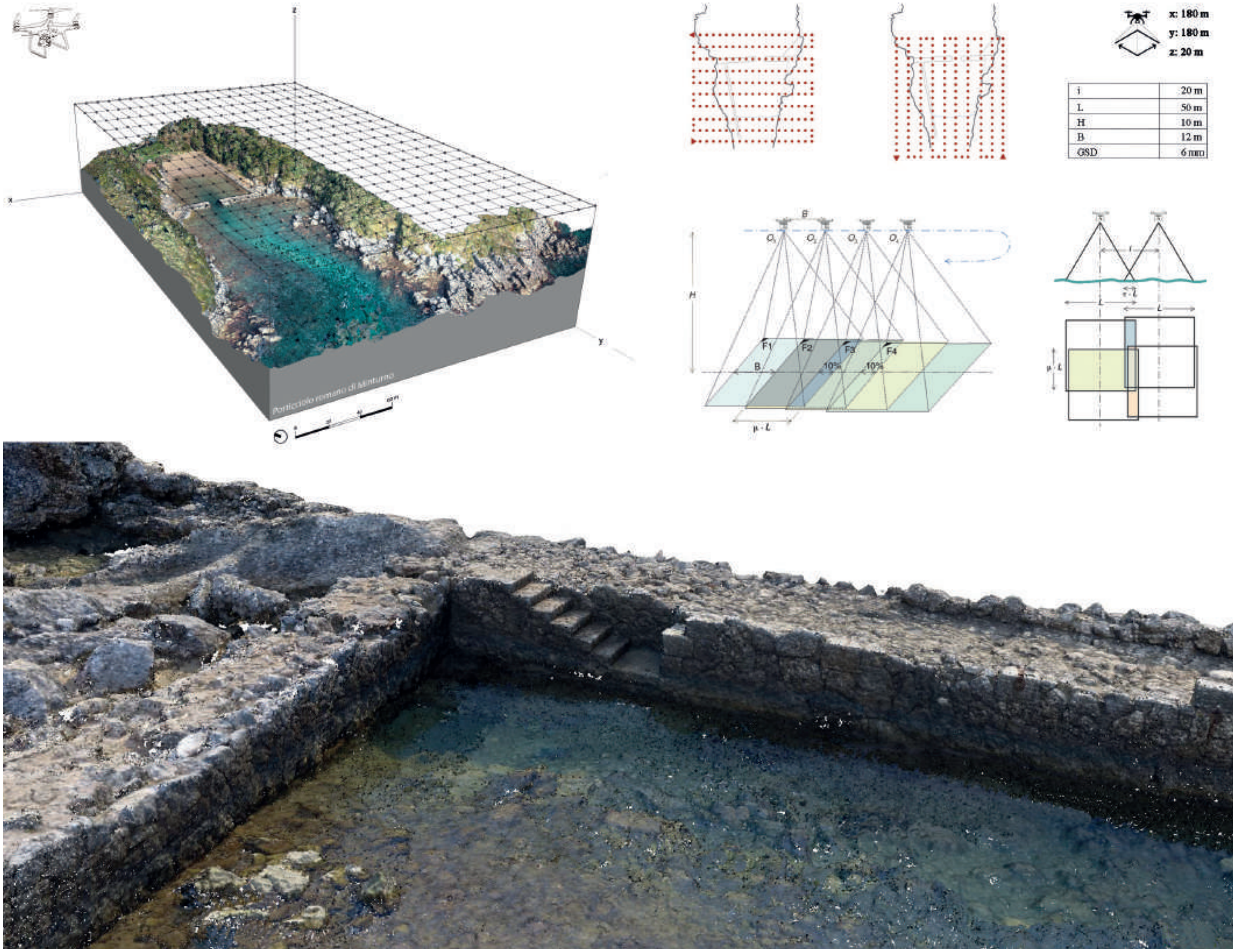


Figure 4. Aerial photogrammetric survey performed by the DJI Phantom 4.

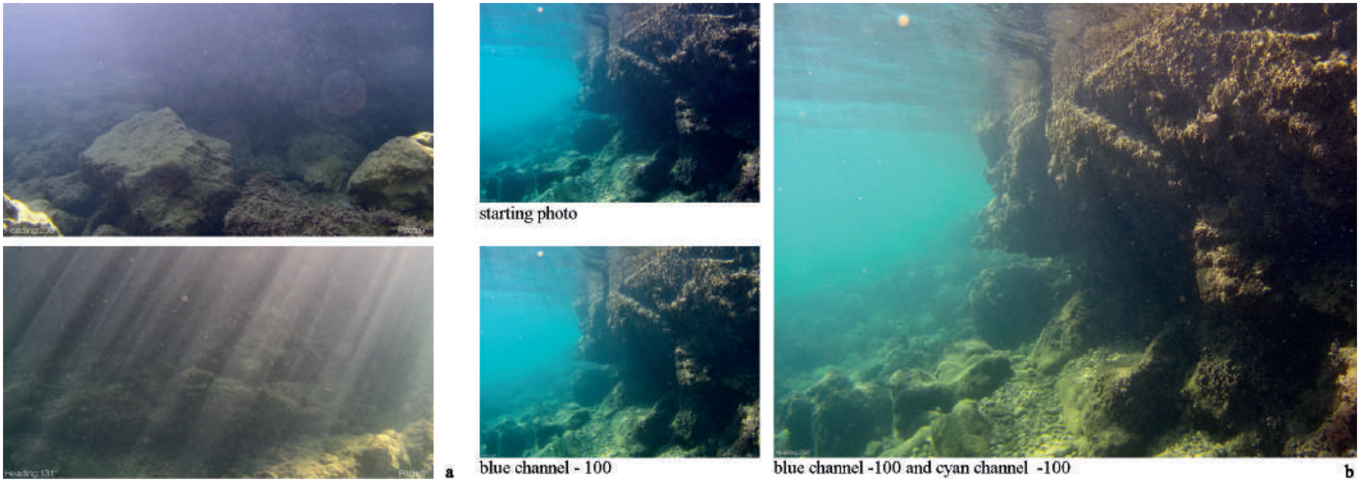


Figure 5. Colorimetric corrections and lens flare of some underwater photographs.

4.3 Evaluation of results and outlook

As anticipated in the previous paragraph, the processing of the photogrammetric data was accompanied by the calibration of the two lenses employed, through the elaboration of the distortion curve relative to the images of the reference chessboard, acquired both above and below water.

The calculation of the specific distortion laws, radial and tangential, allowed the evaluation of the variation of the correction parameters due to the deformations introduced by the water, which appear less significant for the Gladius optics (Figure 6).

Concerning the colorimetric data, given that the rests surveyed are located on a shallow seabed (1.4 - 2 m), the loss of colour due to the limited penetration distance of certain wavelengths is quite contained (almost zero for the images acquired with the Gladius) and was managed by applying correction filters on the blue component of the images (mainly those of the Lucky camera) (Figure 5b).

With regards to precision and metric accuracy, although non-professional and non-conventional sensors were used, the analysis of the tabulated data relating to the errors recorded for each sensor in the sizing of certain reference points (Figure 7), shows a variation in the deviation along the three Cartesian axes between the two point clouds varying between -0.02 m and 0.01 m along the z axis. On the other hand, the deviations along the x-axis and y-axis are between -0.03 and 0.02 m.

Of the two systems used, as could be imagined, the prosumer drone presents more reliable metric parameters. For this reason, the photogrammetric model acquired with the Gladius was linked to the model of the emerged structure.

The process is currently being carried out in a crude manner, linking the emergent and submarine structures through a few reference points visible in both models, without, for the moment, checking for distortions. The method is, therefore, still being refined, but the connection made has so far recorded a small metric deviation (about 0.3 cm), probably because the optics used, between UAVs and UUVs, are quite similar.

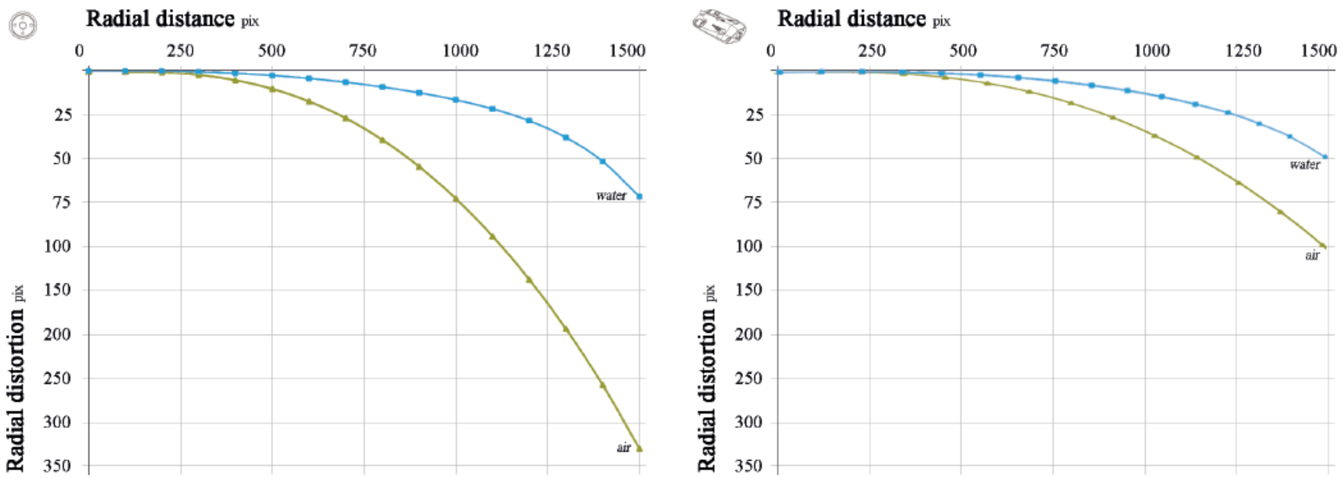


Figure 6. Comparison of radial lens distortion from in-air and in-water calibrations of the UUV Chasing Glaudius (right) and the Lucky fishing camera (left).

Points	Errors			Points	Errors			Points	Errors		
No.	Δx	Δy	Δz	No.	Δx	Δy	Δz	No.	Δx	Δy	Δz
A00	0,02	0,00	0,00	A06	-0,02	-0,01	0,01	A11	0,00	-0,01	0,01
A01	0,01	0,02	0,00	A07	-0,01	-0,03	0,00	A12	0,00	-0,02	0,01
A02	-0,01	-0,03	-0,01	A08	-0,03	-0,01	-0,02	A13	0,01	-0,03	-0,01
A03	-0,01	0,01	-0,01	A09	0,00	0,01	0,00	A14	-0,02	0,01	0,00
A05	0,00	-0,02	0,01	A10	0,01	-0,01	0,01	A15	0,01	0,00	0,01

Average		
Δx	Δy	Δz
0,00	-0,01	0,00

Standard Deviation		
Δx	Δy	Δz
0,003	0,004	0,001

Figure 7. Results of Accuracy Evaluation.

5. Conclusions

Underwater photogrammetry is an extremely open field of investigation.

The search for reliable but inexpensive sensors for the survey of underwater structures is a topic of contemporary experimentation and, as the contribution shows, highly complex.

The analysis of the first results concerning the application of unconventional and/or low-cost sensors for the photogrammetric survey of the Roman harbour of *Minturno* allows us to validate, for the time being, the use of such instruments for knowledge applications, digitisation and updating of the documentation of historical underwater sites. In this sense, the outcome of the activities carried out has highlighted a worrying and inevitable progressive loss of the remains of the *opus reticulatum* of the fish pool of the villa of Mamurra: if compared to the documents of a previous "traditional" underwater survey (Pesando and Stefanile 2015), the images of the masonry attest, firstly, to a rise in the water level to be considered, probably, not occasional if compared to the consequent erosion of the *cubicola* whose reticular scheme is now almost unrecognisable.

Monitoring actions, therefore, understood as continuous and updated digitisation over time, are necessary to protect and preserve, where possible, the historical memory of these heritages. Therefore, the use of inexpensive but reliable sensors is undoubtedly a valid support for the concrete feasibility of these actions.

Notes

1 Some structures, such as those in the Roman harbour, are in opus reticulatum instead of opus incertum.

2 These include, among others, the 'Project for the use and enhancement of the maritime villa known as Mamurrae at Gianola along the Via Appia' - Progetto di fruizione e valorizzazione della villa marittima detta di Mamurrae a Gianola lungo il percorso della Via Appia (POR FESR Lazio 2007-2013. Enhancement of structures for the use of protected areas - Valorizzazione delle strutture di fruizione delle aree protette); the 'Underwater survey of the southern Lazio coast' - Ricognizione subacquea delle costa del Lazio Meridionale - project (Agreement for study and research between the Soprintendenza ai Beni Archeologici del Lazio and the University of Naples L'Orientale).

3 Yaw and pitch for rotations; yaw and jerk for translations.

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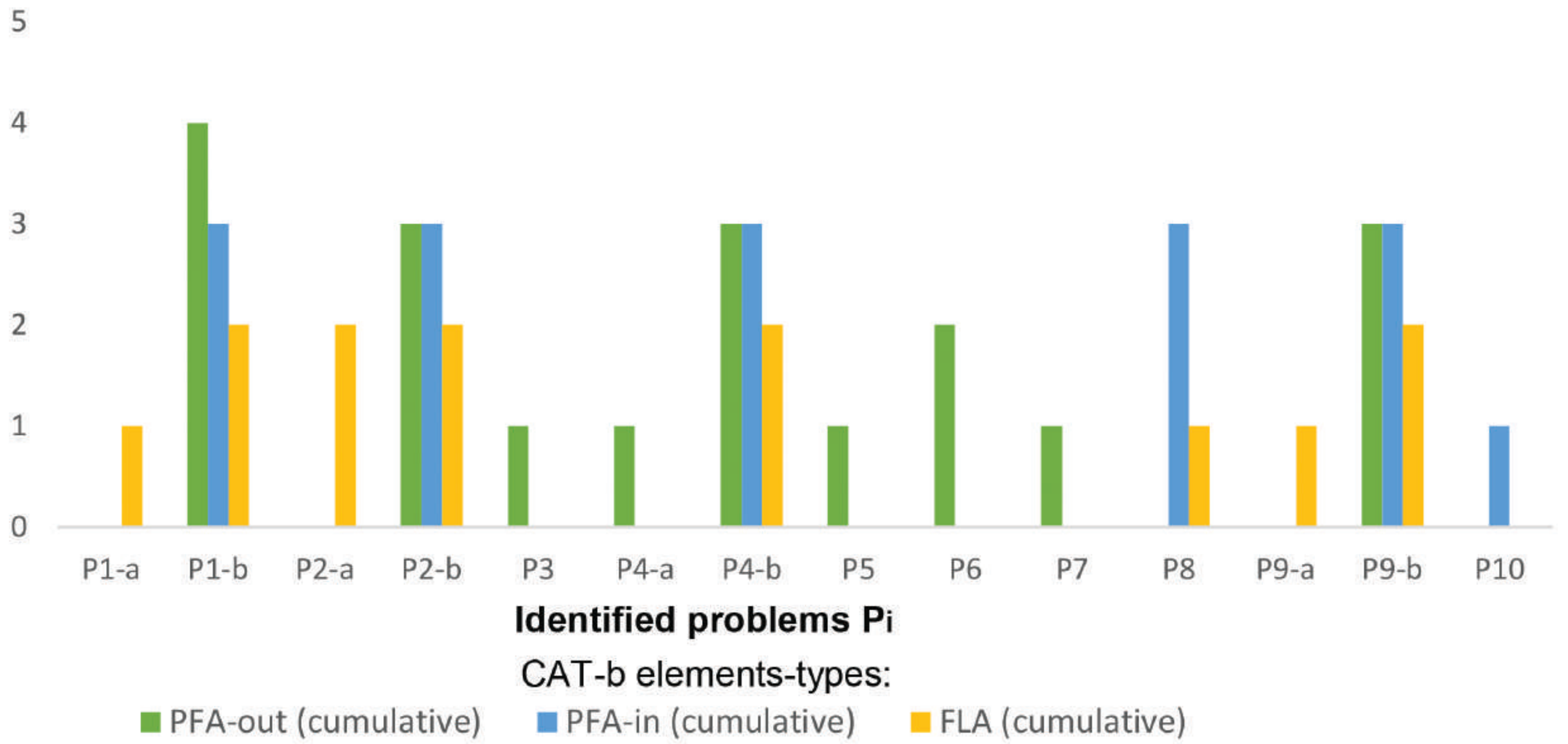

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Keywords:

UAV/UAS, legislation, architectural heritage, Serbia.

ABSTRACT

Worldwide quickly enacted UAV/UAS legislative is permanently improving to prevent unpredicted and potentially hazardous activities. Serbian regulations have generally been harmonized with those of the EU and strictly implemented.

This Paper investigates Serbian regulatory mechanisms negatively affecting surveying effectivity/efficiency. Respecting the methodology, valorisation criteria are set and problems identified. Research results are graphically presented to mutually compare them and obtain sustainable conclusions.

Regulatory and controlling mechanisms on UAV/UAS that influence efficient architectural heritage praxis: actual situation in Serbia

1. Introduction

Serbian UAV/UAS-related legislation generally harmonized with that of the EU, combines national (CAD) and European (EASA) indications to satisfy all requirements. Its strict implementation, legislative and administrative limitations included, especially for operation in densely-populated central city zones or in restricted flight areas, are recognized here as main effectivity/efficiency destructor factors. Thus, to obtain a specific authorization may prove to be extremely complex and long, causing not to complete activities aims. The time between defining needs and flight may take weeks or months to be conducted. It may hinder urgent surveying, preventing private users to operate in emergency conditions. This Paper dominantly investigates negative Serbian regulatory and controlling mechanisms' influence on surveying effectivity/efficiency, reflecting possible solutions to reduce the risk of "missing the opportunity" without breaking the rules. Three central questions are analysed: (1) difference in subject-related mechanisms in EU and Serbia), (2) common mechanisms affecting UAV/UAS surveying of Cultural Heritage sites (hereinafter: "CHS") and (3) aspects of UAV/UAS Cultural Heritage surveying negatively affected by those mechanisms. To conduct this in a scientific manner, sustainable research methodology is defined. Therefore, valorisation criteria are set, current legislative framework investigated and problems identified. Following this, research results are cross-referenced and presented in the form of charts to mutually compare them and obtain sustainable conclusions. A "more global" importance of this study is that this set of problems restrictively influences UAV/UAS surveying of Cultural Heritage sites throughout EU.

2. Previous research

Previous research in this field concentrated on legislative overviews of national and global situations regarding different tangent aspects: (a) control of UAV/UAS during flights above urban environments to make them more secure - legislative-wise and technologically (in Spain concretely) (Chamoso et al.,2018) and (b) laws required to protect the public amid rising concerns about privacy, interference with commercial flights and potential risk to homeland security so to balance between risks and benefits (Kurt,2015), Another thematically connected topic of interest is a review of the state UAV regulations were globally used in 2017 and prior (Stöcker et al.,2017). It emphasizes the importance, impact and diversity of UAV regulations in 19 countries worldwide and presents comparatively the current state of national legislation and its influence on general droning activity. But, elaboration and valorisation of analysed data do not consider the situation in Serbia. Recent and complex comparative analysis of legislation evolution referring to operating a drone in OECD Countries (Serbia excluded) centres on size, weight, flight altitude, purpose of use and restrictions with reference to legal documents and relevant authorities. It is followed by recommendations to harmonize and update legal framework (Tsiamis et al.,2019). An overview of existing EU drone regulations (applicable since 1 January 2021) and main changes to the rules since first regulations were adopted in 2017 are represented in paper (Alamouri et al.,2021). It reveals how new rules help or hinder the use of UAS technology and its economic potential in scientific and commercial sectors. Contribution of this paper is graphically shown on figure 1.

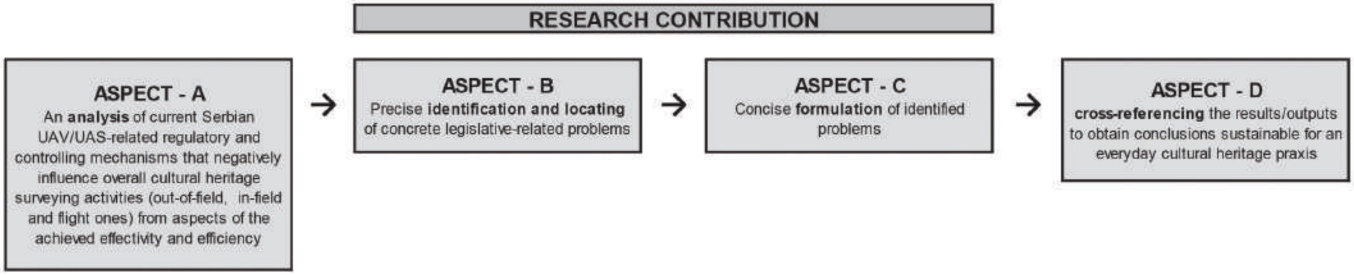

Figure 1. Graphic Illustration of the main aspects of this research contribution.

3. Initial considerations, prerequisites and assumptions

Legislation concerning drones officially EU-labelled with C1 and C2 (take-off mass up to 4kg), is considered hereunder, because they are mainly used for professional work in CHS UAV/UAS surveying. Also, instead of laser scanning, photogrammetric activities, generally more affordable and hence more applicable in everyday global CHS surveying praxis are considered. Due to the research aim, UAV/UAS surveying activities which relate to post-processing of data acquired in-field are not considered.

The assumption is that surveying staff is well educated so that its effectivity/efficiency does not affect the overall effectivity/efficiency of performed UAV/UAS surveying.

3.1. Overview of "Inherited" EU Regulation and Controlling Mechanisms

Although Serbia is not officially an EU country, Serbian Civil Aviation Authority (CAD) has issued national manned and unmanned aircraft regulations complied with EU Regulation 2018/1139 [6]. Serbia's regulation also covers issues EU member states are responsible for pursuant to EU Commission Delegated Regulation 2019/945 [7] and EU Commission Implementing Regulation 2019/947 [8], including changes applicable since January 1st 2021 (Alamouri et al.,2021). Registering on the D-Flight portal is still not mandatory in Serbia, as is affixing a QR code to a drone for identification purposes and any operational liability issues that may arise thereof. Generally, until January 1st 2023, drones without class marking can be used in limited open category, where national authorities usually may impose additional requirements on the pilot. But, CAD has decided to remain aligned with open categories of EU Regulation 2018/1139 and has not imposed additional requirements on pilots of unmarked drones. Also, the CAD regulation has not yet granted a transitional period to ensure gradual conversion from the use of previous certifications to those granted in compliance with the EU Aviation Safety Agency requirements.

3.2. Current Serbian UAV/UAS-Related Regulatory, Controlling Bodies and Legislation

Serbian authorities tasked in Table 1 are in charge of mechanisms controlling UAV/UAS surveying activities regulated by Serbian legislative.

The most important forms of national UAV/UAS-related legislative are presented in Table 2.

ID	Authority	Web Address
CAD	Civil Aviation Directorate of the Republic of Serbia	http://www.cad.gov.rs/en
SMA	SMATSA - Serbian and Montenegro Air Traffic Services	https://smatsa.rs/en/4166-2/
MOI	Ministry of Interior of the Republic of Serbia	http://www.mup.gov.rs/wps/portal/en
MOD	Ministry of Defence of the Republic of Serbia	https://www.mod.gov.rs/eng

Table 1. Serbian UAV/UAS-related regulatory and controlling authorities.

ID	Legislative	Issue
LAW-1	Air Transport Law (Consolidated version)	"Official Gazette of the Republic of Serbia" No 73/10, 57/11, 93/12, 45/15, 55/15- other Law, 83/18 and 9/20
LAW-2	Law on Public Peace and Order	"Official Gazette of the Republic of Serbia", No 6/2016 and 24/2018
LAW-3	Law on Defence	"Official Gazette of the Republic of Serbia", No 116/2007, 88/2009, 104/2009, 10/2015 and 36/2018
REG-1	Regulation on Unmanned Aircraft	"Official Gazette of the Republic of Serbia", No 1/20
REG-2	Regulation on Aeronautical Information	„Official Gazette of the Republic of Serbia", No 142/20 and 61/21
REG-3	Regulation on Aircraft Flight	„Official Gazette of the FRY ", No 40/95 and 68/2001
DEC-1	Decree on Airspace Management	"Official Gazette of the Republic of Serbia", No 86/19
DEC-2	Decree on the Procedure for Issuing Permits for Aerial Photographing of the Territory of the FRY and for Issuing Cartographic and Other Publications	„Official Gazette of the FRY ", No 54/94 and „Official Gazette of the Republic of Serbia", No 72/2009
DES-1	Decision on the form of Flight Approval Application	Issued by CAD (Civil Aviation Directorate of the Republic of Serbia)
DES-2	Decision on General Rules of Conduct in Housing and Residential/Office Buildings	Issued by each town/municipality government separately

Table 2. Serbian UAV/UAS-related legislative in the form of laws and bylaws.

4. Methodology setup

To identify, analyse and systematize data scientifically and obtain meritorious conclusions, a set of initial terms, definitions and categorizations is defined.

4.1. Terms, Definitions and Categorizations Used

For this investigation, the targeting experimental field is a "controlled surveying-activity space" (hereinafter: "CSAS"), whereby that "space" is not spatial but made of various UAV/UAS-related elements divided into categories (hereinafter: "CAT"): CAT-a *legislative elements*, CAT-b *professional surveying activity elements* and CAT-c *elements that represent causal links between elements from two previous categories*.

The CAT-a is made of hierarchically-ordered legislative elements:

laws, including corresponding articles and paragraphs (hereinafter: "LAW") and bylaws, including corresponding articles and paragraphs (hereinafter: "BLW").

CAT-b elements are divided into two hierarchically-ordered sub-categories: Non-flight activities in the form of various Pre- and Post-flight activities: out-of-field and in-field (hereinafter: "PFA-out and PFA-in") and flight activities (hereinafter: "FLA") related to in-field surveying procedures (inspection and mapping).

CAT-c elements are links between proper elements of CAT-a and CAT-b, describing how concrete legislative mechanism(s) influence(s) targeted activity(ies) realization. Investigation of each link allows identification of not only positive, but also negative aspects of their presence and, consequently, valorisation of their potential effects on overall professional surveying practice. Note that some of those links can be "one-directional" (single CAT-b element is affected by one CAT-a element), while others can be "multi-directional" (more CAT-b elements are affected by one CAT-a element). As each of one - or multi-directional links is in the form of implication (directed from CAT-a to CAT-b), overall "sustainability" of CAT-a elements (relevant for concrete CSAS surveying) can be valorised by achieved "successfulness" of CAT-b elements performed by strictly respecting existence of those CAT-a elements.

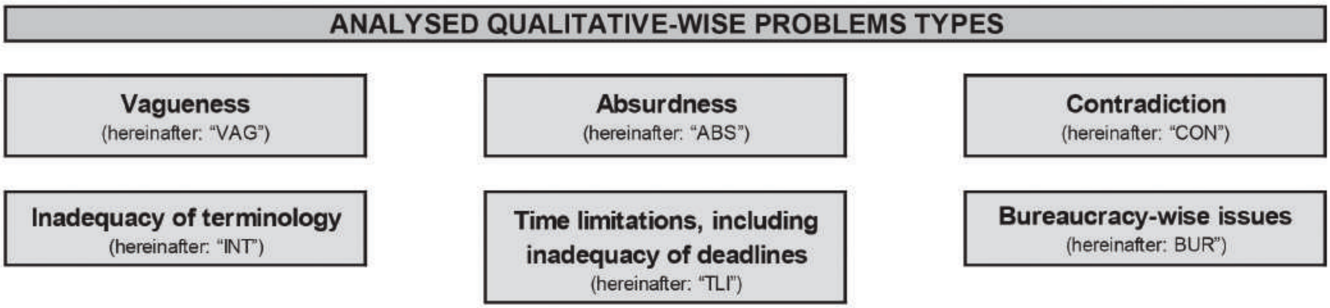

Figure 2. Typology of potential qualitative-wise problems identified as most relevant and expected.

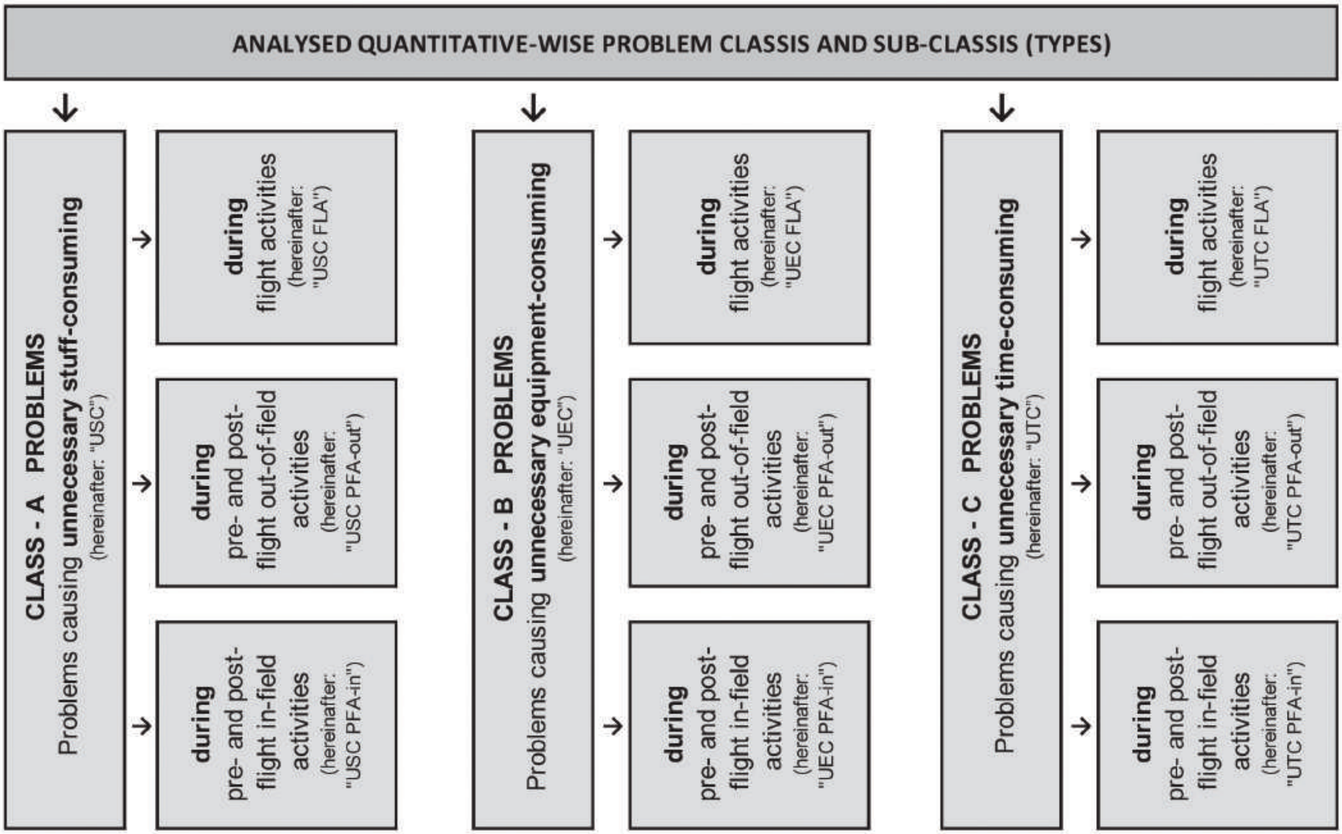

Figure 3. Typology of potential quantitative-wise problems identified as most relevant and expected.

To define “successfulness” of CAT-b elements as a measure of mentioned CSAS sustainability, namely, of sustainability of CAT-a elements, two criteria are introduced: effectiveness and efficiency.
In this paper, effectiveness (hereinafter “EFT”) is successfulness of obtained results of realized surveying activities (here represented as a ratio between planned and achieved results obtained under strict respect for corresponding legislative).
Conversely, efficiency (hereinafter “EFC”) is successfulness of realized surveying activities (obtained results) in the function of overall resources used (staff, equipment and time).

But, recalling that effectiveness and efficiency are substantially strongly interconnected, they are valorised together according a common EFT/EFC criteria. So, this successfulness is valorised in this paper only considering whether CAT-b elements are affected by CAT-a elements or not with regard to those criteria. Thus, each link indicating negatively effect(s) on outcome successfulness is declared “problematic”. Consequently, CAT-a element, part of the “problematic” link, is declared “problematic” also. So, this methodology allows not only to identify legislative-wise problem (in CAT-a hierarchy) but to formulate and systematise it to help relevant institutions find solutions adequately (satisfying professional practice demands in the most proper way).

4.2. Typology and Classification of Potential UAV/UAS-Related Problems

To represent more comprehensively potential problems from EFT/EFC point of view (as research outputs), they are categorized qualitatively and quantitatively. A set of potential most relevant and expected qualitative-wise problems is shown on figure 2 (together with corresponding abbreviations used further in text).Three identified classes of potential most relevant and expected quantitative-wise problems is shown on figure 3 (together with corresponding abbreviations used further in text). With regard to meaning of "efficiency", it is obvious that CAT-b elements efficiency is directly (negatively) affected by problem types classified above.

5. Investigated inputs and outputs

Concrete research inputs and outputs are presented tabularly and marked with respect to abbreviations defined above.Regarding methodology criteria in Section 4, national legislative framework is analysed (following current professional experience in field of interest), relevant links inspected and problem causes (marked with C_i) localized in corresponding legislation hierarchy (Table 3[1]). Concise description of identified and previously localized problems causes C_i (generated by problematic links in Table 3) is in Table 4. Following information in Tables 3 and 4, problems (marked with P_i) are concisely formulated (Table 5). Table 6 features typology of problems formulated according to quantitative-wise and qualitative-wise problems-characterization criteria described in Chapter 4.Occasioned relations between analysed CAT-b elements and formulated problems P_i (Table 5) are in Table 7. Data in Tables 6 and 7 are graphically presented in the form of charts (Chart 1, i.e. Chart 2). Chart 1 represents the number and abundance of problems (cumulative), PFA-in function of analysed quantity -

CAT-a elements	ID	LAW			BLW						
		LAW-1	LAW-2	LAW-3	REG-1	REG-2	REG-3	DEC-1	DEC-2	DES-1	DES-2
	LAW-1										
	LAW-2				C_8[11↔12]						
	LAW-3				C_6[102v↔26]				C_6[102v↔2]		
	REG-1				C_1 [16] C_2 [11,14/1] C_7[8,9]			C_3[13↔15/1-2] C_4 [15,18↔15/1-3]	C_6[26↔2]		
	REG-2										
	REG-3										
	DEC-1										
	DEC-2										
	DES-1									C_5	
	DES-2										C_6

Table 3. Localization of problems causes Ci in CAT-a hierarchy.

and quality-wise problems-characterization criteria. Chart 2 represents an influence of identified problems P_i on CAT-b elements of analysed types: PFA-out (cumulative), PFA-in (cumulative) and FLA (cumulative).

6. Comments and conclusions

With regard to Chart 1, one can conclude the following: There are: 9 quantity-wise problems of 2 quality-wise problem types classified as ABS and BUR, 8 TLI-type problems, while 4 of VAG-type. The highest number of problems are BUR-type (25), 11 are ABS-type, 8 are TLI-type, while the smallest number (4) is of VAG-type. According to abundance of quantity-wise problems concerning analysed quality-wise problem types, one can conclude that: USC-PFA-in, USC FLA, UEC-PFA-in and UTC PFA-in

ID		Description
Problems causes C_i	C_1	Operator's obligation is to maintain permanently a visual contact with UAV/UAS during flight.
	C_2	Although UAV/UAS of category 2 could generally be used in all regions, when needed to fly over people they are essentially unusable in Region IV due to the fact that only UAV/UAS of category 1 can fly over them.
	C_3	UAV/UAS surveying at distances that are less than 500m away from buildings of state/local interest, foreign diplomatic missions as well as significant infrastructure and other facilities, in addition to the usual approvals necessary to get (from CAD, MOD), it is both required to obtain approvals from owners/users of these objects/facilities and to inform local police department(s) about planned activities.
	C_4	In the case of UAV/UAS operating in conditionally prohibited flight zones, after obtaining a positive opinion of relevant authorities (MOD and MOI), the take-off approval(s) is (are) to be issued only (by CAD), whereby the obligation of the applicant is to inform the local police department(s) about planned activities in advance.
	C_5	Single application for take-off approval (by CAD) refers to one flight or series of flights (which may take up to 30 days) allowing the usage of oly one UAV/UAS that can operate on no more than 10 locations.
	C_6	Before starting any post-flight (photogrammetry-wise) processing of the collected data (digital photos/videos), the applicant must submit the recorded material to the MOD experts not later than 8 days after its acquisition (in order to review them and to possibly remove alike any elements of special importance or those that have not been defined in the enclosed proposal of activities and targets to record).
	C_7	To get the airspace allocation, the request should be submitted (to SMA) in cases when the UAV/UAS flights are planned either at an altitude of more than 100m from the ground or near airports/heliports within a radius of 1.5 namely of 5km from ARP (depending on their importance) - regardless of the planned flight height.
	C_8	The use of remote-controlled devices must not endanger the safety of citizens or disturb public order and peace. Accordingly, the operator must ensure that during the flight the horizontal distance of the UAV/UAS from other people is not less than 30m or 5m (if approved by CAD).
	C_9	Restricted time intervals are defined in residential as well as residential-business zones during day- and night-rest periods (both in buildings and their surroundings), when tenants/occupants and third parties (for example various utility services) must behave so as to provide complete silence and peace. The beginning and the duration of those rest periods vary in Serbia from city to city/municipality.

Table 4. Concise formulation of previously localized Pi problems.

quantity-wise problems are prevailing in 4 analysed types (VAG, ABS, TLI, BUR), demonstrating also largely uniform presence of quantity-wise problems among those 4 types ((1,1,1,2), (1,1,1,2), (1,2,1,2), (1,1,1,2); USC-PFA-out, UEC-PFA-out, UEC FLA and UTC FLA problems are 3 of 4 types (ABS, TLI, BUR), characterized also by their fairly uniform presence among those 3 types ((1,1,2), (1,1,2), (1,1,3), (1,1,1)) while UTC PFA-out problems are 2 of 4 types only (ABS, BUR) showing significantly different presence of quantity-wise problems supportive of BUR (2, 9). There are no CON- and INT-type problems. This indicates that bureaucracy issues affect most problems (25). Abundance of problems of VAG, ABS and TLI is quite balanced, while abundance of BUR problems is imbalanced as presence of problems (9) influences out-of-field activities either Pre- and Post-flight regarding unnecessary time-consuming (UTC PFA-out). Note that majority of identified problems are of bureaucracy nature dominantly. With regard to all previously mentioned, the most important conclusion facts are summarized on figure 4.

Notes

1 To present tabularly identified relations between CAT-a elements that cause a concrete Ci without superfluous repetition, while filling-in concrete cells, rows have a priority over columns (filling-in is performed row-by-row regarding the type of influencing CAT-a elements represented by, so that each concrete row-cell is filled-in respecting legislative hierarchy as well (from the "left" to the "right")).

2 Next to the mark of concrete problem cause (Ci), corresponding CAT-a elements affected by are shown in brackets in the form of [X_1, X_2...↔Y_1, Y_2...], where concrete "Xi" refers to article (also paragraph and/or item, if any) of

ID		Formulation	
Problems P_i	$P_{1\text{-}a}$	When CHSs are significantly larger, the operator's obligation to constantly maintain visual contact with UAV/UAS during flight might cause a necessity that he/she permanently change the station points (if possible) and/or to adjust the vehicle's speed to conform with the speed of his/her own movement (regardless of the fact whether activities are pre-planned/programmed or not). That will cause a decrease of EFT by decreasing EFC (of the flight itself) with regard to UTC. Based on the mentioned EFT/EFC consequences, when UAV/UAS is used for surveying, it is absurd to negatively burden the flight realization by respecting the mentioned legislative obligation, especially due to the fact that camera is already present and, among others, used to control the flight.	C_1
	$P_{1\text{-}b}$	In case of reduction of the previously approved flight-date/period (of the requested surveying) due to an appearance of adverse meteorological/other circumstances that make impossible to fly securely or to respect photogrammetric-wise limitations (that refer to proper lighting and shooting conditions that must be satisfied during each uninterrupted in-field photogrammetric activity-phase), to realize planned surveying by achieving EFT declared acceptable at all, it is necessary to increase the number of UAV/UAS (namely, USC and UEC). But, such an increase significantly increases necessary out-of-field activities of administrative nature (one UAV/UAS – one application – one fee).	
	$P_{2\text{-}a}$	Bearing in mind the fact that it is not allowed to have a category 2 UAV/UAS fly over people, when needed to perform surveying in region IV, it is necessary to use a category 1 UAV/UAS. Due to generally poorer vehicle and surveillance equipment performances of such replacement, FLA would increase consequently – causing actually the UTC increase.	C_2
	$P_{2\text{-}b}$	In cases when the problem $P_{2\text{-}a}$ occurs, to maintain the desired level of EFT/EFC of planned surveying, it is necessary to use more than one UAV/UAS of category 1 that consequently generates not only higher UEC, but USC also – together with inevitably arisen out-of-field activities of administrative nature that, in return, induce additional UTC increase (one UAV/UAS – one application – one fee).	
	P_3	Given that CHSs can often be found at distances less than 500m away from buildings of state/local interest, foreign diplomatic missions as well as significant infrastructure and other facilities (having in mind that these objects can also be targets of UAV/UAS surveying activities by themselves), the achieved EFT/EFC of corresponding surveying may consequently be either significantly decreased by means of UTC (namely by means of unnecessary time spent for the formulating, submitting and obtaining of all of the given approvals separately, especially when that is not possible to realize it online) or reduced to zero (in case of rejection by one or more involving authorities).	C_3
	$P_{4\text{-}a}$	When it is needed to fly and/or survey in conditionally prohibited zones, getting permits/approvals (by relevant authorities) is more complex, and often takes longer (especially because of MOI). Accordingly, although requests for their issuing must be submitted not later than 15 days prior to planned flight or series of flights (which may take up to 30 days), it happens more often than not that the approval is obtained immediately before the expiration of the signed date/period. In such case, the overall EFT decreases, because flight(s) can usually be realized incompletely, so as the dominant causing problem actually is the overall EFC decrease (caused by the decrease of UEC and USC from the one side and also UTC from the other side by means of not only time-wasting but time necessary to restart complete out-of-filed procedures of administrative nature from the very beginning).	C_4
	$P_{4\text{-}b}$	In cases a desired UAV/UAS surveying needs to be realized – when approval(s) is (are) obtained just before the end of the required and permitted date/period of flight-time (in situations when it happens more often than not), in order to maintain the initially expected level of EFT/EFC at any cost, the problem of the occurred UTC (by means of unnecessary time-waste) needs to be compensated by the usage of more UAV/UAS.	
	P_5	When various adverse meteorological conditions to take-off and survey safely occur (which happens are more often than not nowadays and are, unfortunately, long-lasting), if needed to realize at any cost the desired one or more locations-surveying in the period approved, it is necessary to use more than one UAV/UAS. Given that one flight-approval application form (issued by CAD) allows only one UAV/UAS to apply so as to operate on no more than 10 locations in a maximal 30-days period of time) in the mentioned case, the described will inevitably affect the overall EFT/EFC by increasing not only UEC and USC but UTC significantly (due to the increase of permission-related bureaucratic procedures which are necessary to initiate for each UAV/UAS separately).	C_5
	P_6	Waiting for the returning of the recorded material (after its controlling by the MOD) disables starting image processing immediately after finishing UAV/UAS surveying activities in CHS, representing, thus, UTC. Such decreasing of the achieved overall EFT/EFC from the aspect of UTC is especially an absurd circumstance in the modern era of digitalization in which software image manipulation is available to everyone.	C_6
	P_7	When CHSs are located within 1.5, namely, 5km away from ARP (depending on importance of airports or heliports), even for flights at altitudes less than 100m, getting the approvals for airspace allocation (by SMA) are also mandatory. But, if meteorological and other circumstances make the permitted UAV/UAS surveying partially or completely impossible (after receiving the allocation), its subsequent realization might also be questionable – but, this time, not only due to the same reasons, but to the fact that previously allocated airspace might be reserved for others. In such case, the overall EFT decreases, because flight(s) could usually be realized incompletely, so that the dominant causing problem actually is the overall EFC decrease (caused by the decrease of UEC and USC on one side and also UTC on the other side (by means of not only time-wasting but time necessary to restart complete out-of-filed procedures of administrative nature from the very beginning).	C_7
	P_8	With regard to an inevitable presence of significant concentration of people and their high movement frequency in limited/narrow public spaces of the Region IV, when legislation is strictly respected, UAV/UAS surveying in that region at altitudes less than those of an average human height, becomes questionable. Namely, in order to provide with certainty that horizontal distance from other people is to be less than 30/5m, it is necessary to increase the number of stuff members (as in-field controllers) and/or to utilize (and to assemble in-field) additional fence/boundary equipment (that, consequently, increases total time of the overall in-field activities). Although, in return, the described steps could disrupt public peace and order in some way, it seems they are inevitable (if REG-1 is strictly respected) besides that their implementation would decrease EFT/EFC of the overall UAV/UAS surveying – regarding USC, UEC and UTC. The said unnecessary resources consumption is a consequence of the vagueness of REG-1 caused by a non-considering the way the mentioned activities should be performed in general so as to be in line with LAW-2 (especially when restrictions of pedestrian movement are not applicable).	C_8
	$P_{9\text{-}a}$	Since the rest period has to be strictly respected, the use of a single UAV/UAS can negatively affect the overall surveying realization (by increasing the total duration of FLA) to the extent that its accomplishing becomes questionable (due to meteorological/other circumstances and the needs to respect photogrammetric-wise directives). When the flight(s) is (are) not realized completely/in one phase, the overall EFT consequently decreases so that the dominant causing problem actually becomes the overall EFC decrease (caused by the increase of UTC – not only by means of time-wasting but time necessary to restart complete out-of-filed procedure of administrative nature).	C_9
	$P_{9\text{-}b}$	When the problem marked as $P_{9\text{-}a}$ is present, and there is a need to realize UAV/UAS surveying at any cost, the solution is to increase the number of UAV/UAS (obviously, if it is reasonable regarding the volume of activities or CHS`s size). Due to the mentioned legislation-wise daily-time limitations, USC and UEC increases together with additional (inevitably arisen) out-of-field activities of administrative nature that refer to the UTC (one UAV/UAS – one application – one fee).	
	P_{10}	When CHS is physically inaccessible for a wide range of reasons so as the operator cannot maintain a permanent visual contact with UAV/UAS, if subject-related legislation is strictly respected, surveying activities cannot be realized. The operator must permanently maintain a visual contact with UAV/UAS during flight while surveying (and, thus, in the mentioned situation too) is an absurd, because the camera is already present on board and used not only to survey but to control the flight in general. To solve this "inaccessibility" problem and, thus, to realize desired UAV/UAS surveying by respecting targeted legislation, it is necessary to use additional equipment (regardless of the fact that this will decrease the overall EFT/EFC due to UEC).	C_1

Table 5. Concise formulation of previously localized Pi problems.
Table 6. Typology of the formulated problems Pi according to EFT/EFC characterization criteria described in the Chapter 4.

Quantity-wise problems-characterization criteria	ID		VAG	ABS	CON	INT	TLI	BUR
	USC (resources unnecessary used in listed activities)	PFA-out		$P_{1\text{-}b}$			$P_{9\text{-}b}$	$P_{2\text{-}b}$ $P_{4\text{-}b}$
		PFA-in	P_8	$P_{1\text{-}b}$			$P_{9\text{-}b}$	$P_{2\text{-}b}$ $P_{4\text{-}b}$
		FLA	P_8	$P_{1\text{-}b}$			$P_{9\text{-}b}$	$P_{2\text{-}b}$ $P_{4\text{-}b}$
	UEC (resources unnecessary used in listed activities)	PFA-out		$P_{1\text{-}b}$			$P_{9\text{-}b}$	$P_{2\text{-}b}$ $P_{4\text{-}b}$
		PFA-in	P_8	$P_{1\text{-}b}$ P_{10}			$P_{9\text{-}b}$	$P_{2\text{-}b}$ $P_{4\text{-}b}$
		FLA		$P_{1\text{-}b}$			$P_{9\text{-}b}$	$P_{2\text{-}a}$ $P_{2\text{-}b}$ $P_{4\text{-}b}$
	UTC (resources unnecessary used in listed activities)	PFA-out		$P_{1\text{-}b}$ P_6				$P_{1\text{-}b}$, $P_{2\text{-}b}$, P_3 $P_{4\text{-}a}$, $P_{4\text{-}b}$, P_5 P_6, P_7, $P_{9\text{-}b}$
		PFA-in	P_8	$P_{1\text{-}b}$			$P_{9\text{-}b}$	$P_{2\text{-}b}$ $P_{4\text{-}b}$
		FLA		$P_{1\text{-}a}$			$P_{9\text{-}a}$	$P_{2\text{-}a}$

Identified problems P_i		PFA-out	PFA-in	FLA
	$P_{1\text{-}a}$			One-time impact
	$P_{1\text{-}b}$	Four-times impact	Three-times impact	Two-times impact
	$P_{2\text{-}a}$			Two-times impact
	$P_{2\text{-}b}$	Three-times impact	Three-times impact	Two-times impact
	P_3	One-time impact		
	$P_{4\text{-}a}$	One-time impact		
	$P_{4\text{-}b}$	Three-times impact	Three-times impact	Two-times impact
	P_5	One-time impact		
	P_6	Two-times impact		
	P_7	One-time impact		
	P_8		Three-times impact	One-time impact
	$P_{9\text{-}a}$			One-time impact
	$P_{9\text{-}b}$	Three-times impact	Three-times impact	Two-times impact
	P_{10}		One-time impact	

Table 7. Occasioned relations between analysed CAT-b elements and problems Pi identified in CAT-a hierarchy.

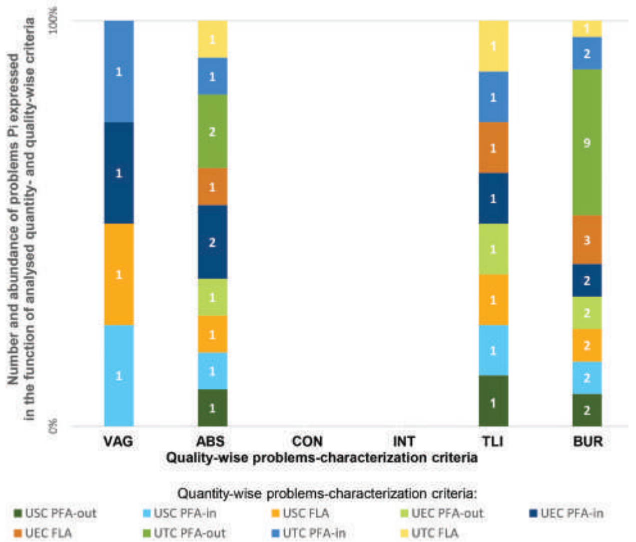

Chart 1. Number and abundance of problems Pi expressed in the function of analysed quantity- and quality-wise problems-characterization criteria.

corresponding law/bylaw which is listed in the left-positioned table-header, while a concrete "Yi" refers to an article (also paragraph and/or item, if any) of corresponding law/bylaw listed in top-positioned table-header). Mark "↔" represents identified relations between articles (also paragraph and/or items, if any) of corresponding CAT-a elements (laws and/or bylaws).

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Figure 4. Summary of the most important conclusion facts.

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ABSTRACT

In the survey activities that supervise the knowledge paths necessary for the acquisition of useful data for the subsequent intervention phases, we often come across emergency conditions, where the timeliness of operations is essential for the protection of the assets on which we are working. Where there is a degenerative process that evolves in slow or rapid times, it becomes essential to "photograph" and monitor the situation until the definition of the interventions that will be carried out to remedy the problem. The unpredictability of the possible evolution of events that cause emergency conditions requires rapid actions both in the detection phase and in the subsequent phases of problem analysis and definition of interventions. This contribution intends to document two experiences carried out on "fragile heritage", which in-volved the research group of the University of Basilicata, in support of local institutions to carry out surveys in the field in "extraordinary conditions".

Privileged documentary observations of surveying of "fragile heritage" in emergency conditions: the case studies of Pomarico landslide and of Montescaglioso abbey

1. Introduction

"La forte carica innovativa nelle procedure di rilevamento e nella restituzione dei dati riscontrati, che è la base delle ricerche, testimonia la continua capacità di rinnovamento di questo settore di studio, ma anche la volontà dei ricercatori di sperimentare metodologie di lavoro per un settore professionale in forte espansione finalizzato al recupero edilizio e al restauro dell'immenso Patrimonio costruito" (Maestri 2001, p.10).

This contribution starts from the aforementioned reflection which highlights the role of research, in the field of survey and representation, applied to the experimentation of technological instrumentation present on the professional market. The new frontiers in the theme of survey and graphic representation aimed at the knowledge and documentation of the built area allow the SSD ICAR / 17 to acquire a central role in the technical procedures related to the safeguarding of that historical architectural heritage. Particularly interesting is the case of "fragile" heritage which is often the subject of sudden degenerative actions (earthquakes, landslides, violent meteoric events, etc.) which are risky for the very existence of the heritage but also for its use. Where there is an emergency condition, it is necessary to intervene quickly and in particularly difficult conditions to document and monitor the situation, or to create the graphic and digital documentation necessary for planning the interventions that will be carried out to solve the problems. This paper documents two different cases where the ICAR / 17 research group of the University of Basilicata[1] was involved in field investigations in extraordinary conditions: the Abbey of Montescaglioso and the Pomarico landslide.

In the first case, the Superintendency of Archeology, Fine Arts and Landscape of Basilicata, following the completion of the restoration works of the Abbey of San Michele in Montescaglioso in the province of Matera, found an ongoing failure on the central drum of the dome requesting the timely intervention of the University to define the causes and ongoing problems. In this case an aerial photogrammetric survey was carried out, using the UAV (Unmanned Aerial Vehicle) piloted on sight. The visually imperceptible water infiltration problem required high-definition detection to pinpoint the lesions causing the problem.

The second case concerns a situation recently recounted in the national news, namely the landslide that hit, from 25 January 2019, part of the historic center of Pomarico in the province of Matera. This landslide instantly caused several collapses as well as damage to urban infrastructures and the load-bearing walls of houses and premises. The safety and monitoring operations of the sites were assigned to the command of the Matera Fire Brigade who needed scientific and technological support in order to define the situation. Also in this case, the research group of the University of Basilicata was involved in the data collection and analysis phases aimed at reading the hydrogeological instability in progress. The aerial photogrammetric survey was carried out using a UAV. The drone was flown over a great distance and the flight was programmated for automatic operation, due to the difficult site conditions and inaccessibility. The survey carried out and the subsequent monitoring operations allowed the creation of the three-dimensional model of the territory useful for the recognition of the landslide in progress and therefore for the identification of the instability.The documented experiences are the result of the research that has been carried out for years at the University of Basilicata concerning the experimentation of new technologies for the survey and documentation of the architectural, urban and environmental heritage. The particularity of the case studies is the emergency condition in which they worked, a very frequent case in a fragile territory such as that of Basilicata.

2. The Abbey of Montescaglioso (MT)

The city of Montescaglioso is located in Basilicata, on a hilly relief in the extreme central-eastern part of the province of Matera. It is bordered by the Bradano river, to the north-east by the Gravina stream and extends into the Fossa Bradanica. It is located, in fact, downstream of the Lucanian Apennine mountain range and at the western edge of the Adriatic Plate. Montescaglioso is an urbanized center located on three hills and is characterized by a vast area of countryside and woods that develops in extension around the settlement itself. The urbanized area, surrounded by walls and cliffs, is located at the top of a plateau identified by two valleys (Valle del Bradano and Valle del torrente Gravina).

Figure 1. View of the historic center of Montescaglioso.

To the south-east it is possible to see the sea of the Gulf of Taranto, to the east you can see the limestone of the Murgia and to the west the cities of Pomarico, Miglionico and Pisticci. The city has developed around the foundation of the Abbey, on the highest part of the hilly relief. Subsequently, urban development has also incorporated the hill to the north-east, with the complex of the Capuchin Fathers, and more recently also the lower part of the hill which is more fragile, less stable than that of the oldest settlements and the historic center. A historical knowledge, even if not in depth, has allowed an important critical activity, the reconstruction of the events and works carried out inside and outside the Abbey. This analysis allowed the profound knowledge of the Benedictine monastic complex of San Michele Arcangelo (1079), aimed at giving a possible answer to the problems of fragility. The problems present in the monastery required, in an emergency regime, a close collaboration between the Superintendence of Archeology, Fine Arts and Landscape of Basilicata (responsible: architect Annunziata Tataranno) and the DiCEM department of the University of Basilicata which made available a group small group of colleagues and researchers. The Montescaglioso Abbey is among the four largest complexes in Italy. Furthermore, the city of Montescaglioso is within the historical and natural archaeological area of the Park of the rock churches of Matera which, since 1993, has been a UNESCO heritage site with the *"Sassi di Matera"*.

Figure 2. Aerial photos taken by the drone.

Figure 3. Abbey of San Michele in Montescaglioso.

The foundation of the monastery dates back to the advent of Benedictine monasticism and, around 893 AD, through various events, donations, privileges and benefits, the possessions of the Abbey extended to large parts of the nearby territory of Metaponto, Stigliano and Gorgoglione. In 1099 the Abbey church itself was consecrated. The current configuration of the monastery is characterized by a central nucleus, consisting of the Church and two imposing cloisters, one medieval and the other Renaissance. Very precious is the part of the arcades, the cells and the ingenious rainwater collection systems that led to the construction of an important complex of regimentation and conservation of the water resource, divided into as many as 14 cisterns. The architecture of the monastery is also characterized by a refectory and a kitchen where the old large fireplace is located in the room. The underground complex of the excavated architecture of the cellars completes the incredible and hidden spatial dimension of the immense artifact. Remains of an imposing wall are present near the Schiavoni gate as a great support work for the slope that houses the terracing of the gardens and gardens of the monastery. The reading of the reliefs, critically recomposed, compared with those deposited at the Superintendency, was fundamental for the knowledge of the site and the architectural organism and specified the area for a preventive critical investigation and an important aid to support the logic of the intervention of an observation flight for an understanding of the causes of internal infiltrations at the top of the dome and along the walls of the drum. This operation of investigation and real critical knowledge did not require the production of plans, elevations and sections of relief, but had as its objective groped to represent the physical space, the architectural quality and the possible causes and transformations that recently they had involved the monastic complex and in particular the large roof which had recently undergone restoration. The inspection carried out on the site, followed by the draft flight plan, made it possible to understand the articulation of the complex and the identification and location of the damaged elements: we finally flew in search of possible clues. The survey with the drone was fundamental because it was very difficult to carry out an accurate direct survey on the dome which, otherwise, would have required the construction of new, complex and expensive temporary works (scaffolding). The drone flight helped to observe the state of the finishing surfaces of the dome, the lantern and the equipment of the tiles on the drum. The assumption of visual information and the processing of photogrammetric data have provided decisive information in the technical investigations aimed at defining subsequent interventions.

"Da qui emerge ancora una volta l'importanza del progetto di rilevamento, che deve costituire una specie di dichiarazione di intenti, creato prima di iniziare le operazioni di misurazione in cui sono individuate. I punti da rilevare e le metodologie di rilevamento" (Docci 2011, p.15).

For the case studied, in addition to making a video of the entire Abbey, a photogrammetric survey was carried out with a DJI Phantom 4 PRO drone, piloted on sight, equipped with a camera with a 20 Mpx CMOS 1 sensor. 154 high-definition (5472 X 3078 pixels) photographs of the dome were used, with a focal length of 24mm, useful for obtaining a photogrammetric model with

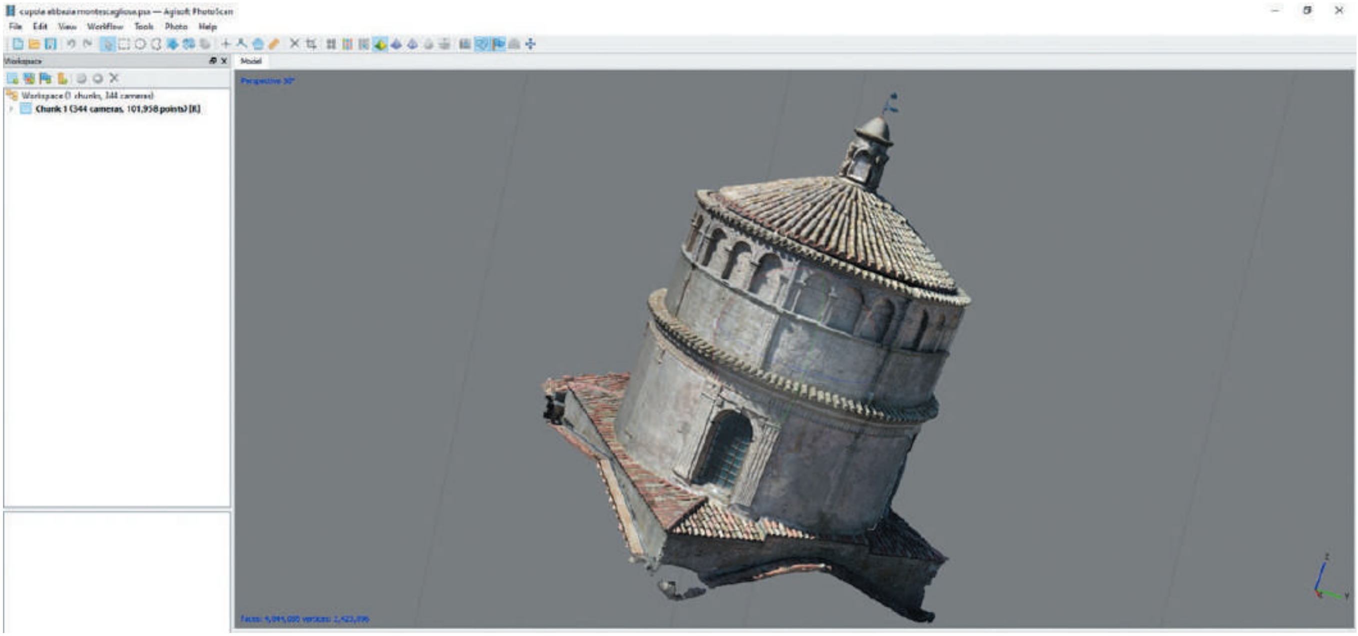

Figure 4. On the Cover: UAV Photogrammetry Application on dome.

sufficient definition to interpret the micro-cracks that caused water infiltrations.

3. The landslide of Pomarico (MT)

The second experience documented here concerns a more dramatic situation, namely that caused by a landslide that hit a part of the historic center of Pomarico in the province of Matera, on 25 January 2019. This sudden event, which instantly caused several collapses and damage to the urban infrastructure and homes, made it necessary to evacuate 30 families who resided in the buffer area delimited in the days following the event by security personnel and the Fire Brigade. The site's safety and monitoring operations were entrusted to the command of the Matera Fire Brigade who requested the scientific and technological support of the University of Basilicata, to investigate the situation. The problem of landslides is an aspect of great importance in the history of the region. There have been numerous landslides that have upset the area over the centuries and still represent a very topical issue today. The hydrogeological phenomena affecting the territory of the province of Matera are the most relevant and extensive. The town of Pomarico, which rises along a narrow sandy-clayey ridge oriented in a NW-SE direction between the Bradano river and the Basento river, is located in an area where the nature of the land is particularly unstable with very frequent hydrogeological instability. The origins of Pomarico are ancient. The instability of the territory on which it stands has always compromised urban evolution and often destroyed and transformed parts of the city. The landslides that affected Pomarico starting from the end of the 16th century destroyed the mother church, part of the castle and many inhabited houses. In 1658 three strong earthquakes caused the collapse of many houses. Geomorphological investigations and scientific

Figure 5. Dome lantern with identification of the crack.

studies show that the ridge on which the town develops is surrounded by numerous dormant landslides, already present in ancient times along the slopes of the town (De Marco, Di Pierro 1981). Following a period of heavy rain in 2019, the Pomarico landslide evolved between 25 and 29 January, along the southwestern side of the historic center. The landslide phenomenon was initiated by a natural mass movement also caused by neglect and ignorance and by the total absence of maintenance of the surface water management networks and the lack of stable principals / observers. The damage caused can be summarized in: - truncation of Corso Vittorio Emanuele, an important connecting artery; - damage to about one hundred real estate units, of which 18 collapsed, 12 damaged and 65 evacuated as a precaution. Based on the surveys and investigations carried out and on the reconstruction of the geomorphological evolution, the Pomarico landslide is attributable to an active and complex roto-translational flow-flow of earth (Sdao 2019). The total length of the landslide is over 760 m, with a variable width between 100 m of the sliding area and 150 m of the terminal portion of the *"Fosso Pezzillo"*. The study also made it possible to carefully analyze the architecture of the part of the historic city affected by the landslide. This conscientious work had, as an essential objective, a possible projection to the reconstruction, regeneration and urban and cultural resilience project. The landslide site retains an intrinsic potential and offers hope to transform itself into an urban part capable of transferring, on an ethical and operational level, a profound meaning of re-configuring the identity through a sustainable project. The entire area constitutes a part of the city to be reinterpreted, mended and rebuilt. In fact, it is characterized by a strong versatility, a fundamental aspect for the transformability and resilience of the city. The transformation project is presented as a "process" aimed at collecting and composing, in a new design, some fragments of the past, dispersed in the present, becoming the "urban facts" of a new theatrical scene in the city.

The involvement of the research group of the University of Basilicata[1] was necessary in the photogrammetric survey operations, in the data analysis and in the subsequent phase of interpretation and reading of the hydrogeological instability in progress. The photogrammetric survey was carried out using a UAV (Unmanned Aerial Vehicle) and, specifically, a DJI Phantom 4 PRO. 158 photographs taken in high definition (4864 X 3648 pixels) with a focal length of 24mm were used. Given the large extent and inaccessibility of the

Figure 6. Pomarico: drone photos before and after the landslide.

area affected by the landslide, it was necessary to proceed with a remote flight, previously programmed for automatic operation. The survey carried out and the subsequent monitoring operations allowed the creation of the three-dimensional model of the territory, useful for recognizing the landslide in progress and therefore for identifying the instability. The same research group is working on possible hypotheses of urban regeneration intervention in the area affected by the landslide.

"Questi strumenti tecnici, devono aiutare a proteggere l'integrità e l'autenticità del patrimonio urbano. Essi dovrebbero facilitare il riconoscimento dei valori e della diversità culturale, il monitoraggio e la gestione del cambiamento al fine di migliorare la qualità della vita e dello spazio urbano" (Bandarin, Van Oers 2014, p. 205).

Notes

[1] Working group: Antonio Conte, Antonio Bixio, Marianna Calia, Salvatore Manfreda, Silvano Dal Sasso, Roberto Blasi, Roberto Pedone.

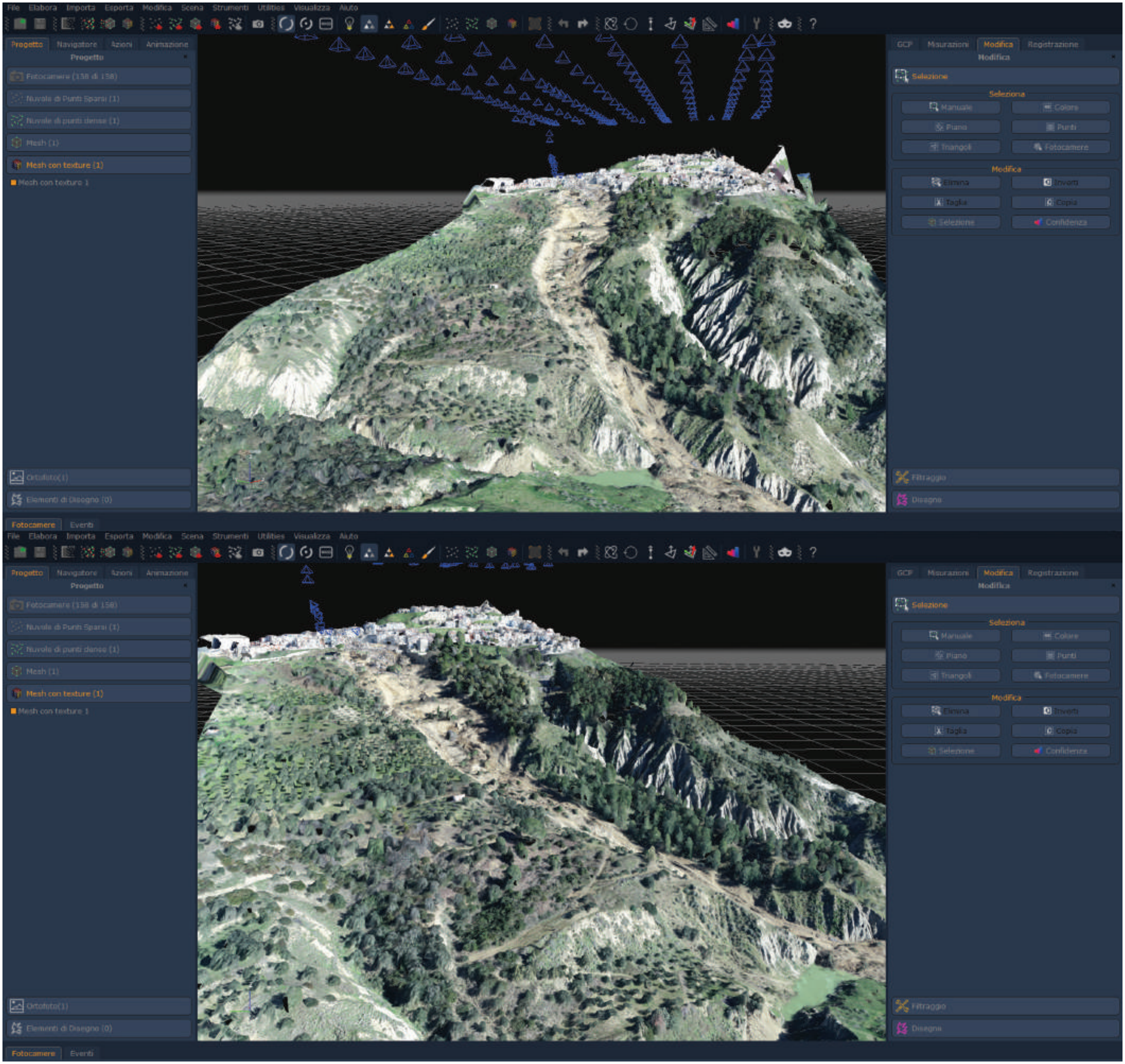

Figure 7. View of the photogrammetric model.

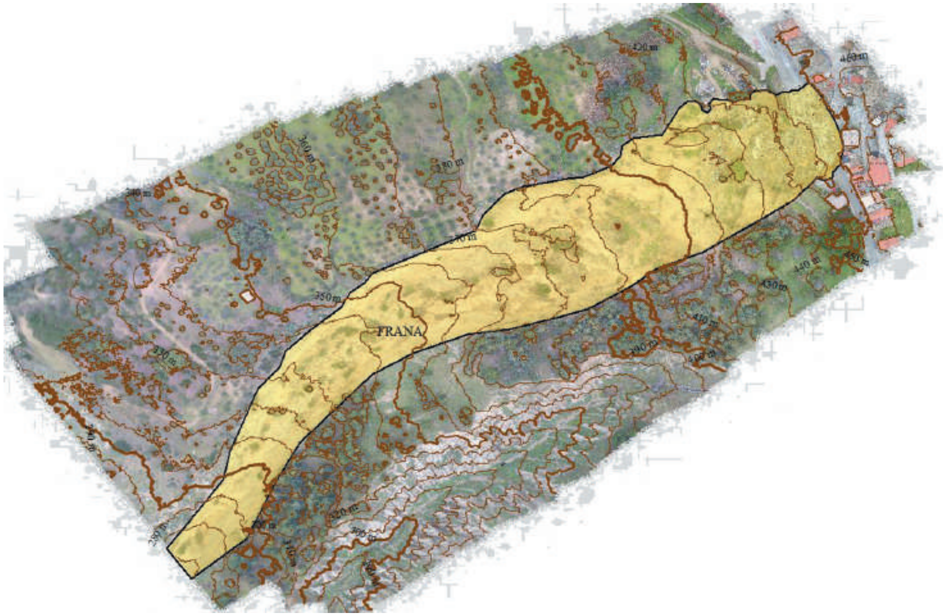

Figure 8. Post-Landslide rebuilt with drone DTM.

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Historical center in seismic areas, Integrated survey; Rubble survey; Virtual 3D Reconstruction, Cataloging procedure.

ABSTRACT

In recent years, since the 2009 and 2016 earthquakes, a number of procedures have been developed for damage assessment, post-earthquake management and recovery design. Very few, however, have investigated the study of a rigorous process for the virtual reconstruction of the pre-earthquake state. The proposed contribution, which analyses the case study of Arquata del Tronto, is inserted in this specific field, developing an original virtual reconstruction methodology, derived from the methodologies experimented in the archaeological field[1].

A methodology for survey, documentation and virtual reconstruction of historical centers in a seismic area: the case study of Arquata del Tronto

1. Premise

"On March 27, 2019, in the provisional premises of the Municipality, was the public presentation of the preliminary results of the studies towards a Manual of the recovery of the city of Arquata. It was an important, at times moving, moment. To see Arquata rebuilt in 3D, thanks to the skillful combination of old photos, maps, surveys, and cartographies stratified over time, gave all of us the feeling of being able to truly hope seeing our towns reconstructed".
The text, written by Nicoletta Tiliacos, journalist and representative of the association "Arquata futura", aptly describes the importance of a virtual reconstruction process, from the point of view of communication, I would dare to say social, even before methodology and as a study. To create a virtual reconstruction following a rigorous, objective and verified system, in line with recognized principles is not at all simple and requires integrated methodologies, procedures, and tools.
Geographic Information Systems (GIS) from perspective, represent the most suitable instruments to manage heterogeneous data (numerical and descriptive values, images, texts, links to other data, etc.) in a structured database[2], divided into two closely linked parts, which collect pre- and post- earthquake data over a much longer period, not simply limited to the immediacy of the seismic event. In the post-seismic phase, the survey procedures, through the use of data acquisition methods, integrated with each other, allow the various phases following the earthquake to be documented, including new collapses, demolitions, removal of debris, etc., and an enormous amount of data (tens of millions of points and mesh triangles), often difficult to read, to be obtained[3]. In the pre-seismic phase, the 3D modeling procedures, in the first instance, allow the 3D reconstruction of the phase immediately before the earthquake, and, subsequently, if documentation exists, the phases prior to that. Subsequently, the analysis of the buildings is detailed through the more specific study of the typology and of quality construction details, as well as the crack pattern, transformations, and anti-seismic devices, studies that contribute to the preparation of recovery manuals (Arrighetti, 2015, Brunori, Zampilli, 2021).

2. State of the art

The importance of three-dimensional modeling of the data, referring to both the state after and the one before the earthquake, has been recognized for some time. Since the publication, in 2008 and 2010, of the Guidelines of the Ministero per i Beni e le Attività Culturali e per il Turismo (Ministry for Heritage, Cultural Activities, and Tourism), in which some directives are established regarding the procedures to be adopted for buildings affected by seismic[4] events particular emphasis is given to the three-dimensional restitution of the organization, (from the survey of the post-seismic state to the virtual reconstruction of the pre-seismic state), which, "although complex, would certainly have been useful for a restoration project". (Mibact 2010, p.16)".
In some studies, following the 2009 L'Aquila earthquake, the use of "a multi-scaled container" was proposed

(Mingucci, 2010, p. 143)[5], where, starting from the 3D survey model of the post-seismic state, emergencies are cataloged as a function of structural analysis and restoration (Buttolo, 2011, p. 513). The studies aimed at a critical analysis of the structure have a similar approach, through the procedures and methodologies of the archeology of architecture, in which the data acquired on site are collected by filing and recording the vertical surfaces using photogrammetry and 3D survey models. Architecture (Gilento, Parenti, Vecchi, 2010, p. 16-17)[6]. In this vein, in 2015, a relatively new discipline, Archeoseismology, developed an investigative methodology that analyzes, in its various historical transformations, the constructive actions on a building and the destructive ones, due to seismic events[7] and, in 2018, some studies have focused their attention on

Figure 1. Arquata del Tronto: photo, taken before 2016, showing the village still standing from the east and, behind it, Arquata Castle. (by M.D'Angelico)

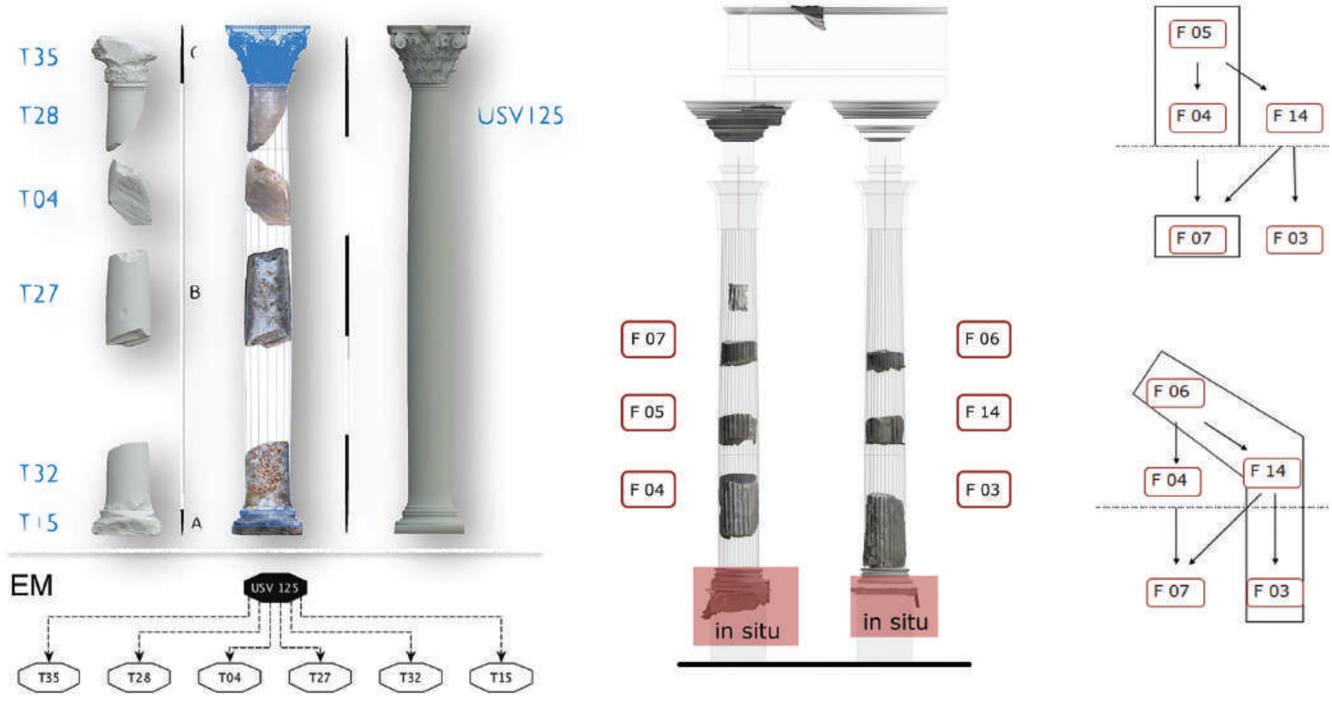

Figure 2. Virtual reconstruction according to the Extended Matrix. Scheme of a column, in which the fragments (T15, T32, T27, ...) are connected to the Virtual Stratigraphic Unit (USV125) (Demetrescu, 2021). Right, Virtual reconstruction of the Arch of Titus at the Circus Maximus. (M. Canciani et Alii, 2018) Schematic related to a geometric 3D model of a pair of columns with their repositioned fragments (F03, F04, F05 ...). (by M. Canciani, M. Pastor)

virtual reconstruction processes of archaeological sites that use an analysis of the virtual stratigraphic units (VSM), represented by 3D volumes, thus extending the usual Harris matrix to the volumetric consistency of the individual elements (extended matrix) (Demetrescu 2021, p.3)[8].

Remaining in the scope of virtual reconstructions, the research conducted by (Giannetti, Donato 2017) adopted a system that permits going through a process of reverse modeling (reverse engineering) and best-fitting algorithms, from a quantitative model, consisting of a triangulated mesh (the post-seismic survey), to a qualitative parametric model, generated by a logical sequence of mathematical/geometric operations (the virtual pre-seismic reconstruction). Beginning with these studies and the methodologies adopted, involving the use of information systems and 3D models of the current (survey) and of the pre-existing (virtual reconstruction) state, connected to each other, our interdisciplinary research group, composed of experts in the field of survey and representation, mathematics, history, and restoration, has carried out various experiences on archaeological sites, such as the Arch of Titus at the Circus Maximus (Canciani, Falcolini, Pastor, Saccone, 2018), and in the historic centers affected by earthquakes, such as in Retrosi in 2017, a district of Amatrice (Canciani et al.2017), and in Vezzano.

3. Methodology

The experiences cited have allowed the development of a survey model, used in the case study of Arquata del Tronto, based on a GIS system and the 3D models connected to it, consisting of seven steps, corresponding to seven different phases of the project.

1. the gathering of cartography via a GIS, in which the individual cadastral parcels and buildings are identified, constituting the basic information unit and to which specific data, documentation, iconography, historical photos, etc. are associated, relating to the pre- and post-seismic;
2. the acquisition of survey data, carried out with commonly used methods, which use drone photogrammetry (UAV) and acquisition via 3D laser scanner (TLS), integrated with each other[9];
3. the generation of square mesh models, useful in the architectural reconstruction of sections and simplified volumetric models;
4. the generation of mesh models derived from the photogrammetric rendering of photographs or videos acquired by UAVs prior to the earthquake and the superimposition of this with the survey models;
5. the virtual 3D reconstruction of the pre-seismic state of the entire urban center, subdivided by road layouts, land and green areas, and buildings, individually modeled, using the quadrangular models and the previously elaborated sections, as well as advanced modeling techniques (Photomatch and camera tracking) and original algorithms (best section); the detailed architectural elements (roofing elements, portals and windows, frames and rafters) are organized according to parametric models, inserted in an abacus, common to all buildings;
6. the modeling of the "normal state", aimed at the restoration project of this phase;
7. the final elaboration of images and videos, using advanced procedures for graphic rendering and aimed at documenting and communicating the virtual reconstruction process, starting from the survey of the actual state.

4. Case Study: Arquata del Tronto

4.1. Arquata del Tronto

The urban center of Arquata del Tronto, the provincial capital, which is the case study of this contribution, stretches along a slight ridge in the upper valley of the Tronto, where the Sibillini mountains meet those of Laga[10], in an extraordinary geographical location, which has always been a focus center for commercial and political exchanges, near the ancient Roman consular of Salaria, and on the border between the Kingdom

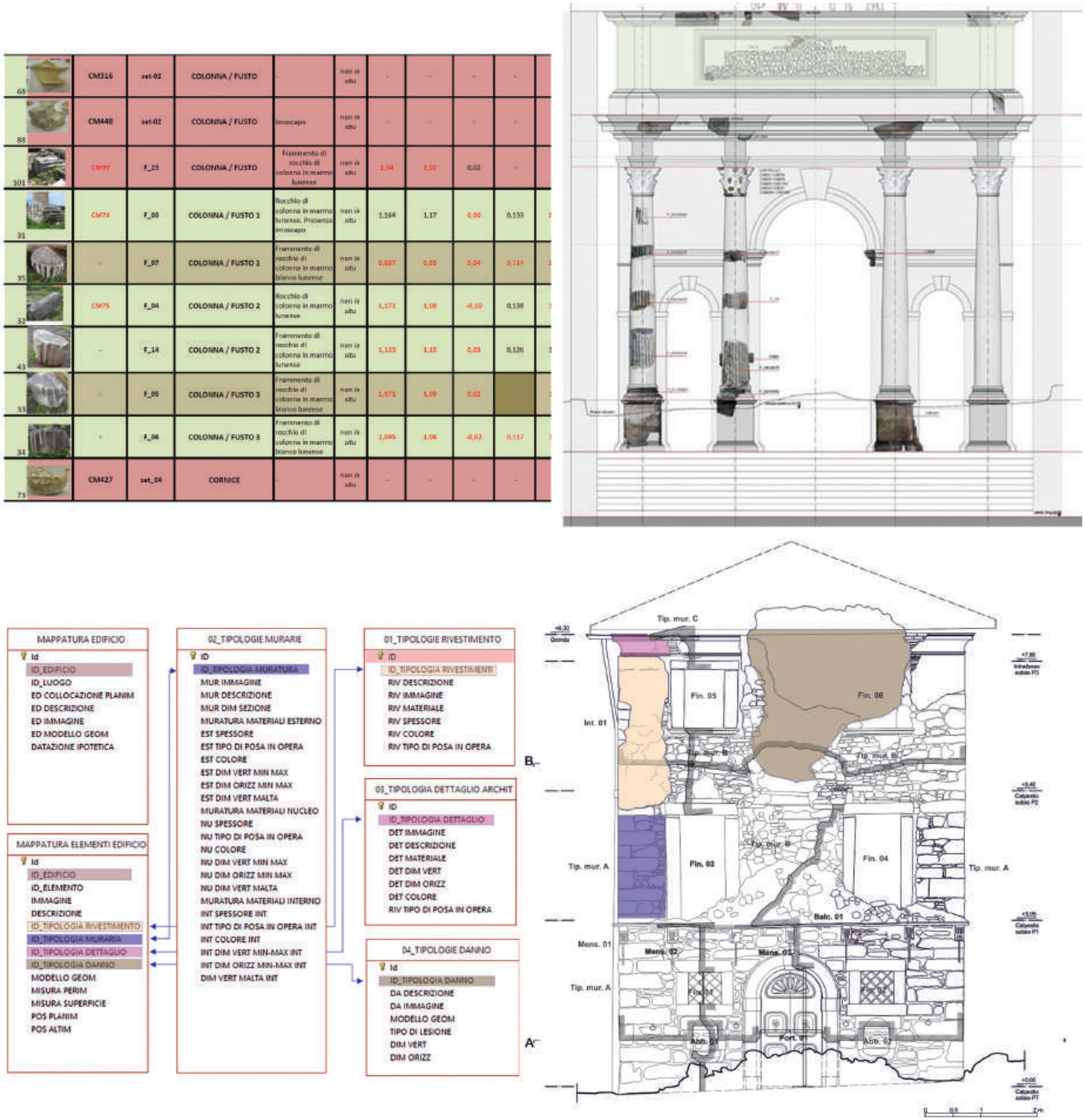

Figure 3. Virtual reconstruction of the architectural order of the Arch of Titus at the Circus Maximus. The fragments (CM1150, CM1151,...) are linked to the metadata of the database and to the 3d model of the elements (attic, entablature, ...) to which they refer. (by M. Canciani, M. Pastor)
Below. Virtual recomposition of a building in Retrosi, Municipality of Amatrice (M. Canciani et Alii, 2017), realized through the definition of post- and pre-earthquake elements, linked to data and metadata. (by M. Canciani)

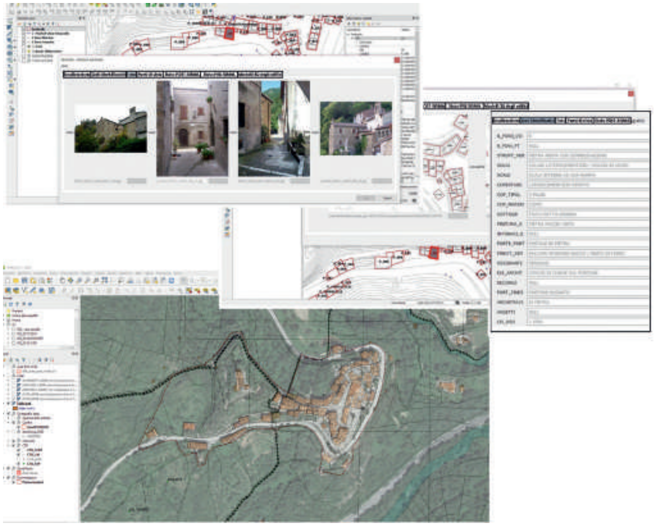

Figure 4. Above Arquata del Tronto: through the GIS system, data and metadata are geolocated, referring to the pre- and post-earthquake status of each single building. (by M. Michelini)

of Naples and the Papal State. The settlement already developed beginning in the Roman era, with a fabric of rural courtyard houses which gradually consolidated, in medieval times, to form a more compact fabric of terraced houses. The buildings of the castle and the tower in the square date back to that period and were then incorporated into the town hall in the nineteenth century, whose profile represents the very emblem of the city. In August and October 2016, the center of Arquata del Tronto was severely struck by two seismic events that caused extensive damage to the buildings, the complete collapse of almost all the buildings in the eastern section around the square, including the tower, and partial damage to buildings in the western section, including the Church of the Santissima Maria Annunziata. In the aftermath of the first emergency phases, the municipal administration of Arquata immediately endeavored to involve the universities in the processes of reconstruction, and, in this context, the Department of Architecture of Roma Tre University, directed by Elisabetta Pallottino, together with an interdisciplinary work group, the development preparatory studies were proposed for the reconstruction of the historic centers of the municipality and the drafting of a recovery manual[11]. In March 2019, these studies were presented to the associations of the city of Arquata, its inhabitants and administrators, as stated above. Of these, this contribution describes the procedures dedicated to the virtual 3D reconstruction of the building, carried out according to the methodology described above, concerning: the structuring of a GIS, the survey of the post-earthquake state and the virtual reconstruction of the pre-earthquake state.

4.2. GIS and the survey of the pre- and post-seismic state

In the first phase, the collection and organization of the cartography was planned via GIS, in which the individual cadastral parcels and buildings were identified, to which multimedia data were associated, relating to the state before and after the earthquake.
In the pre-seismic phase, mesh models were developed, derived from the photogrammetric processing of photographs or videos acquired by UAVs before the August 2016 quake, useful for obtaining approximate models to be superimposed on the models derived from the survey. Subsequently, the data relating to the survey of the phases following the first quake (August 2016), the second quake (November 2016) and the debris removal (April 2018) were acquired. Subsequently, the quad mesh survey models were generated, for the reconstruction of sections and simplified volumetric models. The mesh models were then processed, derived from the photogrammetric restitution of photographs or videos acquired by UAVs before the earthquake.
In this phase, the data acquired by a Terrestrial Laser Scanning (TLS), the model 5010X produced by Z+F[12] were processed and, through the known procedures of data acquisition by laser scanner and the processing of the point cloud[13], it was possible to obtain an

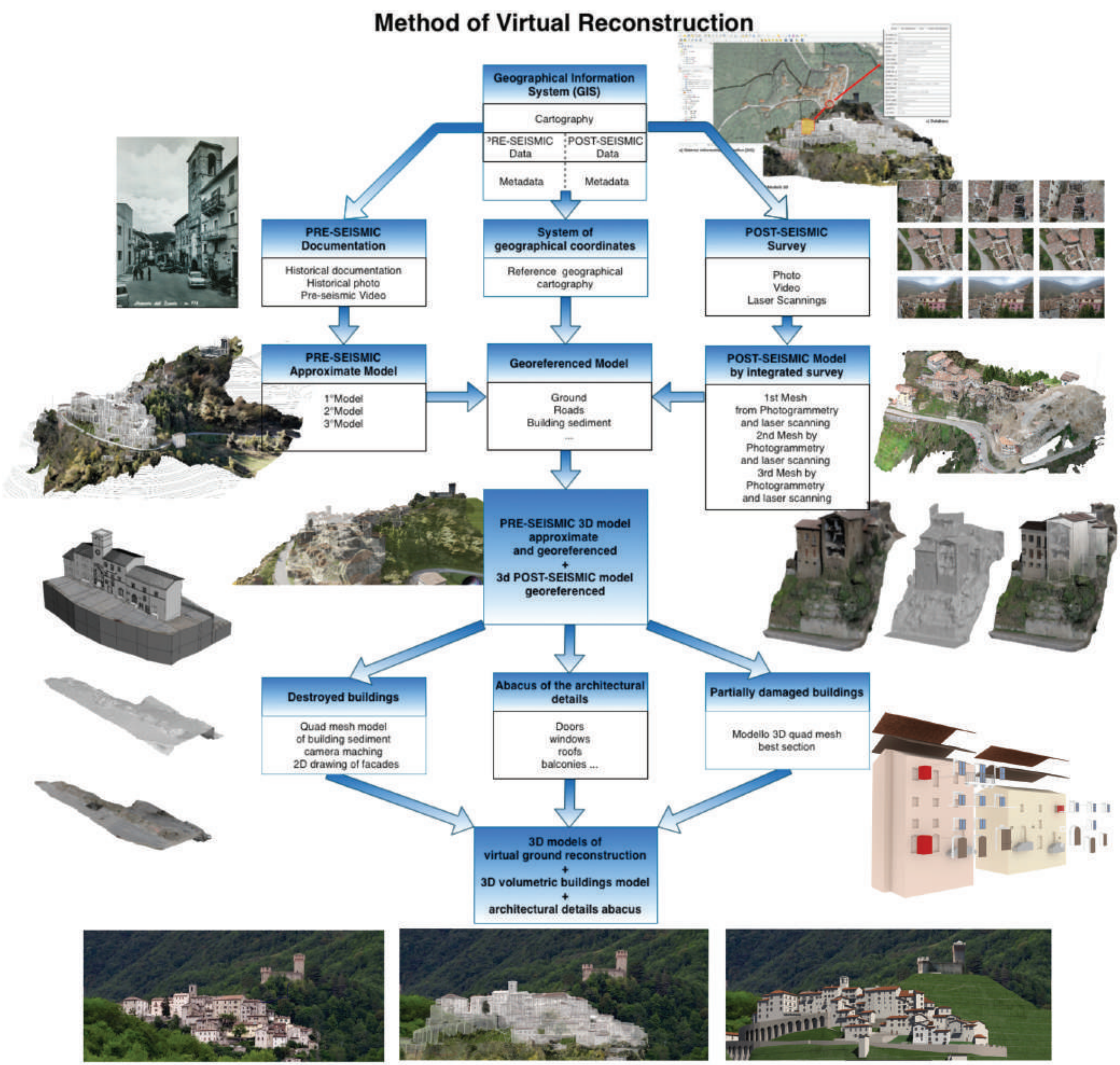

Figure 5. Diagram of the virtual reconstruction system used for Arquata del Tronto. (by M. Canciani)

Figure 6. Above, 2 frames of a pre-seismic flight (July 2016) and 2 frames of a flight after the first seismic shock (August 2016) (by M. Canciani). Below, volumetric model of the pre-seismic situation (August 2016). (by M. D'Angelico)

Figure 7. Above, 2 frames of a second-seismic shock (November 2016) and 2 frames of a flight after the debris removal (April 2018) (by M. Canciani).Below, volumetric model of the post-seismic situation (April 2018). (by M. D'Angelico)

extremely detailed final product, with a resolution of 6 mm. at 10 m. per pixel, georeferenced according to the adopted reference system and at a scale of 1:1, composed of a total of approximately 77,524,000 million points. The images acquired by means of an Unmanned Aircraft Vehicle (UAV)[14] in January and April 2018 were processed by digital photogrammetry software (Metashape) using Structure From Motion (SFM)[15] procedures, and, from this, a dense cloud was derived, georeferenced according to the adopted reference system and composed of approximately 16,490,000 points, and a mesh model of 9,755,000 triangles, endowed with the actual colour, together with an orthomosaic of 25,800 px. x 24,800 px. with a Ground Sample Distance (GSD) of 9.7 mm/px.

In the final phase, the two overall TLS and UAV clouds were aligned and recorded using dedicated software (3DReshaper, Recap Pro and Cloud Compare), together with those of the pre-earthquake state, in order to have

Figure 8. Arquata del Tronto: photo insertion of pre-seismic model (August 2016). (by M. D'Angelico)

a three-dimensional space, from which it was possible to extract various metric data (height differences, altimetric slm elevations, longimetric dimensions, etc.).

4.3. Virtual pre-seismic reconstruction: advanced modeling techniques

The virtual reconstruction of the pre-seismic state, which is inspired by the methods of virtual anastylosis applied in archaeological contexts, described above, was carried out through complex procedures that involved the volumetric modeling of the building and the definition of architectural details selected from a library of objects, which completed the model and constituted a common abacus for all buildings. The virtual reconstruction of each individual building and its modeling was defined through two distinct procedures, regarding the partially damaged buildings and those completely collapsed. For the former, the 3D model, derived from the survey, was used to extract a quad mesh, that is a quadrangular mesh, on which a composition of simple and regularized volumetric elements was elaborated. For the buildings completely destroyed by the earthquake, for which there was no post-seismic data, excepting the sediment, the photogrammetric correcting procedure (software Ortho 3.04) of historical or recent photos (street view) was used, to determine the main elements of the

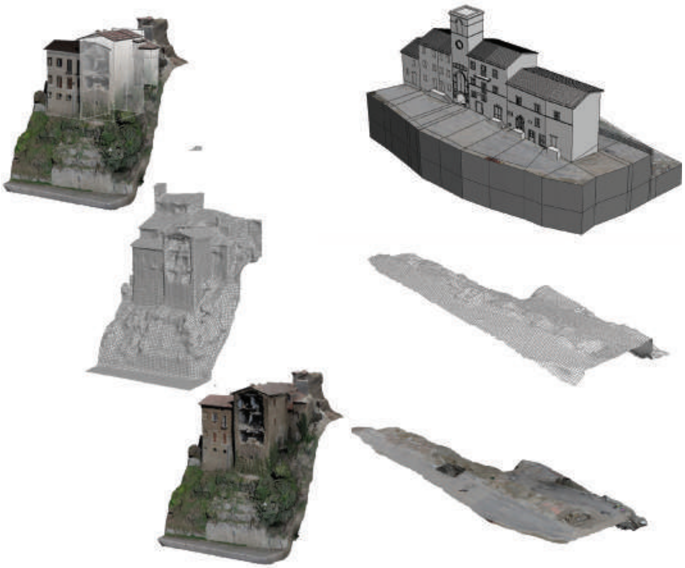

Figure 9. Arquata del Tronto: reconstruction method according to partially damaged and destroyed buildings. (by M. D'Angelico)

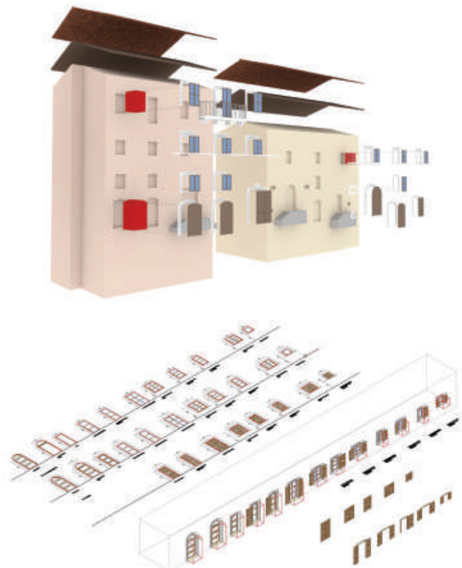

Figure 10. Arquata del Tronto: definition of an abacus relating to the various elements of architectural detail. (by M. D'Angelico)

Figure 11. Arquata del Tronto: camera matching techniques for the reconstruction of buildings. (by M. D'Angelico)

Figure 12. Arquata del Tronto: virtual reconstruction. (by M. D'Angelico)

Figure 13. Arquata del Tronto: virtual reconstructions with photo-insertion. (by M. D'Angelico)

elevations[16] and the Photomatch procedure in the 3D Studio Max[17]. A more in-depth study concerned the architectural emergencies, into which the main and characterizing elements were inserted, such as the Church, the Civic Tower, the Town Hall, and the Rocca di Arquata. The three-dimensional model was subsequently detailed, through the creation of an "abacus", composed of more specific architectural elements, divided according to type, such as windows, portals, cornices[18]. A separate study was carried out for the pitches, roofs, eaves projections, ridgelines, chimneys, and tiles, using semi-automatic procedures, which define the various elements in detail, based on a specific surface of the pitch[19].

5. Conclusions

Virtual reconstruction, as evidenced from direct experience, is not a simple academic exercise in representation and modeling, closed in and of itself. Instead, it represents the ideal support from which to start the development of a restoration project based on objective data. Plus, it represents an indispensable tool to develop, on the one hand, the analyses for the comprehension of the original characteristics of partially damaged and recoverable buildings, and, on the other, to safeguard, through virtual representation, the historical memory of severely damaged or destroyed buildings (Birrozzi, Zampilli 2020, p. 71).

Notes

1 This contribution is the result of joint work by the two authors. Marco Canciani is responsible for the chapters: premise, chapters 1, 2, 3, 4a, 4b and Conclusions. M. D'Angelico is responsible for chapter 4c.

2 Regarding GIS systems (Geographical Information System) we refer to specific texts reported in the Bibliography.

3 The conditions in the field render the survey arduous. References, which generally direct and subtend the construction of the architecture and thus also its survey (planes parallel to the floors and walls), are often lacking. The architectures show serious cracks and collapses, which alter their shape, often difficult to read, yet, at the same time, the damaged structures that remain visible, make the constructive characteristics evident, in response to the earthquake. (Buttolo 2011, p.514).

4 The MIBAC directives concerned the procedures to be adopted for the analysis and comprehension of the buildings and their response

to the stresses due to the earthquake, starting from the identification, classification, and characterization of the constructive and structural characteristics of the walls, the presence of anti-seismic devices, and of the crack pattern, to proceed in to the historical analysis, to the geometric and material relief, and to the state of conservation (Mibact 2010, p.16).

5 In these studies, following the 2009 L'Aquila earthquake, the use of a "multiscale container" is proposed, where, starting from the 3D survey model of the post-earthquake state, emergencies are catalogued in function of structural analysis and restoration.

6 A similar approach is adopted for studies aimed at the critical analysis of the artefact, using the procedures and methodologies of Architectural Archaeology, in which the data acquired on site are collected by means of filing and recording the vertical surfaces through photogrammetry and 3D survey models.

7 As Andrea Arrighetti writes, "Among the elements that most help in defining the construction history of architectural structures found in seismic risk areas, there are all those destructive (collapses, disruptions, cracks, surface deformations, etc.) and constructive (post-seismic restorations, construction elements implemented to mitigate and reduce the mechanisms of damage, etc.) strictly related to the historical seismicity of the study context" (ARRIGHETTI 2015 p.42). Precisely concerning the detailed analyzes on buildings, the possibility of having survey tools available that allow highly precise evaluation of the deformations of the surfaces of the buildings (for example bulges or overhang) represents a non-negligible strong point (Arrighetti 2015 p.112)

8 In this system to which the normally adopted elements of the wall stratigraphic units (USM) are added the elements relating to the virtual stratigraphic units (VSM) and the 3D models associated with them. In the process of the virtual reconstruction of 3D models, starting from the survey model to arrive at 3D reconstruction models of several historical phases, a sort of "white box" is defined, in which the processes used, and the products obtained are clearly defined.

9 This methodology permits the acquisition in a short time of a considerable amount of data, consisting of point clouds and 3D triangulated meshes, derived from the alignment of UAV and TLS data, georeferenced according to GIS and with information coverage of the object both from above and below.

10 Administrative center of a municipality composed of thirteen districts.

11 Programmatic Agreement between the Municipality of Arquata del Tronto and the Department of Architecture (DARC) of the University of Roma Tre, concerning "Research, study and design hypotheses for the reconstruction, recovery, and valorization of the historic centers of the Municipality of Arquata del Tronto, Director prof. Michele Zampilli. For the GIS, the survey, and the virtual reconstruction, director prof. M. Canciani. Work-group: M. D'Angelico, Manuela Michelini, Giuseppe Fioravanti, Francesca Laganà, Maria Pastor Altaba.

12 The scanner used is the model 5010X produced by Z+F, supplied by the Laboratory of Surveying and Digital Techniques of Roma Tre. Main features of the instrument: possibility of managing acquisitions via tablet and of recording clouds on site; GPS system and gyroscope for georeferenced positioning; measurement accuracy up to 2 mm. at 10 m.; acquisition speed up to 1,000,000 points per second; integrated colour data acquisition; time-of-flight technology (TOF).

13 The various data processing phases of the TLS refer to: the alignment/recording of the different scans, in order to determine the correct reciprocal positioning, first for three points and then with a mathematical algorithm (Iterative Closest Point), for all the points in common between the two clouds; the cleaning of the cloud, the elimination of noise and incongruent data; the georeferencing, which allows to rotate the complex of the clouds in order to correspond with the reference system (through the Recap and Autocad software, integrated between them).

14 A similar approach is adopted for studies aimed at the critical analysis of the artefact, using the procedures and methodologies of Architectural Archaeology, in which the data acquired on site are collected by means of filing and recording the vertical surfaces through photogrammetry and 3D survey models.

15 The software used, Metashape by Agisoft, using Structure from Motion (SFM) photogrammetry techniques, allows the following to be determined in successive stages: - camera calibration to obtain more accurate internal orientation data (focal distance, sensor size and projection of the lens centre onto it, lens distortion) the calibration of the camera to obtain more accurate internal orientation data (focal distance, size of the sensor and projection on it of the centre of the lenses, lens distortions); the alignment of several images with a relative overlap of 70%-80%, from which a sparse cloud of points common to several images is obtained; the definition of a dense cloud, which is constructed by the software on the basis of the estimated positions of cameras and the sampling of the images themselves; the generation of a 3D triangulated mesh on the basis of the dense cloud; the projection of a texture, based on the photos, onto the mesh; the generation of an orthomosaic. See K. KRAUS 2007; F. REMONDINO, S. EL-HAKIM (2006), Image-based 3D modelling: a review and the Metashape handbook.

16 The photogrammetric straightening procedure was systematically used, returning all the elevations of the buildings making up

the historic center in vector format, on the basis of the correct proportion between height and width, derived from the restitution. For greater precision and reliability, the investigations obtained were compared and verified, by juxtaposing it to the acquired data (3D survey models, photographic straightening, and metadata acquired via geo browser).
Once the main measures of the façade plan had been defined, it was possible to continue to a more detailed scale. Starting from the survey mesh model, on which the models relative to the historical phases prior to the earthquake are superimposed, the models were exported in .obj format into the three-dimensional modeling software, 3D Studio Max.

17 This methodology applied to the architectural survey makes it possible to draw a prospect directly on the photographic reference inserted in the 3D model, which may be used when only one image is available.

18 The windows, whose main parameters and detail elements are defined (room width and height, number of doors, shutters, frames, thresholds, and element subtracted from the architectural volume); the portals of the buildings, with architrave or arch, frame, door; other particular elements, such as overhanging balconies, iron railings, cornices, angles, stone elements, and decorations.

19 As far as the definition of the roofs is concerned, we worked starting from the plan drawing, based on orthophotos displaying the eaves and ridgelines, the grooves, and ridges (compluvium), and the overhangs. To define the slope of the pitches, it was necessary to extract some data, such as the upper 3D polyline of the volumetric model and the one that defines the perimeter of the pitches (eaves, ridges, lateral edges, or intersections), the line of maximum slope, which defines the gradient of the aquifer, obtained from sections of the models of the pre- and post-earthquake phases. The construction lines of the roof were built with the use of the trim and extend functionality for the different paths of the pitches.
Once the volume of the roof was defined by the eaves, ridge, maximum slope, and groove lines, using a semi-automatic procedure, the architectural elements such as tiles, chimneys, and dormers were inserted.

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ABSTRACT

The presented research focuses on the experimentation of advanced remote sensing techniques and protocols for surveying railway masonry arch bridges to assess their geological risk. Indeed, the integration between terrestrial laser scanning (TLS) and Unmanned Aerial Vehicle (UAV) digital photogrammetry techniques is tested and verified. The aim is to investigate and relate the geometrical structural survey of the masonry bridge with the main geological characteristics of the site to provide helpful information about bridges and their potential hydrogeological risk.

As case study we chose a masonry arch railway bridge belonging to Ferrovia Circumetnea, a still-in-service narrow-gauge railway that almost encircles Mount Etna, Sicily. The advantages and disadvantages of the proposed approaches are examined and highlighted.

Integration of remote surveying methodologies for geological risk assessment of masonry arch bridges

1. Introduction

Railway infrastructure represents a key node for the connection throughout territories as well as a fragile asset due to all the potential risks (i.e. seismic, hydrogeological) to which it is exposed. Masonry arch bridges are a crucial part of this linear infrastructure crossing valleys and rivers, and their main location in geomorphologically binding sites, makes them particularly vulnerable.
To ensure the safety of these assets, a multidisciplinary and multiscale approach that analyzes bridges in relation to their context is required. However, accurate masonry bridge inspections are in several cases difficult, time-consuming, and expensive, further require trained and skillful operators.
Moreover, in situ geological and structural experimental investigations are needed, as well as a detailed geometrical survey of both the bridge and the geological area under study. On the latter issue, the successful use of drones for outdoor applications is even more increasing due to the cost-effectiveness and speed of acquisitions. In the case of masonry bridges, UAVs combined with other digital acquisition systems are becoming increasingly popular, although there are still many critical topics.
The debate mainly refers to the accuracy achievable by UAVs numerical models comparing the results obtained with other digital survey techniques with the aim of a suited data integration. Indeed, among the critical factors for the proper documentation of artifacts, there is the reliability of data obtained to get a colored point cloud (Dell'Amico, 2020; Parrinello et al., 2019).
The presented research focuses on using and implementing advanced remote sensing techniques and protocols. Indeed, terrestrial laser scanning (TLS) and Unmanned Aerial Vehicle (UAV) digital photogrammetry are integrated. The aim is to investigate and relate the geometrical structural survey of the masonry bridge with the main geological characteristics of the site to provide helpful information about bridges and their potential hydrogeological risk.
As case study, we chose a masonry arch railway bridge belonging to Ferrovia Circumetnea, a still-in-service narrow-gauge railway that almost encircles Mount Etna. The advantages and disadvantages of the proposed approaches are examined and highlighted.
The paper is structured as follows: after a brief overview of the state of the art, the methodology, materials and methods are introduced; then the case study is presented and analyzed according to a multiscale approach from the territory to the bridge; following the results of the comparison between the two different techniques are discussed; then, conclusions and future developments are drawn.

2 State of art

2.1 Remote sensing in bridge surveying

The safety and efficiency of masonry bridges need to be guaranteed due to the crucial role these infrastructure assets play in the transportation system. Moreover, as representative of a traditional way of building, masonry bridges are characterized by high fragility and require special attention. Any preventive action, as mainte-

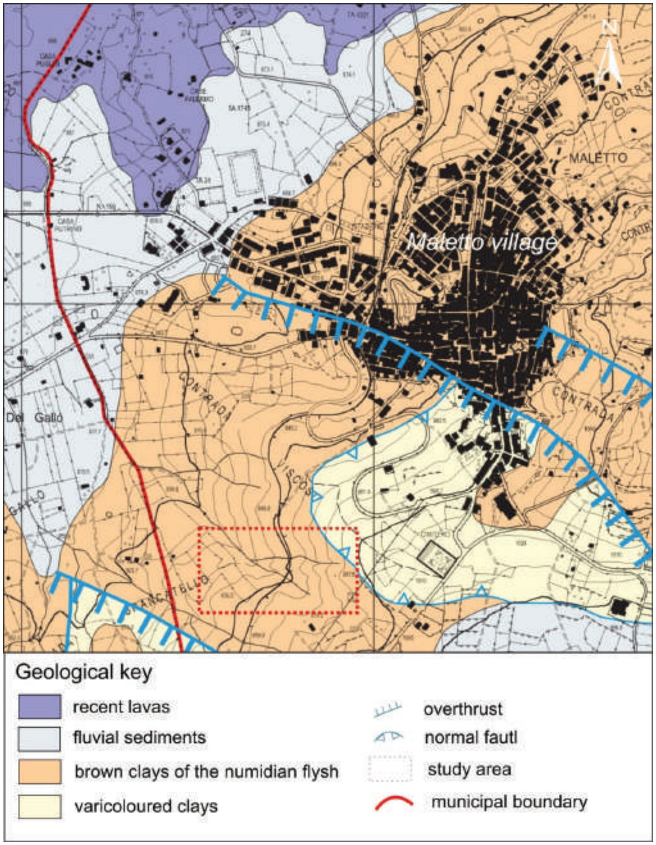

Figure 2. Geological-structural map of the Maeletto village.

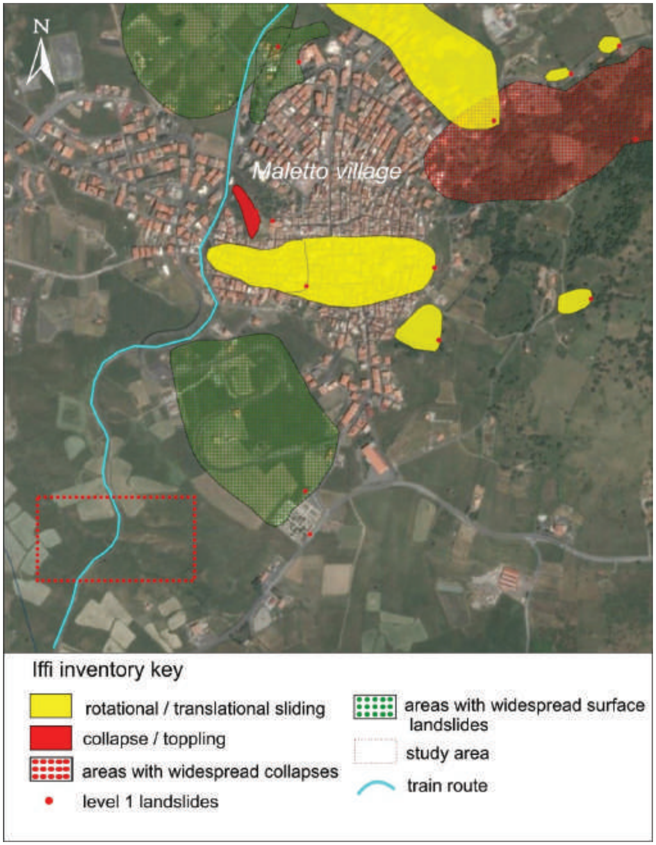

Figure 3. Satellite image of the village of Maletto with overlapping landslides mapped by the inventory of landslide phenomena in Italy (IFFI).

nance is, needs to be achieved as expeditiously, safely, and affordably as possible. Proactive conservation plans answer to the increased need of safeguarding the historical heritage, to mitigate the effects of endogenous and external hazards. Aiming at the digital acquisition of these structures and the creation of digital twins (Pepe et al., 2019), several NDT (Non-Destructive Testing) technologies could be used, such as terrestrial laser scanning, infrared thermography, 360-degree imaging, and unmanned aerial vehicles (Talebi et al., 2022). The 3D survey of masonry bridges is somewhat complex and may require the integration of terrestrial and aerial surveys. Aerial photogrammetry is a fast and relatively low-cost way to obtain 3D information to monitor Cultural Heritage assets, especially for difficult-to-proper-reach assets (Mongelli et al., 2017) (Micelli & Cascardi, 2020). However, it allows the acquisition of all the details of the upper part of the bridge; Instead, the lower parts, such as vaults, are more easily surveyed through a traditional terrestrial survey, as LIDAR.

An essential factor in using these technologies is ensuring the safe inspection and damage assessment of bridges (Mandirola et al., 2022). Such an approach is suitable in the aftermath of a disaster (e.g., after a seismic event) and routinely supports disaster risk reduction strategies toward resilient bridge infrastructures.

In (Biscarini et al., 2020), a multi-sensing approach is proposed to enhance the evaluation of structural and material degradation. UAV photogrammetric survey is used for visual inspection and 3D model reconstruction, while infrared thermography identifies ongoing material pathologies. The result of data integration obtained from the interdisciplinary investigations and the metric information derived from integrated instrumental surveys allow for the creation of HBrIM models with a high level of geometric detail (Marra et al., 2021).
Making accessible the obtained output to professionals and stakeholders involved in the intervention planning for maintenance and conservation is crucial. In (Fabbrocino et al., 2022), a virtual system integrating digital tools and online repositories has been set up to promote visual inspection operations to assess the state of artifacts and ensure data management. In addition to that, computer vision-based techniques have been developed to automate visual inspections integrating with (semi) autonomous drone surveillance to collect images for complete automation of simultaneous inspection and crack detection in railway bridges (Marin et al., 2021).

2.2 Drones in slope surveying

Slope instability problems are the most common and dangerous natural processes for linear infrastructures as highlighted by (Laimer, 2017). According to (Evans, 2005), railway are the most exposed infrastructures to geological risks compared to other linear structures (roads, motorways), as they require a balanced slope ratio and therefore run along slope sides or through valleys, where the exposition to landslide hazard is commonly high. In recent decades, remote sensing techniques have undergone rapid development in the engineering and geological sectors. In particular, the reconstruction of 3D models using photogrammetric techniques and terrestrial laser scanning surveys are widely used thanks to their speed and effectiveness in collecting and analyzing geomorphological and structural data. UAV allows the monitoring of wide areas and infrastructures in a very short time compared to conventional techniques and, above all, they allow reaching inaccessible places. Several authors, in recent years, have implemented photogrammetric techniques in the characterization of landslides. (Dewez et al., 2016) monitored a cliff over time, identifying the points of detachment along the rock mass, through the reconstruction of point clouds from both laser scanners and UAV techniques. (Mineo et al., 2021, 2022), through automatic and semi-automatic approaches, demonstrated that a remote rock mass survey can be conducted according to ISRM procedures even applied to 3D models of the slope. (Carrivick et al., 2016) described the importance and usefulness of structure-from-motion techniques in the geosciences, in particular (Fiorucci et al., 2018) focused their study on the use of remote sensing imagery for landslide mapping. Remote sensing-based datasets therefore represent a useful tool in the study of landslides, which cannot completely replace fieldwork, but in many cases can provide a significant contribution to their geometrical and mechanical characterization and, therefore, to their vulnerability assessment.

3. Materials and methods

The proposed methodological approach is characterized by a synergic combination of two remote sensing techniques: UAV photogrammetry and TLS. Due to their peculiarities, masonry bridges grafted in natural settings are the leading example of the importance in defining a combined operational surveying strategy.

In summary, the methodology is structured as follows:
• *Digital survey*
It is aimed at the acquisition of the geometrical and material configuration of the bridges and its context. This procedure is carried out by using TLS and UAV

• *Digital survey through TLS*
The use of laser scanners allows to return a metrically accurate survey in an expeditious way. In the case of masonry bridges, however, the main challenges can

be found in the limited access to different areas of the bridge, especially if bridges are over waterways or characterized by considerable spans and heights.

- *Digital survey through UAV*

Drone surveying is, in the field of architecture and infrastructure, an approach that makes it easy to detect objects in particularly harsh conditions. This may be the case with infrastructures such as bridges, which, especially large ones, are difficult to survey in their entirety with a single methodology.

- *Analysis of the results*

The results of the survey campaigns are analyzed and a comparison between the obtained point clouds is performed to assess the reliability of UAV data compared to the TLS one. The integration of the data also makes it possible to obtain a complete and well-defined point cloud of the bridge and the context under investigation.

- *3D modelling*

A 3D modelling approach allows to obtain a model suitable for evaluating hydrogeological vulnerabilities and conduct simulation and structural studies consistent with the proposed interdisciplinary approach.

4. Case study

The chosen case study is a masonry arch bridge located in the municipality of Maletto in the north side of the Etna Volcano (960 m on the sea) (Figure 1).
This bridge is part of the Circumetnea, the narrow-gauge railway built between 1889 and 1895 to support the economic dynamics of the agricultural and manufacturing sectors in the Etna area (Garozzo, Santagati 2021).
Bridges and tunnels along this route testify the theoretical knowledge and construction skills of the past, by using traditional local materials, such as lava stone.
The bridge under-investigation is located in a rural area not far from the town of Maletto in a morphologically unstable area due to the particular characteristics of the terrain. The structure crosses a natural impluvium, which, during winter floods, significantly increases the water content of the soils, causing a reduction in their physical and mechanical characteristics.

Figure 4. The Maletto bridge during the 2022 survey campaign.

4.1 Geology

The geological formations outcropping along the slope analyzed and shown on the geological map (Figure 2), are the Oligocene Varicolour Clays and the Upper-lower Oligocene Numidian Flysch Clays (Ogniben, 1960), (Lentini and Vezzani, 1978).
The contact between these two formations is of tectonic origin, caused by an overthrusting during the Upper Oligocene.
In addition to sedimentary ter-rains, Etna's eruptive products consisting of lava flows, pyroclastites, volcanoclastic products and fluvio-lacustrine alluvial deposits also crop out in the area. The tectonic structures show E-W, NE-SW and NNW-SSE directions, and should be attributed to distensive phenomena dating back to Pleistocene and still active, to which the main phenomena of areal erosion are clearly linked. This lithological and tectonic condition makes the slope subject to landslide phenomena, which

Figure 5. Point cloud obtained through TLS survey.

are very widespread in the area studied, as can also be seen in the catalogue of the IFFI inventory of landslide phenomena in Italy (Figure 3).

4.2 Geomorphology

The morphological characteristics of the area are conditioned by the nature of the different geological formations and the geo-tectonic evolution.

The study area is characterized by a hilly morphology with modest gradients and is affected by widespread landslides, (earth falls with slow kinematics and rotational movements).

Some of these landslides develop in tributaries, such as the one studied herein, causing partial damming of the normal water flow.

Another element that conditions and shapes the slopes is the surface water circulation, which causes diffuse erosion phenomena.

The bridge studied in this article crosses a natural impluvium affected by a gravitational phenomenon that interacts with the linear infrastructure. The causes of this phenomenon can be found in the soil saturation due to an increase in water content, which cohesion drop and an increase of pore water pressure, leading to a shear strength reduction (Cruden, 1996).

4.3 The Maletto Bridge

The analyzed bridge (Figure 4) consists of four depressed-arched barrel vaults. The span of all the vaults is equal to 8 meters, accordingly to the archival documentation found in the Circumetnea archives.

The width of the barrel, measured parallel to the abutments, is about 4,2 m.

The thickness of the brick vault is 60 cm, to which a 20 cm concrete layer is applied to support the placement of protective corrugated metal sheets. The spandrel walls are made using lava stone as well as the abutments.

This bridge follows the same design solution as two other ones on the Circumetnea route (located in Maletto and in Mascali municipality).

Figure 6. Point cloud obtained through UAV survey.

4.4 Digital survey

TLS survey

The survey activity for the 3D acquisition of the Maletto bridge was conducted in two different phases. The first experience took place in 2021 using the Leica BLK360 Imaging Laser Scanner (scan rate: 360.000 pts/sec, accuracy: 6mm at 10m / 8mm at 20m, ranges: up to 60 m, size: H 165mm, D 100mm, weight: 1 kg). Ten station points were set up to obtain a numerical model as complete as possible. Due to the presence of the landslide, it was possible just to partially survey the bridge. Indeed, just two of the four spans were clear out. The upper part of the bridge was not surveyed. The obtained numerical model is about 66,5 million points. The alignment error is equal to 0.007 m and the average overlapping is 44%. The second survey campaign was conducted in 2022, after Circumetnea carried out an excavation to clean the site from the previous landslide. Despite the new arrangement, it was impossible to perform a much larger number of scans, due to the presence of a water stream and clay soil. Again, ten scans were performed. The obtained numerical model is almost 250 million points (Figure 5).

UAV survey

The acquisition of photogrammetric data was carried out using a dji quadricopter equipped with a 20-megapixel optical sensor. Three different flight plans, manually controlled, were programmed to geometrically reconstruct the bridge structure in a detailed 3D numerical model. The acquisition positions were chosen according to an angle of view ranging from 0 to 45° plus a nadiral flight to acquire images of the upper part of the bridge. To have an accurate GSD, the offset distances were lower than 20m.
Moreover, oblique photographs were also taken with the camera tilted at -30° to capture hidden structural elements such as the arch bridge intrados, thus allowing achieving further details and characterizing the blind spots of the bridge. A further nadiral flight was carried out to reconstruct

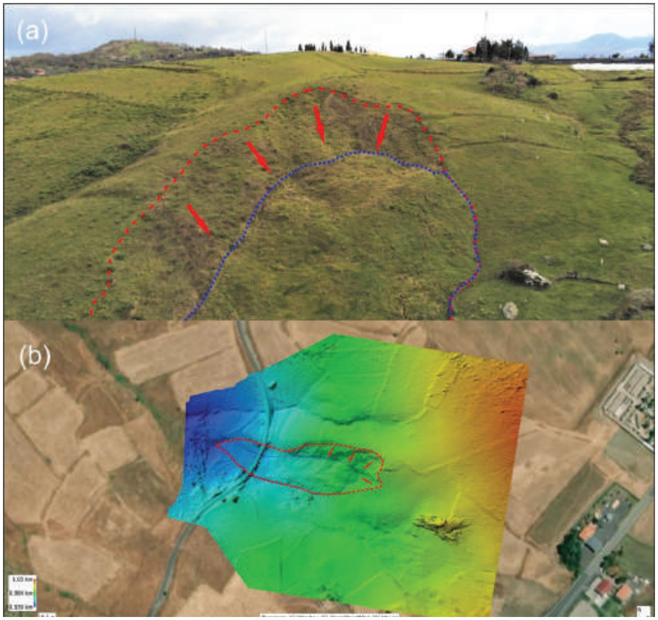

Figure 7. Aerial photo taken by drone of the partial detachment niche and respective landslide body (a), DEM digital elevation model of the study area, with geometric reconstruction of the entire landslide (b).

a geo-morphological model of the area affected by the landslide movement, which included the involved portion of the bridge. In the post-processing phase, the acquired images were combined to create two different dense point clouds using the structure from motion (SfM) technique as proposed by (Westoby et al., 2012) who used two-dimensional images acquired from multiple viewpoints, with at least 70% overlap between two adjacent frames, to de-fine a three-dimensional model of the framed subject.

The adopted SfM procedure produced two dense point clouds with different characteristics in terms of quality and quantity. The cloud (Figure 6) representing the single model of the bridge has a ground resolution of 4.28mm/pix and a total density of 63 million points. The second cloud allowed reconstructing the geometry of the landslide body; it has a ground resolution of 4.13 cm/pix and a density of 13 million points. From this cloud, a digital elevation model (DEM) with a resolution of 8 cm/pix and a high resolution orthomosaic were derived (Figure 7).

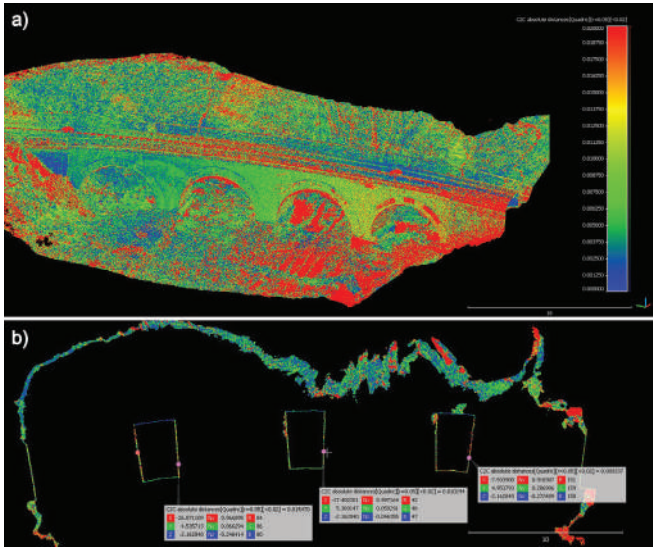

Figure 8. C2C analysis between UAV and BLK360 point clouds (a) C2C analyses of horizontal slices between UAV and BLK360 point clouds (b).

Comparison between TLS and UAV surveys

Three different point clouds were obtained from this research work: the first BLK point cloud with the landslide, the second BLK360 point cloud, after the earthworks, and the point cloud obtained through UAV survey. Excluding the first TLS campaign, which will be the subject of a future comparative analysis inherent in aspects more related to the landslide, some metric and visual analyses are proposed for comparative purposes, to evaluate the accuracy and the reliability of the TLS and UAV models. The comparison was performed with the open-source software CloudCompare, using the Cloud-to-Cloud algorithm (C2C), which allows measurement of the metric deviation between two clouds. The BLK360 point cloud was chosen as the reference cloud because it is characterized by higher accuracy. The comparison was performed by analyzing the global accuracy of the entire point cloud. The global comparison shows that most deviations range from 0 mm to 1,25 cm (blue and green points). Larger deviations (red points) occur where the drone point cloud is missing, especially at bridge spans. Figure 8 provides a blue/red color scale for the C2C analyses between the BLK360 and UAV point clouds.

Considerations on the integration of surveys

The survey of masonry bridges is particularly challenging, precisely because of the morphological characteristics of these structures. The integrated survey is often the best strategy for a restitution as accurate as possible. In the case of the bridge of Maletto, a hybrid strategy has been adopted. In the case of the bridge under investigation, it was not possible to achieve enough overlap between the clouds in both survey LIDAR campaigns to eventually make automatic alignments feasible. The use of the point cloud from drone, therefore, in addition to allowing the survey of parts that would otherwise be difficult to reach safely (such as the railroad), was used as a reference to perform the alignments between scans taken from camera points that were too far from each other. The point cloud obtained through aerial photogrammetry is very dense but has a lot of noise, especially at the arches. The cloud from laser scanner, on the other hand, the cloud is less dense but does not have the same noise issues.

5. Conclusions and future developments

In recent years, aerial photogrammetric surveys for the generation of 3D models have experienced a significant increase in scientific fields, due to major technological advances, including the development of the structure-from-motion technique and its implementation in almost fully automated processing software, as well as huge advances in the quality of optical sensors. The commercial accessibility of unmanned aerial vehicles and their increasingly advanced technology has made photogrammetry a valid alternative to TLS for small areas documentation and monitoring. In this research work, the integration of UAV and TLS techniques has been experimented. The comparison between the two point clouds demonstrated that the obtained results are comparable in terms of metric accuracy; as for points density, it is directly proportional to the parameters given for reconstruction in the SfM software. Furthermore, the geological and geomorphological survey in situ showed a widespread landslide resulting from the presence of arenaceous-clay lithologies associated with the presence of tectonic structures. Through the aerial photogrammetric survey, it was possible to reconstruct the geometry of the landslide body, which affects the central arches of the bridge, finally verifying whether this phenomenon may over time compromise the static nature of the bridge. Future works will take in consideration the possibility to integrate this survey with thermal analysis and IoT data (monitoring sensors) to create a Digital Twin of the bridge able to support all the diagnostic and intervention steps.

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ABSTRACT

The paper describes an efficient workflow wherein UAV photogrammetry is combined with other 3D survey techniques (terrestrial photogrammetry, laser scanning and total station) to provide compre-hensive documentation of a historical building. The output orthoimage of the tiled roof allowed high-lighting the covering damage state. The research aims to test and evaluate the feasibility of auto-matically mapping roof damage using an image classification procedure based on supervised ma-chine learning. The methodology was validated on a historical building, now suffering from a seri-ous state of neglect.

Aerial-photogrammetric survey for supervised classification and mapping of roof damages

1. Introduction

Unmanned aerial vehicles (UAVs) have wide-ranging applications in the Cultural Heritage field (Barba et al. 2020). The flexibility and ease-of-use of modern consumer devices allow the visual inspection and digital documentation of even difficult-to-access or dangerous areas by enabling remote image acquisition and close-range aerial photogrammetry (Ronchi et al 2020). Indeed, a consistent and comprehensive photogrammetric survey project ensures accurate metric restitutions to support conservation and maintenance activities. UAVs are also useful in an integrated survey approach, supplementing other 3D measurements that typically miss the roofing data. The paper proposes an efficient survey workflow where UAV photogrammetry complements other 3D survey techniques such as terrestrial photogrammetry, laser scanning and total station survey in the comprehensive documentation of a historical building. The specific focus of this paper is to test and evaluate on a selected case study a semi-automatically mapping of roof damages through automatic image classification based on supervised machine learning (Grilli et al. 2019, Russo et al. 2021). This methodology could easily be used for the maintenance of the built heritage, especially when the critical conditions of a building do not allow access to roof structures from below.

2. Case study

The selected case study is *Palazzo Littorio* in Caronno Pertusella (VA), a representative building that housed the local branch of the Italian National Fascist Party in Italy. After World War II, the building was used as a House of the People and then as a police station until it was closed and abandoned in the mid-80s, now showing serious signs of damage, particularly to the roof. The style of the building partly follows the dictates of Italian rationalism and partly the Art Nouveau style, especially the internal theatre space, and it presents two lateral additions to

Figure 1. Aerial photos of the case study: Palazzo Littorio (Caronno Pertusella - VA).

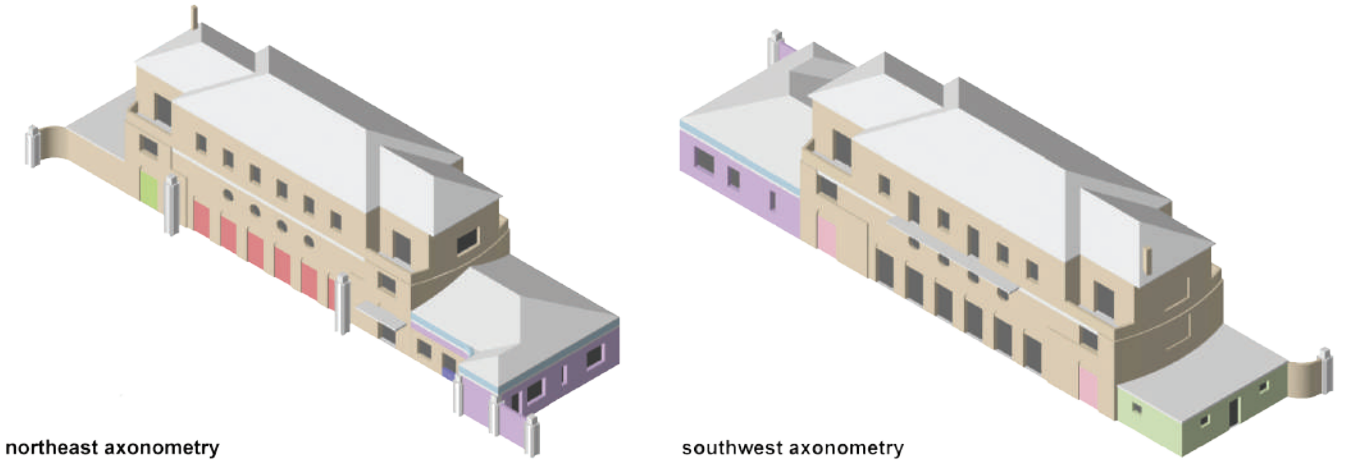

Figure 2. Schematic model of the Palazzo Littorio in Caronno Pertusella: main body in the middle, and the two 1-storey additions on either side of the main body. In green, the volume added to the east (bathrooms for the heliotherapy center), and in lilac, the one added to the west (after-hours club). The added volumes use the original surrounding wall and in red, in brilliant green and pink, the infills of the doors closed for safety reasons in different years.

the original volume that do not alter the impressiveness of the 3-storey central body, built-in 1930. The additions date only a few years after construction (Balin et al. 2021).

The building state of abandonment and degradation for over 30 years now necessitates intervention by the local administration to its preservation, reuse and valorization due to its location in the village center. The main problem of the building is the state of damage to the roof structures, especially in the area of the stairs, which makes an inspection from below too dangerous at the moment. Even in the absence of a definitive idea for reuse of the building, there is an urgent need to protect the existing roof structures, repairing provisionally the roof covering and so protecting the entire building from damages caused by water infiltration. The correct and detailed assessment of the state of preservation needs to be carried out in safety, and the use of the UAV is an ideal method to carry out an investigation that should not only be qualitative. The UAV also proves to be optimal for complementing surveys carried out with more traditional techniques from ground level, that inevitably leave undetectable areas.

3. Digital survey

An integrated digital survey based on range-based and image-based techniques was designed to comprehensively document this heritage building.

A TLS (Terrestrial Laser Scanner - Leica RTC3601) was used for the complete geometrical survey of the building exterior and interior. For creating 360° spherical panoramas, 3 HDR (High Dynamic Range) cameras allow for 5 bracketing exposures2. The VIS (Visual Inertial System) uses the other 5-cameras to track the laser scanner path. The integration of VIS and IMU platform enables real-time raw alignment between pairs of scans during on-site capturing. This raw registration ensures real-time control over the minimal needed overlap among scans and the completeness of surveyed areas. Therefore, the number and position of scans were planned ac-cording to a target-less acquisition mode. The survey consists of 84 scans (34 indoor) with a greater than 50% overlap to ensure proper cloud-to-cloud alignment to optimize the raw registration. The TLS acquisitions were generally set with a spatial sampling

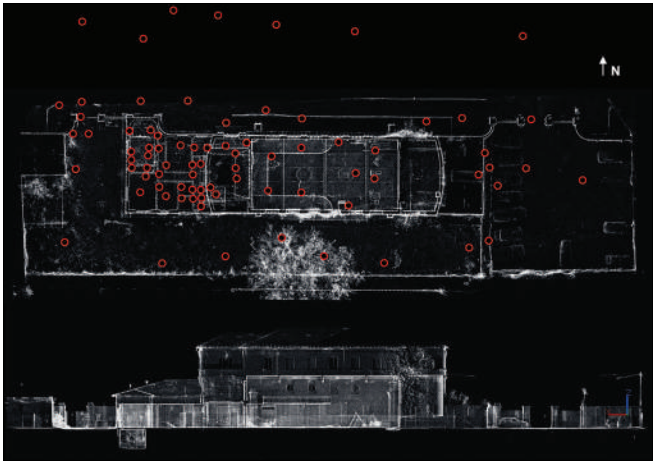

Figure 3. TLS scan stations and point cloud axial longitudinal section northward.

Figure 4. TLS panoramic images of the north facades and of theatre in the inner salon.

of 6mm@10m, ensuring the 1:50 graphic representation scale (1cm plotting error). The TLS workflow is performed according to the standard following steps: i) cleaning raw single scans, removing objects that can affect the ICP algorithm efficiency (moving automobiles, vegetation,

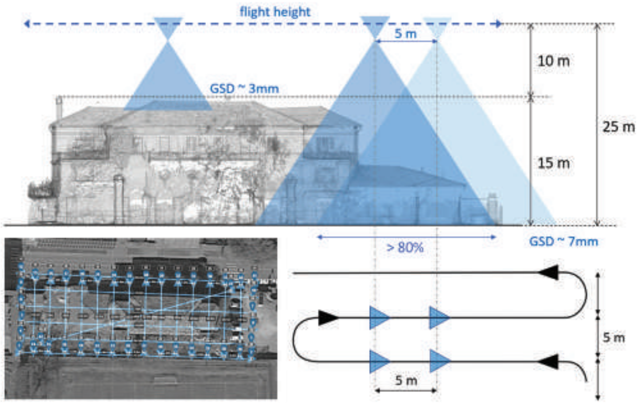

Figure 5. Aerial photogrammetric survey: GSD and overlap calculation and shot positions.

people, etc.); ii) scans alignment optimization; iii) in-deep individual scans filtering (removing noise, distant points and points measured with a sub-optimal incidence angle with the surface). The result is a measurable point cloud that represents the complete geometric model of the building.

The aerial photogrammetric survey was, on the other hand, essential for the roof measurement, which is the focus of this research.

The drone acquisitions were designed with 3 main goals: i) obtain an orthoimage of the tiled roof covering (1:50 scale); ii) quantify the extension and localization of the damage tiles; iii) integrate the terrestrial photogrammetry survey of the vertical facades with inclined shots. In addition, detailed photographic documentation was acquired to gather qualitative information on some critical areas. The instrumentation used is a Phantom 4 pro V.2 with an integrated camera of 8.8mm focal length and 2.6µm pixel size3. The flight mission was designed to meet the survey criterion (i): the flight height was set at 25m to ensure a 3mm GSD on the roof, and the distance among the photos was set at 5m to achieve more than 80% coverage on the ground level (overlap and sidelap).

The drone acquisition was supported and integrated by terrestrial photogrammetry, terrestrial laser scanning and total station measurements. A terrestrial photogrammetric acquisition was also carried out to produce orthoimages of the building facades, useful for materials and decay mapping (5mm GSD). The workflow follows the standard steps of the photogrammetric processing: i) images orientation by structure from motion; ii) tie points filtering and camera calibration optimization; iii) absolute orientation (scale and referencing in a local coordinate system); iv) dense image matching (dense cloud elaboration); v) mesh model creation; (vi) orthoimages generation.

4. Roof orthoimage classification

The drone images allowed an initial visual and qualitative inspection to understand the damage level and the possible risks of the roof elements. Together with the aerial photos, the roof orthoimage provided an overall view of the roof covering, combining these initial qualitative considerations with quantitative data such as the position and size of the most damaged areas and the most damaged roof tiles. It is noted that there are more tiles with holes to repair on the north pitch of the roof than on the south pitch. This identified critical area should always be kept under control during routine maintenance. The reason could be identified in the recent heavy hailstorms, as well as the low quality of the local clay tiles. This justification would also explain why several tile replacement works have been made over the years, as noted by the survey.

The tiles found are all of the interlocking tile typologies (*Marseillaise* tiles) with approximately 24x42 cm. With UAV survey, it was possible to identify 3 main categories of roof tiles. The 30s original clay tiles are very dark/black. The faded red roof tiles belong to the early 60s when the major change of use from the House of the People to the police station took place and to the later years for maintenance, now covered by a very variable grey patina dirt and biological growth. Lastly, the newer ones used during the last urgent repair works in 2020 have an intense red color, partly because they are cleaner.

These three roof tile types and the holes were detected and classified on the orthoimage thanks to an automatic

Figure 6. Roof photo of the north side towards the west corner before (left) and after (right) the urgent repair works in 2020. The 3-types of tiles are easily recognizable: the oldest dark ones, the new brilliant red ones and the other dull red ones.

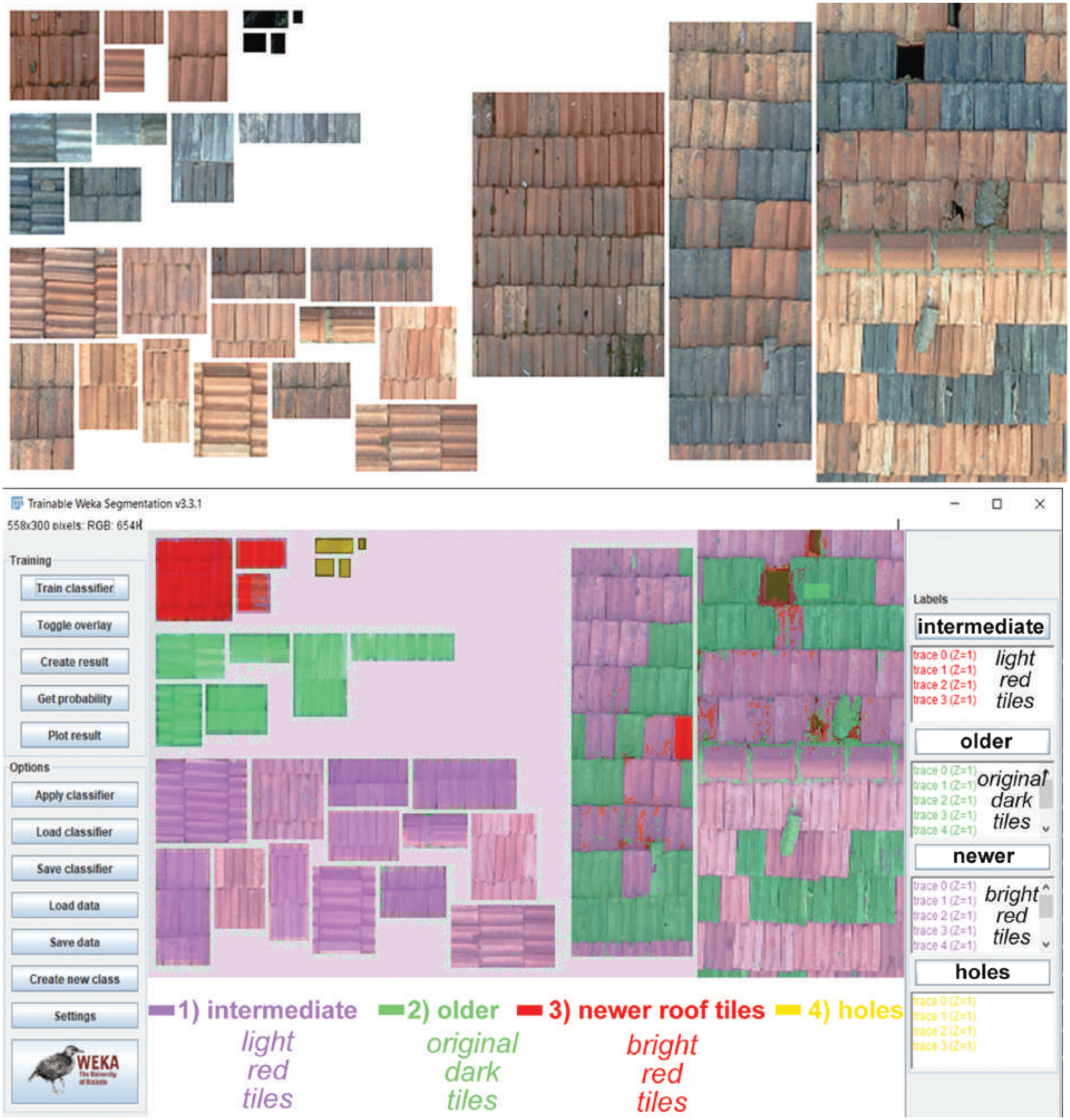

Figure 7. Mosaic composed of meaningful samples of the original orthoimage.

supervised procedure of an image segmentation system based on a trainable classifier (Grilli et al. 2018). Fiji4 (Schindelin et al. 2019), an open-source image analysis and processing software package that exploits WeKa5 (Frank et al. 2016) as an engine for machine learning models, was used for these experiments. An initial dataset of manually annotated images where the classes are defined is used to train the algorithm in a supervised way. In this case, for the classifier training, a mosaic composed of meaningful samples of the original orthoimage is used, where the following 4-classes are visible: 1) light red clay tiles - *intermediate* reference period between 1930 and 2020; 2) dark clay tiles - *older* original ones from 1930; 3) bright red clay tiles- *newer* of the latest 2020 repairs; and 4) *holes*. Each pixel in the image mosaic of the samples has been manually labelled with its corresponding class.

This solution was adopted to facilitate the computational capacity of the image-processing package. Indeed, the software supports images with a maximum resolution of 2 gigapixels, while the entire roof orthoimage has a 4662x1546 pixels resolution (1cm GSD). For the same reason, the orthoimage was than divided into 75 tiles of around 310x310 pixels, to be automatically classified as single images. Two python scripts were used to automatically divide the orthoimage into identical tiles and to automatically reassemble them after classification. In training the classifier, different sets of image feature parameters were computed and tested to identify the most effective ones in our case. Moreover, in order to assess the automatic procedure performance, the classification was also performed manually on the same orthoimage,

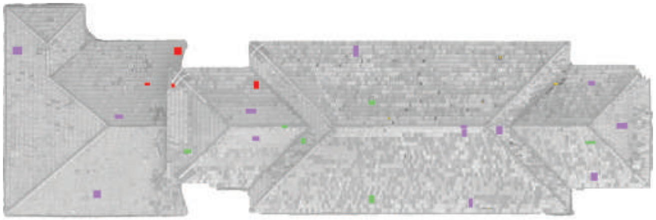

Figure 8. Position on the orthoimage of the chosen samples used for the classifier training.

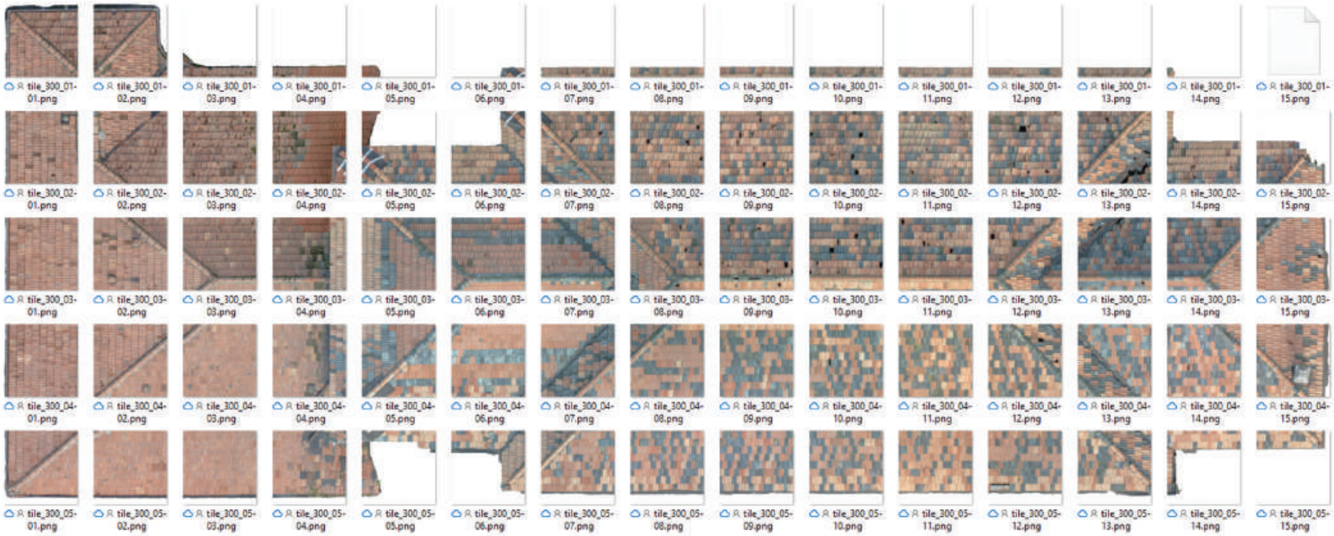

Figure 9. Orthoimage decomposition in 75 tiles (5 rows and 5 columns) of about 310x310 pixels resolution.

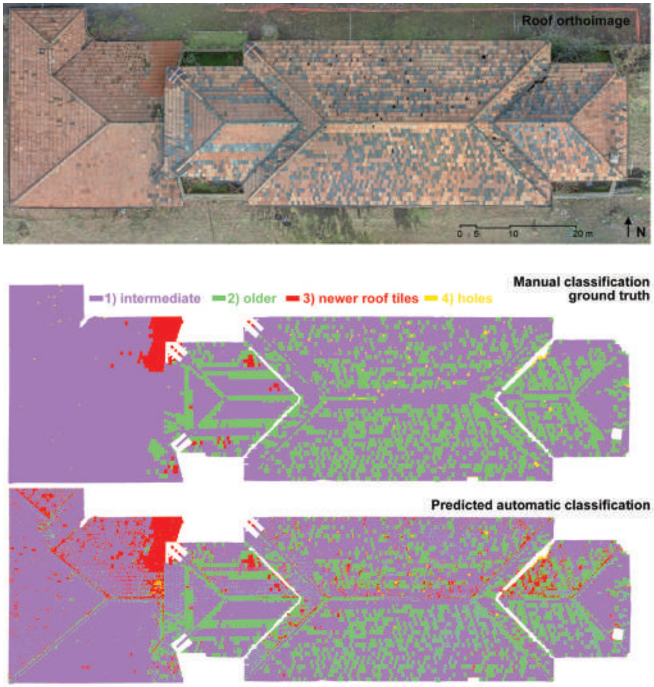

Figure 10. Original roof orthoimage and its segmentations (manual and automatic) in the chosen classes.

relying on the support of photos taken before and after the 2020 roof repairs and limited information from the municipality about maintenance works. The automatic classifier (Fast Random Forest) results were compared against this ground truth reference.

Comparing for each point the label provided by the classifier with the same manually annotated, for each class, true positives (TP), true negatives (TN), false positives (FP) and false negatives (FN) are determined at the pixel level and reported in a confusion matrix (Markoulidakis at al. 2021).

The TPs, i.e. the number of pixels that truly belong to a class, are reported on the diagonal; the FPs are in the columns, while the FNs are in the line. For example, 3.3% of the pixels classified as *newer* tiles are actually of the *intermediate* category. Simultaneously, 2.9% of pixels classed as *intermediate* should actually be in the *older* tile class.

In particular, the precision, recall and F1-score (Mohanchandra et al. 2015) calculated for each class were taken into consideration. The report with these data allows the following considerations. Precision and recall of the *intermediate* and *older* roof tile class are

confusion matrix (pixel numbers)		PREDICTIONS				TRUTH		
		intermediate	older	newer	holes	pixels	area [m^2]	tile numebers
TRUTH	intermediate (light red tiles)	3524826 66,8%	97432 1,8%	173661 3,3%	3138 0,1%	3799057	379,9	5836
TRUTH	older (original dark tiles)	155669 2,9%	1147038 21,7%	51888 1,0%	281 0,0%	1354876	135,5	2081
TRUTH	newer (bright red tiles)	9975 0,2%	97 0,0%	90839 1,7%	70 0,0%	100981	10,1	155
TRUTH	holes	3980 0,1%	2820 0,1%	5860 0,1%	11682 0,2%	24342	2,4	37
PREDICTIONS	pixels	3694450	1247387	322248	15171			
PREDICTIONS	area [m^2]	369,4	124,7	32,2	1,5			
PREDICTIONS	tile numebers	5675	1916	495	23			

	precision	recall	f1-score
intermediate (light red tiles)	95,4%	92,8%	94,1%
older (original dark tiles)	92,0%	84,7%	88,2%
newer (bright red tiles)	28,2%	90,0%	42,9%
holes	77,0%	48,0%	59,1%

$$Precision = \frac{TP}{TP + FP}$$

$$Recall = \frac{TP}{TP + FN}$$

$$F1 - score = 2\,\frac{Recal * Precision}{Recall + Precision}$$

Figure 11. On the upper part, there is the confusion matrix and related calculation of area and tile numbers for each class; on the bottom, the tab with the parameters for evaluating classifier reality.

very high; which means that the classifier is reliable for these classes. On the other hand, for examples, the precision of the *newer* tiles class is very low (~28%), which means that there are many FP, the majority of which are of the *intermediate* class; however, the recall is very high; meaning that there are few FN so that most of all new tiles have been identified correctly by the classifier, but many tiles of another class have ended up in this one. Finally, the precision of the *holes* class is acceptable (~77%); the majority of the holes have been correctly identified (few FP). Nevertheless, the recall is low (~48%), so many holes have not been identified and ended up in other classes (*older* class).

Therefore, this statistical data is helpful for both evaluating machine learning classifier performance and extracting practical information. Indeed, the sum along the lines of the confusion matrix gives us the number of pixels that belongs to that class according to the ground truth; while the sum on the columns is the number of pixels predicted by the classifier. From this information, it is possible to calculate the corresponding area and therefore the number of corresponding tiles for both true and predicted class. For example, the original tiles (1354876 real pixels and 369445 predicted) occupy an area of about 380m^2 and 370m^2 have been predicted. These values correspond to 6332 real tiles and 6157 predicted ones, with an error of about 10 tiles. The *holes* class is unquestionably one of the most significant, yet it also has the lowest recall. The classifier has predicted 1.5 m^2 of holes, but there were 2.4m^2 in total; therefore, 23 instead of 37 tiles to be replaced has been predicted. Future research will aim to improve the metrics used to classify these areas.

In summary, the workflow used consists of the following steps: 1) Orthoimage generation; 2) Identification of the classes; 3) Manual categories classification to create the ground truth; 4) Ad-hoc mosaic image creation with all classes visible, composed by orthoimage samples, used for the algorithm training; 5) Orthoimage splitting in equal tiles; 6) Automatic classification of all image-tiles; 7) Re-composition of the classified roof orthoimage; 8) Classifier validation; 8) metric useful information extraction.

Naturally, once the algorithm and the entire procedure have been validated, the same workflow can be applied to other case studies, omitting steps 3 and 8. Indeed, manual classification is a time-consuming process, and the research goal is to have the same results automatically.

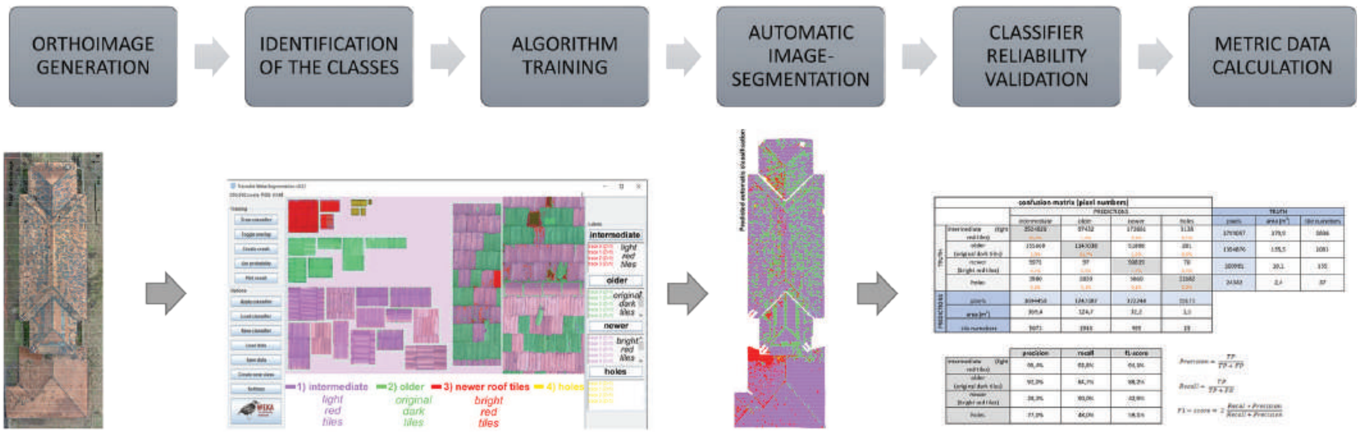

Figure 12. Workflow of the proposed methodology for damage mapping of roof covering based on supervised image segmentation.

5. Conclusions

A trainable automatic image classifier was employed on the roof orthoimage to determine the amount of damage accrued over time. The methodology employed proved to be quick and practical to be used as support for the municipal administration, providing not only an accurate geometric survey but at the same time also estimating the urgency and expense of the roofing works.

The proposed approach yields consistent and repeatable results and is effective for digital documentation and conservation activities, providing metric data such as those relating to the damaged areas to be repaired. The supervised image classification allows recognizing, localizing, and measuring the extent of the areas occupied by each labelled category. Therefore, it is possible to repeat the same procedure for other case studies and categories, such as semi-automatically map materials and decay on the facades.

Notes

1 For architectural scale survey, the instrument has excellent performance and specifications: 0.5-130m acquisition range, 360° (horizontal rotating base) x 300° (vertical rotating mirror) 360° Field of View, 4 mm at 10 m estimated noise range, and 2 million points per second max acquisition speed.

2 Each camera station captures 36 images, each with a resolution of 4000 × 3000 pixels.

3 Camera sensor size of 12.65 X 9.49 mm and resolution of 4864 X 3648 pixels.

4 Fiji Is Just ImageJ distribution of ImageJ and ImageJ2 which includes many useful plugins contributed by the community (https://fiji.sc/).

5 Waikato Environment for Knowledge Analysis, collection of machine learning algorithm (https://www.cs.waikato.ac.nz/ml/index.html).

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ABSTRACT

The proposed contribution illustrates the case study of a close-range aerial photogrammetric survey on portions of the roofs of the University of Pavia historic complex. The research activities were carried out for semi-automatic generation of systems for recognition and monitoring of technological elements. The procedure involved the semi-automatic segmentation of the mesh using feature-region extraction algorithms, starting from SfM mesh models optimised in polygonal edge detail. The pipeline was evaluated from the architectural scale (recognition of chimney pots or skylights) to the scale of technological details (recognition of the roof tiles).

The processing of UAV 3D models for the recognition of coverages at the technological scale: opportunities for a strategy of conservation monitoring

1. Introduction

Fast remote survey technologies represent an increasingly central issue in the documentation and inspection of historic buildings' state of conservation[1]. This survey strategy is optimal for monitoring situations in which the physical presence of the operator has implicit risks to safety and costs for equipment, such as roof inspections[2]. The inspection activities using UAVs, together with advanced post-production technologies for the generation of digital twins, allow the development of innovative monitoring methods in which the presence of operators in the field can be greatly reduced, increasing human safety, and optimising maintenance costs (Tkáč, Mésároš 2019). The process of documenting the architectural Cultural Heritage must take into account numerous aspects, including the ability to represent the material conservation of the building and to know how the material itself has changed and altered over time. The usability of an architectural asset - i.e. its continued active use - requires the suitability of the asset to meet the basic needs of its users. The required performance of a building, as a technological and environmental system, is evaluated to fullfill specific requirements and to satisfy the needs of users.

The performance can vary according to the state of conservation of the materials (Morandotti et al. 2014) and it is necessary to develop management projects based on the repeatability of inspections and the periodization of maintenance. In the case of historic buildings with historical layers of construction and technology, it is essential to design the diagnostics and the planning of interventions starting from a preliminary cognitive phase. The goal of extending the technological-constructive and material knowledge of the heritage for the design of conservation practices is what guides the process of integral documentation[3] and represents one of the tools for enhancing the historical memory of the heritage (Galantucci, Fatiguso 2019).

The research scope concerning the conservation and monitoring methodology for the existing built heritage brings out the importance of a preliminary investigation of digital documentation (Balzani, Maietti 2017).

This is combined with the possibility of elaborating digital models - Digital Twins - and virtual simulations of different scenarios. In the research case of this contribution - about remote roof monitoring - it is essential to have access to the structures and the coverings in order to proceed with the collection of the necessary data (De Marco, Parrinello 2021). Using UAV instrumentation it is possible to obtain two types of data from the same dataset: two-dimensional images (photographs and extracts from videos) and photogrammetric models obtained thanks to the Structure from Motion SfM technique. A photographic dataset for maintenance is obtained through regularly scheduled repeated inspections.

A similar dataset make it possible to appreciate any modifications and alterations over time, both in the two-dimensional and three-dimensional versions. In particular, this contribution focuses on the analysis of dissimilarities over time on built coverages starting from SfM models.

Figure 1. The University of Pavia consists of 47 buildings located throughout the city, 16 of which are listed for cultural interest. They are characterised by sloping pitched roofs with terracotta roof tiles.

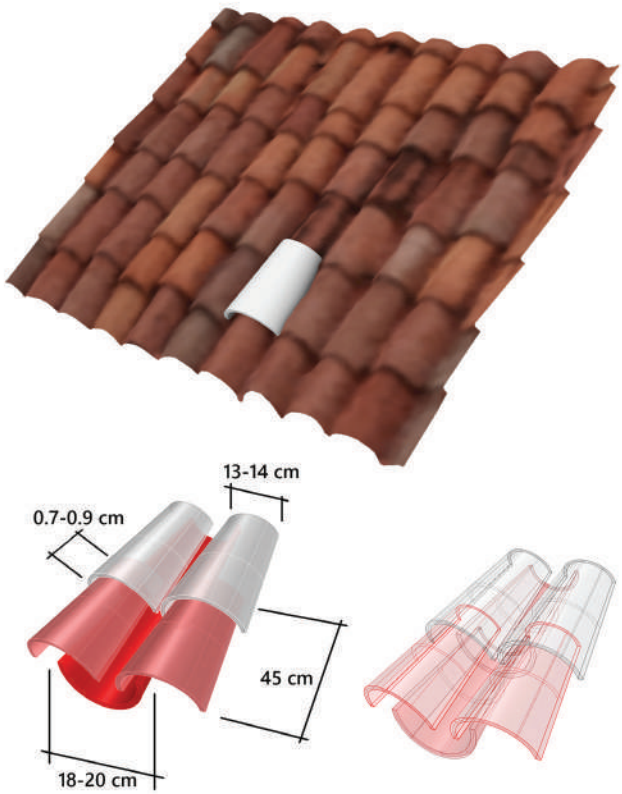

Figure 2. The detailed analysis of the elements that make up the roof covering is fundamental for the subsequent development phases of the project. In order to optimise the models, it is necessary to know the minimum extension area of the regions that are identified, and it is therefore necessary to calculate the existing elements in the roofing.

2. Previous analysis and works

Image segmentation of two-dimensional representations is one of the greatest challenges in the field of image analysis and computer vision. To segment an image means to partition it into different regions according to defined and meaningful parameters. These parameters can be represented by image characteristics such as, for example, intensity, colouring, application of textures. In order to achieve this, different varieties of algorithms dealing with image segmentation exist today. The main algorithms are divided into two[4] different varieties (El Merabet et al. 2015): "edge-based" and "region-based" segmentation. From literature studies it is still possible to state that the definition of edges of regions is less accurate (Kermad, Chehdi 2002) and this may be associated with the difficulty of describing ideal parameters. The case study of this research is the automatic recognition of elements present in the roofs of buildings at the University of Pavia, in particular the identification of roof tiles. These elements, repeated over large areas and characterised by variable states of preservation, are difficult to detect by image segmentation[5] algorithms.

The tiles are not uniform in size (their overlapping does not allow for a complete exposure of the element), colour, state of conservation, shape (some tiles are damaged) and poor visibility in the case of elements covered by vegetation. For all the difficulties indicated and mainly related to colour variation, a series of segmentation tests were carried out on the three-dimensional regions, starting from SfM photogrammetric acquisitions made with UAV instruments. Segmentation of three-dimensional models can follow different partitioning methods, such as morphology or salient regions, which is a current problem in computer vision and shape recognition applications (El Sayed et al. 2018). Structure-from-Motion (SfM) or MultiView Stereo (MVS) represent established practices for the acquisition of three-dimensional models of buildings and urban complexes. The generation of point clouds of buildings allows the modelling of mesh surfaces, of variable quality and reliability depending on the acquisition phase and the computing power available for data post-production (Bouzas et al. 2020). Another approach is the cataloguing of elements not from models but from the labelling of two-dimensional images acquired by UAV instrumentation. In this case Object Detection is used for the identification of objects in images[6]. The application of these algorithms on images is based on the displaying of contrasts and variation between pixels for the recognition of shapes and therefore figures. The research conducted so far concerns technological elements with a high contrast compared to the background, a characteristic that is difficult to find in roof tiles. Image recognition requires an extensive dataset populating phase through image labelling and a large starting dataset to obtain labels including as many case studies as possible. It would therefore be possible to identify the individual tile in its ideal condition (labelled as a tile in "good condition"), but not the reliably altered tile, which makes it difficult to use this method to classify discrepancies but only to use it to count objects in good condition. In view of the project objective of using a method of identifying coverages to evaluate discrepancies over time, it was preferred to proceed with an analysis from three-dimensional models that add the spatial feature, which complicates the machine calculation but does not require initial training. It produces a mapping that can be used to make comparisons in temporally successive inspections.

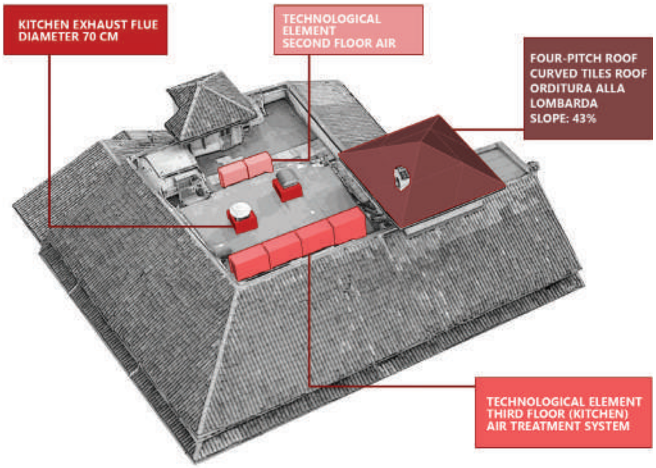

Figure 3. Phase of analysis and partitioning of the roof into technological elements. Analysis conducted on an architectural detail scale that does not take into account the individual elements that make up the roof covering.

3. UAV PILOTING STRATEGY AND QUALITY ISSUES IN COVERAGES' DATA CAPTURING

The inspection of building coverage levels by remotely piloted UAVs has become a widespread action in architectural documentation procedures in recent years, adopting SfM photogrammetric methodologies to elaborate 3D models. It has also included the possibilities of merging UAV-based photogrammetric data with thermal visible-imagery acquisitions[7]. For these target any variables relating to the flight and safety conditions of the UAV must be guaranteed during the operations and included in the planning of the survey, with a relative impact also on the quality and definition of the photographic data collected[8]. They include the weight of the aircraft, strictly linked to the dimension and quality of the camera, but also the flight path for acquisition and the maintainable distance (both during flight-motion and positional hovering) between the UAV and the target surface of the survey, as they are key factors influencing the digital data at the basis of the 3D SfM modelling processing. A comparison of assumptions and best practices in the calibration of these variables can be considered according to the type, scale and context of the surveyed site[9].

The case study of the central complex of the University of Pavia involved a careful evaluation and planning of the SfM photogrammetric acquisition campaign by UAV for the documentation of the historical roofs,

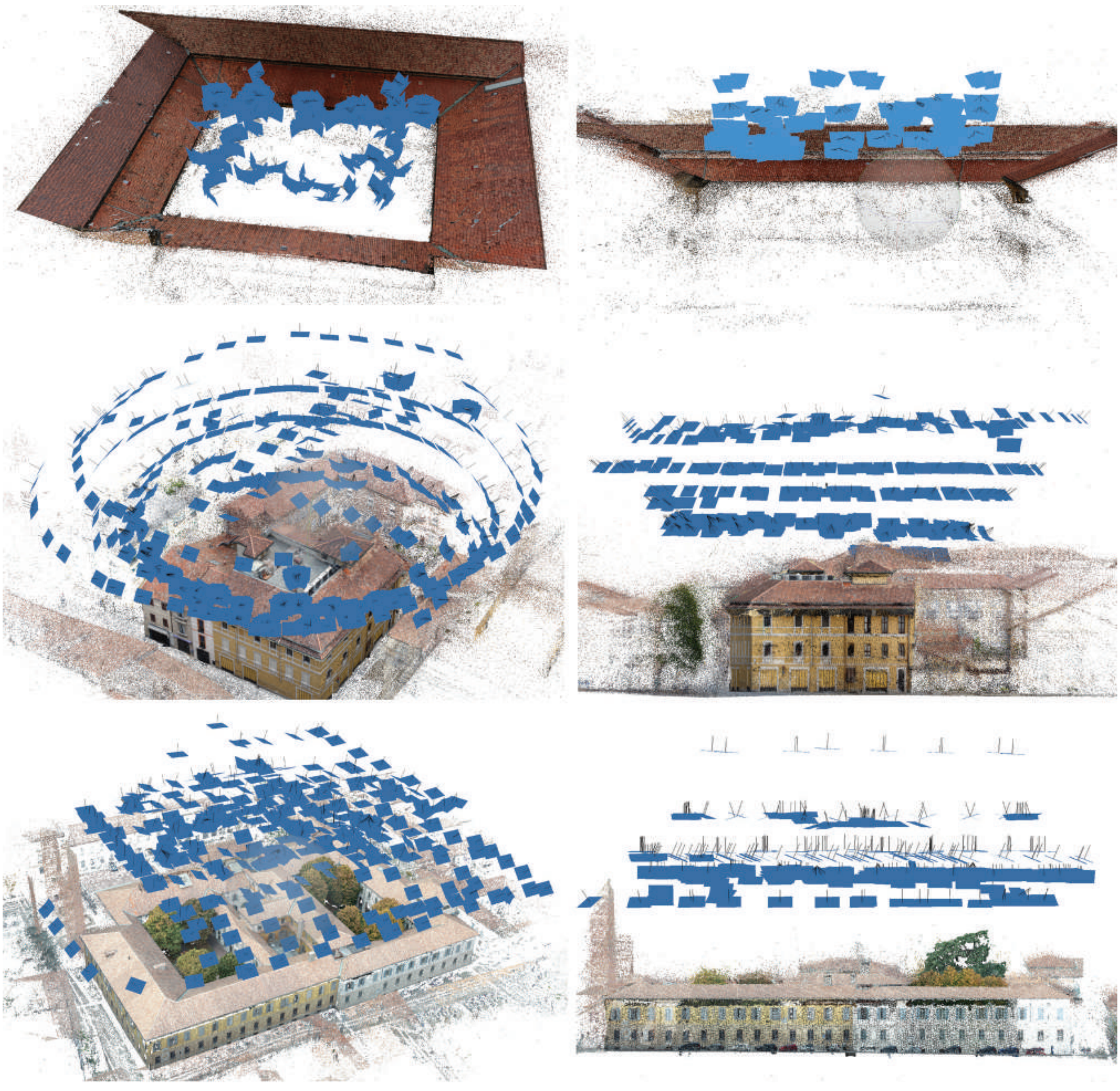

Figure 4. Example of flight plans adopted in manual mode with Ultra-Light UAVs for the survey of the coverages of the University of Pavia. The case of historical courtils, compared to other blocks, have limited the UAV piloting due to the lack of upper levels for the instrument's take-off and the diffuse presence of satellites and other noise elements for the Remote Controller signal.

matching each criticality detected on site with a strategic choice of pilot actions at the instrumental and flight-procedure level:

• Architectural site included in dense urban area. Use of "Ultra-Light" UAVs, in accordance with the valid regulations in Italy[10];

• Infrastructuring of the building area with satellites and Wi-Fi repeaters of the academic network. Short-range piloting (max. 50-60 m) for widespread RC signal interference;

• Presence of colonies of birds of protected species in the specific area. Adoption of UAVs with paraelic equipment[11], to guarantee the safety of the aircraft and the animals.

These main critic issues forced the choice of Ultra-Light class UAVs, such as DJI Mavic Mini (249 gr) and DJI Spark (in lightened condition, 290 gr)[12], which do not provide applications for semi-automatic flight planning, on a "grid plan" or by "point of interest".

The photographic acquisition was therefore done in a totally "manual" flight-mode, relying on grid guidelines and sensor metrics (distance and height from Home Point, horizontal distance from obstacles) as displayed on the RC Viewer, to calibrate regular flight paths and distances between UAVs and roof surfaces during the flight mission.

In the case of the roofs of some localised blocks of the complex, the presence of elevated accesses, terraces or open levels made it possible to set the take-off position (and the consequent RTH - Return to Home Point option) at an advantageous height (12-15 m) for the remote control, also considering the surrounding area without higher buildings within a 300m radius distance.

The case of the roofs of the historic courtyards, on the other hand, provided a more complex framework of organisation for the on-site UAV survey operations, with:

• Absence of levels, terraces or dormer windows at high altitude. Piloting of the UAV from the ground floor level inside the courtyards (with an average height of the front of 10-12m);

• Extensive use of the premises by students during daylight hours and impossibility of limitation of access to the courtyards - Limitation of flight-missions to hourly slots (maximum slot of 60′ according to the timeplan of academic lessons);

• Widespread presence of metal elements (pipes, rainwater downpipes, ducts, hooks) - articulation of UAV piloting manoeuvres with respect to signal disturbances;

• Presence of tree elements with wide crowns compatible with the height of the roofs - Specific manual UAV piloting and variation of the acquisition path due to obstacles.

4. Feature-based regions from the processing of semi-automatic segmentation on 3D meshes

With respect to the state of the art and to the image-segmentation experiments carried out on the roofs of the University of Pavia complex, a semi-automatic recognition process by feature-based regions was evaluated. The objective was to pursue a segmentation, as automated as possible, of the roof elements according to their geometric

Figure 5. Dense point cloud elaborated with SfM process from Ultra-Light UAV (DJI Spark) survey.

ROOF TILES	**DJI Spark**	**DJI Mavic Mini**
Acquisition distance	5-7 m	10-15 m
Camera resolution	3968x2976	4000x2250
Density of points/tile	15.500	1.500
Density of polygons/tile	35.300	5.600
Geometric resolution	0,012 m	0,030 m
Max. mesh curvature	±0,030	±0,015

TECH ELEMENTS	**DJI Spark**	**DJI Mavic Mini**
Acquisition distance	5-10 m	10-25 m
Camera resolution	3968x2976	4000x2250
Density of points/block	36.000	17.100
Density of polygons/block	8.500	39.300
Geometric resolution	0,035 m	0,053 m
Max. mesh curvature	±0,015	±0,015

Table 1 and 2: PilotUAV features and photo acquisition.

constitutive characteristics, reconstructed by the Structure-from-Motion process applied with aerial photogrammetry, compensating the image-recognition actions (not applicable due to the lack of image contrasts in the 2D photographic data) with a parallel analysis conducted on the 3D model. From the survey data, dense point clouds (approx. 500,000 points/sqm) and high-poly meshes (approx. 1,150,000 poly/sqm) were produced from datasets of 70-10 photos for documented pitch area of the coverage (3.5-5 m x 1-2 m)[13]. Datasets on different areas of coverage of the Central University of Pavia and other buildings in the complex were acquired, with the mentioned types of UAVs (DJI Spark and DJI Mavic Mini), comparing the survey data. The data analysis focused on the recognition of classes of technological elements detected on the roof, both qualitatively and for the segmentation experimentation, as key targets of the conservation monitoring objectives. In particular, with reference to the elements of the roof covering ("roof tiles"), the following average characteristics of the digital survey data were observed in Table 1. With regard to the macro elements of the roofs (chimneys, air conditioning elements, pipes, other technological systems), the following average characteristics of data were observed in Table 2.

The semi-automatic computing was based on the recognition of geometric qualities of the mesh (curvature, edges, relative grid of polygons and minimum recognition area of regions), identified from the particular variation of the surface mesh and then classified, in case of similarities, by related region areas. These properties, interpreted as geometric qualities of the virtual mesh, can be related to the interpretation of technological-constructive factors of conformation of the real elements of the roofs and their system. Thus it is possible to associate the semi-automatic reading made on the mesh from the UAV survey with a detailed critical analysis, where it is possible to verify and interpret the morpho-metric variation highlighted in terms of conservation characteristics and damage conditions of the elements of the roof. In this way, it is possible to apply two scales of analysis and data processing to the morpho-metric apparatus of the roofs: the macro-scale of the construction system, aimed at recognising the architectural, infrastructural and functional systems that define the entire roofing apparatus (pitches, chimneys, roof windows, air systems, satellites and pipes); the micro-scale of the constructive element, in this case the brick "roof tile" element, aimed at identifying singularities of shape in correspondence of missing, dislocated, fractured or interesting units, also

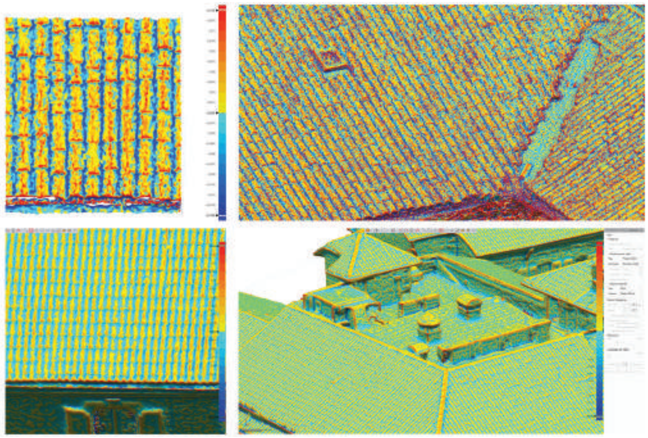

Figure 6. Curvature analysis applied on the 3D mesh model. The application of quality correction processings (such as Refine Shape) to the polygonal grid enables to improve the curvature analysis map, enhancing a double level of recognition of technological shapes at the micro and macro scale.

considering the sliding or substitution of a course of roof tiles for the entire development of the pitch. On the Geomagic Wrap software platform, the Extract Region tool enabled the calibration of two sensitive parameters for the analysis:

• the "Minimum Area" for recognition, to be calibrated to the scale of analysis of the significant constructive elements of the roof, in the order of 640 cmq in the case of observation of the "roof tile" element or in the order of 3,700 cmq in the case of observation of the macro-elements of the pitches and technological apparatuses;

• the "Curvature Sensitivity", range of 65-85 in relation to the mutual curvature values and the geometrical resolution of polygon grids in the mesh model.

The process allowed the automatic recogniction of the arrangement of technological elements, as well as constructive irregularities, for the missing, sloping or damage of patterns of roof tiles.

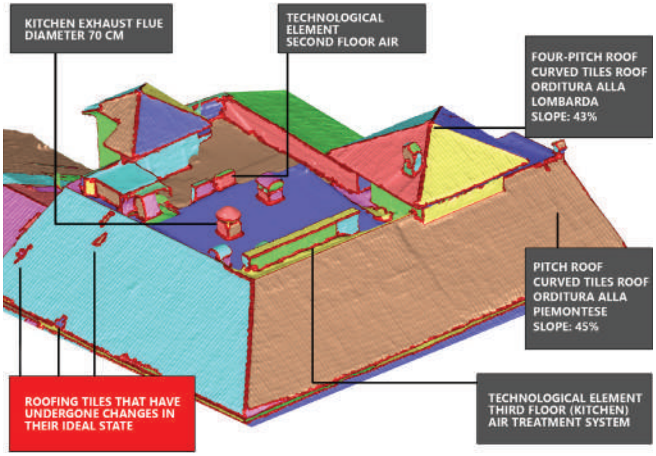

Figure 7. Elements with criticality detected through curvature analysis. Tiles that have slid are visible. As the overlap between adjacent pantiles increases, the localised slope detected by the model varies becoming more evident.

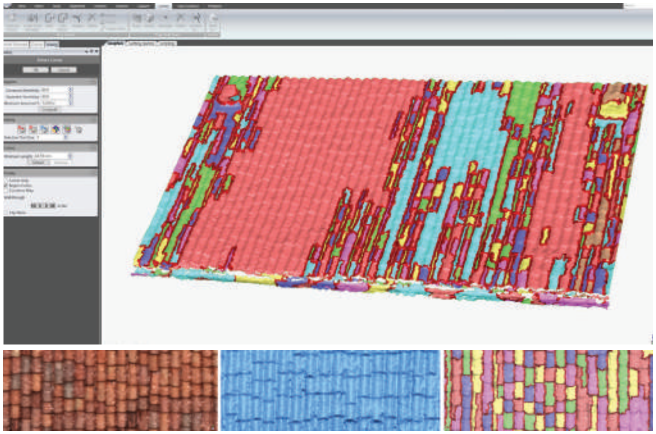

Figure 8. Elements with criticality detected through curvature analysis. Tiles that have slid downwards are visible. As the overlap between adjacent pantiles increases, the localised slope detected by the model varies becoming more evident.

5. Application for monitoring

The interaction between digital models and diagnostics is a tool for understanding related data. In the field of Cultural Heritage, digital technologies for maintenance include GIS data visualisers - information systems. By integrating, entering and updating data, Information Systems enable the development of analyses to monitor the state of preservation over time and guarantee an updatable archive of heritage and the development of management protocols. Starting from mesh partitioning data into elements, it is possible to activate monitoring systems based on the comparison of temporally successive stages.

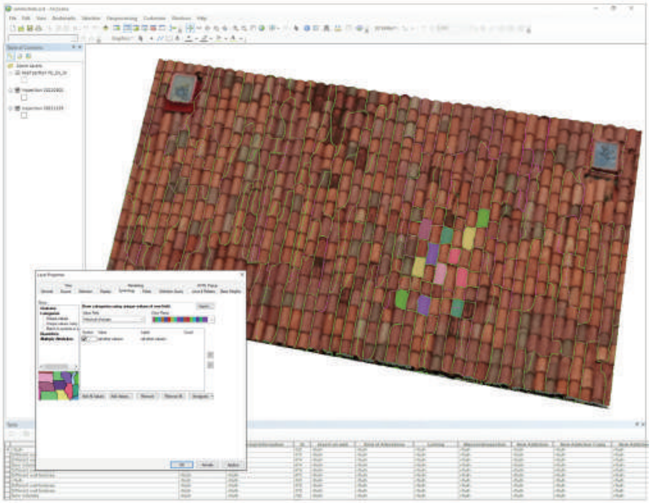

Figure 9. Import of optimised mesh and mesh edge traces on the georeferenced GIS - Informative System.

By importing meshes and vector contours into information systems, such as GIS systems, it is possible to structure a temporal layer system of building conditions. The layer sequence highlights alterations by keeping track of them, so that any internal pathologies can be correlated with the condition of the roof covering. It is essential to define a correct planning of maintenance actions (Della Torre, 2003), taking into account the location, the building's zero state condition and any sudden traumatic events such as earthquakes or exceptional climatic events.

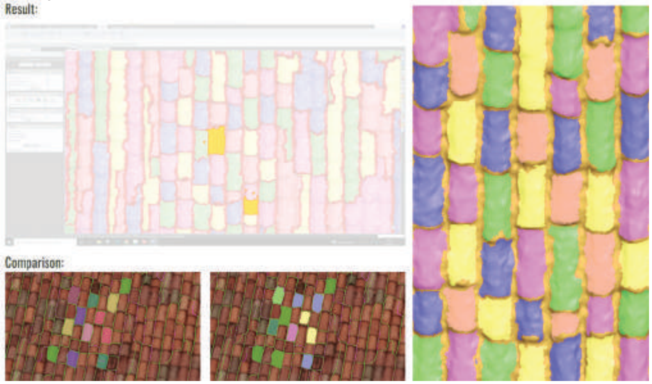

Figure 10. Use of image comparison software. On a portion that has been altered, it is possible to calculate the percentage of inconsistencies found.

Notes

1 The editorial responsability, althought the authors shared the same methodological approach, premises and conclusions, is due to: chapters 1, 2, 5 to Elisabetta Doria; chapters 3 and 4 to Raffaella De Marco

2 The construction sector recorded an 8.7% reduction in accident reports over the five-year period 2015-2019 and an even greater decrease in positively assessed cases. The construction sector recorded an 8.7% decrease in accident reports over the five-year period 2015-2019 and an even greater decrease in positively ascertained cases, which fell from 35,083 in 2015 to 29,104 in 2019 (-17%) in a working period marked, however, by the stoppage of numerous construction sites due to COVID-19. For more information, see: Dati INAIL 2020 AAndamento egli infortuni sul lavoro e delle malattie professionali. 2020 n° 8. ISSN 2035-5645

3 For additional information specific to non-invasive studies from point clouds see: Galantucci, Fatiguso 2019

4 "The first category consists of detecting the dissimilarity and transitions between objects in the image. Its major drawback concerns the sensitivity to noise, texture or illumination changes. The second category of segmentation methods consists of grouping adjacent pixels according to a certain similarity criterion". El Merabet, 2015, p. 3173.

5 For further details on the difference between the different types of algorithms, in particular Region-Based Segmentation and Edge Detection Segmentation, see: H. G. Kaganami, Beiji 2009.

6 For more details see the contribution being published: Doria, E., Carcano, L., Parrinello, S.(in press): Object Detection Techniques Applied To UAV Photogrammetric Survey. REAACH-ID Symposium 2021.

7 Several case studies focused on processing images acquired by UAVs with a RGB camera combined with a thermal camera, exploiting common 3D processing for Structure from Motion photogrammetry to develop typological maps where geometrical features are joint to technological qualities for the evaluation of conservation and energy dissipation conditions. For a detailed reference, see: Dahaghin M., Samadzadegan F., Dadrass Javan F. (2021) Precise 3D extraction of building roofs by fusion of UAV-based thermal and visible images, International Journal of Remote Sensing, 42:18.

8 For an experimental study on the quality of photographic data from UAVs, useful for interpretation in the architectural field, depending on the altitude of acquisition, see Brown, Miller 2018.

9 An overview of acquisition protocols from the comparison of different study cases of UAV SfM digital survey is presented in Picchio, 2020.

10 The updated EASA - European Union Aviation Safety Agency regulation (in force since January 1st, 2021, replacing the previous ENAC version) maintains simplified flight conditions for Ultra-Light UAVs. Ultra-Light class corresponds to class C0: MTOM < 250 gr (Maximum Take-Off Mass). For this class, it is also allowed to fly over people not involved in surveying operations (not over crowds), and to fly with UAVs over urban contexts without specific requests for permission and qualification of the operations, maintaining a flight speed of less than 19 m/s. The general rules of the OPEN flight category (120 m height and VLOS flight) always remain valid.

11 The inclusion of UAV paraelics depends on the model, and is not guaranteed for all aircrafts. It must be considered that the paraelics constitute an additional load to the UAV (min 26 gr, considering the official DJI paraelics for DJI Mavic Mini -2 pieces-, a total load of 60 gr.), to be counted in the MTOM value, and that it reduces the values of battery life, influencing modes, times, stations and take off/landing paths of the aircraft in the survey plan.

12 Survey operations with DJI Spark were conducted on the historical courtyards of the University of Pavia in acquisition campaigns from 2018 to 2020, prior to the Covid contingency period. In that period, the current ENAC regulations classified UAVs with MTOM less than 300 gr. as Ultra-Light.

13 The SfM photogrammetric processing of photographic data acquired by UAV has been conducted on Agisoft Metashape software.

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UAV survey, Heritage protection, Social Network Analysis, Cloud Archaeology; Han City.

ABSTRACT

Chengcun Han City is an important part of the UNESCO Mixed Heritage Site of Mount Wuyi, China. To tackle the problems caused by the size and location of the site, the current study thus aims to explore the feasibility of combining digital survey methods with tilt photography and remote sensing technology. The orthophotos lead to the creation of an ABIM (*Archaeological Building Information Model*). The value hierarchy established based on social network analysis provides new ideas for archaeological surveying and constructing an unmanned remote sensing monitoring system for large sites.

UAV survey for documentation and conservation of Han City in the UNESCO mixed heritage site of Mount Wuyi, China

1. Introduction

The site of Chengcun Han City, located in Mount Wuyi City, Fujian Province, was the capital city of Minyue Chiefdom, a vassal state built between 202 BCE and 110BCE, imitating Chang'an, the capital of the Han Dynasty. Emperor Han Wu (156BCE- 87BCE) expanded the territory of his Empire by sudden military conquers of border vassal states, such as Xiongnu, Nanyue, and Minyue, between 121BCE and110 BCE. The Minyue Chiefdom was sacked by Han's troop in 110BCE and its people was banished northward to Wuyue Region (now Zhejiang Province). The sudden destroyed (so-called "Pompeii in China") city was lost and forgotten in the remote rural area ever since for more than 2000 years, till rediscover in 1958. As the best-preserved example of Western Han city, it was an important part of Mt. Wuyi, which was listed as the mix UNESCO World Heritage in 1999.

At present, the site is mainly surveyed by the archaeology excavation grids. The close-up photogrammetry was carried out during the first trial dig at the Chengcun Han City in 1958 . The Bureau of Cultural Heritage completed the site map based on several digs and onsite explorations between 1958 and 1980. The digital survey of the site, however, is still a challenging task for two main reasons: firstly, the massive size of the site, which covers an area of approximately 480,000 square meters and cannot rely entirely on remote sensors; and secondly, the lack of manpower caused by the remote rural location. Therefore, we developed a hierarchical conservation management strategy based on the Social Network Analysis (SNA) to solve the size problem and proposed a mapping routine established by Unmanned Aerial Vehicle (UAV) inclined photogrammetry technology to save manpower. This study could shed some light on our exploration of new and more economical methods for the preventive conservation of large heritage sites.

2. Literature review

2.1 Hierarchical Strategy by SNA

In the past four decades, social network analysis (SNA) has become a major analytical paradigm in sociology and now occupies a strategic place in disciplinary debates on a wide variety of issues. As SNA can be used to classify, process, and quantify relationships in the process of establishing a value system (Lu 2018). In such a value system, the higher value points can be identified by the results of centrality and shortest paths calculation. For instance, in the reconstruction of a medieval Russian river trade network, SNA develops a topological trade network diagram demonstrating the relationships between cities, which shows that Moscow, at that time, was at the center of the river network in terms of both centrality and accessibility (Pitts 1978). For large heritage sites, SNA is thus proposed to incorporate into the entire process of conservation planning and graded preventive conservation system establishment (Chen 2015; Sun 2013).

2.2 UAV tilt photogrammetry

Recent years have witnessed the boom of UAV technology. 6,896 UAV remote sensing-related papers have been published between 2000 and February 2022 in the ISI Web of Science literature database, and approximately

90% of them were published after 2013. The potential of drones in scientific research has also been reported in journals such as Nature and Science, respectively. However, the application of UAVs used in the large-scale site is more concentrated in surveying and mapping, agriculture, forestry, power industries, ecological protection, and large-scale disaster prevention. To acquire UAV data, conventional single-lens UAVs are replaced by the tilt imagery by combining folded-route and wraparound-route image acquisition methods. The limitation of two data collection methods, UAV tilt photography and ground photography, is discussed to achieve the construction of fine-grained real-world 3D models. Although there are some applications in the field of archaeology, drones are only used as a tool for mapping, and no database yet has been formed to monitor prevention.

To establish the value system, the first step is to recognize all the nodes/actors of the network on the basis of archaeological excavation reports. Secondly, these nodes/actors should be mapped out on the captured images, which can visualize the site and facilitate real-time comparative monitoring. Using the panoramic images taken by the UAV, rapid pointing is used to obtain 3D point cloud data of the remains of the field archaeological excavation site in a real-time, efficient, high-precision and non-contact manner, to establish a high-precision model, to visualize and mirror the site points, and to provide an all-round display interface for effective judgment of road relationships, the condition of the city walls and building sites, etc., providing a reference basis for the conservation monitoring of ancient cultural sites at different levels.

3. Site mapping area conservation monitoring management grading

Based on archaeological excavation reports, 41 points were identified for testing at Chengcun Han City (Figure 1). A mapping control network and a deformation monitoring control network were laid out around the site using the National 2000 coordinate system. Four to six permanent mapping control points were buried using the borehole method, taking into account the overall harmony of the surrounding landscape and not damaging the heritage. The mapping control network and the deformation monitoring control network share datum points to meet the needs of the digital work.

3.1 Quantitative analysis of the importance of each node

Two criteria are used in the value SNA to calculate the relationship between the nodes. First is the centrality of the nodes, as the more it is close to the center, the fewer paths than other nodes from the resources. Second, the number of artifacts varieties excavated in each node, the more varieties suggesting the more essential or prominent historical value of the node. The distances between nodes were measured with the UAV data, with the palace as the center. The artifacts excavated from each node were counted for their presence or absence.

Both data were weighted in the same proportion, using a multi-decimal matrix, and imported into UCINET for quantitative analysis. The importance of each node is shown in Figure 2 as the strength and number of connections between place nodes and artifact nodes. As such, the integrated entry degree of each node is visualized and analyzed in terms of the size, shape, and color of the nodes, which specifies the position of each node in the particular social network.

This allows us to rank and category the importance of each node in the Chengcun Han City, which is eventually divided into three levels: the critical conservation areas, the general conservation areas, and construction control zones. At the same time, the nodes are divided into two groups according to their current conditions: either in good condition or damaged. For instance, Node 1 is an essential site in good condition, and Node 20-22 are essential but damaged sites. As such, the sites can be protected accordingly.

Node 1 Gaohu South-ground Palace District
Node 2 Gaohu North-ground Palace District
Node 3 Maodao Hillock
Node 4 Northwest Corner Pedestal
Node 5 Xiasi Hillock
Node 6 Xiasi Ground
Node 7 Gaohu South-ground Eastern Slope
Node 8 Gaohu North-ground Eastern Slope
Node 9 Big Hillock Top Site（South City Gate）
Node 10 Garden End Site
Node 11 Gaohu Lower Pit Site
Node 12 inner part of the middle section of the Western Wall
Node 13 North Watergate, East Wall
Node 14 West Watergate
Node 15 South Watergate, East Wall
Node 16 South City Wall
Node 17 East City Wall
Node 18 North City Wall
Node 19 West City Wall
Node 20 North Hillock of City Gate No. 1 (Ancestral Temple)
Node 21 North Hillock of City Gate No. 2（Altar Land）
Node 22 North Hillock of City Gate No. 3
Node 23 South Hillock of Citygate
Node 24 Drum Tower Mound Architectural Plateau
Node 25 Zhao historic house Villages Site
Node 26 Cucumber Hill Site
Node 27 Front Gate Garden Site
Node 28 East City Gate
Node 29 West City Gate
Node 30 North City Gate
Node 31 Oogway Hill Beacon
Node 32 Ceramic Workshop Area
Node 33 Yuanbao Hill Iron Smelting Workshop
Node 34 Official District of Wengzhong Alley Site
Node 35 Dutou Cemetery
Node 36 Guo County
Node 37 Burial area behind the Cattle Pen
Node 38 Burial area behind the pavilion
Node 39 Fulin Hillock Site
Node 40 Burial area under the iron Hill
Node 41 She Tou Burial Area

Figure 1. Distribution of exploration area of Chengcun Han City site.

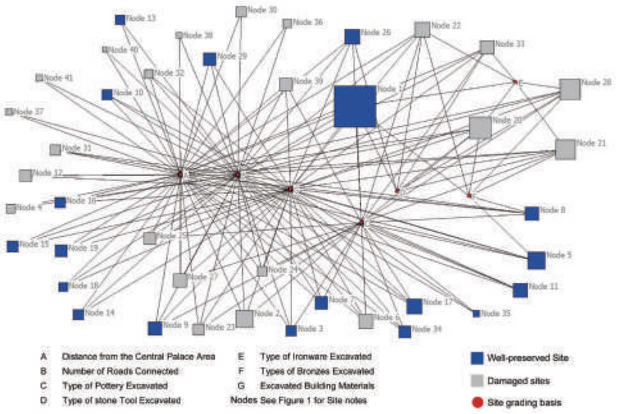

Figure 2. Visualisation of Quantitative Expressions in Netdraw of UCINET.

4. Application of UAV technology in site archaeology

Two nodes are UAV surveyed in detail with a DJI PHANTOM4, and the survey area was routed using flight control software at an altitude of approximately 110 m. A total of 1204 images were acquired, and 1202 images were screened for validity (Figure 3).

4.1 UAV route planning

The city's topography is complex, and the road system is irregular, but there is still a clear spatial separation at the high platform of the site left by the buildings, and the terrain is flat. When planning the flight route, the LocaSpaceViewer software was used to export the KML file of the survey area, import it into the DJI GS PRO ground control station, plan the flight route by the mapping aerial photography mode within the survey area, and set the overlap rate of the UAV heading and side direction to over 80%. At the same time, we introduced the encircling route image acquisition method, using the remote control to control the UAV over the center of the subject site (the center of the top view) as the point of interest, using the vertical axis of the site as the encircling axis, and setting the flight height (100m) and encircling radius (300 m) to control the UAV's circular flight around the site, with a continuous shooting interval of 2s to ensure the overlap of adjacent aerial films. As the entire complex of buildings at the site is distributed in groups, the flight path around the site was centered on the palace area and the northern post of the city gate (the ancestral temple site), the first monitoring points (Figure 4-5).

Figure 3. Part of the aerial footage of the drone tilt photography.

4.2 Aerial film processing

DJI PHANTOM4 was used to acquire the site's tilt and vertical image data. The images came with POS data, and the characteristic points of the site-building clusters themselves were used as image control points. The coordinates of the image control points were measured with a total station. Context Capture 3D modeling software was used for modeling. The image data taken by the UAV was imported to realize the image association of control points, solving the problems of aerial triangulation based on the tilt photography of light and small UAVs, realistic 3D models, and accuracy evaluation of buildings in 3D scene models (Figure 6). The final 3D model of the actual scene is formed, and with the help of the software platform, spatial measurement of features can be carried out on the model, three-dimensional measurement of length, width, and height can be carried out, and area and earthwork analysis and calculation can be carried out (Figure 7), which significantly reduces the workload of archaeological research. Further generating large-scale topographic maps provides essential data to guide archaeological site investigation, ABIM model application, and site protection planning.

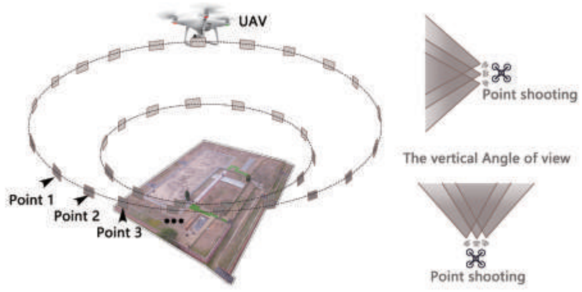

Figure 4. Flight schematic of the drone in point-of-interest surround mode.

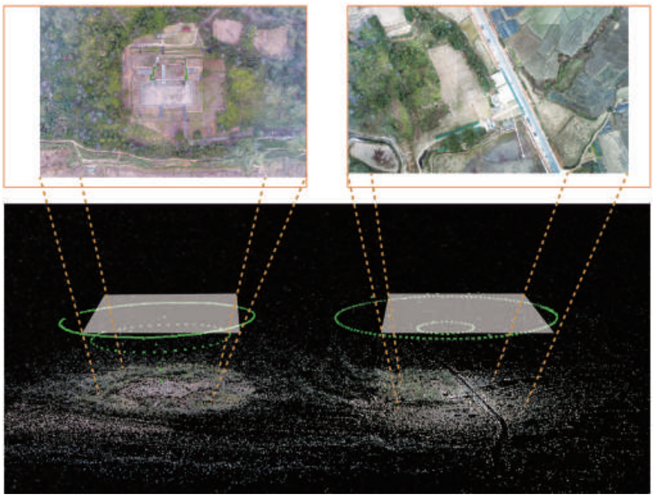

Figure 5. Point cloud map of circular flight.

5. Site survey routine

The onsite visit found that the current management relied on civilian cameras and manual inspections with low covering areas, poor data accuracy, and high workforce costs- the current distribution of civilian cameras ae shown in figure 8.

5.1 UAV remote survey routine

Based on the value of SNA, we developed a survey routine for Chengcun Han City Site. The high timeliness and high flexibility of UAVRS technology compared to traditional satellite remote sensing provides the possibility of long-term monitoring of dynamic changes in the site system. The monitoring process is as follows (Figure 9).

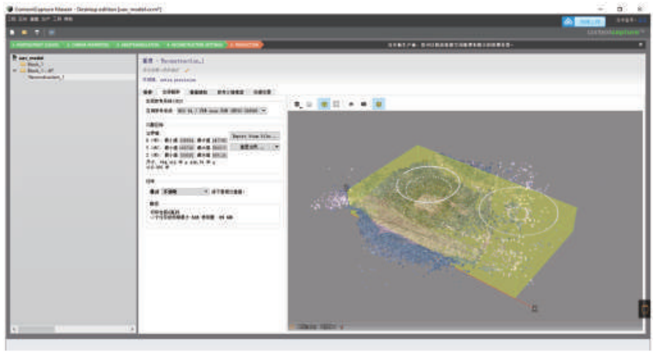

Figure 6. Apply Context Capture software to determine the modeling scope.

• Image acquisition: Most of the sites are immovable conservation sites and require a fixed patrol route to be set. Use the Litchi for DJI APP to set up the patrol points (Figure 10) and set the parameters (lens orientation, cruising speed, flight height, etc.) for each point, then save the route. At take-off, UAV remote sensing is used to obtain information on the target by carrying different sensors (optical cameras, LIDAR scanners, etc.) to get information on the same angles taken at different times.

• Graded protection: The integrated approach of "UAV remote sensing + manual inspection" is used to implement construction control monitoring. Daily multi-airline monitoring is implemented for crucial protected

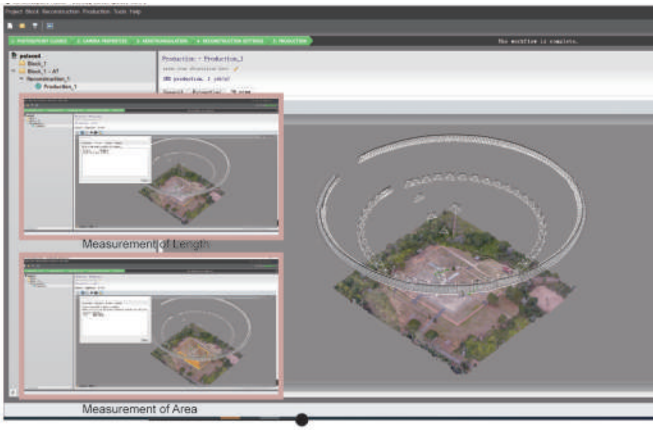

Figure 7. Measurement of site height, area and earthwork volume.

areas, for general protected areas, multi-day protection monitoring is implemented, and for construction control zones, weekly preventive inspections are implemented.

• Data Preprocessing: The pre-processing of UAV optical remote sensing data mainly includes radiation correction, geometric correction, and image stitching. For more significant sites, it is easy to cause differences in the color of the same feature in different photographs, so color correction is required. Secondly, geometric correction corrects for non-linear aberrations, instabilities in the orientation elements outside the sensor, and geometric distortions caused by the complexity of the terrain. Further, stitching can yield high-resolution images.

• Information extraction: the pre-processed multi-temporal, same-angle, and high-frequency spatial data information will be analyzed electronically and automatically for comparison, which can track monitoring and analysis to obtain the evolution characteristics of biohazards and artificial damages, and realize the early identification and monitoring and early warning of significant disasters and potential damages.

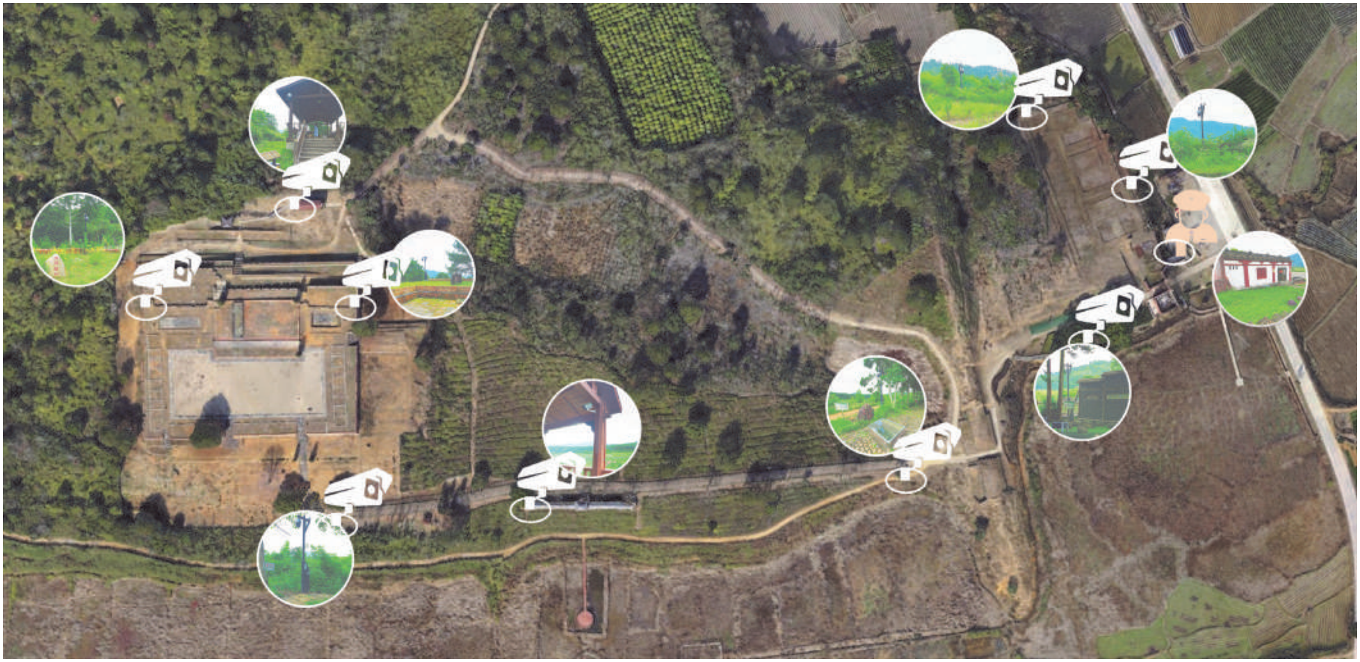

Figure 8. Plan view of the current status of site monitoring.

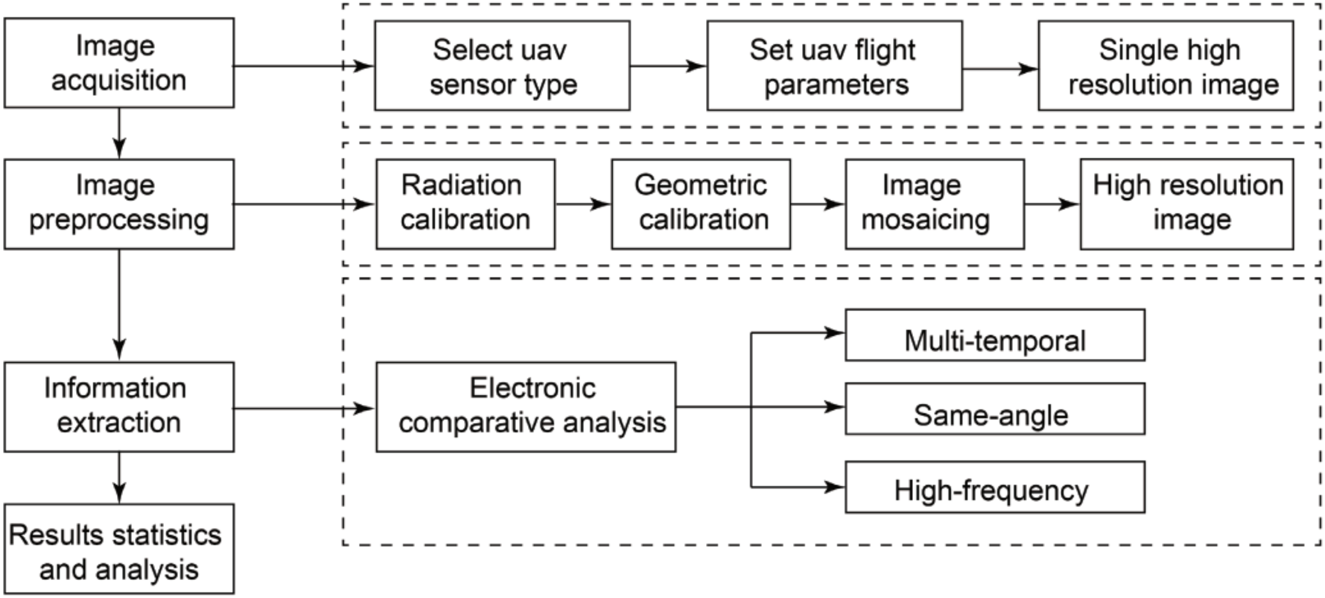

Figure 9. Basic process of extracting site monitoring information by UAV remote sensing.

5.2 Documentation

With the accumulation of UAV monitoring data on a temporal and spatial scale, these data will provide essential support for the visual display function of our work in building a monitoring and early warning system. By forming a monitoring cloud through this process (Figure 11), it will provide prevention history and enable the real-time display of heritage preservation trend analysis and carry out popularized display and dissemination of heritage monitoring and specialized research and communication.

The monitoring management center combines daily monitoring with special monitoring while interfacing with the national general platform and anticipating the computerization of the basic data management system and the archive management system. The data from these two areas will be archived and managed in a database, which will be updated in time for the heritage archives.

6. Conclusion

The development of new survey technologies, such as UAV drones, has contributed to the progress of heritage conservation, and the quantitative SNA has led to a clear hierarchy of heritage core value. As a result, the conservation of large sites has formed a certain amount of accurate and systematic processes, significantly improving accuracy while reducing labor costs and the date size. The Han Dynasty city of Chengcun, a China National Heritage and a part of the UNESCO Mix World Heritage, has been presented to the world as a new face of 'cloud archaeology.' At the same time, it clear the path for other heritage sites with similar characteristics.

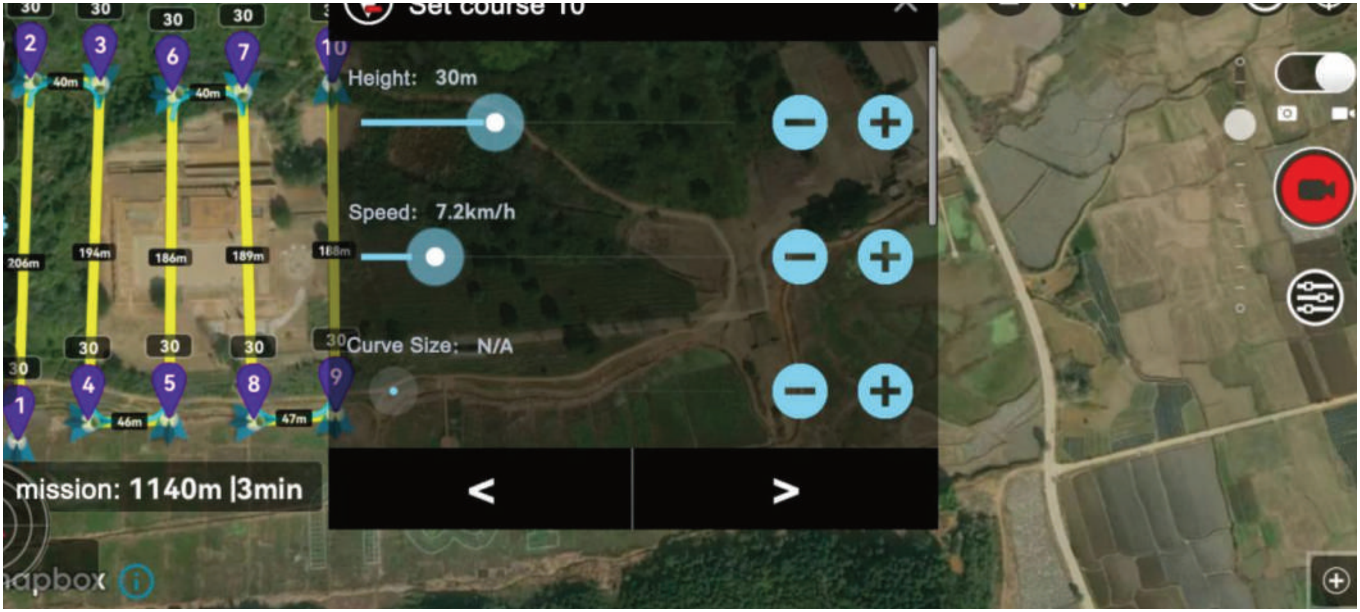

Figure 10. Set waypoint parameters with Litchi software.

Figure 11. Monitoring and visualization of Chengcun Han City.

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Keywords:
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ABSTRACT

The cliff-burial was an ancient funerary ritual once popular in the Far East, in which the dead were buried high on the cliffs overlooking rivers in the log coffins (the "hanging coffins") left in the natural caves, excavated grottoes, or on some woodpiles. Hence, the conventional 3D survey means is less practical. This study explores the possibility of using UAV (consumer–level drones) in the survey with substantial improvement in accuracy, range and flight control, and compares the accuracy effects of different measurement methods.

Digital survey of the Cliff-Burial sites with consumer-level UAV photogrammetry: a case study of Mt. Wuyi

1. Introduction

Nowadays, in some remote areas of Southeast Asia and Pacific Islands, e.g. the Sagada in the Philippines (Figure 1), the Torajas of Sulawesi and the Dagos of Orchid Island, Taiwan, the cliff-burial ritual characterized with burial sites on the escarpment or the cliff cave facing the water is still in practice (Chen 1992). In China and other countries (Figure 2), has lost in history. The earli-est sites found are in Mt. Wuyi region with a 14C radiocarbon date of 3620 130 BP (Chen 1992) and was regarded as the origin of Hanging Coffin (cliff-burial) culture by genetic results and ar-chaeological evidence (Zhang, Li, Zhou, Huang, Yu, Liu, Shi, Liu, Chia, Huang, Guo, Shoocongdej, Ji, Su 2020). The conservation of the historical information of the hanging coffins is thus an urgent task, not only because it is required by the UNESCO heritage management but also because it is significant in the fields of ethnic migration and cultural assimilation. Historical literatures between the Three Kingdoms period (220BCE-280BCE) and the Qing Dyn-asty (1636BCE-1912BCE) indicate that there used to be a large number of hanging coffins in Mt. Wuyi region (Chen 1992). The most recent major comprehensive survey of hanging coffins in Mt. Wuyi was carried out in August 1979, and found only 18 relic sites with more than 19 coffins se-verely damaged over time, leaving no coffin intact (Cultural Heritage Group of Chong'an County Culture Museum 1982). Limited by the technology available in South China in the 1970s, infor-mation on the specific cliff height, location, coffin form and remains of each site is mostly recorded in vague description, without accurate documentation such as images, 3D model or geographic co-ordinates, which prevent further conservation research and management.

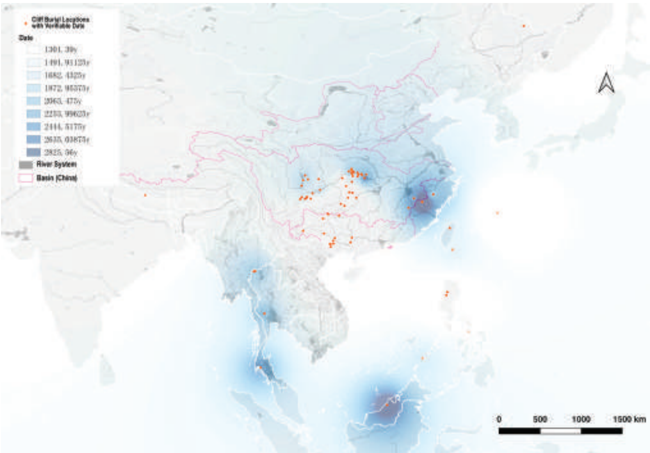

Figure 1. Spatial-Temporal Graph of Global Cliff-Burial Sites.

The current research thus aims to explore a safe and low-cost surveying method that can acquire and process the maximum amount of detailed information in a short time. Unlike other types of tombs and burials, the cliff-burial sites are difficult to reach without facilities. For example, the Jinji Cave site in Mt. Wuyi has a height up to 30-50 metres above the creek (Zeng, Yang, Fu 1980). Coffins on the Luoping River sites (Badong County, China) and the Tabon Cave site (Palawan Is-land, Philippines), are as high as 100-200 metres above water (Chen 1992), Although remote sensing technology, such as 3D laser scanning technology and photogrammetry, is safer and more efficient than manual contact measurement in the process of high slope investigation (Ye, Xu, Liu, Dong, Wang, Ning 2020), such height almost ruled out the possibility of traditional means, such as ground laser scanning and traditional aerial photogrammetry. Nevertheless, the boom of the con-sumer drone market and the rapid growth of photogrammetry technologies had opened new oppor-tunities for digital surveys of Cultural Heritage with economical devices. The UAV surveying re-quires the least amount of time measuring a building elevation compared to total-station equipment and 3D laser scanning, and the accuracy usually depends on the quality of the 3D model con-structed, which usually lead to a lower average accuracy than the other two (Li 2019). However, given the requirements of consistency over accuracy, small UAVs equipped with low-resolution amateur cameras can also acquire photogrammetric data for Cultural Heritage sites (Calantropio, Chiabrando, Rinaudo, Teppati Los 2018). This sheds new lights in the feasibility of using con-sumer-level drones for cliff-burial heritage site surveys.

2. Application of UAV photogrammetry in Cultural Heritage on cliffs

The UAV photogrammetric documentation have been applied to slopes, cliffs, high dams, and other similar terrains. Nevertheless, the environment of the waterfront cliffs is difficult for conven-tional aerial means, as the traditional aerial photography requires large, long-range fixed-wing UAV. The complex environment of high slopes and the limited space of cliff projects prevent large UAV to be brought down. As such, small-sized rotary-wing UAVs equipped with single lens are more suitable for photogrammetry on slopes or cliffs. The use of UAV oblique photogrammetry should enforce the following processes: site survey, route planning, flight operations, and data post-processing (Ye 2019).

Currently, two major types of photogrammetry for small-sized consumer drones are: the conven-tional oblique photogrammetry and the nap-of-the-object photogrammetry. Both techniques have strengths and weakness and should be chosen with the specific terrain to survey in mind. Com-pared to oblique photogrammetry, nap-of-the-object photogrammetry enables efficient acquisition of sub-centimetre or even millimetre ultra-high resolution images of the ground (e.g. landslides, dams, high slopes) or the surface of artificial objects (e.g. tall ancient buildings, landmarks) and thus implement the fine-grained 3D reconstruction (Tao, He, Xi, Liu, Niu, Duan, Zhang 2019). The nap-of-the-object photogrammetry provides an excellent digitally survey method for cultural herit-age on the precipice, but is unsuitable for large scale DOM and DSM geographic information ac-quisition for surrounding environment. In the modeling of high dam in hydropower project, 3D modelling incorporating oblique photogrammetry and nap-of-the-object photogrammetry enables effective fine-grained, high-resolution modelling of elevations, steep slopes and shaded areas (Zhang, Wu, Shang, Lyu, Wang 2021).

In the case of an Ottoman monument located in Xanthi, Greece, the high precision 3D reconstruc-tion models generated by the Structure-From-Motion (SFM) and Dense Multi-View 3D Reconstruc-tion (DMVR) algorithms also point to the applicability of using this technology in low budget Cultural Heritage digitisation projects (Koutsoudis, Vidmar, Ioannakis, Arnaoutoglou, Pavlidis, Chamzas 2014). Then the combination of SFM-DMVR algorithm and low-cost UAV technology makes it pos-sible for operators of non-surveying-and-mapping majors, such as architectural background, to ac-quire and process 3D data at low cost (Sun, Cao 2015).

In the case of the Huashan rock paintings in Guangxi, China, for example, the use of nap-of-the-object photogrammetry allows large outdoor artefacts on cliffs and high slopes to be digitised in three dimensions with a high degree of accuracy, thus providing a reference for the appreciation and conservation of the artefacts (Luo 2021). In addition, Luo (2021) provided examples of opera-tional procedures for photogrammetric studies on cliff heritage, and added manual waypoint detec-tion to ensure proper signal reception at key waypoints caused by the recessed cliffs and tree cover. Being three-dimensional solid, the hanging-coffin, however, is different from the plane rock painting in terms of the UAV route planning and the lighting environment in the caves.

In summary, using UAV photogrammetry in the digitally survey of the cliff environment is not only technically feasible but also with a measurement accuracy sufficient for Cultural Heritage conserva-tion purposes. Nevertheless, as this technology has never been used in previous cliff-burial sur-veys, more experiments are needed before the on-site survey.

3. Preliminary Study

3.1. Hardware and Software

In this research, the former cliff of Baiyun Temple located in the west of Mt. Wuyi was selected as the main subject of a digital survey by UAV photogrammetry and reconstructed by DJI TERRA software based on SFM-DMVR algorithm. The UAV type used in this stage was the DJI Mavic Pro
as a mid-priced consumer drone, whose size and weight are also suitable for carrying in the hilly sites (Figure 3).

3.2. Digital Survey Test of the Baiyun Temple Cliff-Burial Site

The nap-of-the-object photogrammetry, as a new photogrammetry method invented in 2018, af-fords a method for grasping high precision images of vertical surface by segmenting intricate ter-rain into units. (Tao, Zhang, Duan, Ke, Xi, He 2021; Tao, He, Xi, Liu, Niu, Duan, Zhang 2019). Therefore, on the first step, we have used the nap-of-the-object photogrammetry as the main tool to scan the coarse model of the Baiyun Temple site to obtain the basic conditions of its caves (Fig-ure 4). From the coarse model we can obtain not only the basic dimensions of Baiyun cliff cave and the approximate shape of the objects in the cave, but also the placement position and angle of the object.
Then the further step is the attempt of planning a refined photogrammetric route to meet the possi-ble requirements of a higher precision model, which mainly depends on Waypoint Master(WPM) software. In photogrammetric 3D digitization, the key to improving model accuracy is to improve the imaging range. To calculate a refined photogrammetric route having a wider image range, we tried to determine the UAV camera declination, elevation and horizontal angle from the former in-formation from the coarse model (size, shape and coffin position).

3.3 Preliminary Survey and Test of the Jinji Cave Cliff-Burial Site

Unfortunately, the hanging coffins at the Baiyun Temple cliff-burial site have been damaged and lost, while most of the better-preserved sites such as Jinji Cave are in a forbidden zone, where UAVs are not allowed to take off without a special flight permits due to an air traffic control. The current research, therefore, includes ground data collection and simulation tests of the Jinji Cave site to propose a detailed plan for UAV flights and photogrammetry once the permission was granted.

TYPE	SIZE & WEGIHT	FOV	PIXEL	PAN&TILT	PRICE
DJI SPARK PRO	83 x 83 x 198mm (H x W x L)	78.8°	12.35 megapixel (Effective)	-90°- 30° (Pitch Angle)	6499CNY (in China)
	743g (Total)		12.71 megapixel (Total)	0° / 90° (Roll Angle)	

Figure 3. Table of Basic Information of Consumer UAV Equipment (Mavic Pro Technical Parameter 20221 ; DJI NEWS 20162).

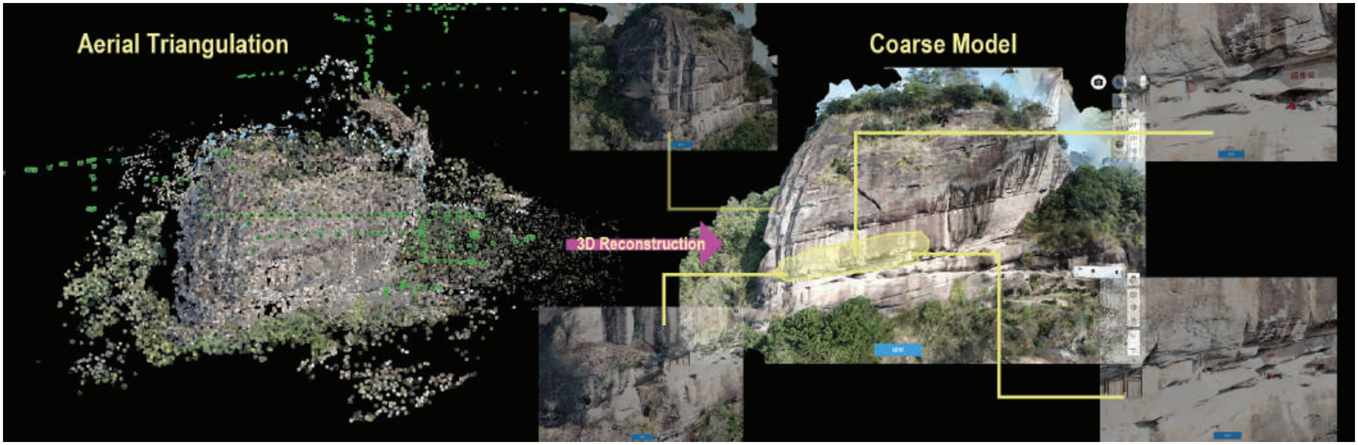

Figure 4. Coarse Model Results of the Baiyun Temple Site Based on the Nap-of-the-Object Photogrammetry Data.

The spatial pattern of cliff-burials from southern China to SE Asia has a variety of types; in section, the cliff-burial caves in Mt. Wuyi (especially the Jinji Cave site) are predominantly shallow, inwardly concave, and the coffins are placed in a direction roughly parallel to the cave openings (like the Type 1 in Figure 5). For the experiments, we selected a building elevation opening with no flight restrictions as the simulated environment for the Jinji Cave site (Figure 6), the color and orientation of the elevation and the height of the opening are all similar with the Jinji Cave. A solid model of a coffin made of similarly colored cardboard was also placed in the simulated cliff cave. The test was set by setting the UAV's elevation position, distance to the cliff face and camera rotation angle to test whether it could effectively record the coffin form and position information in this Jinji Cave site-like environment.

By adjusting the angle of pitch and deflection of the lens, and the point at which they adjust the an-gle, we were able to derive two imaging means each for the vertical and horizontal directions, in response to the specificity of the spatial environment of the cliff-burial (Figure 7).

Type A and Type 1 both involve imaging the fitted plane at a vertical angle after cutting and fitting the spatial plane to the complex cliff face form, ignoring the geometric complexity added to the cliff face by the cliff cave and the hanging coffin.

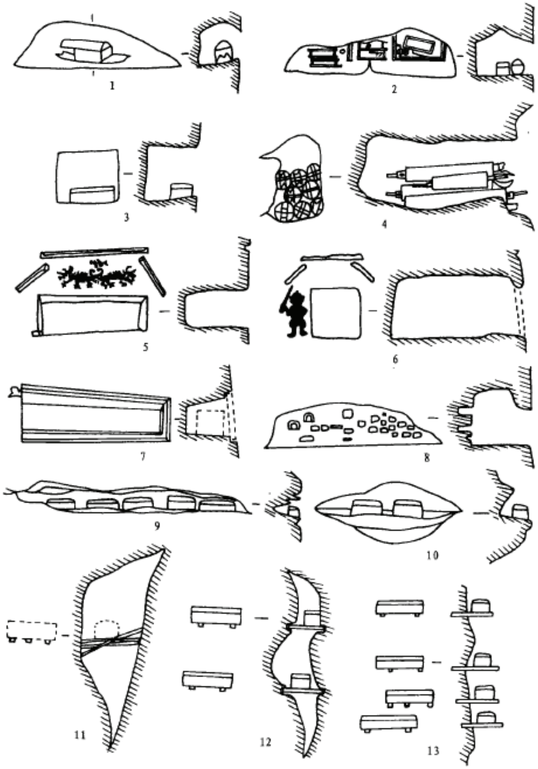

Figure 5. Diagram showing the different forms of cliff burial places (Wu 1999) p. 316, Figure1.

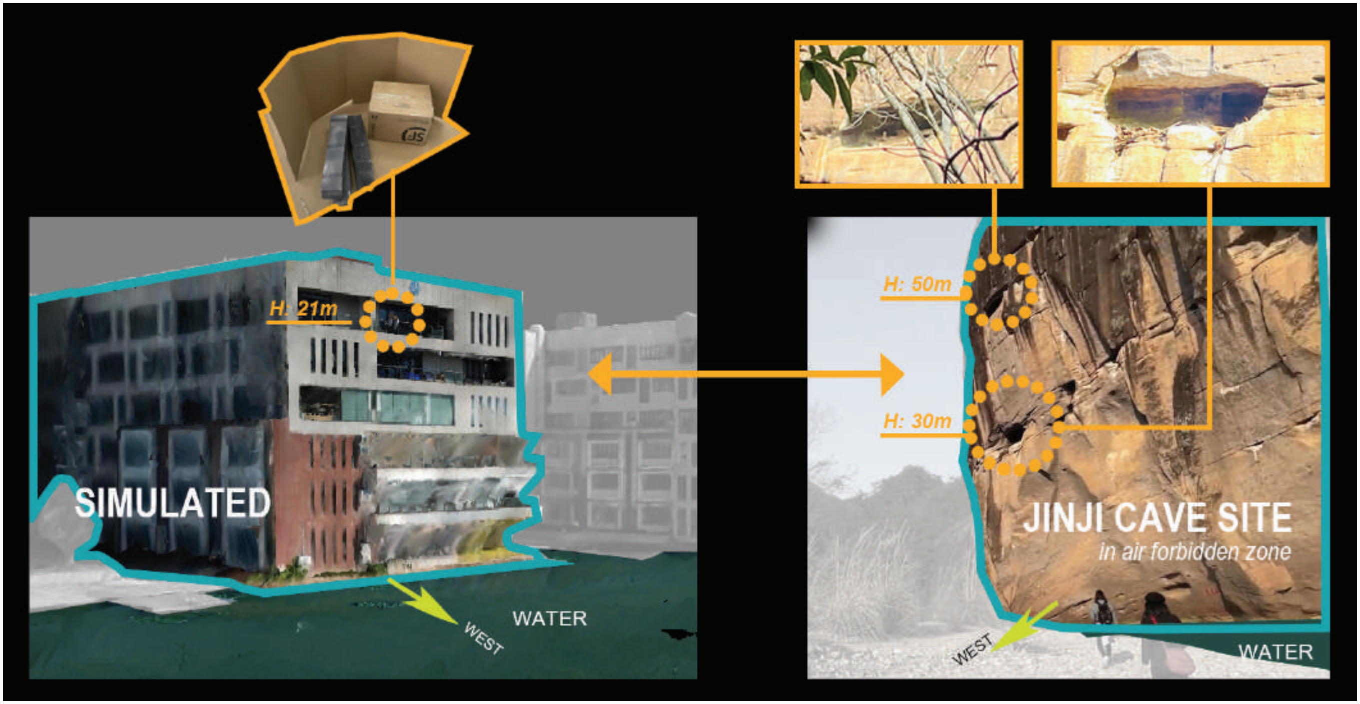

Figure 6. Simulating Tests for Jinji Cave Cliff-Burial Site.

Type B, on the other hand, is a quadrilateral fit to different morphological assemblages of objects within the cliff face, with the vertical direction vectors of the long and short sides of the quadrilateral determined as the horizontal imaging angle.
Type 2, on the other hand, images from the angle on the profile, with the camera lens first given a certain pitch angle in the direction from top to bottom. The pitch angle not only helps to prevent overexposure of the image that tends to result from photographing the white cliff face (Luo 2021), but also improves the imaging range and fore-aft overlap rate of the surface of the coffin or object being probed close to the inner side of the cave. When the field of view limited by the field of view (fovy) leaves the vertex of the object under test (HC elevation in Figure 7, 2), lowering the pitch an-gle raises the camera to increase the overlap rate inside the cliff cave, thus obtaining more infor-mation about the depth inside the cave and the top of the cave.

During the simulation, we designed experiments to investigate the effect of three different close-in photogrammetry methods on the data obtained by the photogrammetry, using a combination of Type A and Type 1 as the basic control group, while Type B and Type 1, or Type A and Type 2 as the experimental group.

4. Results

The results of the similar environment simulations (Figure 8) show that the 3D reconstructed mod-els derived from photogrammetry in the A2 and B1 methods are able to obtain better information on the morphology, scale and position of the objects than the simple angle-perpendicular-to-the-cliff face measurement method (A1). The A2 approach not only provides a more accurate indica-tion of the shape of the object in the vertical direction, but also has a greater imaging range of the depth and interior of the cliff concave, while the

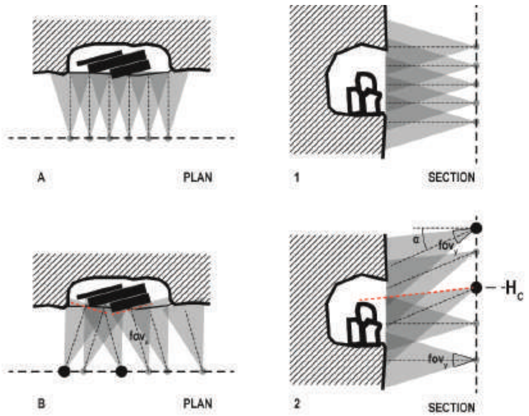

Figure 7. Diagram of Imaging of Cliff Cavity Areas Based on UAV Lens Rotation Declination Angle and Elevation Position.

B1 approach is better at reflecting the scale in the horizontal direction and produces a more concise model.

The A2 method can be used to investigate the vertical stacking of hanging coffins and the morphol-ogy of cliff caves, while the B1 method is suitable for horizontal assemblage and refinement of specific dimensional information. By organically combining the B1 and A2 methods for different types of cliff-burial sites, the digital information obtained can also be further enhanced in terms of accuracy.

Trial flights at Baiyun Temple have shown that elementary hand-controlled flights facing a cliff-bur-ial cave environment can be sufficient for initial information acquisition. At the same time, based on the results of the simulated test in similar environments, we have derived an accurate survey

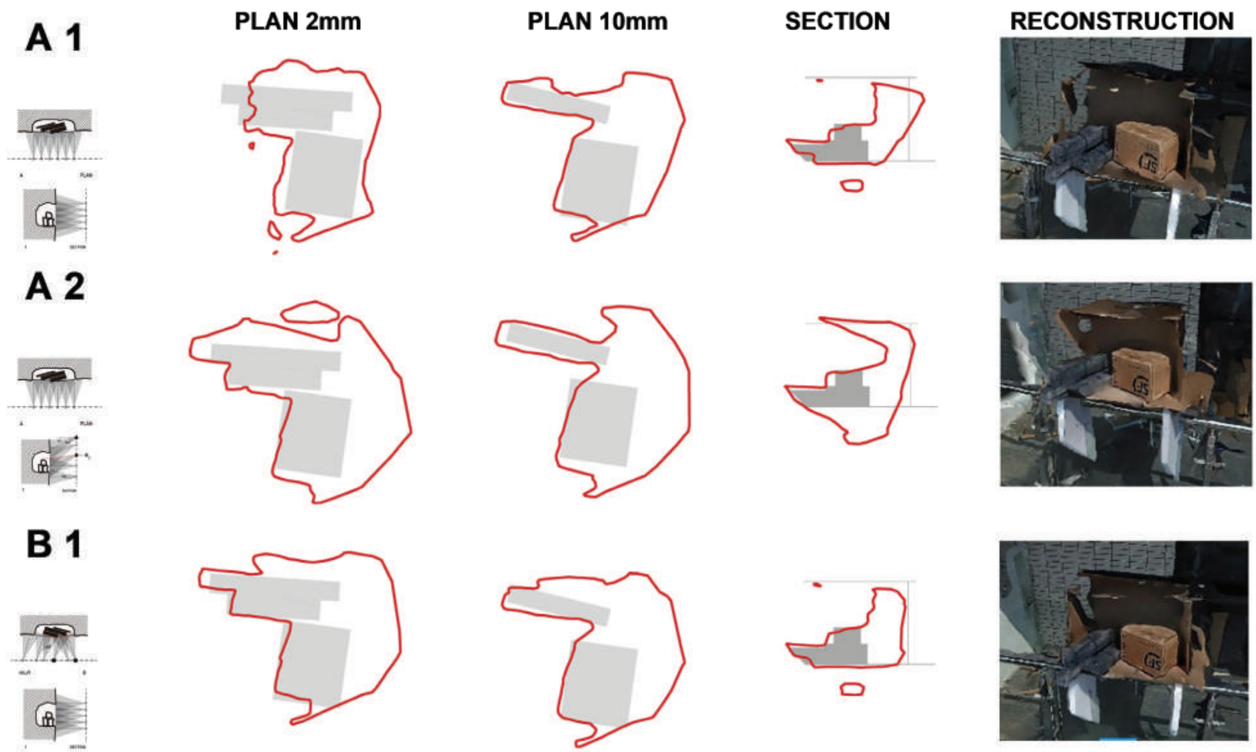

Figure 8. The Effect of Three Different Nap-of-the-Object Photogrammetry Methods on the Results of 3D Reconstructed Models (Results of the Simulations Based on Similar Environments).

trajectory based on the elevation position and scale of the cliff cave, the more efficient pitch and rotation angle of the UAV (Figure 9).

5. Discussion

The results of the simulations and their application to the refined route planning of the cliff burial sites not only demonstrate the feasibility of digital survey tools for UAV photogrammetry, but also suggest operational details for the cliff burial heritage site in terms of imaging methods, reflecting the differences between the application of photogrammetry in other cliff environments. This would lay the foundation for the global cliff-burial culture research. Furthermore, in Matera, Italy, there are several hypogeum sacred sites used as tombs which can be compared with the ones studied in China and East Asia. A survey method extendible on other excavated funeral sites would be tested and codified, as a possible follow up cases studies in Far East Asia and Europe.

The flight control did not allow for detailed UAV photographic measurements of relatively well-preserved cliff-burial sites, and even though the simulated experiments had a high degree of similarity in spatial context, the existence of exceptions cannot be denied. In addition to this, although the type of cliff cairn tested in the experiment is sufficiently representative, findings of the current study may not applicable to other types of hanging coffins (Wu 1999).

Possible directions for further research are the use of drones for nap-of-object photogrammetry to study cliff-burials in other profile caves, and the pillar holes (Figure 10) on cliff surface. It might reveal how hanging coffins were transported up the cliff (Jiang 1978), and the greater applicability of this technique to the study of cliff-dwellings, in the Mt. Wuyi and elsewhere.

6. Conclusion

This study takes two cliff-burial sites in Mt. Wuyi, the Baiyun Temple and the Jinji Cave, as cases for in-depth investigation. The UAV photogrammetry experiments not only proves the applicability of the technology in the special environment of the cliff-burial sites, but also proposes corresponding optimization measures for our study. It thus validates a new, efficient and safe method of digitally investigation of the worldwide historical and Cultural Heritage of cliff-burials. In further study, more experiments are needed to solve the problems caused by the poor lighting condition in the caves.

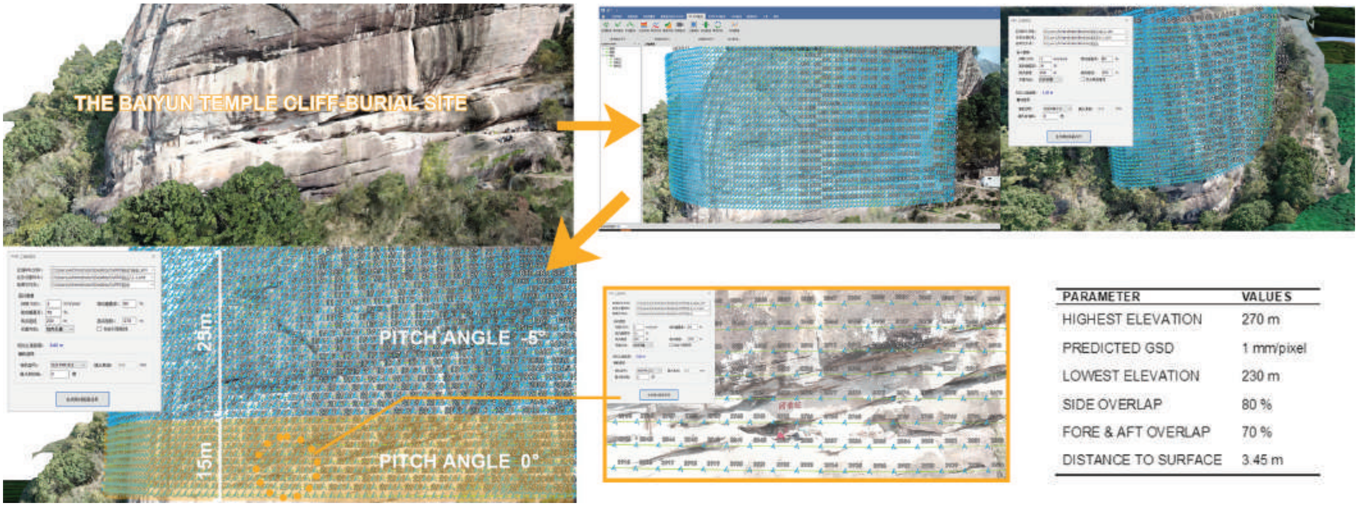

Figure 9. Accurate Survey Trajectory of Baiyun Temple Cliff-Burial Site.

Notes

1 Mavic Pro Technical Parameter, 2022. Mavic Pro Technical Parameter [online]. Available from: https://www.dji.com/cn/mavic

2 DJI NEWS, 2016. DJI Releases "YU" Mavic Pro Portable Drone. [online]. 27 September 2016. Available from: https://u.dji.com/cn/articles/36

3 WU, Chunming, 1999. A TYPOLOGICAL STUDY OF CLIFF BURIALS IN SOUTH CHINA. Acta Archaeologica Sinica. 15 August 1999. No. 03, p. 311–336. DOI CNKI:SUN:KGXB.0.1999-03-001

Figure 10. Suspected Pillar Holes on the Cliff Surface of Jinji Cave Cliff-Burial Site.

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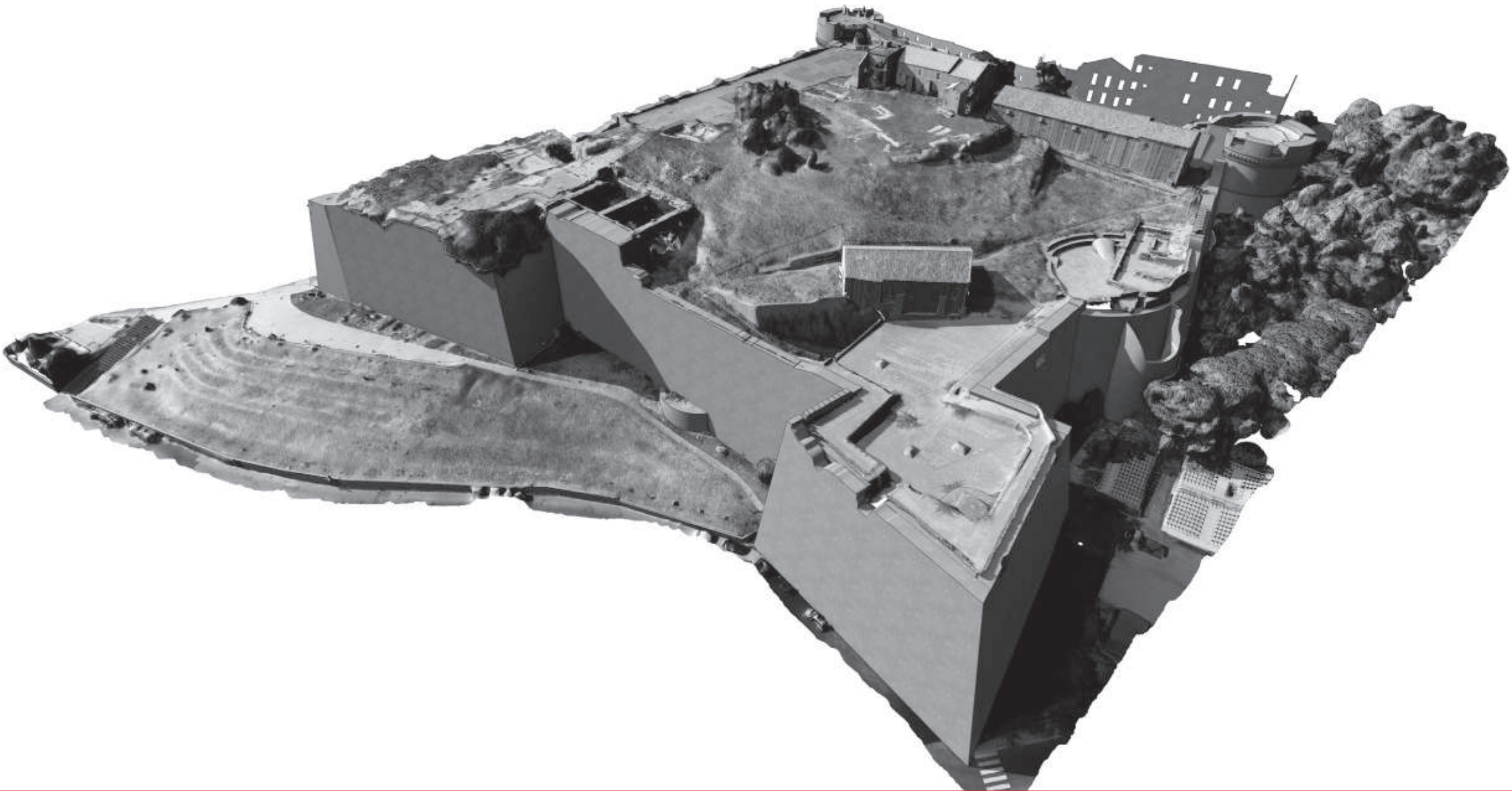

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UAV survey, Integrated Point-cloud, Visual Programming Language, Adaptive Family, *Króton*.

ABSTRACT

The potentialities of the use of the UAV survey as base for the generation of the context mesh are illustrated through the experiments on the case study, the Crotone Fortress, proposing two workflows for the importation of the triangulated model, maintaining its real geographical coordinates, in the Autodesk Revit environment through a Dynamo Visual Programming Script [VPL]. Starting from the georeferenced context of the photogrammetric mesh, nine federated BIM models were produced: four of the urban context, four of the detailed areas, and the architectural model of the fortress.

Image-based georeferenced urban context reconstruction in a BIM environment: the case of the Crotone Fortress

1. Introduction

Nowadays, the digitization of the built heritage and the processes of recording the surrounding environment have achieved great advances and can rapidly reach a vast number of users with multiple inputs (Stylianidis 2020).

Currently, the application of BIM methodology to the built environment is still a challenge, as it was not designed to interface directly with the real world, making it more suitable for the design than operations: to provide an efficient interface between software and physical data, it is imperative to create flexible and adaptive data collection systems (Brumana et al. 2017).

UAVs can be the basis for creating an interactive database of images for the metric reconstruction of 3D geometry. In the drive to achieve effective and accurate data collection, UAV technology is the main operational tool for creating BIM of existing large infrastructures (Barazzetti et al. 2016). The aim is to build a link between the data collected and the BIM models, thus improving the productivity of the model. Moreover, there are many studies concerning the semi-automated generation of NURBS, i.e., Rhinoceros, to be transformed into solid and exported to the BIM environment via a VPL script developed in Grasshopper (Acosta et al. 2022).

The results of some research, mostly related to restoration projects for identifying areas of degradation, identified according to shared protocols, based on the projection of photogrammetric orthophotos on BIM objects that, although geometrically accurate, are not parameterized. While other techniques used to reproduce “real-world” texture, to preserve access to intelligent objects with dissemination and preservation of Cultural Heritage in mind, involve “Decal types” or the creation of surface materials texturized via “Diffuse Maps” derived from photogrammetric ortho-imagery (Ferreyra et al. 2021). Conversely, outside BIM modeling, Grilli, Remondino (Grilli, Remondino 2019) are working to progressively improve the ability to recognize objects through artificial intelligence algorithms.

Such applications involved reverse-modeling procedures, i.e., the conversion of numerical models produced by point clouds into mesh surfaces, generating polygonal links that allowed to obtain a more fluid 3D model of historical centers, so to obtain a reliable qualitative model of the entire territory, to further optimize within environments such as 3D GIS (Parrinello et al. 2018).

Novel methodologies concerning the replication of complex details found in antique buildings, deal with manual/user-supervised cutting of the photogrammetric model; then, the resulting 3D model “pieces” (OBJ) are directly imported into a BIM environment and correctly placed in space using the point cloud as a guideline, to be later exported in as IFC objects and the exported to Revit for semantic enhancement. In this case, the limit of the proposed methodology is that it requires the use of many types of software and is quite slow (Barrile et al. 2022).

As of today, a few nodes within existing dynamo packages can “bake” the graphic results of various analyses (e.g., energy or solar analysis) performed on flat surfaces, such as floors, entirely within the Revit environment, have been developed. For instance,

Figure 1. Territorial overview with archival image overlay[2].

the workflow developed using Honeybee, Archi-Lab and Steam Node packages[1] is therefore capable of displaying, via a reprojection, the analyses result once these had been "transformed" into a UV map.
Although the long-term purpose of a BIM modeling is to standardize as many elements as possible, when the object to model is unique, as in the case of the urban context, which is typically different and distinctive from any asset, the aim should focus on standardizing the process to reproduce it most authentically, for further in-depth study.
Hence, a methodology involving two workflows to reproduce texturized photogrammetric meshes of the urban context and some detailed areas of interest within a BIM environment is hereby proposed. The aim is indeed to bridge the gap between the type of detail a survey can reach, specifically a photogrammetric one, when speaking about the colorimetric data and what is possible to reproduce in a BIM environment when talking about peculiar rather than unique elements such as the urban context or detailed relevant elements, such as frieze/decorations or damaged areas.

2. Case study

The Calabrian fortress known as the Castle of Charles V is one of the most imposing in southern Italy. It represents traces of a quadrangular profile around a hill's upper slopes, fortifying them and reinforcing the corners with two circular towers (*Torre Aiutante* and *Torre Comandante*) and two polygonal bastions (*Bastione Santa Caterina* and *Bastione San Giacomo*). The case study is the emblem of the historical memory of the Crotonians, as it was built upon the site of the original Greek acropolis (*Króton*), firstly transformed into the Roman citadel and later into medieval fortifications.

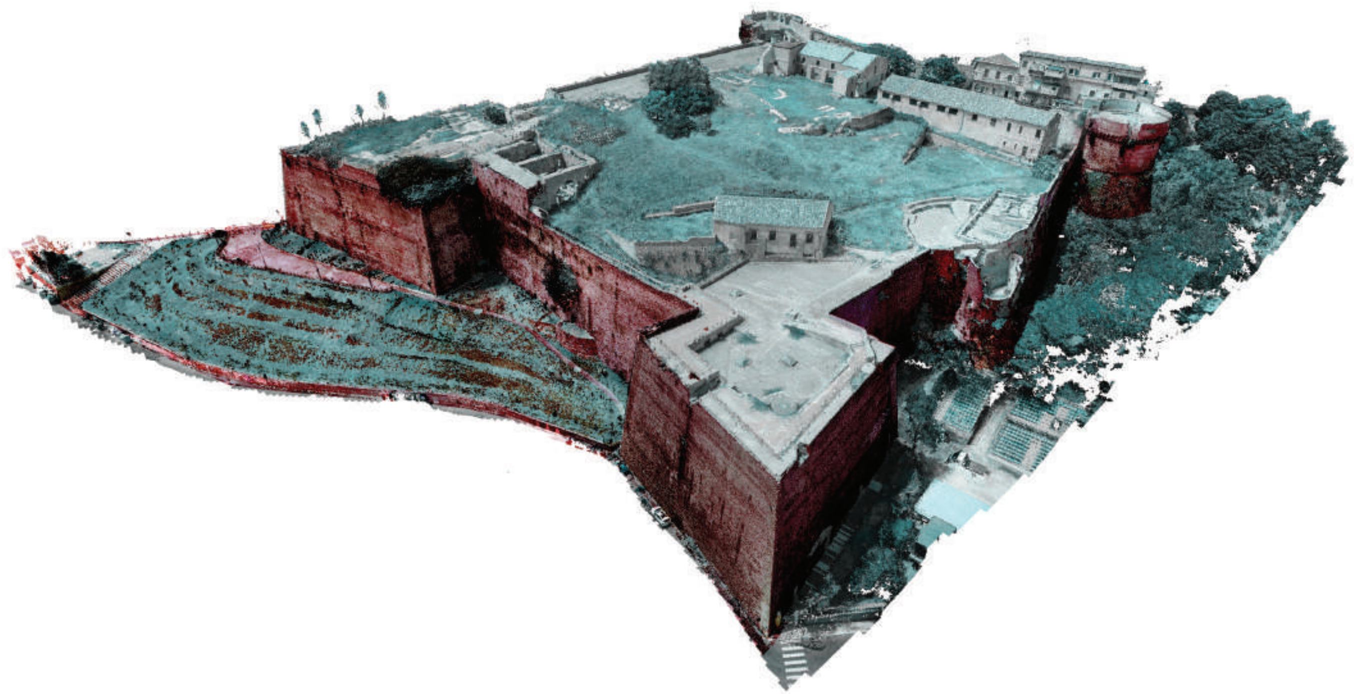
Figure 2. Integrated TLS (red) and UAV (blue-green) point clouds.

The fort became one of the 75 castles belonging to Roger II's vassals during the Norman period. It was accessed through what is now Piazza Castello, due to a partly fixed stone bridge and a partly wooden drawbridge. After the Swabian conquest, Frederick II decided to restore the castle with the city port. In the 14th century, the medieval fortress underwent some adaptations imposed by using artillery, although the heaviest changes date back to the end of the 15th century, when Ferdinand I ordered the fortification of the most exposed maritime sites in Calabria. Another major restoration was carried out by Charles V at the end of the 16th century to comply with the latest fortification criteria, followed by those of the 17th and 19th.
As time goes by and due to the technological advance of war weapons, the castle lost its strategic-military importance and during the 19th century it was partially dismantled also because of damage caused by frequent earthquakes. To date, it houses a Civic Museum of archaeological interest[2].

3. Methodology

The Scan-to-BIM approach involves first surveying the structure and the surrounding landscape on which to develop a 3D model. Thus, the starting point of the present work is a TLS and UAV survey carried out by the *Laboratorio Modelli* of the University of Salerno in July 2021. The aero-photogrammetric project was correctly scaled and georeferenced using 6 Ground Control Points (GCP) (Barba et al. 2019). A working HBIM methodology is then proposed for the realistic and correctly georeferenced modeling of architectural assets and the relative urban context, focusing on the accurate morphological-colorimetric reproduction of some suitably selected detailed areas. The proposed

Figure 3. Photobashing of the Scan-to-HBIM process.

techniques were validated on a medium scale heritage case study, with a special focus on a detailed area that allowed to verify the accuracy of the application. The suggested methodology can be organized in four phases, resumed as follows:

- GEO: Georeferencing;
- FSC: Federate modeling and Shared Coordinates setting;
- ARC: Architectural modeling;
- LOI: Level of Information enhancement.

The procedure is iterative, so it may employ repeating some steps along the whole BIM modeling process or, at least, exchanging some of them.

Particularly the LOI phase, although not explicitly addressed in this article, represents, at different levels, a constant throughout the process, whether performed manually or via VPL scripts, by populating ad hoc parameters with different types of information.

The GEO phase into the BIM environment is here optimized by importing the mesh models, thanks to VPL scripts, in the same local coordinate system of the photogrammetric model. This way, it is possible to revert to the global coordinate system by simply imposing the same rigid translation – in the opposite sense – to the "Project Base Point" (PBP)[3] of the Revit projects. It was carried out by directly importing the triangulated models, commonly known as polygonal meshes, obtained directly from the photogrammetric modeling process. Once the exact georeferencing of both the macro-areas of the urban context (Workflow A) and the detailed areas (Workflow B) had been carried out by operating on the PBP, it was, therefore, possible to organize the federation of the architectural model with no difficulty. The FSC stage requires the projects (RVT) to be linked into a super-ordinate project using the PBP as a reference, thereby taking them as a guideline for integrating the architectural modeling of the castle – ARC stage. Following the

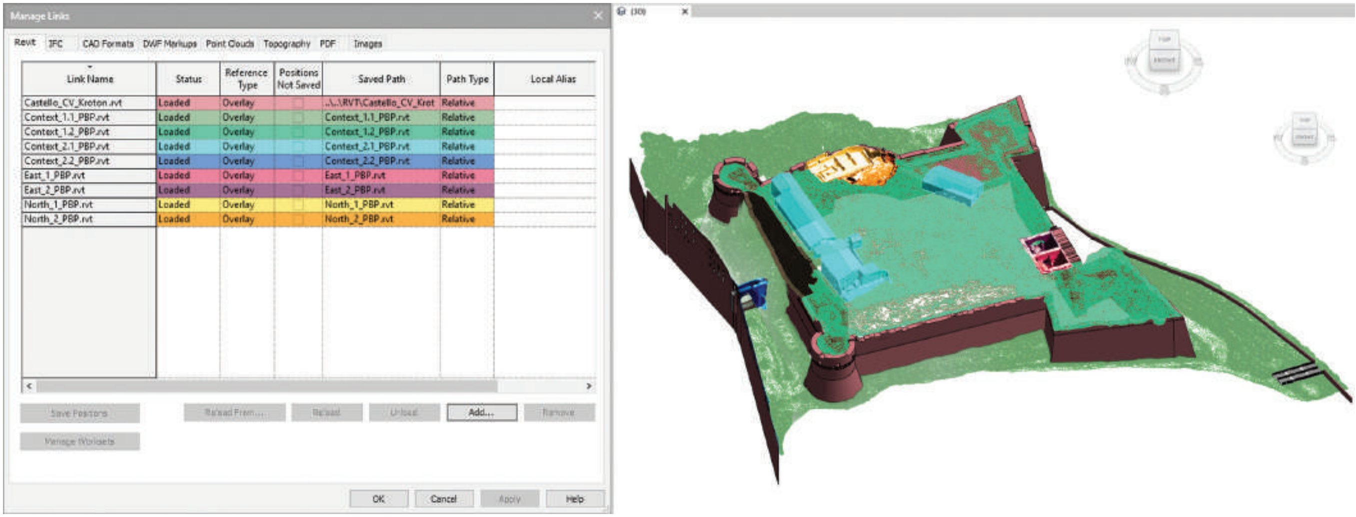

Figure 4. Overview of the federated linked models.

georeferencing of all the parts that constitute the overall model, it is necessary to "publish the shared coordinates"[4] to all the linked projects.

3.1. Global to local system transformation

Working with topographic coordinates, in some software not designed to manage this type of coordinates (i.e., Meshlab, Dynamo, etc.), often involves approximation problems in the correct interpretation of the same coordinates, leading to an incorrect visualization consequent reproduction of the mesh.

For this reason, it was decided to operate a transformation from the global system to the local system – so that the x, y, z coordinates of the points of the cloud and consequently the vertices of the mesh have the same order of magnitude – by operating a rigid translation.

The rigid translation aiming to shift from a global to a local one was performed at the end of the photogrammetric process by operating on the GCP used to scale and georeference the model.

A fixed quantity was subtracted from both the longitude and latitude of the control points in the photogrammetric project.

These quantities will then represent the inverse translation to be imposed in the BIM environment by georeferencing the PBP, thus operating the rigid inverse translation.

3.2. Workflows premises and meshes setting up

For an ordinary notebook (Core i7 16GB of RAM, 2GB VRAM) to be able to process the script and manage the results, it is advisable to keep the mesh-faces count under 600'000 units, for the first method proposed, and under 20'000 units, for the second one, simplifying and splitting in more than one project the original photogrammetric mesh model[5].

Thus, to ease the process we reduced the face count of the meshes by simplifying them – via smoothing and decimate tools.

Those ones employed in the second methodology proposed were then texturized, still within the photogrammetric software, to later export the texture as a PNG. Meshlab, developed by ISTI-CNR was indispensable to the mesh cleaning and repairing step, removing all the stray triangles/faces and fixing any problematic vertex and/or edge.

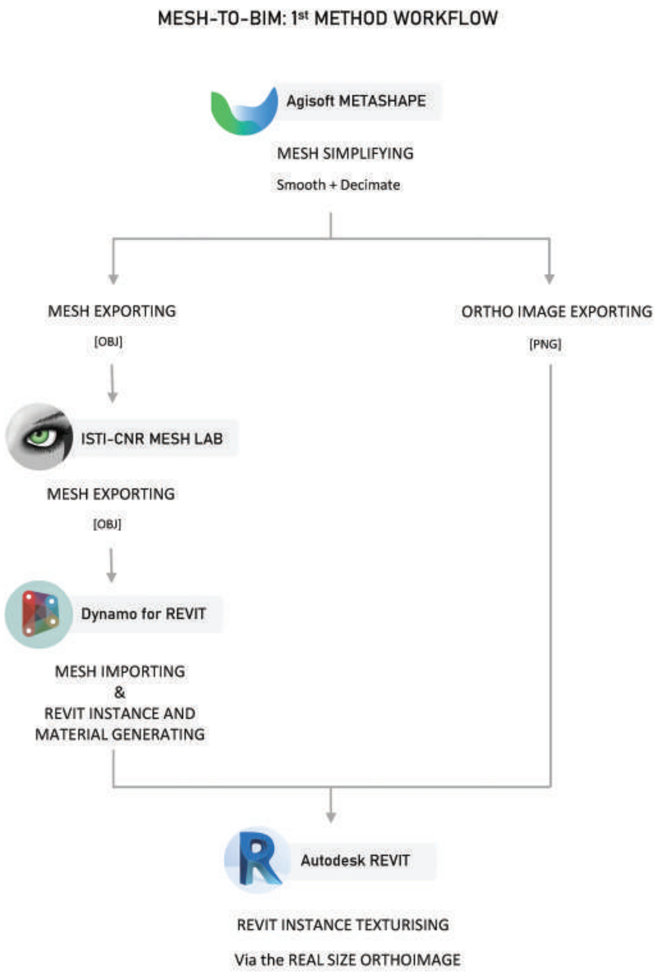

Figure 5. Workflow A scheme.

3.3 Workflow A

The first proposed workflow involves using a simple VPL script to implement photogrammetric meshes (OBJ) of large areas of the urban context in the BIM environment. Together with related material, they are generated as instances falling under the categories "Site" for the predominantly horizontal areas of the urban fabric and "Mass" for some characteristic vertical elements of the urbanized area.

The mesh models of the general context, once projected in Revit, were textured through the full-sized orthophotos, imported in the "material browser" as color maps.

The first workflow works quite good for larger urban areas that constitute the unique context of an architectonic asset, specifically whenever they are predominantly horizontal; on the contrary, this method does not work flawlessly in case of particularly articulated areas worth being reproduced precisely together with their colorimetric information, for their historical value or so to estimate their extension for further analysis.

3.4 Workflow B

The northern and the eastern areas chosen for the second method application represent some of the remaining structures of the 14th century adaptation before the Charles V's 15th century restoration.

Though the second workflow starts from photogrammetric meshes (PLY-ASCII encoding) properly simplified as explained above, this time, the meshes of the selected detail areas have a much smaller extension and are exported with the relative texture (PNG).

The surface is first treated separately, reducing the color scale from 256 to a range varying between 8 and 15 (indexed colors) depending on the colorful nature of the image in question.

In Meshlab, it is then possible to reassign the texture to a mesh, projecting the colors to its vertices and from the vertices to its faces. Once the mesh has been re-exported in PLY-ASCII format, it is possible to directly read the numerical information that describes it, operating a selection of the chosen data, particularly the indexes of the faces and their relative colors (Microsoft Excel). Both the mesh in 3D format (PLY) and its data in numerical format (XLSX) are then used as input, together with a family of triangles with adaptive vertices (Triangular Face.RFA), for reproduction in the BIM environment through the second VPL script, which was developed explicitly for this purpose.

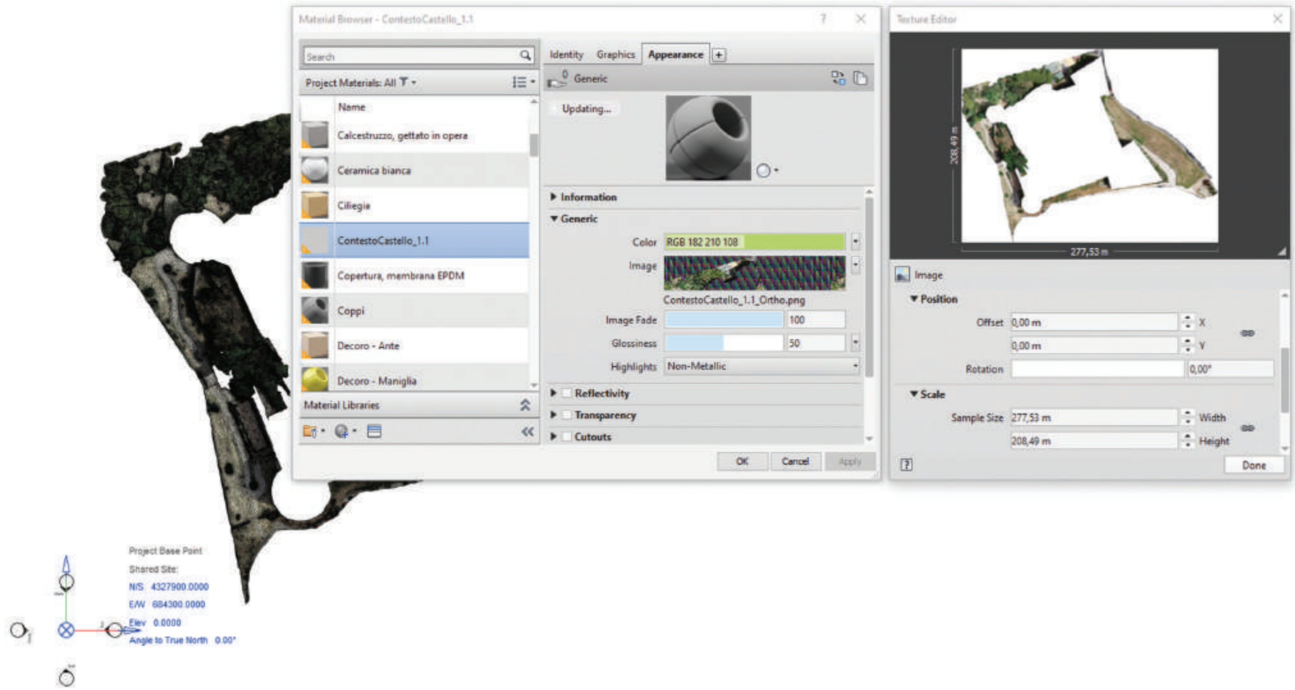

Figure 6. Real-sized orthoimages used as textures for the Revit materials.

4. Results

This study provides an efficient semi-automated approach to extract geometric information from a complex topography acquired with laser scanning and photogrammetry data to create a BIM as-built based on the extracted information to perform a correct contextualization. This approach allows obtaining the necessary parameters to create BIM models of historical architecture with complex shapes from an integrated point cloud.

The results show that the proposed approach could efficiently and accurately extract geometric information from the existing architecture survey for subsequent recovery or restoration projects of existing buildings. Depending on the required level of detail, it is possible to obtain both a contextualization precise enough and a morphologically and colorimetrically accurate reproduction of selected areas of detail, for those elements of the built environment with a typically unique formal and cultural value, thus, worthwhile for informative modeling within a wider monitoring system. In particular, modeling detailed elements carried out on parts of the context is reproducible for any unique detail that can be catalogued under a "Category" other than "Site". Noteworthy is indeed that these detailed areas were imported into the BIM environment not as a whole but by reading the coordinates of the vertices of the individual faces that make up the polygonal triangulated model and the relative real colorimetric data.

5. Conclusion

Although the automation of the protocols used to produce these types of procedures has yet a long way to go, they are fundamental in defining the basis

Figure 7. Results of the workflow A with evidence of texturing defects in vertical elements.

from which to develop multimedia systems capable of reproducing the complex spatial relationships that exist between the built environment and historical architectural artifacts.
Indeed, the informative digitization of complex territorial realities aims to promote programs of historical heritage renewal, updating the existing database and developing, through a 3D digital system, practices for the conservation and restoration of the architectural heritage (Parrinello et al. 2018).
The management of the existing heritage cannot be separated from a thorough investigation of the state of conservation of the materials and a detailed 3D reconstruction. The morphological and colorimetric

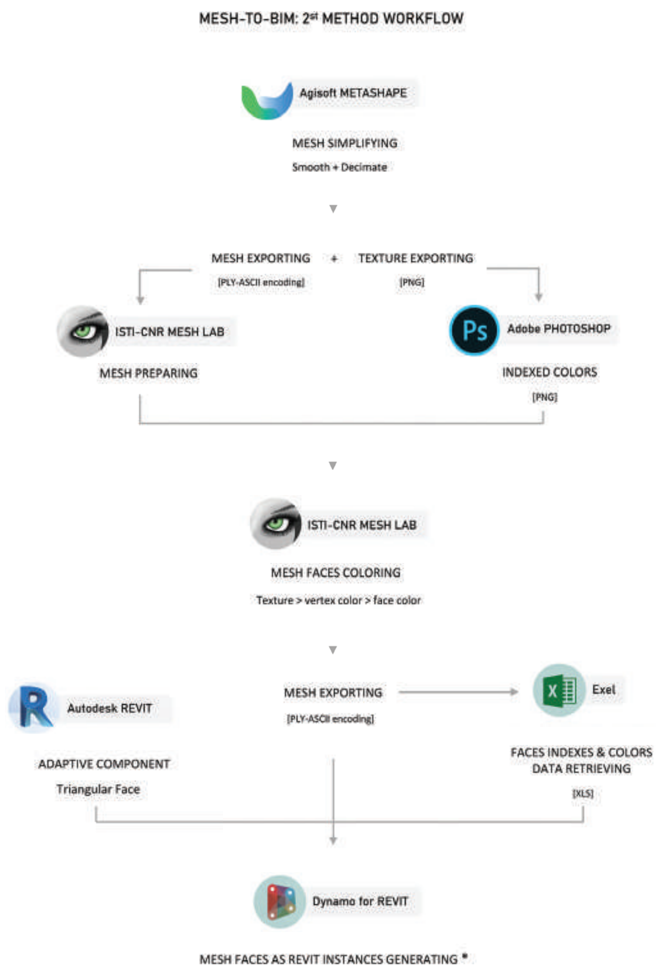

Figure 8. Workflow B scheme.

reconstruction of peculiar complex structures, elements and friezes in a BIM environment is vital for the building of databases to store data and facilitate the planification of restoration or partial reconstruction (Barrile et al. 2022). Indeed, the semi-automated implementations proposed here can be easily applied in subsequent case studies to improve the automation of the methodology and further develop its potential to estimate the geometric dimensions of any area under study accurately.

Notes

1 To learn more about how to "bake" the results of a daylight analysis from Honeybee (Dynamo) to Revit as colored surfaces, visit: https://hydrashare.github.io/hydra/viewer?owner=SamDehghani&fork=hydra&id=Bake-Honeybee-Results-To-Revit-As-Colored-Surface&slide=0&scale=1&offset=0,0.

2 To further investigate the historical evolution of Crotone castle, we suggest visiting the following web pages: http://www.archiviostoricocrotone.it/chiese-e-castelli/il-castello-di-crotone/; http://www.archiviostoricocrotone.it/urbanistica-e-societa/fortificazione-della-citta-e-castello-di-crotone-negli-ultimi-anni-aragonesi/; http://www.archiviostoricocrotone.it/urbanistica-e-societa/fortificazione-della-citta-e-castello-di-crotone-in-eta-moderna-1550-1780/; http://www.archiviostoricocrotone.it/chiese-e-castelli/nuove-ricerche-sul-castello-di-crotone/.

3 A Revit project store internal coordinates for all the elements that compose the model in a project. In detail it is possible to distinguish between two different origin points: the Project Base Point (PBP) and the Survey Point (SP): the PBP defines the origin (0,0,0) of the project coordinate system. Use the project base point as a reference point for measurements across the site; the survey point identifies a real-world location near the model, such as a corner of the project site or the intersection of 2 property lines. It defines the origin of the survey coordinate system, which provides a real-world context for the model. To learn more about Project Base and Survey Points visit: https://knowledge.autodesk.com/support/revit/learn-explore/caas/CloudHelp/cloudhelp/2018/ENU/Revit-Model/files/GUID-68611F67-ED48-4659-9C3B-59C5024CE5F2-htm.html.

4 When multiple models and files are combined in a single project, shared coordinates are used to establish the positions of the files in relation to each other. The Shared Coordinate tools (particularly the "Acquire Coordinates" tool or the "Publish Coordinates" tool) are used to establish the relative positions of the different files and ensure that those relationships are maintained. To learn more about shared coordinates visit: the https://knowledge.autodesk.com/support/revit/learn-explore/caas/CloudHelp/cloudhelp/2020/ENU/Revit-Collaborate/files/GUID-B82147D6-7EAB-48AB-B0C3-3B160E2DCD17-htm.html.

5 A polygonal mesh is at least composed of vertices, edges and faces. In the case of a triangular mesh, its faces have three vertices, located in space by their coordinates (x, y, z). To compose each triangle, it is therefore necessary to know the indices of its vertices, intended as the number that identifies the place of each vertex in the complete list. To learn more about polygonal meshes visit: https://www.scratchapixel.com/lessons/3d-basic-rendering/introduction-polygon-mesh.

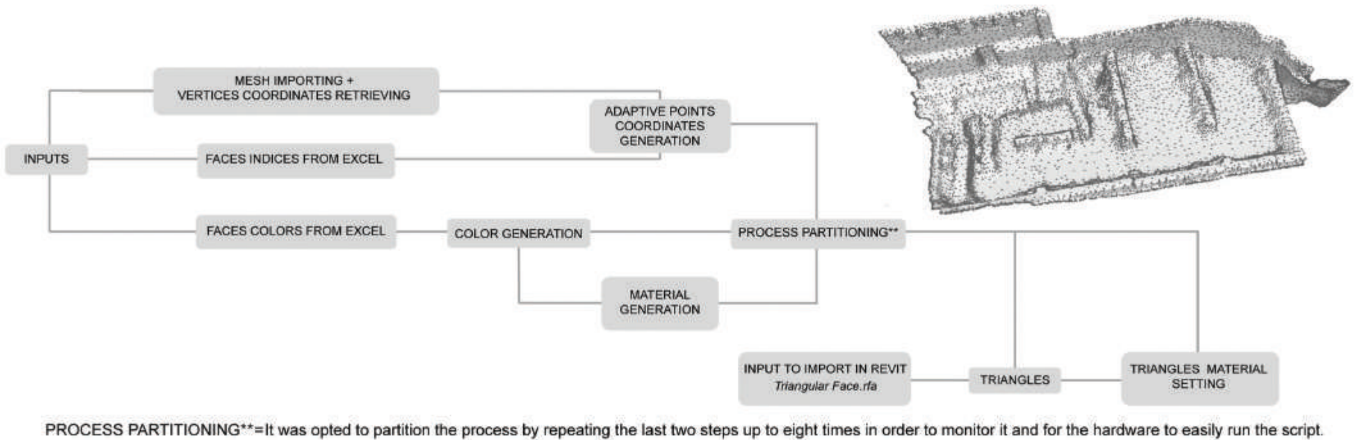

Figure 9. VPL script to reproduce mesh as Revit instances*.

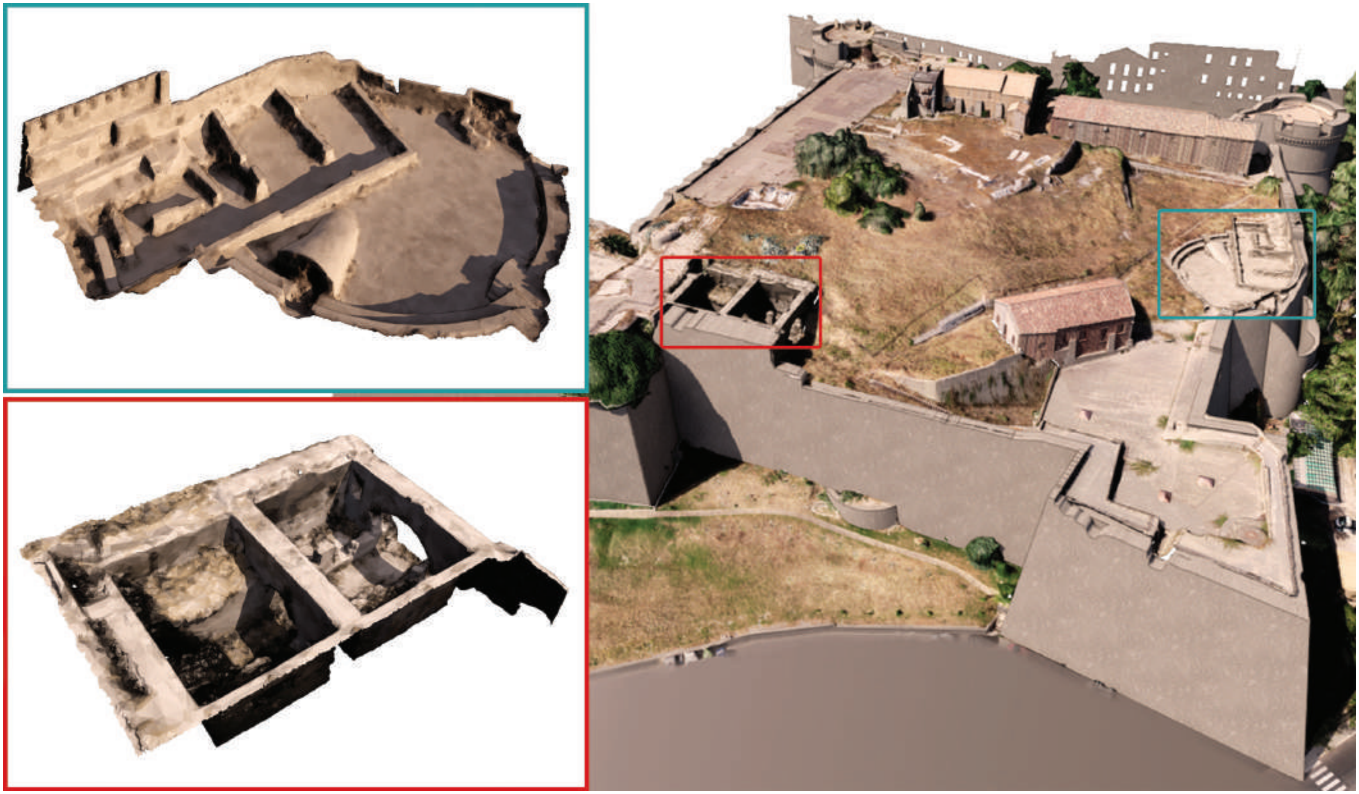

Figure 10. Results of the workflow B zooming on the detailed areas reprojection in Revit.

Figure 11. Rendered federated models

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ABSTRACT

The present paper describes the first results of a research project aimed at the metric-morphological and archaeological study of the Church of San Silvestro in L'Aquila.

The workflow has been set up on a preliminary digital survey of the multi-layered structure conducted using integrated acquisition methodologies and techniques, TLS and UAV, which have allowed both to develop a reliable metric basis for archaeological investigations, but also to highlight their potential use in the field of documentation of architectural complexes located in seismic areas for preservation and monitoring.

The Church of San Silvestro in L'Aquila. An integrated approach through TLS and UAV technologies for the architectural and archaeological documentation

1. Introduction

The study is part of a wider research project aimed at providing valuable data for a better understanding of the dynamics of construction and settlement of the city of L'Aquila, from its origins to its current conformation, through the analysis and study of the building fabric of its historic center.

In particular, sites of great importance have been analyzed, which have allowed us to give back helpful information on the building patterns present in the city center and the transformations of building techniques following the numerous seismic activities that have affected the territory.

The project has foreseen the realization of detailed and punctual surveys of the internal and external morpho-constructive characteristics of various architectural complexes, carried out through laser scanner instrumentation and aerial and terrestrial photogrammetry, to evaluate possible vulnerabilities or specific features and, at the same time, to carry out stratigraphic readings of the wall faces, compared to the historical-constructive analyses that emerged during the field investigations.

The analysis has provided a level of detail based on a macro-reading of the city fabric, mainly based on the reconnaissance and macro-stratigraphic analysis by sample of several buildings since the data obtained from a single structure would have inevitably led to misinterpretation of the final data overestimating or underestimating the effects attributable to each earthquake. Moreover, it was decided to initially analyze the vestments of the best-preserved ecclesiastical buildings from a stratigraphic point of view, without restoration, plastering or reconstruction so invasive as to erase the stratigraphy, through a well-established study methodology (Arrighetti 2015; Brogiolo, Cagnana 2012).

Therefore, the proposed work explores the case study of the church of S. Silvestro in L'Aquila, exemplifying and presenting the methodology of analysis and research conducted on a larger scale on the overall historical buildings of the city.

Figure 1. Aerial view of the religious complex of the Church of San Silvestro in L'Aquila.

2. The Church of San Silvestro in L'Aquila

The church of San Silvestro is located in the quarter of Santa Maria, which in 1265 became the property of the inhabitants of Collebrincioni through a royal decree of Charles I of Anjou (Signorini 1868; Equizi 1957).

Many researchers agree in attributing the construction of the building to a date after the earthquake of 1349, based on the studies of Signorini (Signorini 1868, p. 269 ff.). However, other sources testify a San Silvestro already in 1265 or 1285 (Equizi 1957, p. 114), anticipating the building site by almost a century. The first mention of an abbot of San Silvestro dates back to 1323, an element that highlights the potential role of collegiate assumed by the church (Signorini 1868). In 1349, at the death of Angelo di Giovanni di Collebrincioni, the abbot of San Silvestro was appointed executor of his will. He was able to count on a large sum of money to reconstruct the building, which had become necessary after the severe seismic event that occurred during the same year. From that moment on, the bequests to San Silvestro became more conspicuous and numerous, enough to confirm the role assumed by the church as a centralizing pole and a place of reference for the L'Aquila community.

During the earthquake of 1461-1462, sources attest that the stability of the supporting structures was not compromised, despite the collapse of the roof and the bell tower (Colapietra 1978). Therefore, probable restorations were carried out to secure and restore the portions stressed by the seismic event. During the sixteenth and seventeenth centuries, the church underwent simple aesthetic improvements, while, only in 1722, further restoration and consolidation works were carried out. In 1780 the roof was restored, and, according to what was reported, it was the only one in town that was visible (Equizi 1957, p. 115).The last major restoration works date back to 1967 when a radical transformation was carried out by Moretti, who, after the works carried out, was able to assert that only the façade should be attributed to the 14th century, while the central structure could be dated to the second half of the 13th century (Moretti 1972, pp. 690-710).

With a Gothic-Romanesque aspect on the outside and a Gothic-Renaissance one on the inside, in its present state, the building appears as a multi-layered structure strongly altered by the interventions carried out in modern times and by those following the earthquake of 2009, which have partly erased the visibility and the legibility of its external and internal facings.

Figure 2. Historical views of the church dated respectively 1600, late '800 and early '900.

3. Methodology of integrated digital survey of the architectural complex

As mentioned above, the methodology adopted within this research work has set as its first objective the development of a digital survey of the entire structure, carried out through integrated acquisition techniques and intended to provide a graphical basis as reliable as possible from the qualitative and geometric-morphological point of view.

The religious complex of the church of San Silvestro was the subject in February 2021 of a double intervention of non-invasive geometric documentation, carried out in the first instance by Terrestrial Laser Scanning (TLS) and subsequently implemented by a photogrammetric survey SfM developed with photographic captures from the ground and through a UAV device. These were integrated during the acquisition and processing phase and also in their results, to obtain 2D and 3D elaborations at different scales of detail, intended for multidisciplinary applications and analysis (Bertocci et al. 2019). In particular, the main objective of these surveys and digital elaborations was to provide metric-morphological guidelines and digital support for developing the stratigraphic analysis of the complex and its architectural components.

The methodology followed for the elaboration of this digital documentation has provided a preliminary phase carried out on-site to plan the digital survey activities, with particular attention paid to the definition of the flight paths of the UAV. In this regard, it was preferred to carry out the acquisitions in manual mode to have greater control by the operator, given the urban context in which the church is located.[1]

The first operations conducted for the site documentation involved the use of a TLS technology. To acquire the metric and morphological data of the study site, a Faro CAM2 Focus[M] 70 instrument was used, a laser-scanner with phase-difference technology, through which 59 descriptive scans of the external perimeter of the building and its principal interiors were performed.[2]

The data acquired during the survey campaign using TLS were imported and processed within the Leica Geosystems Cyclone software, through which the main phases of filtering, registration, certification and processing of the global point cloud were carried out,

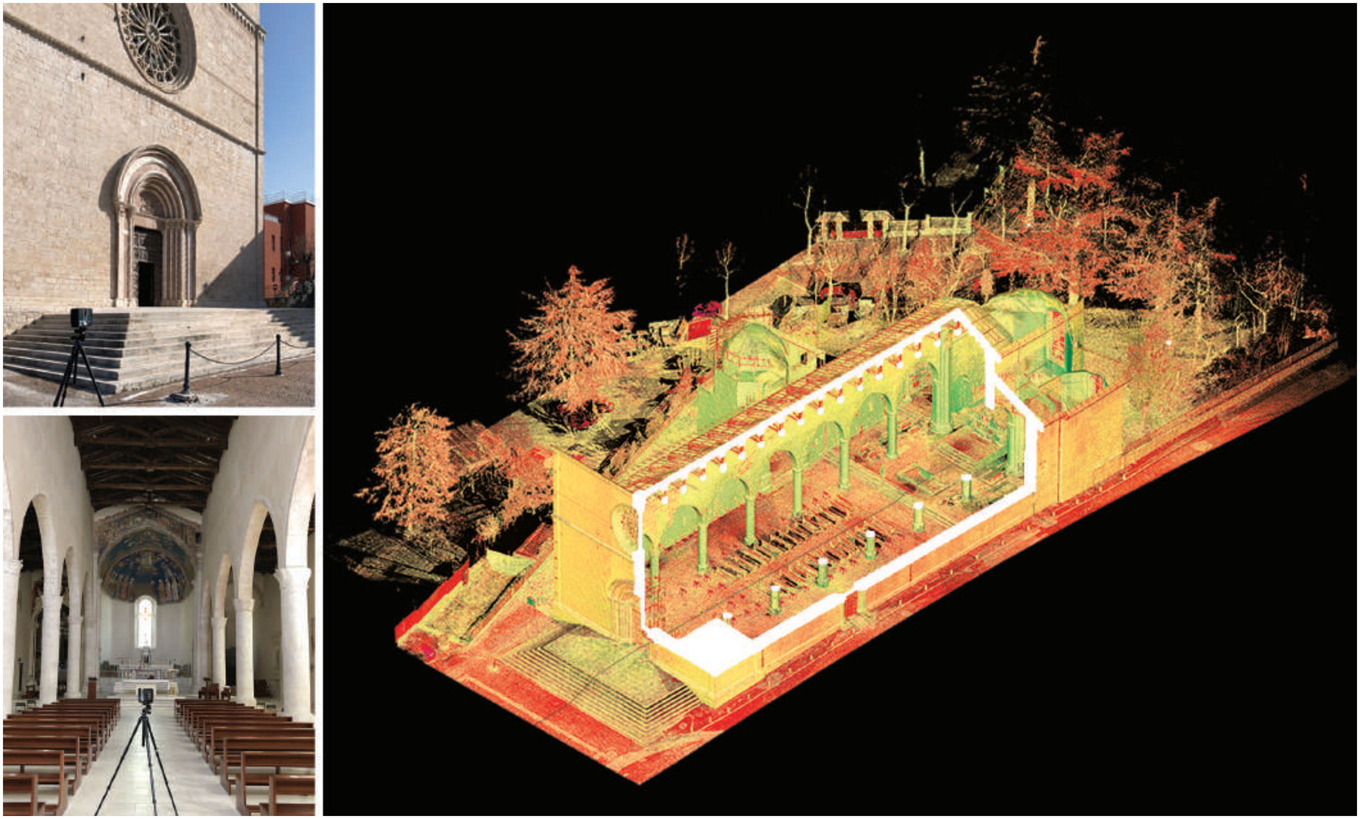

Figure 4. Data acquisition phases using TLS and axonometric cross-section of the point cloud of the Church.

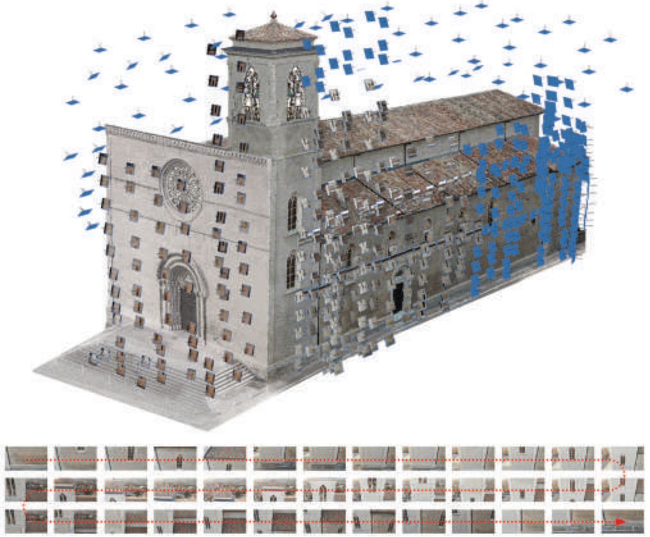

Figure 5. Photographic data acquisition paths using UAV and close-range devices.

according to a methodology widely established by the research team (Bertocci et al. 2021).

Parallel to the development of the laser-scanner survey, a series of SfM photogrammetric survey campaigns were carried out, aimed at integrating the metric-morphological data derived from the point cloud from TLS with a product capable of representing, through mapped 3D models, information about the appearance and the state of preservation of the different architectural elements of the study complex.

For this purpose, different instrumentation and photographic optics were used. Several digital cameras were used for the close-range acquisitions, including a Canon EOS 1100D SLR and a mirrorless Olympus OM-D EM-1 Mark II, with various lenses models. A DJI Mavic Air model UAV has been used in addition to the detailed photographic surveys on the ground to develop the SfM aerophotogrammetric survey of the church of San Silvestro.

The massive acquisition through these devices, with photographic datasets of about 550 photos from drone and 700 from the ground, was carried out to ensure a broad overlap between the various captures to facilitate their integration during the photogrammetric processes. With a specific focus on the methodology of acquisition and SfM photogrammetric processing of photographic data from the drone, the operational workflow developed by the research group is described below.[3]

Images were taken using the drone's integrated camera at nadiral inclinations, at 45° and orthogonal to the main elevations of the church. The three flights performed lasted approximately 20 minutes each and were conducted at times when there were not too many shadows on the structures.[4]

The photographic data acquired by the drone was subsequently processed within Agisoft Metashape Pro, an SfM photo-modeling software. Through specific SfM processes[5], it was possible to obtain in a short time not only the global textured model from which the orthophoto plans were then extracted, but also the metric mapping in the form of dense clouds of all those upper parts of the church (such as roofs, bell tower and second-order windows) that the TLS survey had not succeeded in acquiring (Ferdani 2020).

These assets were finally referenced and calibrated according to homologous point coordinates extracted from the TLS survey, thus determining the integration between the two digital survey methodologies and obtaining both the mapped 3D model of the church and

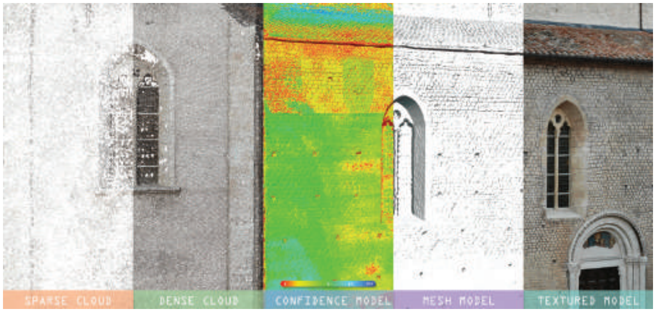

Figure 6. Main photogrammetric processes within Metashape software: sparse and dense clouds, confidence, mesh and textured models.

a global point cloud including the scans from TLS and the dense cloud from UAV.

Through a careful process of data digitization[6] and discretization of these assets, reliable 2D graphic elaborations were produced, mainly including elevations and floor plans in 1:50 scale, both in the form of wireframes and orthophotos.[7]

The corpus of elaborates produced allowed to accurately and comprehensively document the church, both from a metric-morphological and chromatic-material point of view (Minutoli et al. 2020).

4. Archaeological analysis of the architectural complex

The virtual reconstruction of the digital-twin of the church, based on the elaboration of the data developed by the integrated reality-based survey, and in particular on those acquired by the UAV photogrammetry, describing the elevated areas of the church not caught by the laser-scanner, led to the second aim of the research project: the archaeological analysis.

The latter, conducted both on-site and digitally on the graphical drawings, mainly concerned the external walls of the church, the first witnesses of the transformations undergone by the structure over the centuries.

Given the complexity of the structure and its not optimal readability, a diachronic approach was taken, i.e. an initial macro interpretation of the evolution of the artifact was carried out through the evaluation of the stratigraphic relationships established between the different structures[8]: CF1 - Bell Tower[9], CF2 - Church[10], CF3 - Chapel and CF4 - Rectory[11].

In addition to these first investigations conducted on-site, a more in-depth analysis of the architecture and construction techniques adopted was then carried out, focusing mainly on the understanding of the Masonry Stratigraphic Units (MSU) of the east elevation, the only one without plaster and restored more lightly.

The results of such analysis have then allowed proceeding to make targeted comparisons with the other three visible elevations and, consequently, to develop the following hypothesis concerning the identification of the various construction phases of the church:

Phase 1 – n. d.

Probable construction of the present bell tower (CF1).[12]

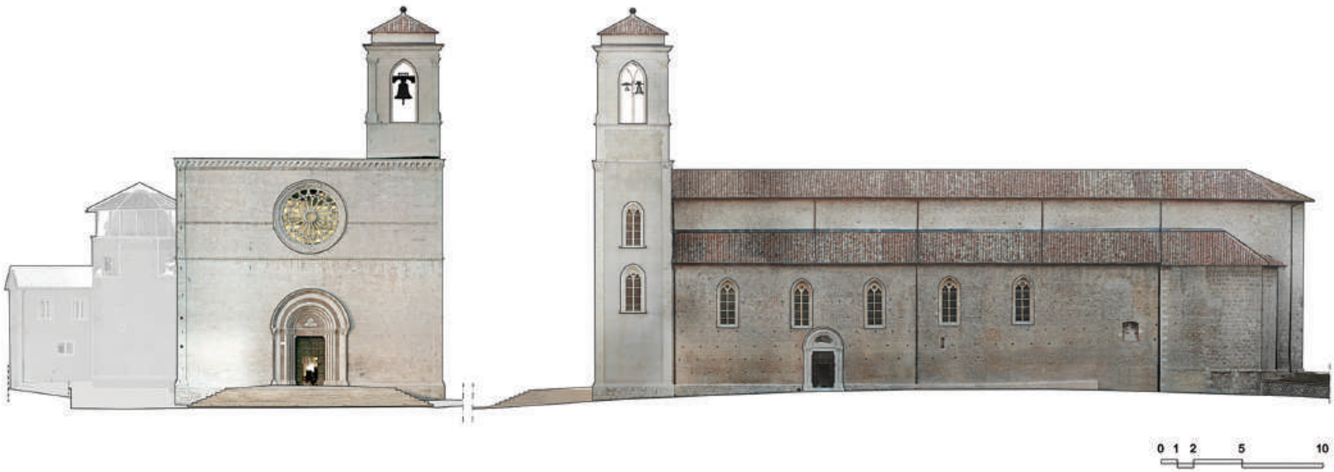

Figure 7. 2D Orthophotoplans of the north and east elevations of the church.

Phase 2 - ante 1265
Probable construction of the church (CF2) with masonry in blocks in support of the pre-existing bell tower (CF1), terminal transept and mullioned windows with two lights (or single lights) on the side elevations. The internal portions, marked by a tripartition of the naves with columns, seem to be those of the first phase, except the presbyterial part built in the following phase.

Phase 3 - 1330
Significant reconstruction of the apsidal portion that redefines the entire presbyterial area.
Two massive polylobate columns are erected, creating systems of arches.

Phase 4 - 1461-62
Another significant modification to the structure with the elimination of the transept, the construction of a connecting wall between the two parts and the displacement of the portal on the east side within the curtain wall of the hypothetical transept.

Phase 5 - XVI Century
The openings of the church are redefined with the creation of large windows on the two levels of the building and the probable displacement of the portal in the central portion of the west elevation.

Phase 6 - 1967-69
The most documented phase thanks to the documents found within the Archives of the Superintendence of L'Aquila.
These documents show how the extensive interventions carried out by Moretti in 1967 brought the church back to its medieval appearance, obliterating the activities carried out in the previous phase, reopening or rebuilding the large windows on the side elevations, and finally, moving the portal to its current position (probably corresponding to the original one).[13]

Phase 7 - post 2009
Realization of small interventions to block some structural degradations triggered by the 2009 earthquake.

5. Conclusions

The results obtained from the research experience presented in this paper have allowed validating the methodological protocol established within the research project on the evolutionary dynamics of L'Aquila's architectural heritage.
The methodological synergy between integrated digital survey techniques, TLS and UAV, and the historical-archival studies conducted, has allowed the development of a rich and reliable palimpsest of documents, graphics and three-dimensional assets, which in turn has become the metric-informative basis for the processing of archaeological and stratigraphic analyses of the church of San Silvestro in L'Aquila.
The potential offered by short-range aerial devices for the acquisition of otherwise inaccessible architectural data, such as the drone used in this case study, has allowed optimizing and speeding up the documentation and knowledge of the structure. The change of perspective offered by a UAV, from frontal to nadiral, leads not only to a shift in scale, from human to architectural, but also to a different perception of the object of study, visualizing it in its entirety and highlighting the stratigraphic relationships established between the various parts of the architectural complex.
The contribution intends to underline how the virtualization of the architectural heritage, especially the one located in seismic areas, carried out through an integrated approach that foresees not only TLS technologies but also the more dynamic one of drones, is configured as a helpful multidisciplinary tool both for the monitoring and the safeguard of the structure, but also for the direct interpretation of its constructive dynamics.

Acknowledgment

Andrea Arrighetti wrote the paragraph "Archaeological analysis of the architectural complex" (4), Alfonso Forgione

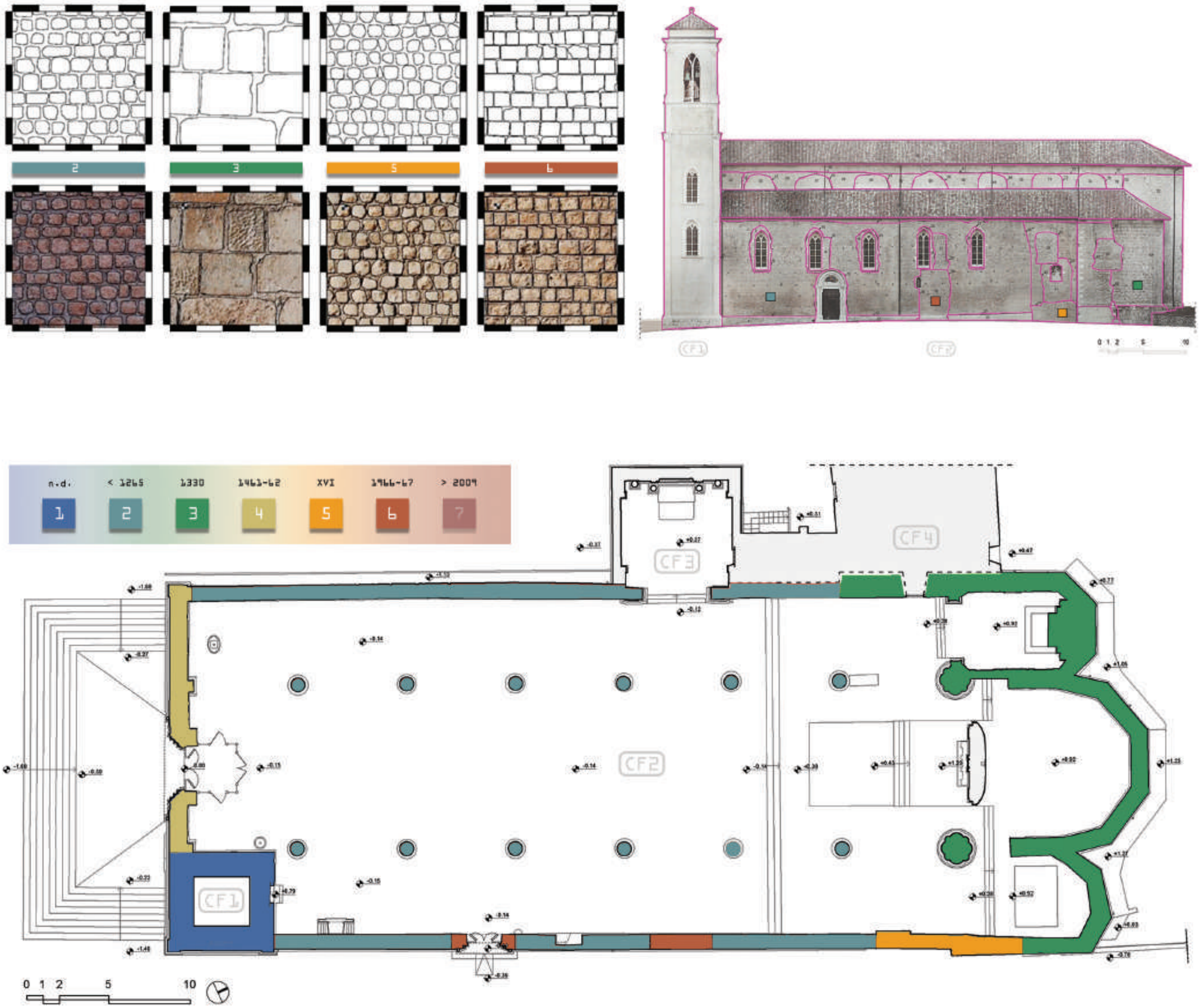

Figure 8. Archaeological analysis: wall construction techniques of the main phases, MSU stratigraphic analysis of the east-elevation and plan of the church's construction phases.

wrote the paragraphs "Introduction" and "The Church of San Silvestro in L'Aquila" (1, 2), Andrea Lumini wrote the paragraphs "Methodology of integrated digital survey of the architectural complex" and "Conclusions" (3, 5).

Notes

1 In this case, it has been chosen not to perform automatic flight by waypoints, although the device had integrated GPS, in order to avoid both possible data missing, but especially potential collisions with the object of the survey or with other neighboring buildings.

2 Between two adjacent scans, an overlap of around 50% of common points was tried to be maintained. These were all processed in B&W, both for reasons of acquisition speed and because the chromatic data would have been integrated later through SfM photogrammetry.

3 Bearing in mind that this will be the same as that carried out for the close-range shots on the ground

4 Mainly around 5 and 6 p.m., considering that the surveys were carried out in February and that this interval allowed a more diffuse light.

5 Once the images were imported, the software, through image-matching processes, identified homologous points between the shots and reconstructed their position and orientation for each one. These procedures have thus allowed elaborating an alignment between the images acquired in the form of a sparse cloud.
Through further specific DSM algorithms, this sparse cloud of points was subjected to densification by using all the pixels of the images. The dense cloud points were subsequently triangulated and polygonized, creating a 3D mesh model. This was finally mapped with the texture of the photographs, resulting in a digitally mapped 3D model of the church surfaces.

6 Contrary to the traditional methodology in which the so-called orthoimages referenced by Cyclone software were exported and then proceeded to their digitization in a CAD environment, for this case study, it was chosen to rely on the interoperability of Autodesk Recap Pro and AutoCAD software.

7 In particular, a complete planimetry of the building at the ground floor level (about 1,5 meters from the ground) and four orthophotos related to the external elevations of the structure have been realized. Photoplans of the complex's interior were not taken because, since the walls were covered by plaster, they would not have yielded data of interest from an archaeological point of view.

8 Although the reflections were mostly limited to the exterior elevations, given the extensive presence of plaster that characterized the surfaces of the interior walls

9 The bell tower (CF1) presents well-defined edges and perimeter masonry constructively continuous and very thick (about 1.45m) compared to that of the church (CF2). Therefore, it seems conceivable that it was a pre-existence compared to the church.

10 The church's facade (CF2) presents an extended cut visible on the west side near the cantonal, which denotes its reconstruction later than the masonry. Moreover, the apsidal masonry shows a masonry thickness, a course, and a building technique that differs considerably from the church's perimeter masonry.

11 The areas on the west side, with particular reference to the chapel (CF3) and the rectory (CF4), are visibly leaning against the church's walls. Therefore, as far as it can be seen from the external portion, they are later than the west perimeter walls of the religious building.

12 Probably put in place with different purposes than the religious ones but of which at the moment there is no material or written evidence.

13 These operations are carried out using bare materials and construction materials similar in origin and manufacturing to the ancient ones, even if the construction technique is well recognizable inside the oldest walls.

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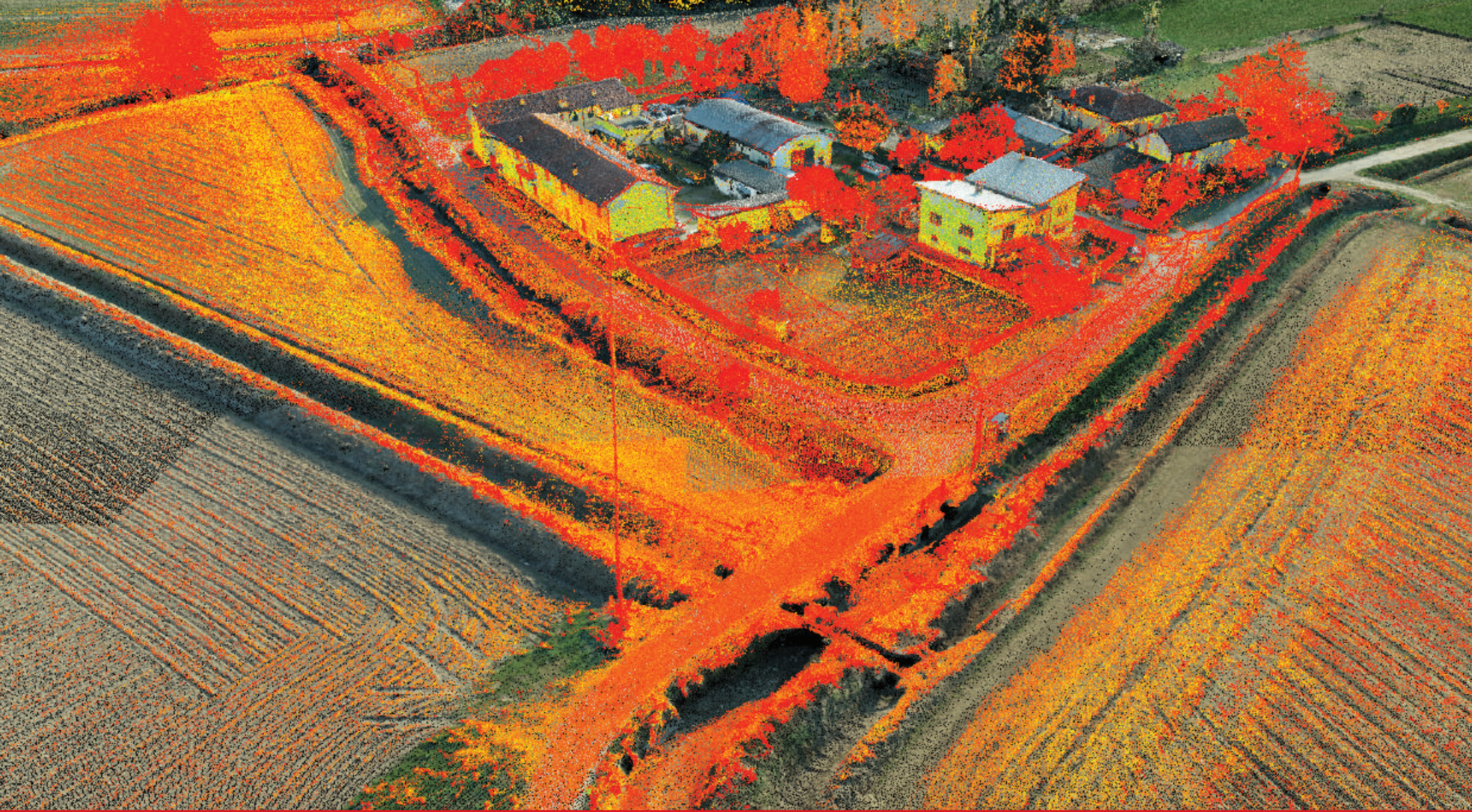

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ABSTRACT

The paper describes part of a research, developed by DAda-LAB laboratory of the University of Pavia, that addresses the issue of documentation and representation of the canalization landscape. The 2D and 3D outputs, starting from different digital database, invites us to reflect on the limits and potential of the use of UAVs for multiscale documentation. In particular, the research activity presented tests the effectiveness of integrated point clouds, obtained by fast survey acquisition methodology, for the development of 3D digital models, aimed at the management of the canalization landscape.

Fast survey technologies for the documentation of canalization systems. The case study of the settlement "Il Cassinino" in the Naviglio Pavese surrounding

1. Introduction

The irrigation canals transform the land by framing the fields in ordered geometric surfaces that define new spatial relationships in the agricultural landscape. The built presence of water qualifies the natural spaces that, properly leveled to allow its distribution, give the countryside a domestic dimension. The feeling of harmony and security aroused by rural areas is actually the result of consolidated anthropic actions that over time have modeled the irregular shapes of the natural landscape to meet specific agricultural needs (Pandakovic, Dal Sasso, 2013). Understanding these places, signified by man through the water, implies confronting their complexity, generated and maintained in balance by the mutual interactions and rules of man-nature (Figure 1).

The landscape representation is not aimed at expressing knowledge of the territory in an absolute sense, but rather the result of a study perspective that takes on significance in relation to its specificity (Parrinello, S., 2013; and Favaro, Vallerani, 2019). In the context of the Po Valley, historical maps and drawings enhance, through signs and symbols, the presence of water: each blue line highlighted in the predigital cartography represents (Figure 2), in addition to the physicality of water, the relationships between amphibious landscapes and human settlements (Vallerani, 2019).

2. Fast survey technologies for multiscalar investigation campaign

Representing this landscape imposes a multiscalar investigation able on the one hand to return the ordered conformation of the elements in a wide extension (rectangular plots separated by ribbons of water and rows of trees); on the other hand, to investigate the mutability of the morphology of gentle slopes, minor riverbeds, and embankments. In this sense, the limit of the finite size of paper supports dialogues poorly with the ability to restore a territory in its dual scalarity (Ruggiero, Torti 2019). Digital advances have partly allowed overcoming this gap of the traditional representation in scale: Google Earth or Google Maps satellite maps, easily accessible to everyone, allow to approach a territory by observing it from above in its extension or entering it in a three-dimensional visualization (Bocconcino, 2018). Despite this, the barely noticeable orography of water landscapes is not visible

Figure 1. Relationships between urban settlement and waterways in the Cassinino's landscape.

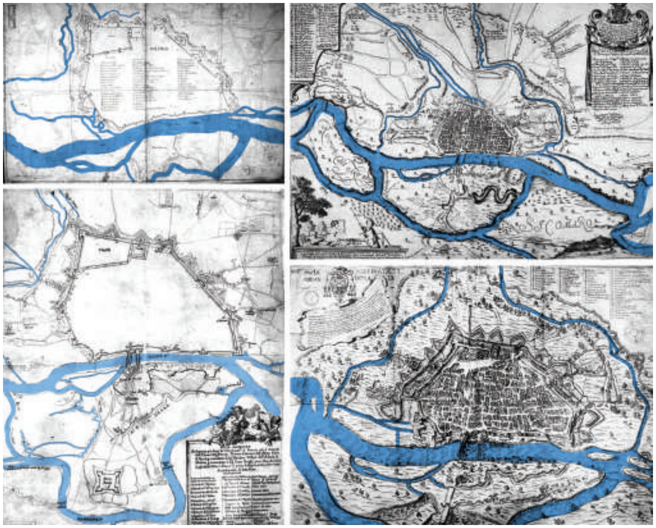

Figure 2. Historical maps to underline rivers and canals in Pavia hinterland.

Figure 3. Canals views from Google Heart that highlight the problems of the 3D representation of irrigation systems.

from satellite maps (Figure 3), whose three-dimensional view is limited to urbanized areas, for which there is a greater cognitive interest[1].

In the context of the new digital documentation technologies available today, the contribution explores the representative and communicative potential of drone data for the definition of multiscalar maps, which are easily readable in terms of results, and capable of expressing different levels of information content. The study aims to investigate the innovative aspects, advantages, and limitations of the use of drones for the representation of agricultural flatlands, through a comparison of the database with others obtained from MLS and TLS laser documentation[2]. The choice of the use of drones and other mobile systems meets the need to conduct extensive documentation in a short time. Fast survey acquisitions, in addition to allowing the replicability of the method in large areas, allow obtaining in a short time a multiplicity of representative data of the same condition. In the case of natural environments, which are subject to continuous changes, this feature is particularly important: the same survey campaign, conducted only with TLS instruments, would generate an overall database characterized by point clouds representative of different moments (Parrinello, La Placa, 2021). The longer time needed for the acquisition would in fact allow seasonal or artificial changes, such as mudslides, leveling of embankments, tree pruning, etc.

3. The case study of "Cassinino" settelment

The agricultural landscape of the Lombardy plain is characterized by a structured anthropization, the apex of which is the system of "Navigli Milanesi". These canals, once navigable, continue to provide irrigation services, distributing river waters in a network of minor canals that cross the territory[3]. The presence of the water network has significantly influenced the location and development of rural settlements. The residential areas are connected to the roads by small vehicular bridges and crosswalks over the water; the fields, leveled ad hoc to ensure the flow of water, are separated by raised banks; the trees, arranged in rows, follow the course of the major irrigation canals; hydraulic elements of different sizes (locks, mills, norias, etc..) are distributed in the countryside to ensure the functioning of the entire network (Figure 4).

Figure 4. Elements of the irrigation systems.

Among the rural settlements just north of Pavia, there is the locality of "Cassinino". This area was selected for the experimentation because contains different morphological and typological characteristics. The close relationship between the buildings and the irrigation systems present underlines: the old canal (or "Navigliaccio") which runs parallel to the Naviglio Pavese; some bridges crossing the two canals, the presence of numerous canals for the irrigation of the fields, as well as Norie and production farms that exploit these systems. The difficulty of acquiring and representing the heterogeneity of these characteristics has motivated the research towards the experimentation of a fast and integrated digital acquisition, such as to allow to obtain reliable and qualitatively responsive outputs for each system, natural or artificial, identified.

4. UAV ACQUISITION METHODS

The use of nano and micro UAVs has changed the methodology of territorial image acquisition, implementing the quality of the objects acquired where a high resolution is requested (Colomina and Molina 2014). In particular, the digital acquisition of a landscape is driven by the use of low-cost high-precision drones, capable of acquiring a large amount of data in a short time, without losing the quality of the morphometric information. Several investigations concern the geometric quality testing of the photogrammetric point cloud, at structural-diagnostic (Tamakawa, Yamamoto, 2022) and urban-territorial levels (De Marco, Pettineo, 2022; Parrinello and Picchio, 2019). Based on these studies, which also see the most recent experiments in the field of representation for Cultural Heritage, the acquisition methods with UAVs are increasingly improved and implemented: the goal is to obtain 3D point clouds complete and metrically reliable, from which to structure specific and multiscalar landscape analysis.

In the context of the Pavia flatland and of the settlements that are related to its irrigation landscape, a digital acquisition methodology was tested with a high precision UAV, a DJI Phantom RTK. The aim of this experimentation was to understand how much the acquisition planned with this UAV, usually aimed at documenting the buildings and public space, it could also apply to the definition of the irrigated landscape (embankments, basins, canals, locks) with a good morphometric 3D point cloud quality.

Figure 5. UAV's acquisition plan on Cassinino settlements, with the division in 13 sub-areas.

The drone acquisition campaign was structured by considering the area conformation (extension, morphology, presence of constraints, and vertical obstacles) and the resolution of the point cloud, and therefore the images, to be obtained. Based on the performance of the instrument and the minimum height at which it can fly, the Ground Sample Distance (GSD) of 1 cm/pixel was designed. In particular, due to the presence of trees, hanging cables, and possible interference with the flight plan, the flight was planned at an altitude between 35 and 40 m above the ground. The area was then divided into 13 sub-areas, with a margin of at least 10% of overlap between each pair. Within, this margin, photogrammetric targets (tot 14) have been placed, useful for merging the sub-areas together. The maximum extension of each area (almost 6.000-8.000 sqm) was also dependent on the UAV battery life. In order to carry out the entire survey in a relatively short time (a total of 1.5 days, also considering the technical times of batteries recharge), each sub-area was acquired with the lifetime of a single battery (Figure 5).

Figure 6. Canals point cloud definition for the construction of reliable models.

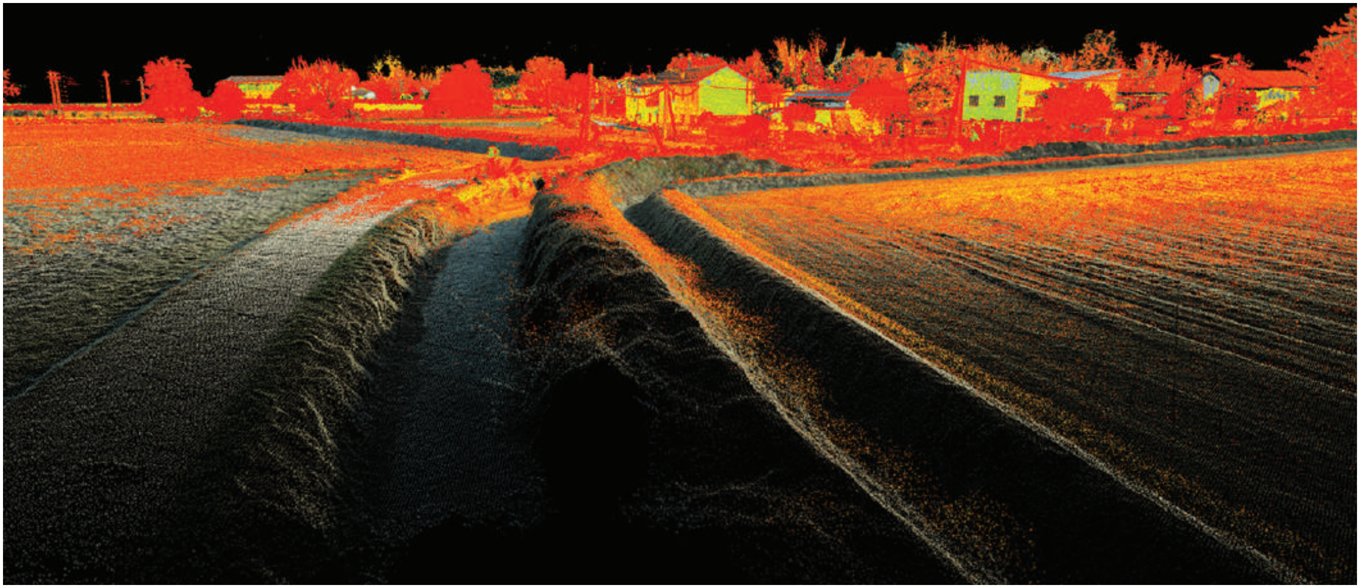

Figure 7. Point clouds integration between Mobile Laser Scanner (Stencil KAARTA) datas and UAV (DJI Phantom RTK) datas.

This ensured that each sub-area was surveyed in a single-phase according to nadiral and oblique axes acquisition methods, guaranteeing uniformity of weather exposition and instrument settings. Each photo dataset (consisting of almost 350 pictures), was processed on photogrammetry software (Agisoft Metashape), individually. In each area, the model of the point cloud was generated at the maximum resolution that was possible to obtain. Subsequently, based on the targets prepared during the acquisition phase and other architectural points identified in the post-production phase, thanks to the resolution of the images (Figure 6), the sub-areas were merged together, generating a single mesh model of the analyzed area.
The reliability tests of the obtained data were structured on different levels. A first investigation concerned the reliability of instrumental acquisition. Recent studies have verified that direct georeferencing, offered by tools such as the DJI Phantom RTK (Taddia et al., 2019), is an alternative way to accurately reconstruct models without the use of any GCP (Rabah et al., 2018), whose location takes time away from survey planning operations (Gabrlik et al. 2016). For this reason, the error calculated for the acquisition phase on each sub-area is less than 2 cm.
A second test focused on alignment between sub-areas. In this case, the error was calculated on the targets, both photogrammetric and morphological, and foresaw a maximum error of 0,08 m.

Figure 8. View of merged point clouds. The image shows the necessity to use UAV acquisition to complete the datas of the inner areas.

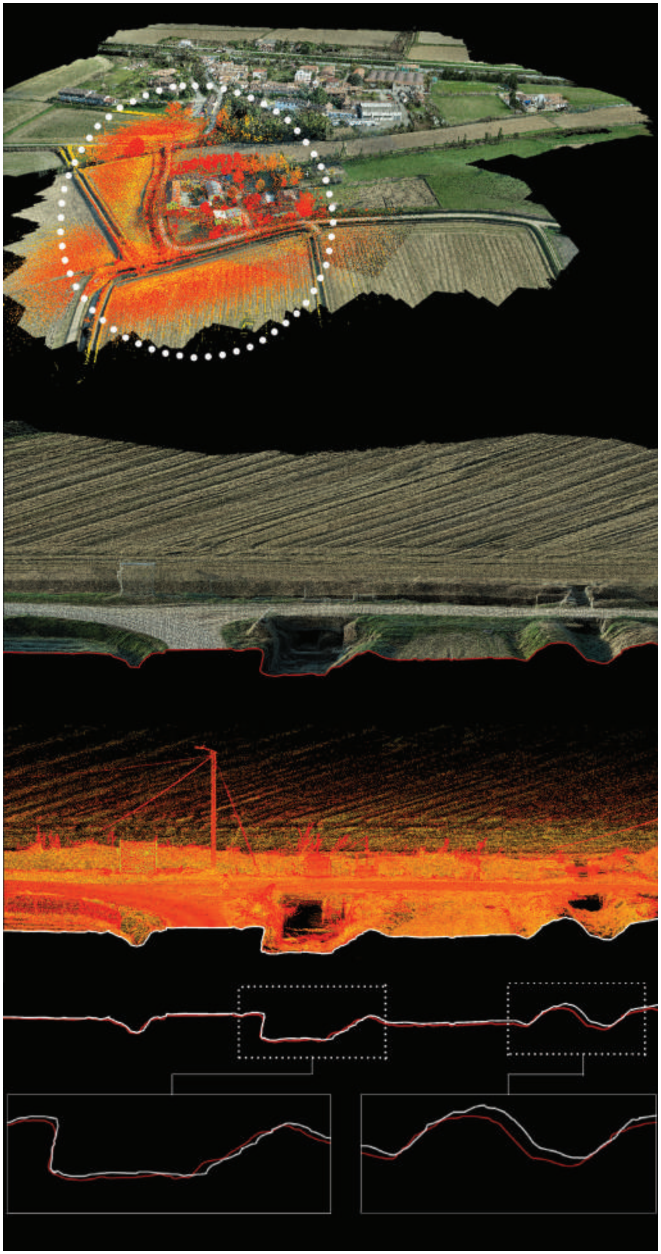

Figure 9. View of merged point clouds. The reliable test enphasize the morphological problems of UAV's point cloud related to the laser scanner one.

A third and last test, not less important, has instead regarded the qualitative reliability of the correspondence between the point clouds and the reality: in particular, in order to establish an adequate representation of the canals and the elements of the irrigation landscape, it is important to verify how much the point clouds from UAVs are able to morphologically configure as cognitive bases from which to start specific analyses at an architectural scale. For this reason, some portions of the photogrammetric point cloud have been selected and compared, in all their extension, with other datasets obtained by digital tools, able to return complex morphologies in a reliable 3D representation.

5. Morphological comparison between Mobile, TLS, and UAVs

With the aim of verifying the morphological reliability of the point clouds obtained by working in a rapid survey with UAV systems, a documentation campaign with laser scanners (TLS and MLS) was carried out. The data obtained from lasers[4] were compared with those from drones generating an overall informative database (Di Filippo et al. 2018). The horizontal propensity of the landscape and the low density of the built space in the Cassinino area has generated some problems of acquisition with mobile laser scanners. This condition motivated the use of data from DJI Phantom RTK as a basis on which to align clusters generated by mobile data processing (KAARTA stencil) (Dell'Amico, 2021). The MLS and UAV point clouds were aligned with an error, calculated on common targets (n. 14), of maximum 8 centimeters (Figure 7). The integrated point cloud allowed to obtain a spatial scale representation of the flatland landscape (Figure 8). In particular, using the KAARTA the operator was able to acquire the points related to the terrain orography, moving both near the canals and in their banks. This has ensured completeness of information which, integrated with that of the drone, offers an overall three-dimensional image of the territory. However, analyzing the morphological aspects of the integrated point cloud, some problems were evident in the database obtained by drone.

Figure 10. On the left: Terrestrial and Mobile laser scanner for the definition of territorial, architectural and detailed elements of the Naviglio Pavese. On the right: UAV's point clouds, with different levels of detail from territorial to architectural elements.

The analyzed irrigation canals have small dimensions (max depth 50 cm) and morphological characteristics that are difficult to acquire with image-based instruments (presence of vegetation, different exposures, etc.), especially if managed with a view to large-scale acquisition and therefore at considerable heights (Figure 9).
In order to see how much drone acquisition can be functional to the morphological and qualitative restitution of these watercourses, it is necessary to go down in scale, passing from a representation at territorial scale to one at architectural scale.
To understand the morphological conformation of the canals and the spatial relationships that they establish with their surroundings, it is necessary to change the parameters of the comparison, structuring the analysis from more detailed point clouds.
For this reason, the second experimentation was carried out on a restricted area of the case study, corresponding to the Cassinino basin.
This represents the most characteristic part of the irrigation system of the entire area analyzed: there is a control building, mechanical elements of various sizes, and hydraulic elements for the lock operation. To realize point clouds of greater detail, the DJI Phantom RTK drone flew above this restricted area at a height of 15 m (below which no high vertical obstacles were present), designing a GSD of 0.5 cm/pixel.
The generated point cloud was compared on Cyclone environment with the one obtained from the TLS survey, using photogrammetric targets placed along the Naviglio Pavese banks. Both from a metric and a morphological point of view, the integrated database produced at the architectural scale fully meets the requirement of a reliable representation of the canalization elements.
Although this mode of acquisition differs in its aims of achieving a fast survey for the representation of the irrigated landscape, a comparison between these two systems is necessary to develop metric reliability checks, that make one more aware of the approximation provided by mobile systems.

6. Conclusions

With the aim of obtaining a graphical representation (currently missing) that allows to understand, within a single work, the coexistence of irrigation courses and the slight orography in these rural areas, the point cloud of the drone is configured as the best modeling base for 2D and 3D restitution.
The photogrammetric point cloud has the advantages of high metric accuracy on a large scale, realistic restitution of the data, and a high acquisition speed that ensures replicability.
From the drone cloud, it is possible to define the location and size of water and hydraulic elements, as well as the inclination and therefore the directions of water flow. This allows approaching extensive management of the area under investigation.
On the contrary, with the specific goal of evaluating the conditions of hydraulic features or canal banks, this type of extensive acquisition from UAV is no longer sufficient. The integrated MLS-UAV point cloud solves the problem of the morphological interpretation of the embankments, keeping the acquisition time relatively reduced; while the integrated TLS-UAV database reduces the approximation in the detailed modeling of historical hydraulic elements (such as the elements present in the Cassinino basin), at the expense of an increase in acquisition time and therefore possible changes in the irrigation landscape.
To obtain multi-scalar metrically and morphologically highly reliable representations of the irrigated landscape in a short time, it seems currently appropriate to operate with three-dimensional modeling of the territory starting from the database obtained from extensive surveys by UAV, and integrate, where necessary (in specific portions relevant to morphological or architectural complexity) with the MLS-UAV and TLS-UAV databases (Figure 10).
This process ensures replicability of extensive contexts and the development of in-depth analyses where they are necessary for the management of hydraulic/ landscape heritage.

Notes

1 The goal of satellite maps is to facilitate travel and make places and roads recognizable to people. For this reason, rural areas are investigated differently than urban areas and lack, in many cases, multiscalar digital restitution.

2 For further discussion of integrated documentation, MLS-UAVs, see Dell'Amico, La Placa, 2019 & La Placa, Doria, 2021.

3 For a critical description of the landscape of the Lombardy flatland see Bigatti, 2020.

4 Using different types of mobile laser scanners, the same portion of land mapped by drone was documented. On the contrary, the acquisition with TLS instrumentation took place only on a limited portion, characterized by a considerable architectural complexity. For further specifications regarding the instruments used, see Parrinello, La Placa, 2021.

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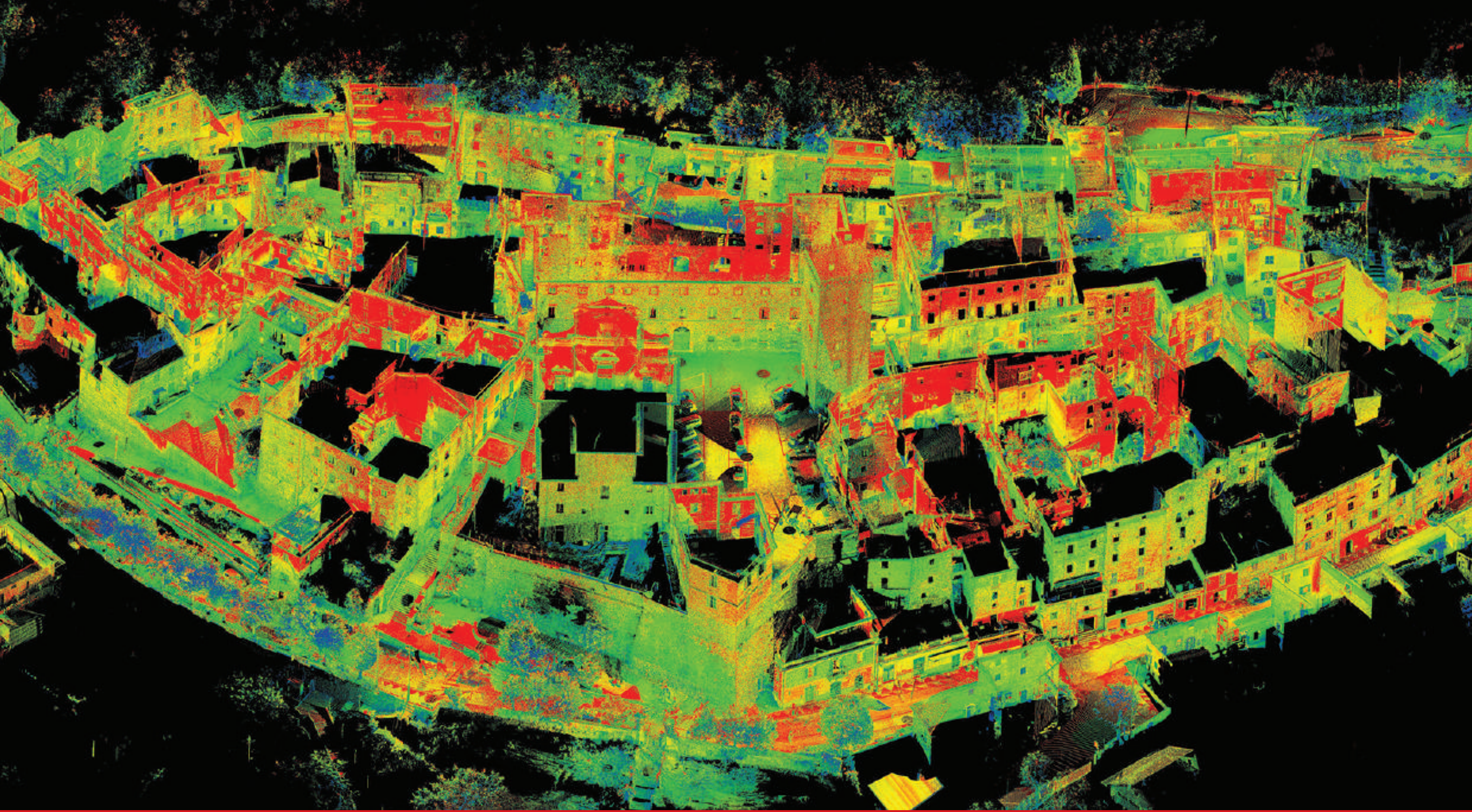

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ABSTRACT

In the field of Cultural Heritage fast survey becomes essential, because it responds to needs to restore historical, architectural and environmental heritage to avoid damage and degradation. In recent years there have been several applied research in this field. This paper reflects on two different case studies (which were acquired with deferred and fast survey techniques using UAVs), investigating integrated survey and information level of reliability for redevelopment and restoration purpose.

Fast assessment survey for protected architectural and environmental site

1. Introduction

In last 10 years, in field of representation, communication and valorization of Cultural Heritage, there has been a succession of experiments with innovative digital processes and a very large production of high-potential and low-cost technologies. This has led to a radical upheaval in a sectorization of some disciplines, proposing ever wider objectives in scientific, productive and social fields, extending, in fact, the possibilities of managing and using knowledge. In field of survey, most of the processes and methodologies now considered consolidated (TLS - SfM) are now further strengthened thanks to the development of automatic control technologies that expand the possibilities of investigation in different scales, from territorial to architectural detail. Ever-growing offer of remote-controlled UAV technologies, equipped with high-resolution cameras, has raised horizons - literally - in the field of scientific research, offering accurate results - from a metric and material point of view - that can be reached quickly.

Speed in field of Cultural Heritage is a fundamental aspect, which responds to a need to urgently recover historical, architectural and environmental heritage, avoiding deterioration, instability and loss. It can be said that a survey is fast when relationship between data acquisition times and quantity of useful data acquired is positive. The research focuses on a part of building heritage spread throughout Italy, historic town: urban agglomerations - historic center, walls, scattered buildings - which integrate perfectly with the surrounding areas. These places are open and/or complex spaces, made up of historical-artistic artifact and elements of environmental-landscape value. For this reason, survey, at the same time, must satisfy accuracy from architectural scale (blocks and individual buildings) to urban one, and detailed one. It is therefore necessary to have integrated digital sensing techniques that combine data accuracy and relatively short fieldwork times. To test critical issues and skills of these techniques and for the purpose of recovering the widespread built heritage, a case study is tested, declined on three different scales: the medieval town of Pofi and its Parco della Rimembranza (little city park), the first seen as an architectural value and the other as a territorial value, which is entered through a gate, the detail value.

2. Cases study

First evidence of existence of Pofi can be found in a document from the Montecassino archive, dated 1019 (De Santis et al, 1997) where the town is described as "Castellum" (Cioci, 2013). The term Castellum, in addition to real fortress, also indicates a fortified town, including a church (S. Maria) (Campoli F. M., 1982).

Expansion of the city in medieval times was characterized by construction of tower houses that followed an ovoid shape around the first fortified part of the town (Campoli E., 2010). Materials used in town construction were local basalt (gray or black), extracted from the volcanic rocks on which was built Pofi. Medieval part of Pofi represents the first case study.

Main part of the Castle consists of a massive 25 m high basalt stone watchtower and walls with two gates and fortified ramparts. The two gates were called "Ulivo" and

"Melangolo". Ulivo gate was demolished in 1872 due to a new urban layout that connected the new market square with the medieval village. Melangolo gate still exists today and is made of a double perpendicular passage with a triple defensive closeout. It was made of local chiselled basalt stone with a wall texture consisting of regular parallelepiped ashlars joined by mortar (Cristofanilli, 2004). Melangolo gate represents a detail of city walls, and it is the second case study.

Environmental area located outside the town walls and called "Parco della Rimembranza", was made by Giovanni Battista de Carolis between the end of the seventeenth and the beginning of the eighteenth century (Campoli, 1982). He built the so-called "Villino al Giardino", whose entrance was located in Via Carbonaria (now called Via Marconi). The gate consists of two chiseled tuff monoliths. On the south-west side there are terraces bordered by walls that mark the slope up to the Villino, made with local sandstone and lava stone. A staircase leads from the park entrance to the Villino and is bordered by walls with sandstone/tuff blocks and lava stone. The area of environmental value is the third case study. (Figures 1,2,3)

Figure 1. Nadiral view of Pofi's ancient town.

Figure 2. View of the environmental area next to the town.

Figure 3. Merangolo gate, object to be studied in detail.

3. Differed survey

Firstly, we take advantage of a type of data acquisition belonging to fast survey category. It can be called "deferred survey", which means the existence of a time distance between the period of data collection and their processing (Empler, 2017).

Data consists of digital archive documentation made available by institutional and non-institutional corporation, by open access platforms or, more generally, by web data. This survey should not be confused with simple documentary or cartographic research: the research consists on using directly drawings or representations, on the contrary, in deferred survey, unprocessed collected data are used (aerial photos, panospheric images from google, geotiff, etc.) as well as editable data and vector shapefiles. A problem of data coming from this surveys is the difficulty on checking their quality, accuracy and

reliability, also because they could grant condition of things of places that may no longer be the current one.
First survey session therefore consists in acquisition of "derived" data (Calvano, Guadagnoli, 2016) from two website: official website of Lazio Region and Open Street Map.
Lazio Region website provides shape files that contain both spatial information in vector format and attributes that can be associated with spatial information themselves. They are a series of numerical and textual metadata concerning, for example, height of buildings, number of floors, etc.
Type of data and data accuracy allow to provide only general state of places in urban and territorial scale. Indeed, it is possible to model a morphology of the ground and generic volumes of buildings, and their distribution on the ground.
However, geodata acquired thanks to this process (latitude, longitude) made it possible to georeference subsequent data deriving from massive data acquisition. The procedure, to become multidimensional, requires changing from a concise model to a detailed one through massive acquisitions data. (Figure 4)

4. Massive acquisition

Pofi's hancient town has a complex morphology, made up by very narrow streets and views of the landscape panorama. This spatial conformation meant that it was not possible to use a single survey technique: acquisitions via TLS were conducted with the aim of acquiring ground attacks of buildings along streets, but limitations were found regarding the upper part of the buildings and the roofs (Carnevali et al. 2018).
We therefore proceeded to use UAV technology with the aim of obtaining, in a short time, a three-dimensional digital model of roofs and ground.
It must be compatible with numerical model deriving from Laser Scanning, considering an integrative workflow between processes based on elaboration of structured point clouds (from TLS) and unstructured point clouds (from UAV).
Survey campaign in Pofi was organized into three days, by acquisitions of various density depending on the object of study (open environmental space, city walls, detailed elements). We used a TLS FARO CAM2 Focus 3D X 130 series, a phase shift laser scanner with color camera, multi-sensor GPS, compass, height sensor and dual axis compensator, used for 174 automatically merged scans per day, which were then automatically merged with SCENE.
During acquisitions step we positioned, in addition to spherical targets, also two-dimensional targets of a size that could be clearly visible even from drone (Ground Control Point - GCP).
We used a 3-axis mechanical DJI - MAVIC PLATINUM PRO drone, equipped with an integrated 12 MP camera and Gimbal. In two days, we took 1265 photographs in nadiral and inclined modes, at different heights; we defined shooting parameters according to different purposes: to guarantee the integration with data by laser scanner, to obtain a high level of automation in the subsequent phases, and to allow a GSD (Ground Sampling Distance) ranging from 2cm for territorial areas to 5mm for detailed elements (see next paragraph). We processed pictures within Agisoft Metashape: were created two chunks corresponding to every day acquisition, in order to simplify automatic point clouds creation by images with same exposure and lighting.
Following Sparse Clouds creation, we placed markers on same place of two-dimensional targets and on other recognizable points, associating spatial coordinates from laser scanner point cloud. This made it possible to obtain two dense clouds, suitably scaled and georeferenced, automatically registered. This essential step also allowed an automatic merging process based on common georeferenced coordinates between structured and unstructured point clouds within the Cloud Compare software, allowing the creation of an overall and unique numerical model (Rodrìguez Navarro 2012; Bolognesi et al. 2014; Federman et al. 2017).
For each case study, through appropriate selection and cleaning, we extrapolated three point clouds - one for the park, one for the town, one for the gate- each decimated

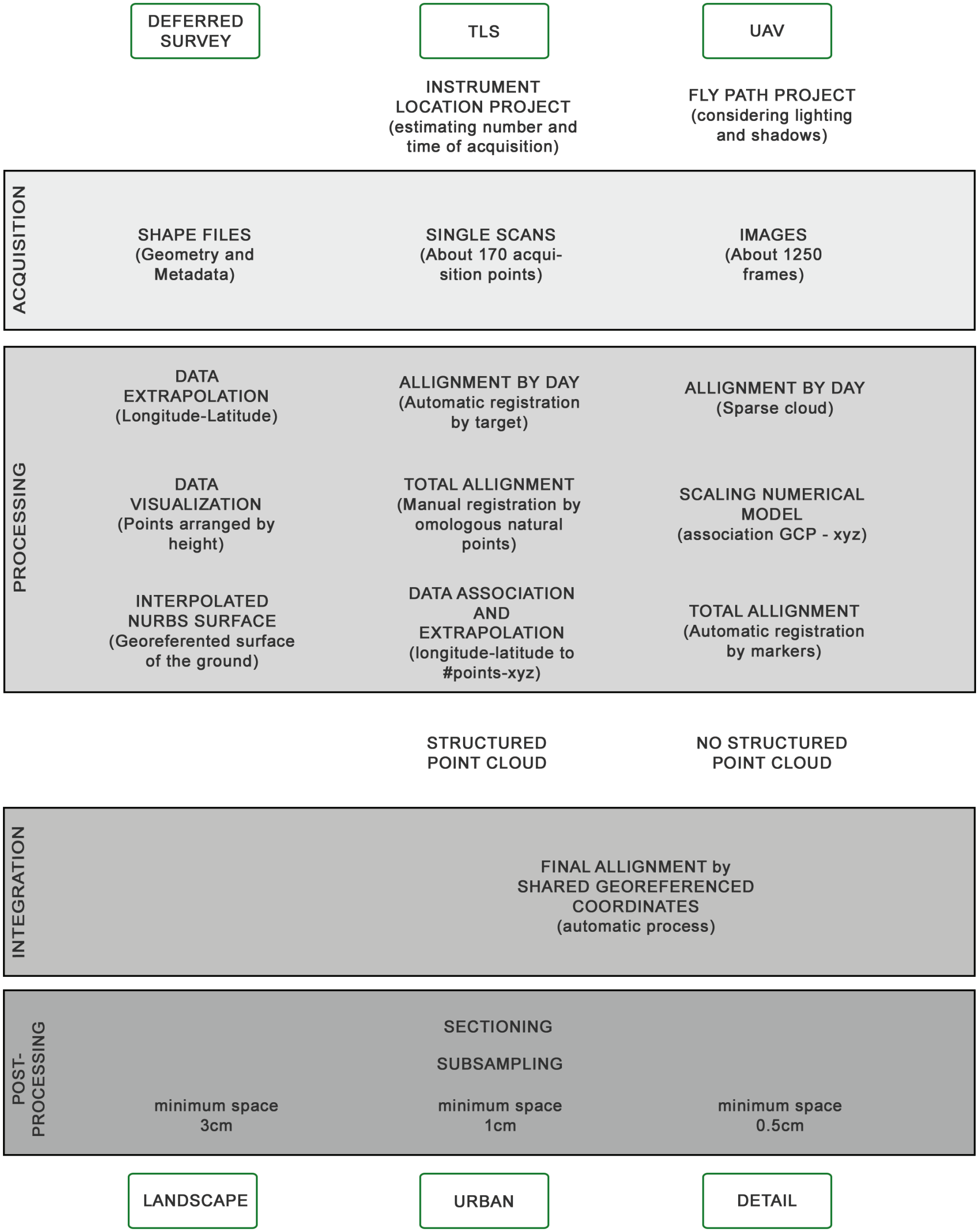

Figure 4. Workflow.

with a different criterion - 3cm, 1cm, 5mm. This is in order to obtain results with representation scale of the specific case study and in order to ensure homogeneous representations of documents that will be the basis of a conservation and enhancement planning. (Figures 5, 6, 7)

5. Data acquisition accuracy and process accuracy

In acquisition stage, evaluating data accuracy according to purposes, we considered frame scale (depending on camera lens and sensor). Therefore the first flight was set at an altitude of about 50 m AGL (Above Ground Level) which corresponds to a GSD on the ground of about 2 cm. Second flight was set at an altitude of about 25 m above ground level, which corresponds to a GSD of about 1 cm. The third flight was set with a close distance, to obtain a GSD of 5mm, which is consistent with detailed scale of representation, positioning drone not in nadiral or inclined mode but mostly in a parallel position with main position of the gate. In order to obtain a numerical 3D model (unstructured point cloud), it is necessary to consider two different levels of accuracy: relative and absolute ones. Relative accuracy refers to alignment stage of pictures and is closely linked to the error with which images are relative positioned one to the other. Absolute accuracy refers to the error found between points of the 3D numerical model and their real position in space (georeferenced coordinates), depending on the survey and depending on frame scale. Thanks to this procedure we were able to certify that numerical model's relative accuracy is about 6,5 cm for the garden area, it is about 4 cm for the historical town and the walls, and it is about 10 mm for the gate. The absolute accuracy calculated is instead about 5 cm for environmental value area, it is about 2,5 cm for urban-built area and about 5mm for the detailed object. Empirically, we can deduce that GSD values identified during acquisition stages lead to an accuracy (relative and absolute) in processing step ranging from one to three as large as GSD values. Acquisition and processing phases, thanks to the GCP coordinates detected by the scanner, made it possible to scale the object according to its real size starting from

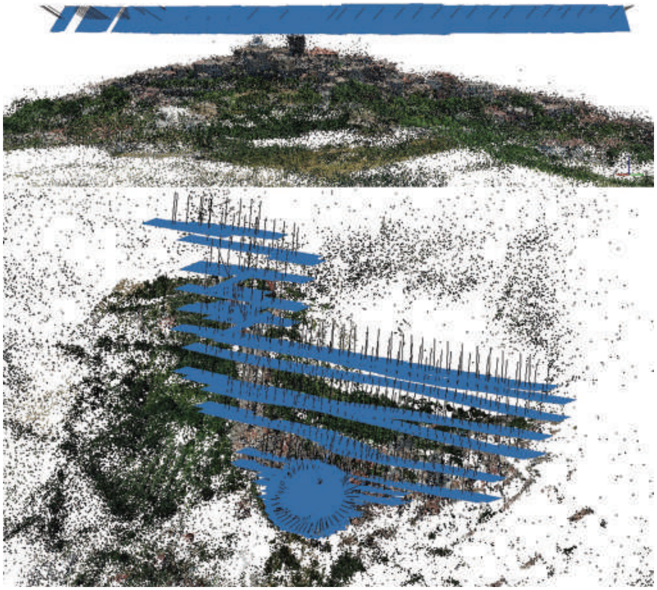

Figure 5. Views of the flight plans in the two different acquisition days (nadiral and 45 ° images).

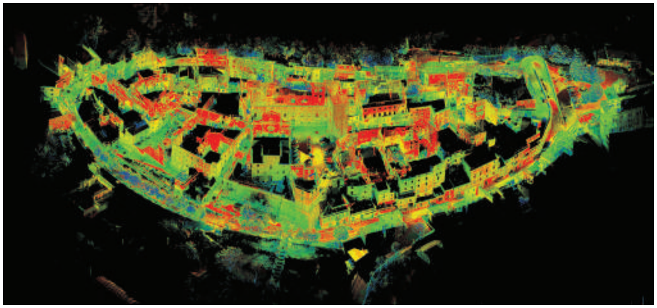

Figure 6. Structured point cloud by TLS.

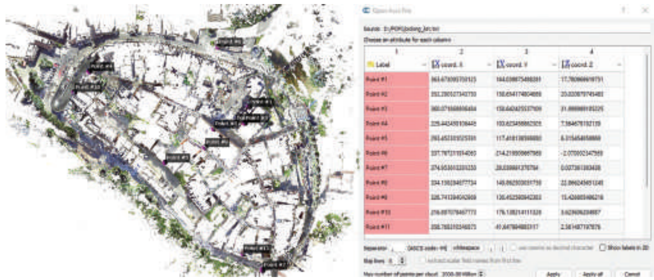

Figure 7. Query of structured point cloud and coordinates acquisition.

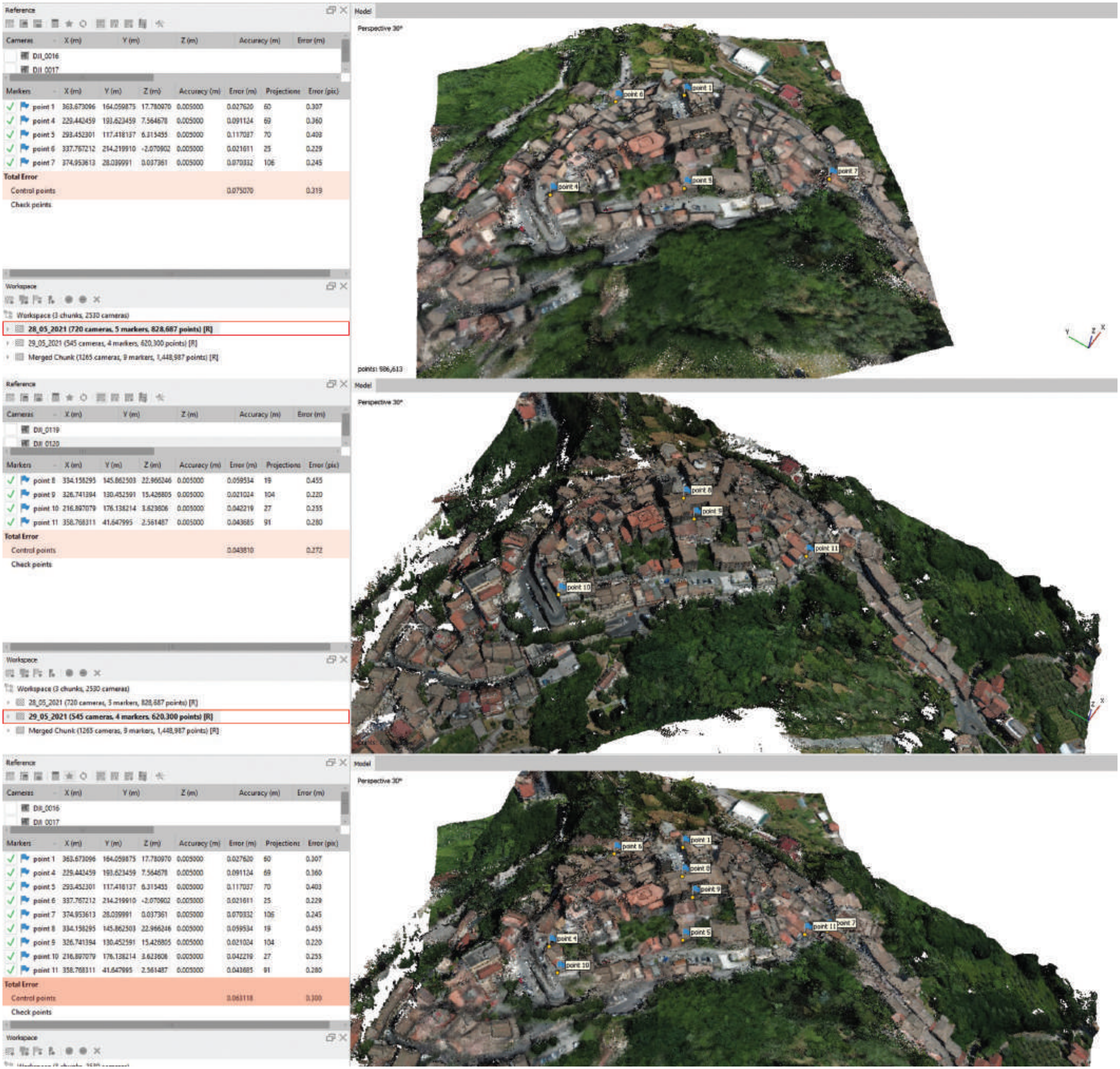

Figure 8. Creation of dense clouds scaled based on coordinates from TLS and automatic integration of the two numerical models.

the frame scale. In this way we created a coordinate system coherent with the real one and coherent with single case study. (Figures 8, 9)

6. Results and research enhancements

Research investigates data reliability collected by photomodeling from UAV, integrated with TLS data and derived data, depending on whether they are areas of environmental, architectural-urban or detail value, for dissemination and conservation purposes. Massive acquisition technique - numerical and image-based - and fast development of digital technologies facilitate and speed up traditional technical-scientific processes Cultural Heritage survey and they propose new strategies of perception and transmission of heritage for its conservation and / or valorization over time.

The development of the entire illustrated procedure (deferred survey + TLS + UAV), including data processing for an area of 54,000 square meters, required six days, (three days for survey campaign and three for data processing) and we obtained a homogeneous and geo-referenced point cloud of the entire ancient town of Pofi.

Procedure allows to understand what are, nowadays, timing of fast survey, guarantee speed and decreasing margins of error (about few cm) for urban spaces or single objects.

Numerical integrated model can be further elaborated and placed at the base of a continuous 3D model (mesh and mathematical models) characterized by dimensional features (measurability and scalability of the model), geographical features (position and morphology of the ground), geometric features (complex shapes of the fabric and buildings) and chromatic ones (RGB value).

These models can be subsequently integrated, from a BIM oriented perspective, with information deriving from specialist surveys aimed at both conservation and enhancement aspects of assets surveyed.

This Procedure was tested in the application field and proved to be effective: data collected allowed specialized people to structure a project to make alleys and medieval walls of the historic center safe and to reuse the park.

If we think of the urgency that characterizes safety measures and these projects, also to allow access to PNRR by municipal administrations, fast integrated survey proves to be an essential tool for knowledge and planning. (Figures 10, 11)

Figure 9. Point cloud automatically integrated between TLS and UAV based on shared coordinates.

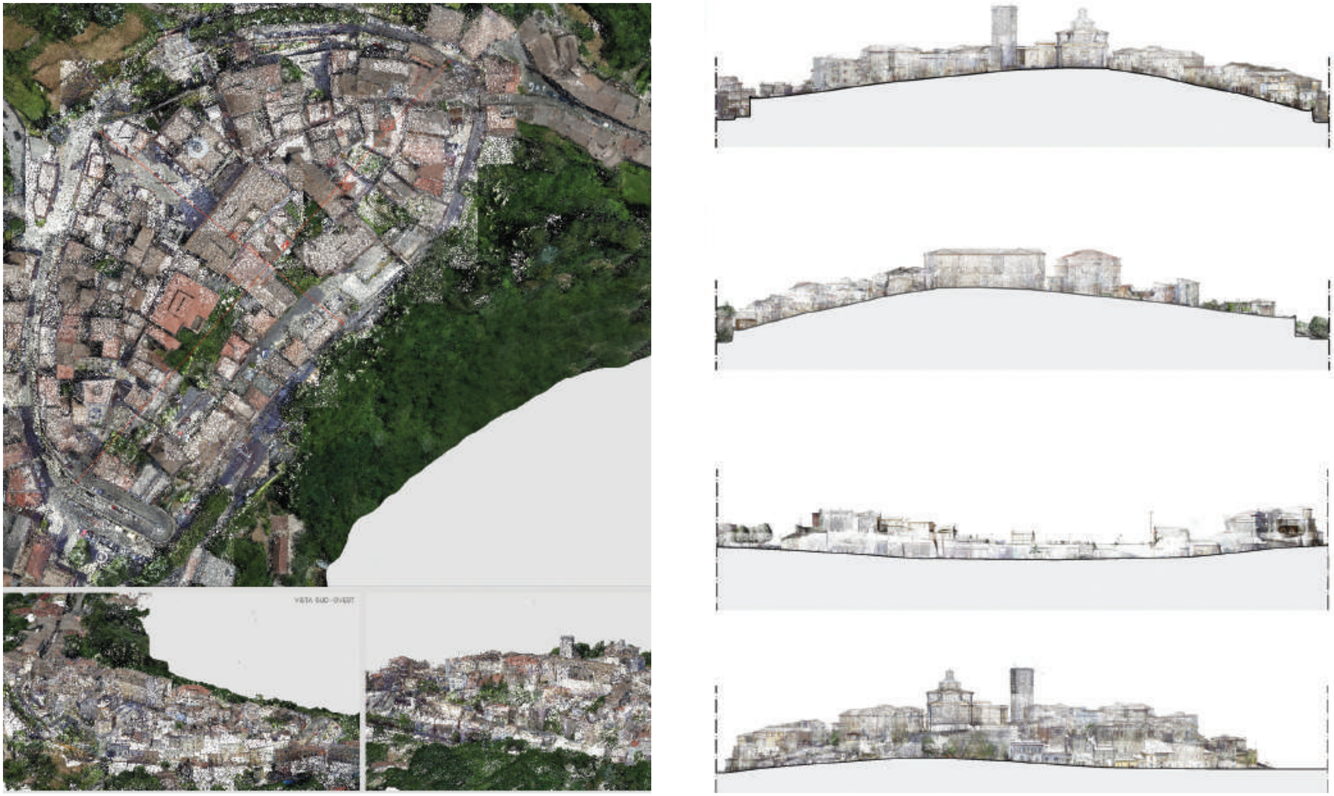

Figure 10. Territorial section analisys used as a basis for conservation and valorization planning for ancient town.

Notes

The authors shared the entire methodological process and contributed together to the results achieved. In particular, paragraphs 1 and 4 were edited by Maria Laura Rossi, paragraph 2 and 6 by Tommaso Empler, paragraph 3 and 5 by Adriana Caldarone.

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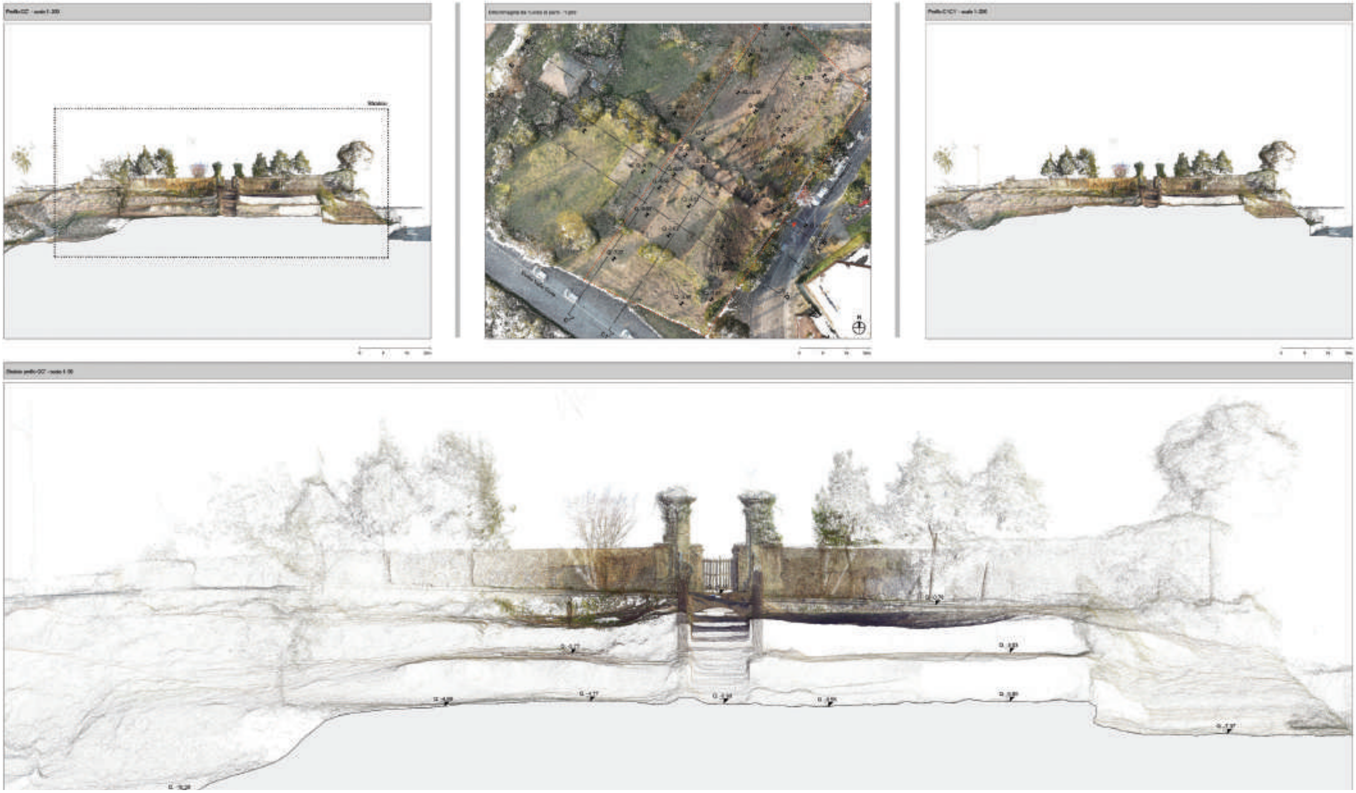

Figure 11. Studies for park settlement.

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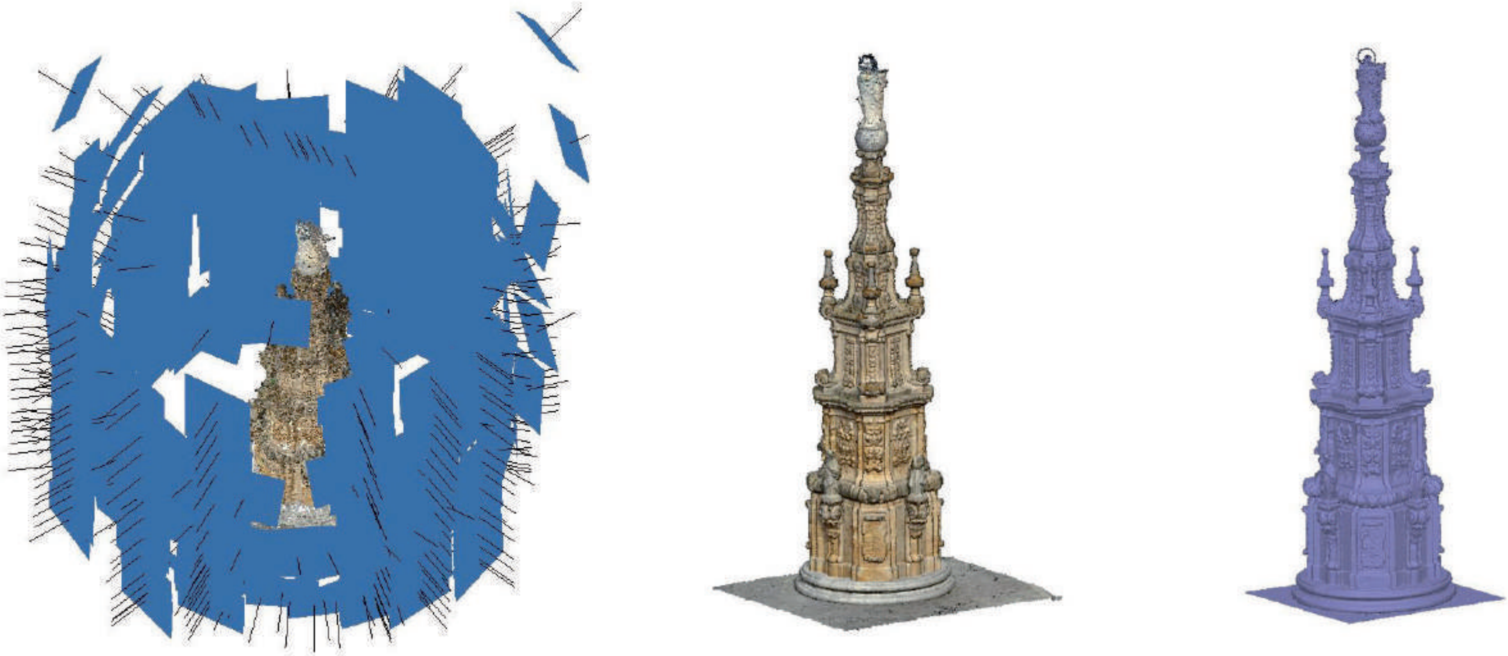

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ABSTRACT

Salento spires, like Neapolitan models, are a particularly interesting phenomenon of Baroque street furniture both for the decorative elements and the role that have in the urban space. Chronologically later than the spire of San Gennaro and that of San Domenico in Naples - the first one between 1637 - 1660 and the second one between 1658 – 1737 – they were built in the second half of the 18th century except the one of San Vito in Lequile in the late 1600s and that of Bitonto in 1731. Both the celebratory solutions – that is spiers and columns – have the same urban value that is the perspective fulcrum of the Renaissance and Baroque urban scenes. This paper is due campaign of surveying regarding Salento and Apulian baroque spiers never sur-veyed in detail before. The specific literature has only superficially analyzed these architectures with only approximate surveys and with a certain lack in methodological rigor. Main objective of the contribution is therefore surveying the spire of the Immaculate Conception in Nardò and later the comparison with Neapolitan models and its compositional/spatial analysis (fig.1). The sculptural component of these architectures and their vertical development requires to integrate the TLS acquisition technologies with digital photogrammetry using an UAV to complete the acquisi-tions from below and also providing better ortophotographic quality.

Keywords:
Architecture, Urban scene, Puglia, Pyramid obelisk, Triumphal column.

Salento baroque spires survey. Integrating TLS and UAV photogrammetry

1. Introduction

A characteristic architectural element of the Salento Baroque period is the spire, which in many cases occupies a significant position in the squares of the region.
Its signficance in the urban scene is that of a triumphal column or pyramid obelisk, namely, as the perspective fulcrum of the Baroque city scene. As sporadic as they are rare, they are in fact fulcrums for the convergence of perspective views and an exaltation of the dynamism of Baroque city planning culture (Morini 1963, p. 243).
However, the image of the seventeenth-century city of Salento is not merely the result of widespread Baroque building work, with churches, chapels, palaces, individual houses, street furniture and decorative elements, but is above all the perception of urban spatiality that arises from it, where each individual element has its own role and precise position in a rhythmic succession and structured concatenation.
The Baroque spires are a refined expression of that study of effect and surprise which in Salento, unlike the grand models of Rome and Naples, is the result of a successful combination of earlier medieval urban schemes, Islamic influence and new Baroque settings. Through appropriate positioning and combination, these give rise to charming and surprising urban scenes (Rossi 2017, p. 29).
It should also be considered that the image of the Baroque city is closely linked to fleeting occasions of festival; it is at these times that the new settings are experienced and the city is their location. Ephemeral events are opportunities for experimenting with future developments, which, even several years later, can acquire a permanent character. It can be argued that "coming in being for the city, the fleeting festival leaves permanent traces within its space" (Fagiolo dell'Arco 1997, 13).
The Spire of the Immaculata in Naples is an expression in stable form of the temporary floats prepared for the procession of the Immaculate Virgin. From the start of the eighteenth century, there was a series of solutions with ever greater leaps in height, leading to a competition to build it, in which the leading personalities of the time participated. Among the various proposals, the Neapolitan sovereign identifies that of the young Giuseppe Genuino, who, compared to the others, found the best compromise between the majestic mass – with a height of 130 palms – and the right proportions of the pyramid structure, marble decoration and sculptural ornamentation (Salvatori & Menzione 1985, pp. 59-74).

2. State of art

The literature on Apulian and Salento Baroque culture is particularly extensive and a major contribution was provided by the systematic analysis of the phenomenon and its widespread dissemination in the Atlas of Italian Baroque series, particularly the volumes on the Land of Otranto (Cazzato, Cazzato 2015) and the Land of Bari and Capitanata (Fagiolo, Cazzato, Pasculli Ferrara 1996). The theme of the spires is broadly developed in the discussion of those in Naples and there are numerous

studies of the restoration projects and the personalities responsible for them. A significant reference is the work done on the Neapolitan spires during the restorations in the early 1980s, for which precise and detailed surveys were conducted (Salvatori, Mention 1985). The studies on Cosimo Fanzago – to whose inventiveness historians attribute the conception of the Baroque spire, interpreting the formal passage first from the victory column, with the spire of San Gennaro, and then from the pyramid obelisk, in that of San Domenico – are the result of the extraordinary research work by Gaetana Cantone (1974; 1984). Neapolitan historical iconography also offers numerous views of the spires of San Gennaro, San Domenico and the Immacolata (Sarnelli 1697; De Rogissart 1706). (Figure 1, Figure 2).
The studies on Apulian spires are more sporadic; there is no systematic discussion of the topic, comparison with reference models or examination of their diffusion in the territory. There is an interesting contribution by Cataldo, who emphasises the role of the columns and spires as mnemonic and symbolic key points, including those in the Salento area (2013).
Despite their acknowledged urban planning and artistic role, no significant survey campaigns have been conducted with scientific rigour. Their geometric-decorative complexity and vertical extension impedes access, making them particularly difficult objects to document and survey. (Bertocci, Parrinello 2015).
Therefore, in an attempt to at least partially fill this gap, a campaign for the survey of Apulian Baroque spires was launched in order to establish a scientific documentary support as a knowledge base for future restoration work and to contribute to their promotion as an extraordinary expression of the urban decor of Baroque culture.

3. Methodology

Due to their particular vertical extension and decorative richness, it was considered best to integrate active sensor (range-based) techniques with structured light laser scanners and passive sensor (image-based)

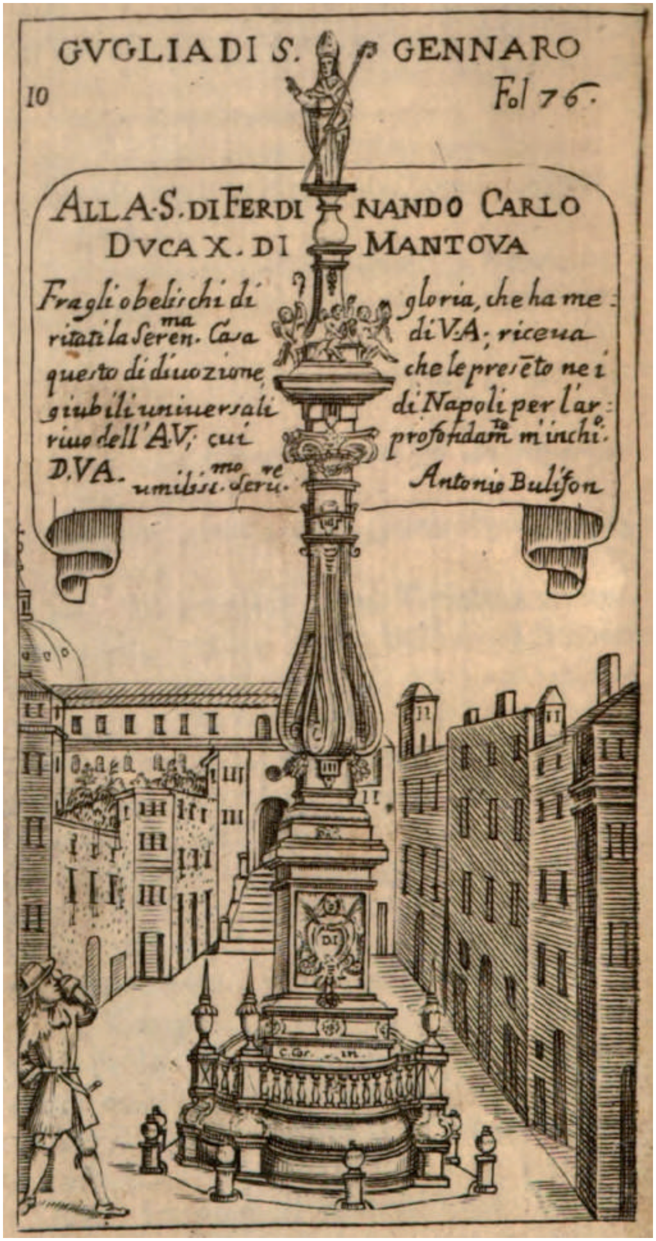

Figure 1. San Domenico spire in Naples. Sarnelli 1697, f. 93.

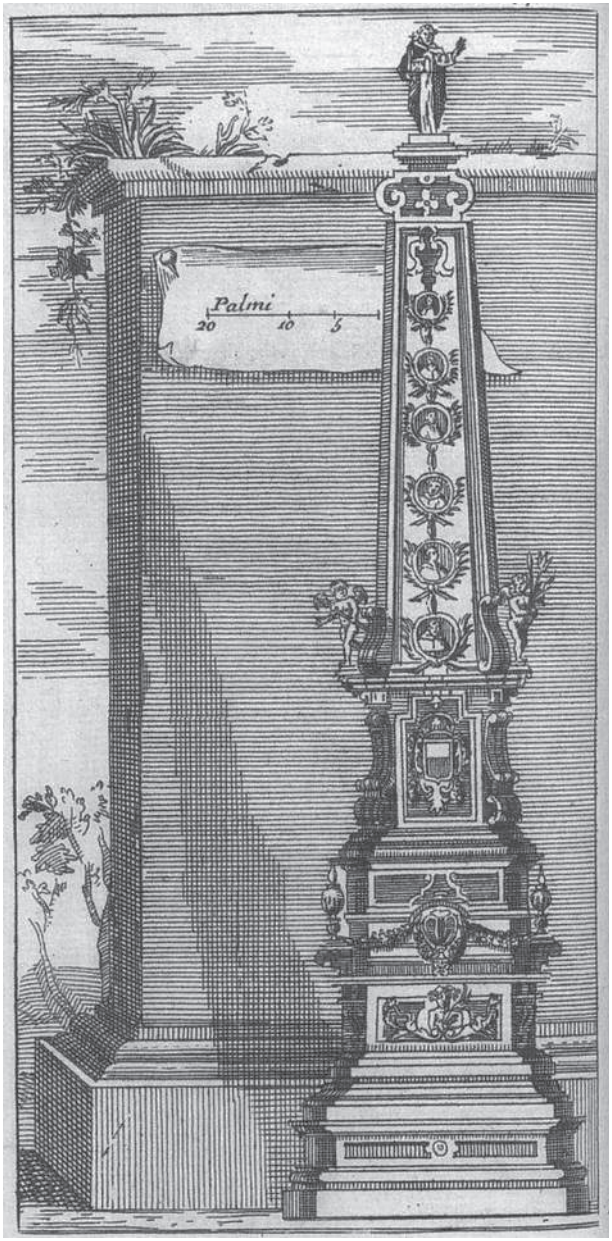

Figure 2. San Gennaro spire in Naples. De Regissart 1706, f. 525.

techniques with sensors that capture ambient light, in order to obtain information from which to reconstruct three-dimensional data of the scanned scene (Catuogno 2021). Point clouds, acquired with the use of artificial targets and natural points, made it possible to rotate and translate the individual scans and to recompose the entire model. We then used a phase shift CAM70/Faro Focus3D TLS scanner and carried out the recording and processing with Faro Scene software, in order to obtain a prefigurative rendering of the graphic as a basis for the graphic reconstruction of the artifact. TLS (Terrestrial Laser Scanner) scans were made of the sides of the spires, positioning the instrument so as to reduce the obstructed areas. A resolution of 6,136 mm was used, measured on a plane 10 metres from the emitter, with 3X quality. Each scan lasted an average of 7 minutes. While the laser scanning techniques provide accurate metric data definition and geometrically reliable representations, digital photogrammetry allows us to integrate the quality of the TLS scans with orthorectification for better legibility and therefore recognisability of the rich decorative/sculptural characteristics of these objects. Photogrammetric modelling, regarded as an evolution of photogrammetry, uses automatisms based on SfM (Structure from Motion) algorithms to reconstruct the scanned scene with the aid of SIFT (Scale Invariant Feature Transform) matching algorithms and CMVS (Clustering Views for Multi-View Stereo) densification. The photogrammetric modelling software used is Metashape from Agisoft.. A DJI Mavic 2 Pro was used for the photogrammetric acquisitions, developed by DJI Company, Shenzhen. DJI Mavic 2 Pro is an quadcopter equipped with a high-resolution colour camera. Indeed, DJI Mavic 2 Pro, featuring the collaboratively developed Hasselblad L1D-20c, brings innovative experiences to the field with advancements in drone photography and UAV photogrammetry. The Hasselblad L1D-20c allows the user to obtain a higher standard for aerial image quality. A fully stabilized 3-axis gimbal with its powerful 20MP 1" sensor, it offers

Figure 3. Areas without data in the orthographic views of the spiers's of Lequile, Nardò and Vernole points cloud.

improved lowlight shooting capabilities in comparison to other drone cameras.

3. Research development

At the current stage of the research, TLS surveys have been made of the most representative spires in the Apulia area, namely that of the Immaculata in Piazza Salandra in Nardò, San Vito in Piazza San Vito in Lequile, Sant'Anna in Piazza Vittorio Veneto in Vernole, and the Immaculata in Piazza Cattedrale in Bitonto. (Figure 3)

The TLS acquisition scheme is always the same: the instrument is positioned planimetrically so as to have a number of acquisitions equal to the number of sides, including the rounded ones, in order to obtain comprehensive coverage of the object surveyed.

The following number of scans were therefore acquired:

spire of the Immaculata in Nardò, 8 scans;

- spire of san Vito in Lequile, 6 scans;
- spire of sant'Anna in Vernole, 8 scans;
- spire of the Immaculata in Bitonto, 4 scans.

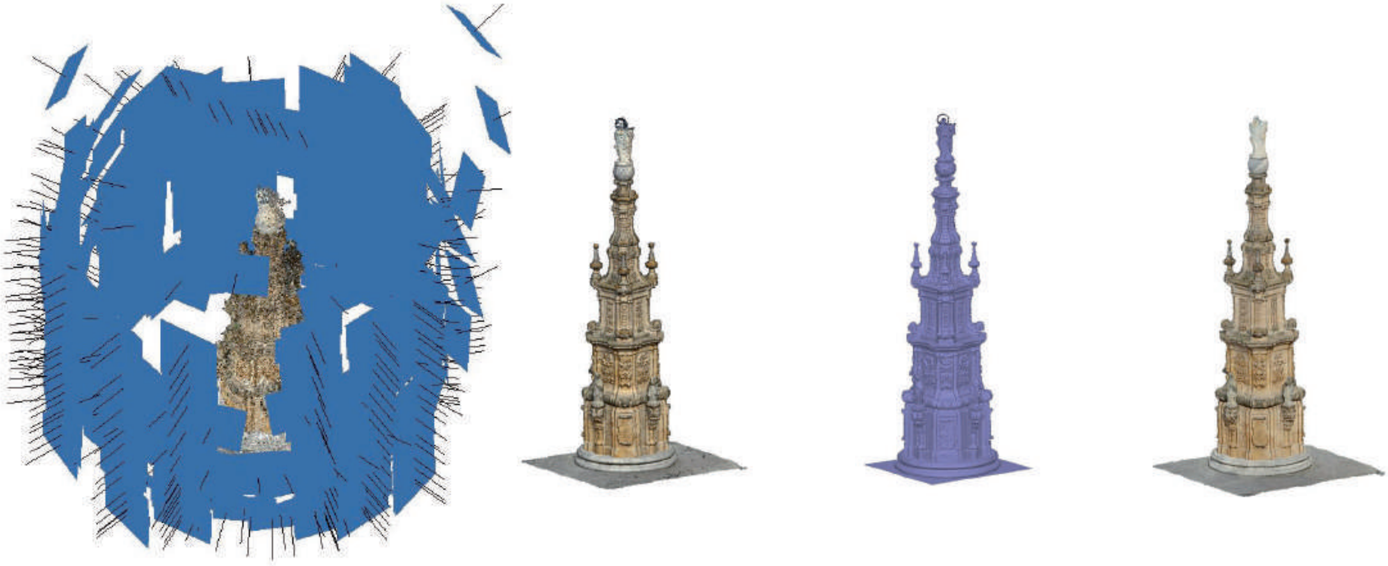

Figure 4. Workflow of the Nardò spire with Agisoft's Metashape software. Authors: V. S. Alfio, M. Lasorella, G. Rossi, G. Vozza.

Chequered targets were positioned on the lower part of the spires, making sure that the same three targets were visible in the consecutive scans. The targets were used during the recording phase, after pre-processing, and on the higher sections, where the targets could not be placed, natural points were selected. Finally, after the recording, the overall point cloud was generated.
The accentuated vertical extension and rich decorative features of the spires - composed of statues, volutes and pinnacles – caused large areas of shadow in the TLS scans from street level, on the upper parts of the frames and behind protruding sculptural elements.
Photogrammetric integration with drone scans proved essential in order to eliminate data-less portions or reduce them to a minimum. (Figure 6)
At the current survey stage, UAV photogrammetric scans have only been made on the spires in Nardò and Bitonto. For the Nardò spire in particular, the photogrammetric acquisition was made from top to bottom and vice versa, following a zig-zag path to obtain coverage of the eight sides of the spire, with an acquisition of about 300 frames. On the Bitonto spire, however, we followed a spiral circular path from bottom to top, acquiring 210 frames.
The post-processing of the images of the individual blocks was carried out in the Agisoft Photoscan environment. A software based on SfM/MVS algorithms, where a 3D model or 2D orthophotos can be obtained in a rapid and automatic way. In general, the several processing steps that lead to the construction of the model are: alignment of the images, building a dense point cloud, building mesh and building an orthomosaic. (Figure 4)
The final phase – carried out at the present stage of research only for the spire of Bitonto - included the reading of the information contained in the orthophotographic views in order to interpret/discretize them graphically, to be carried out with a specific layering and diversified for each object/case of application. The graphic dimension of the traditional orthogonal projection views, realised in vectorial CAD

Features	**Specifications**
UAV Platform	
Max. take-off weight	907 g
Maximum Speed (P-Mode)	48 km/h/13.4 m/s
Flight time	~31 min
Camera: Hasselblad L1D-20c	
Sensor	1" CMOS; Effective pixels: 20 million
Photo size	5472 × 3648
Focal length	10.26 mm
Field of view	approx. 77°
Aperture	f/2.8–f/11
Shooting speed	Electronic shutter: 8–1/8000 s

Table 1. Features of the DJI Mavic 2 Pro.

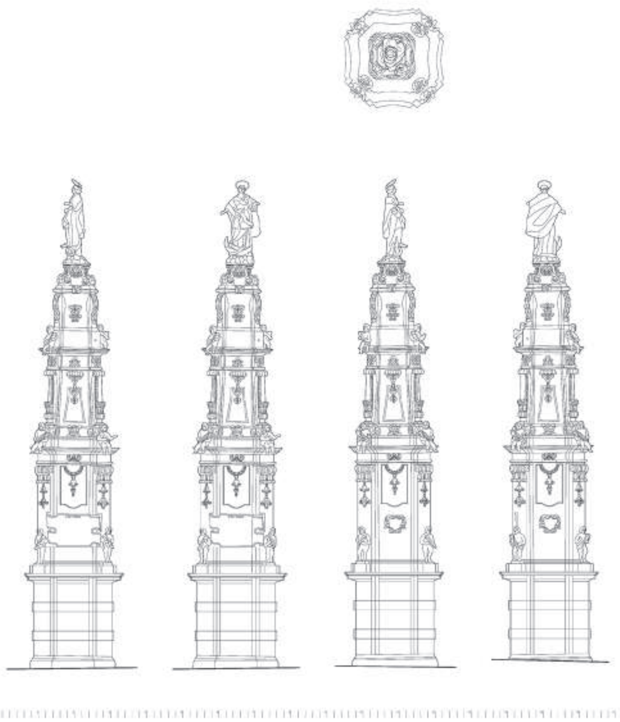

Figure 5. Immacolata's Spire in Bitonto. CAD representation. Authors: S. M. C. Cafarchia, G. Laterza, F. Lattanzio, D. Sanzio, S, Scaringella, E. Tesse, D. Pastore, G. Rossi.

Figure 6. On the left, comparison TLS and digital photogrammetry orthographic views. Authors: V. S. Alfio, M. Lasorella, G. Rossi, G. Vozza.

Figure 7. On the right, Immacolata's Spire in Nardò. East and North orthographic views. Authors: V. S. Alfio, M. Lasorella, G. Rossi, G. Vozza.

Figure 8. Immacolata's Spire in Nardò. West and South orthographic views. Authors: V. S. Alfio, M. Lasorella, G. Rossi, G. Vozza.

Figure 9. Immacolata's Spire in Bitonto. Orthographic views. Authors: R. Pavone, G. Rossi.

environment, was equipped with conventional codes and signs of the representation of architecture, inevitably related to the graphic scale of reduction. (Figure 5)

4. Conclusions

The activities carried out to date have contributed to the completion of only a part of the survey gap and represent the first cognitive support conducted with scientific rigor, providing an indispensable aid for future restoration and maintenance work. The use of range-based and image-based techniques is a further confirmation of the need for the integration of the various techniques and technologies currently available in order to ensure adequate metric control, total coverage and the elimination of data-less areas.

From an analysis of the documentation collected and initial comparison with the Neapolitan models, it seems that those in Salento and Puglia based their interpretation of the ancient obelisk exclusively on the model of the spire of San Domenico in Naples, presenting a three-sided solution with bevelled corners in Lequile, a four-sided spire in Bitonto (Figure 9) and four sides with large corner bevels in Nardò (Figure 7, Figure 8). The interpretation of the victory column and its variation in a spire modelled on that of San Gennaro, also in Naples, is not found in Apulia, where the contemporaneous diffusion of the traditional triumphal column is preserved in refined examples such as those of Presicce, Maglie and Lecce, and in simpler solutions whose diffusion continued up to the last century. The orthographic reconstruction and subsequent graphic interpretations of details in scale and in orthogonal projections allow true observation for the first time. It is certainly more abstract but is an undoubtedly valid substitute for real observation, which is severely restricted by the impossibility of viewing the summit portions. The precious details of the architecture can be seen in the orthographic reconstructions from the surveys, which confirm the effectiveness of drone photogrammetry techniques and provide, for the first time, new and unprecedented image of the spires that were not possible with the survey techniques of the past.

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Point cloud, Virtual tour, Remote access.

ABSTRACT

The COVID-19 emergency has forced significant changes in terms of heritage space fruition, causing the loss of cultural experiences. One of the most affected sectors are libraries, which have drastically reduced the number of daily accesses. The proposed work aims to generate an interactive platform for the virtual fruition of a library heritage case study, obtained from active and passive optical sensors surveys. The aim is to remotely guide the external user to find the location of the interested volume, in order to decrease the time spent on the site and increase the number of daily accesses.

Toward a virtual library experience based on UAV and TLS survey data

1. Introduction

Adopting a single approach to meet the demand for heritage digitization is a great challenge today.
On the one hand, the unicity of the sites, and on the other hand the users' expectations, require a case-by-case assessment of the resources to be used (Napolitano et al. 2018). However, the differentiated application of the collected data represents a not negligible opportunity to optimise the digitization process (Barba et al. 2020). In fact, this may guarantee, starting from a single survey campaign, the production of outputs both for professionals and for wider public dissemination.
The issue becomes more relevant if related to the recent COVID-19 medical emergency, forcing significant changes in the practical aspect of our lives, undoubtedly affecting the enjoyment of the heritage spaces and causing the loss of cultural experiences (Messina et al. 2021). The deprivation of a direct contact dimension with Cultural Heritage assets has led to the proposal of alternative ways of accessing and experiencing these sites, bringing established expertise in digital technology to develop highly detailed three-dimensional models in a multidisciplinary research context (Dell'Amico 2020).
Hence, the integration of different recording techniques and instruments allow combining qualitative information – concerning the history, the conservation state, the characterization of the artefacts – with geometric quantitative information (Trizio et al. 2019).
Starting from this awareness, it is proposed an integrated tool to manage and disseminate collected data about the Library of Montevergine, located in Mercogliano (AV) and housed in the eighteenth-century abbey palace of Loreto, holding a book heritage of great value. The site is undoubtedly a point of reference for students, scholars, and the curious who wish to explore topics of religious interest; it is in fact specialised in this subject, with a focus on its origins as a monastic library founded by Virginian monks, but at the same time adheres to an increasingly specialised and differentiated demand of the users.
The importance of remote recognition of library spaces, and in particular for remote consultation and shelves position of, lies mainly in the impossibility of allowing so many people to access the library at the same time and, consequently, the need to reserve access in advance. Furthermore, the capability of a virtual inspection

Figure 1. UAV capture of the *Loreto di Montevergine* Abbey Palace.

Figure 2. Orthophoto from UAV data of the *Loreto di Montevergine* Abbey Palace.

facilitates the visit for on-site consultation, acting as an additional tool to support visitor orientation.
In this perspective, the virtual visit, in addition to its purpose of enhancing the value and virtual accessibility of the property, result in a very interesting and promising tool for the management of specific contents.

2. Loreto Library survey campaign

The *Loreto di Montevergine* Abbey Palace - erected in place of the old one, nearly entirely destroyed by a strong earthquake in 1732 - was built by Abbot Federici in 1733 and completed in 1749 under the rule of Abbot Letizia. During the past it was almost exclusively used as an abbey residence. Today's architectural complex preserves an archive of approximately 7000 historical parchments and a library open to the public with over 200.000 volumes, and in recent years has taken on the character of an up-to-date and functional cultural institute.
The 3D documentation of the site consisted in: i) a Terrestrial Laser Scanner (TLS) survey of the inner courtyard and the interior spaces of the library building; ii) a UAV aerial photogrammetry survey of the exterior spaces and roofs of the entire complex of the Loreto Abbey Palace.
Concerning the TLS survey, the Cam2 Focus X150 plus by Faro (range: 0.6-150 m, max measurement speed: 2.000.000 points/sec, HDR integrated camera, vertical Field of view: 300°, horizontal FOV: 360°) was implemented. 70 scans were acquired, ten of which to

Figure 3. Some of the panoramic images of the *Loreto di Montevergine* Abbey Palace, in equirectangular projection, captured by the laser scanner camera.

survey the inner cloister, with an average density between 100 and 200 points/dm^2; the remaining 60 scans have an average density between 300 and 700 points/dm^2. The highest density is found in the acquisitions of the interior spaces of the library, motivated by the survey conducted at shorter distances. The phases of co-registration of the scans and global alignment were carried out via Faro Scene 2019 software package (FARO SCENE 2022) by using the 'Cloud to Cloud' automatic registration and ICP algorithm. The 70 TLS scans were co-registered and subsequently aligned to build a global point cloud of the library. The final point cloud has about 1.5 billion points. For the co-registration between scans, the mean point error on the reference pairs ranges between 3 and 7 mm, whereas the standard deviation about the final global alignment is less than 10 mm.
The UAV employed for this application is DJI Phantom 4 (sensor specifications: 4000x3000 pixels; 6.17x4.55 mm; Pixel Size of 1.56 µm). For the acquisition of photogrammetric captures, a single-grid image capture mode was chosen, with a flight height of approximately 43 m from the take-off point (inner courtyard). The flight plan, programmed in the DJI Ground Station application, provided parallel flight lines with overlap and side lap set at 80% and 60% respectively. It was decided to proceed with the acquisition of nadiral images only, as all the external elevations had already been surveyed by TLS. The designed GSD measures 1.64 cm/pixel at ground level.
In order to process the photogrammetric data, Metashape software package by Agisoft (ver. 1.7.0 build 11736) was used. The following parameters were set for the processing of point clouds during the 'Align Photos' phase: i) Accuracy: High (original images); ii) Key-Point limit: 40.000; iii) Tie-Point limit: 40.000. To optimise the camera alignment process, f (focal distance), cx and cy (principal point offset), k1, k2, k3, k4 (radial distortion coefficients), were fitted.
In the computation of the Dense Cloud, the parameters used were: i) Quality: High (1/4 of the original images); ii) Depth filtering: Disable; once the complete elaboration of the photogrammetric captures finished, the software

Figure 4. Simulated searching feature in the original library platform linked to the relative bookshelf in a specific panorama of the virtual tour.

gave back the textured 3D model of the Loreto di Montevergine Abbey Palace, then used to extract the orthophoto. The definition of a topographic control network, aimed at materialising a common reference system, has enabled the integration of TLS models for internal areas and UAV photogrammetric models for external areas. For this case study, the network consists of a closed polygon with 6 vertices, the latter being subject to geometric levelling operations for a rigorous plano-altimetric survey.

The points of the reference network are materialised by means of centring nails, fitted with washers, driven into the road pavement; while artificial checkerboard targets for the detailed points are employed, appropriately distributed on the faces of the block for a total of 15. The compensated coordinates of the target centres are required for both TLS cloud registration and external orientation operations of the photogrammetric dataset obtained from the UAV campaign.

3. Towards a virtual fruition

The transition from the survey to the virtual visit takes place thanks to the combined use of spherical images acquired by terrestrial laser scanner and photogrammetric captures from UAV, here reused for the immersive contents. This saves time and effort, allowing full benefit to be derived from the data acquired: without further photography, 360° captures can be immediately linked together and act as information containers, forming the so-called Virtual Tour (VT).

The virtualized space, in which the user can move and interact, simulates the real life fruition: the sensation of ‘being there’ is realised through a visualisation

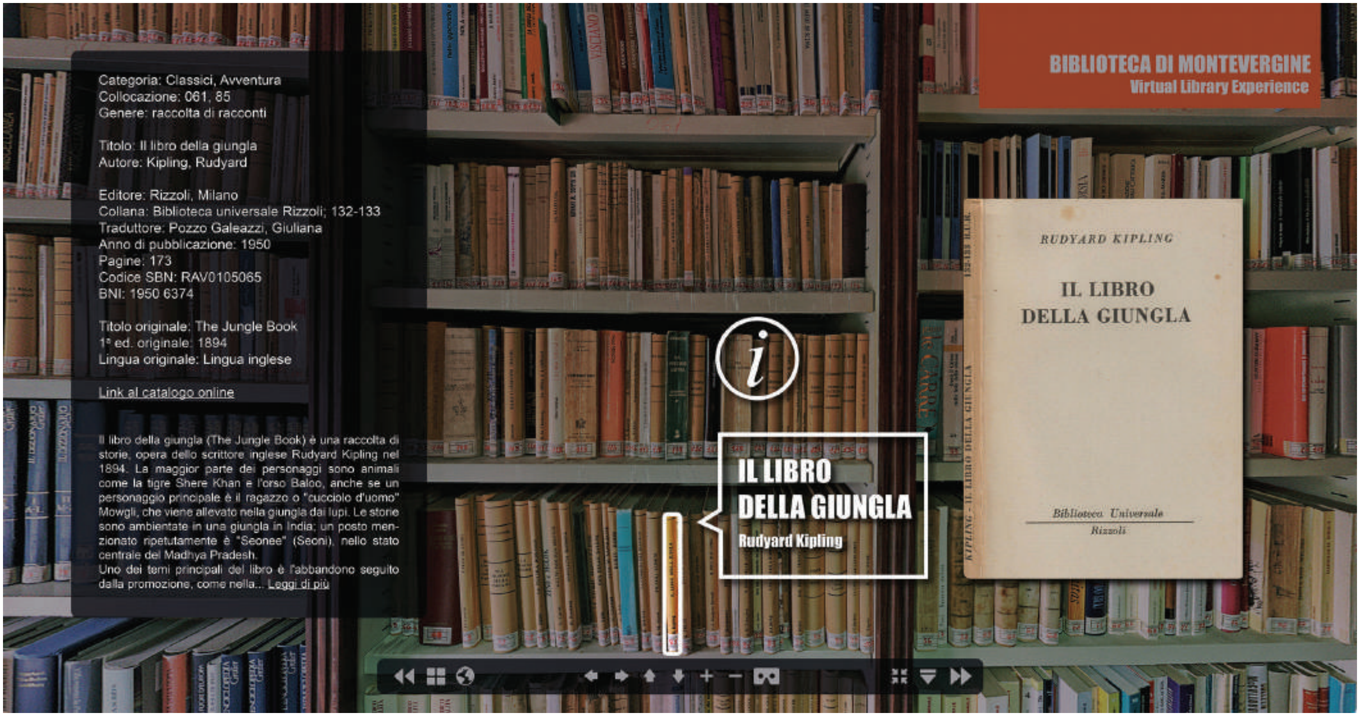

Figure 5. Search result inside the Virtual Tour environment.

mechanism based on immersion, for which a 360° image is configured as a digital model on a 1:1 scale, centred in the point of view of a generic observer, who, looking around, is able to experience in first person a reality that does not exist, but potentially perceives as true (Olivero et al. 2019).

Immersive imaging for Virtual Reality (VR) applications can be revolutionary in several fields, from business to leisure (Slater, Sanchez-Vives 2016), by exploiting the peculiarities of the easily explorable three-dimensional view. For the digitisation of the Loreto Library the potential for transmigration from a survey to a virtual environment should be noted. Through the combined use of an updatable computer catalogue and an existing online platform, the integration of 360° images allow creating an interactive VT of the library rooms with little effort.

The VT environment was generated through the use of krpano software, a high-performance tool to show the panoramic images in a customisable web app environment.

It uses simple.xml text files to store the viewer's settings: this type of extension can be compiled or modified with any text editor, making it easier for no expert users to understand and use. The interface is typical of programming, in fact, it is possible to build the front end through the script for strings, and call predefined commands from the software depending on the action to be obtained. By updating the script each time, a local viewer allows the progress of the project to be viewed before it is uploaded online, according to the needs and the information you want to include in the VT.

The VT, therefore, is an empty container, which precisely - because of this versatility - can be used in an

Figure 6. Left: html script structure of the Virtual Tour; Right: Inspector function during the virtual visit, directly linked to the online catalogue.

innovative way and not only for the simple visualisation of real environments: in this case for the digital and immersive implementation of the catalogue of the titles and volumes housed in the library. In fact, the idea is to allow the title search through a standard user interface, first choosing a volume and then visualising it precisely in the spatial location inside the virtual library room. It is also possible to visualise, by selecting inside the view, more information about the chosen book such as author, date of publication or other. The books have been divided by shelf for these functions to facilitate the navigability to the visitor, moreover specific targets have been used to allow actions within the interface such as opening the information or simply selecting a volume.
This type of application can be used through both a web app and a mobile app, Android or iOs. Finally, it is an excellent VR support integrated within the environment that can also be viewed without the use of a specific visor but simply using the screen of a smartphone.

4. Results and discussion

The application developed can be a useful support, especially in relation to its speed of implementation and lightness of data, moreover integrated into a system that already exists. The dedicated web pages of the library already makes the search easily available, but it is the VR application that actually shows the path in the system and the effective spatial location, significantly reducing the time for searching a volume.

The same type of application can be realised with different technologies, as in the case of BIM modelling. However, in that case, it is necessary to examine whether the amount of work required is actually too onerous for the desired task. In addition to the incredible volumes to be modelled, there is also the difficulty of making such content available online due to the specific typology and considerable weight. It would, therefore, always be good to contextualise and clarify the purpose and consequently re-evaluate already available solutions, readjusting them, as in the case of VR, gaining time and effort. In this perspective, it would be reductive today to relegate a VT to its initial virtual fruitive function: in addition to its aim of asset 'remote exploration', it is also a very interesting and promising tool to manage technical information, usually linked to the objects within the VT through specific hotspots. In this work, the personalisation of these points of interest plays a key role, since it gives the user information not only of a general nature (including the view of historical photos or historical information about the building), but also related to effectively helping users. This makes it possible to reconstruct a digital spatial map of cataloguing. In this way we are not only dealing with an online catalogue, nor only with a VT, but with a search in the virtualized space of the original library.
Finally, this tool enriches and enhances the property itself, intriguing users who normally access the online search with a preview of the beauty of historical places, attracting people's interest in the architectural heritage as well as in books and reading.

5. Conclusions

The development of 360° Virtual Tours is one of the ways that can promote the uniqueness and richness of a country's local heritage through digital technology.
The use of a VT allows for the visibility of different media elements to make the desired information easily visible effectively. Thus, this type of application expands the possibilities of knowing a given asset in an immersive way without losing the feeling of an on-site visit.
Given the versatility of that kind of application, it would be useful to rethink the VT environment with special information to fit the virtual container to a specific mission, however guaranteeing the immersive panorama walk through.
Finally, the practicality of this workflow also demonstrates that this type of approach can be easily replicated on other possible similar applications, effectively extending the applicability of this study.

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ABSTRACT

The research presents the results of the architectural survey and subsequent graphic representation and modelling of the Royal Palace of Aranjuez in the Community of Madrid. The aims of this research are the digital knowledge of the site through the use of SAPR systems and the creation of an interactive database, containing a set of historical, graphic and digital data. The management of the digital data from the drone constitutes a significant tool for the knowledge of the architectural artefact and the garden behind it, determining the possibility of managing, with greater attention, the requirements for the use of the internal and external spaces.

UAS applications for the survey of monumental architecture. The case study of the Royal Residence of Aranjuez in Spain

1. Introduction

The research is aimed at the knowledge of the Royal Palace of Aranjuez located in the Community of Madrid, through an investigation centred on a methodology characterised by different phases. Starting from some consolidated techniques in the discipline of representation up to the use of computer technologies applied to geometry that become a tool for restitution, analysis, information of the Spanish Royal Residence. The building, declared a UNESCO World Heritage Site, is considered to be one of the best examples of the country residence of the Kings and Queens of Spain. Over the centuries, the Bourbons never ceased to develop the splendour of the Royal Site, where they spent the spring period every year. As is well known, in Europe since the early Middle Ages there has been a strong territorial identity, generated by a process of centralisation of power, where people from the upper classes felt the need to reside in fortified residences. In the Renaissance period, with the rise of monarchies, royal families felt the need to build monumental dwellings, regardless of their function, in order to display their power and wealth. Some royal families, out of a need to escape from the monotonous life at court, built secondary residences where they could spend their holidays, intended as 'places of pleasure'. These structures, of great architectural and naturalistic importance, were hunting or country estates or seaside resorts. These functions varied according to their geographical position and the peculiarities of the surrounding territory. The ensemble of royal buildings, gardens and parks today constitutes a valuable complex of great artistic and cultural value (Figure 1). This contribution addresses the theme of European royal holiday buildings, focusing on the Royal Palace of Aranjuez. The building presents the characteristic geometries of Habsburg classicism with an alternation of white stone and brick. The Residence was built at the behest of Felipe II on the site of the old palace of the Masters of Santiago. It owes its architecture to Juan Bautista de Toledo, who began construction in 1564, and Juan de Herrera, who only managed to finish half of it. The original project was continued by Philip V in 1715, but not completed until 1752 by Ferdinand VI. In 1775, Charles III entrusted the extension to the architect Francesco Sabatini, who, with substantial modifications, gave the Palace its current characteristic form, adding, in 1781, two new sectors that delimited a Frenchstyle courtyard of honour in front of the main façade. The Royal Residence is surrounded by a total of 111 hectares of richly decorated gardens. The Island Garden, designed by the architect Juan Bautista de Toledo, and the King's Garden next to the Palace, inspired by Italian Renaissance gardens and whose current appearance is due to Philip IV. Philip V added two new French-style gardens to the existing ones: the Parterre in front of the Palace and the end of the Island Garden. The Prince's Garden in the Anglo-French style was directly influenced by Marie Antoinette's gardens in the Petit Trianon. As the palace came to an end, Ferdinand VI created urban connections linking the royal site with the entire Spanish city. Of great interest is the network of blocks with a trident of streets radiating out from the 'Parterre' Palace.

2. SAPR SYSTEMS FOR THE SURVEY OF ARCHITECTURAL COMPLEXES

The applications of different mini UAVs in the The choice of methodological approach was determined by the need to document the building and the various surrounding green areas. (Figure 2) The analysis of the existing bibliography is limited to iconographic studies of the site and to comparative examples of archival documents. For the survey analyses, the reproduction of the original drawings and of the various construction phases of the complex demonstrate how the Royal Palace of Aranjuez constitutes an architectural element of considerable interest on the international scene.

The choice of the type of survey to be carried out was determined by the analysis of various factors: the location of the investigation, characterised by points that cannot be physically reached due to the conformation of the architectural complex and the high height of the compositional elements of the monument. (Figure 3) Another disturbing element was the influx of tourists, which influenced the measurement phase. It was therefore decided to carry out a survey based on the use of digital instruments, in order to acquire as much information as possible in as little time as possible. On site, a survey was chosen using a SAPR system with a quadriplegic drone, through which, with processing in digital software, it is possible to obtain high-density point clouds. (Balletti, 2019). This activity made it possible to respond to the documentary aspects and needs of the Cultural Heritage, using low-cost instruments for architectural and landscape surveys. Following the acquisition of high resolution images obtained from flight programming, in order to obtain a complete restitution of the area analysed, it is possible to proceed with the photogrammetric process. This technique is developed with the use of software that allows the acquisition and management of accurate and georeferenced three-dimensional data with the generation of point clouds. Its workflow is based on several phases. An algorithm (Barba, 2019) evaluates the

Figure 2. Royal Palace of Aranjuez, View towards west with reflex camera. (Gennaro Pio Lento, 2021)

Figure 3. Royal Palace of Aranjuez, westward view of the inner courtyard and main entrance with reflex cam-era. (Gennaro Pio Lento, 2021)

camera's internal parameters, such as focal length, radial and tangential distortions, the positioning of the camera for each shot and the scattered cloud. In the next step, more pixels are reprojected for each aligned camera, creating the Dense Cloud. In the next Build Mesh step, a polygonal mesh model is generated based on the dense cloud data. Finally, the polygonal model is textured in the Build Texture phase. (Palestini, Basso, 2017). The final methodological phase is characterised by a processing of the collected data, allowing the generation of graphic and digital products, represented respectively with two-dimensional drawings and three-dimensional modelling, acquiring a series of information, from metric to material and geometriccompositional, representing an important knowledge tool.

3. The photogrammetric technique for image processing

The methodological process implemented is based on processes of documentation, management and use of knowledge through tools to be used as models for the elaboration of digital archives with a high level of description and detail of the architectural and natural heritage. In order to obtain a geometric and spatial knowledge of the analysed artefacts, it is necessary to use a complete investigation methodology characterised by different phases. A preliminary analysis followed by the production and subsequent management of the data produced by these activities is closely linked to the digital processes of documenting the architectural systems of European royal residences, with particular attention paid to the characteristic architectural features. (Figure 4) In order to document the architectural artefacts from the architecturallandscape scale to the scale of greater detail, we proceeded with the use of various integrated surveying techniques for the construction of digital archives that could be interrogated, photographic instrumentation by means of digital camera and fourperson drone, attempting to alternate the various techniques according to the different objectives required for the detailed analysis of the royal residence. The camera was used to acquire highdefinition and sharp images, (Palestini, Basso, 2017) in particular for the closeups of the architectures analysed and some architectural details, following a photographic acquisition methodology with converging axes, while the drone was used to acquire the entire volume with particular attention to the portion of the upper crown of each architectural artefact, being the most complex to reach. (Figure 5) In order to implement this methodology, a vertical grid of modules with a compatibility of at least 70% was idealised for the drone activities. Manual shots were taken along each vertical and horizontal axis of the grid, varying the height and axis of rotation of the camera, without modifying the distance from the object to be acquired. (Parrinello, Picchio, Dell'Amico, 2018).

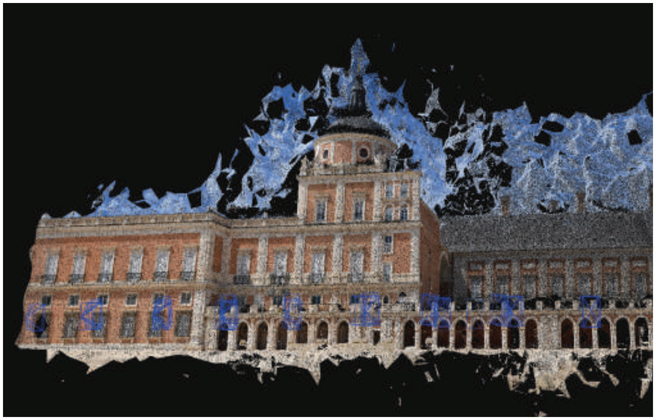

Figure 4. Royal Palace of Aranjuez, Southward view of the side elevation, dense point cloud obtained through the process of aerial photogrammetry with the identification of the shooting points. (Gennaro Pio Lento, 2022)

Of considerable interest is the preliminary programming of the positioning of the drone, in order to avoid missing data in the vicinity of projecting volumetric elements or natural features that represent obstacles to be controlled. In order to obtain instrumental reliability, both in terms of metric quality and descriptive and qualitative correspondence in relation to the analysis of the architectural artefact, the point clouds generated by the interaction of different instruments that are compatible with each other, were inserted within a single reference system. (Figure 6) During the processing of the collected data, several problems were encountered in the generation of the photogrammetric point clouds, including occlusions of some portions due to different losses of GPS signal of the drone in some areas, resulting in several gaps. (Parrinello, Picchio, 2019).
This error was resolved by using the technique of merging

Figure 5. Royal Palace of Aranjuez, southward view of the side elevation, precision orthophoto from textured mesh. (Gennaro Pio Lento, 2022)

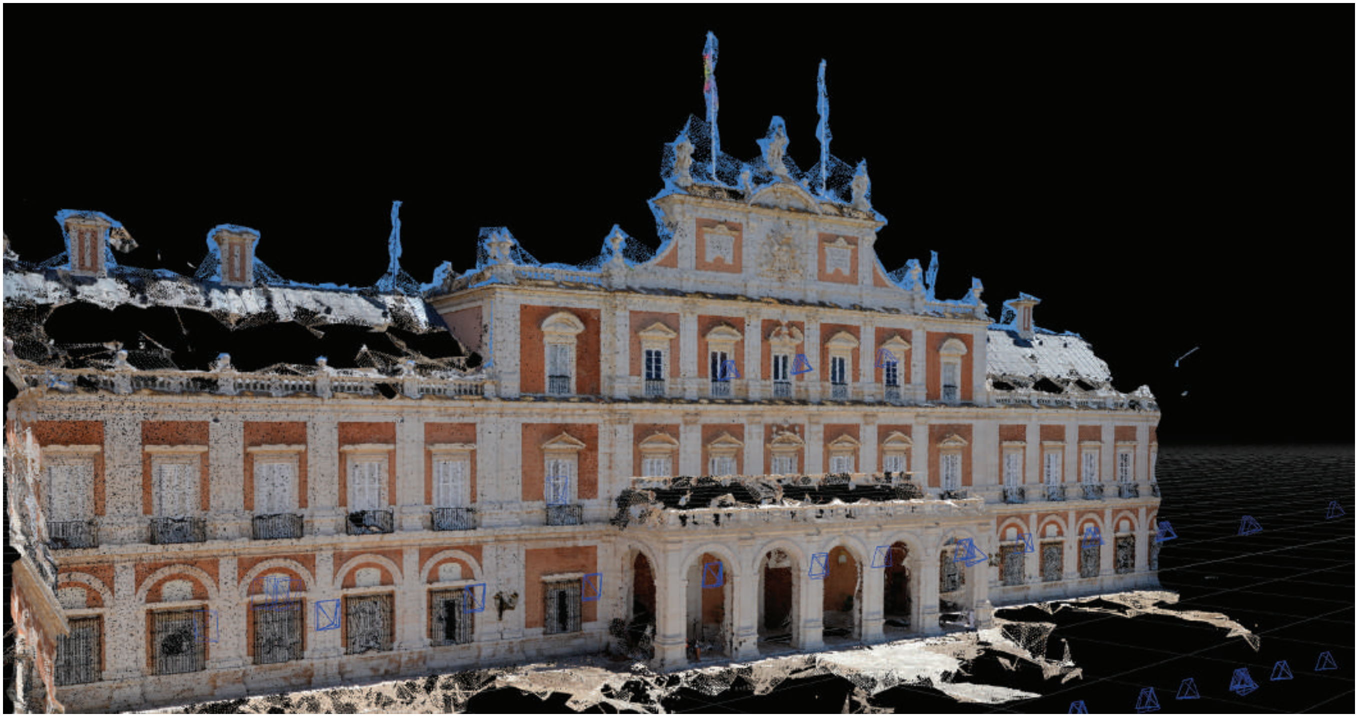

Figure 6. Royal Palace of Aranjuez, View of the main elevation, (Gennaro Pio Lento, 2022)

different point clouds generated by acquisition and processing processes at different scales of detail into a single project, choosing common points. The final result is the obtaining of a complete analysis, reducing the margin of error to a minimum, with the aim of optimising the detailed and complete acquisition of the actual architectural artefacts and the connected naturalistic spaces, generating, the construction of the documentation phases of an interactive and reliable database (Figure 7).

4. The 3D modelling process

In order to document the Cultural Heritage, characterised by the system of different Royal environments such as architectural structures and naturalistic spaces, information technologies applied to the survey elaborated and coming from SAPR instrumentation, become a necessary tool of analysis, restitution and detailed information of the architectures analysed through which it is possible to define the final graphic rendering compatible with the purpose of the survey activity. (Piras, Di Pietra, Visintini, 2017) (Figure 8). The digital representation, as well as the creation of models, in addition to covering a graphic role of three-dimensional reproduction of the object, is the tool for verifying the congruence of conventional representations, such as two-dimensional graphic drawings with respect to virtual graphics. Digital modelling is of great importance, since it allows us to deal with the dynamics of drawing relative to digital representation, it covers the main critical and theoretical exercise of method for digital technologies by defining the questions of a geometric nature necessary for the creation of virtual models. (Remondino, Barazzetti, Nex, Scaioni, Sarazzi, 2011). These models, suitably processed and rendered with the use of specific software, aim to represent the Cultural Heritage starting from digital images at different scales and from acquisitions with low-cost instruments, as well as the availability of technologies for the processing, management and visualisation of 3D data. (Rinaudo, Chiabrando, Lingua, Spanò, 2012).
In order to obtain a three-dimensional model of high quality

Figure 7. Royal Palace of Aranjuez, View of the main elevation, from the dense point cloud to the processing of the precision orthophoto from textured mesh. (Gennaro Pio Lento, 2022)

Figure 8. Royal Palace of Aranjuez, View of the main elevation, from the dense point cloud to the identifica-tion of the various types of openings of the three levels with the precision orthophoto from mesh. (Gennaro Pio Lento, 2022)

Figure 9. Royal Palace of Aranjuez, Eastward view of the courtyard of the King's private garden, from the dense point cloud to the processing of the precision orthophoto from textured mesh. (Gennaro Pio Lento, 2022)

and which is congruent with reality, we have tried to aim for a standardisation of some acquisition and production processes, following the survey phases, including a series of independent and generally shared steps. (Lerma, Navarro, Cabrelles, Villaverde, 2010). This framework, which has matured over the last few years, has resulted in: the use of consolidated three-dimensional modelling techniques; significantly faster digital production processes; and higher quality, accuracy and fidelity of reconstructions (Figure 9).

5. Conclusions

Summer residences, hunting or agricultural estates, monumental and celebratory buildings represent a heritage of inestimable historical, artistic and architectural value, which to date has been subjected to individual studies, mainly of a popular nature, and never compared with each other, through survey and digital modelling, on a European scale. The research activities relating to the analysis of the current state of the architectural artefact and the places connected to it were carried out by means of instrumental surveys performed with a fourwheeled drone and multiple software packages, through which it was possible to digitise the results with two- and three-dimensional images capable of perceiving the spaces and configurative geometries of the structure in the surrounding landscape (Fig 10). It turns out to be a fundamental element for the communication of the architectural artefact examined, through which it is possible to define in parallel the final graphic rendering compatible with the purpose of the survey and the subsequent processing data, through the use of digital software, which has made it possible to obtain point clouds and 3D models, indispensable for documenting and enhancing the charm of the particular type of architecture analysed. To this end, the theme of digital modelling is of great importance, since it makes it possible to deal with the dynamics of drawing relating to both traditional and innovative digital representation of the real holiday architecture, expanding the scarce graphic and iconographic documentation to the use of computer technologies applied to geometry that become a tool for restitution, analysis and information of the real Spanish residence.

Figure 10. Royal Palace of Aranjuez, view to the south of the side elevation, three-dimensional model by screen acquisition obtained with the integration of digital software. (Gennaro Pio Lento, 2022)

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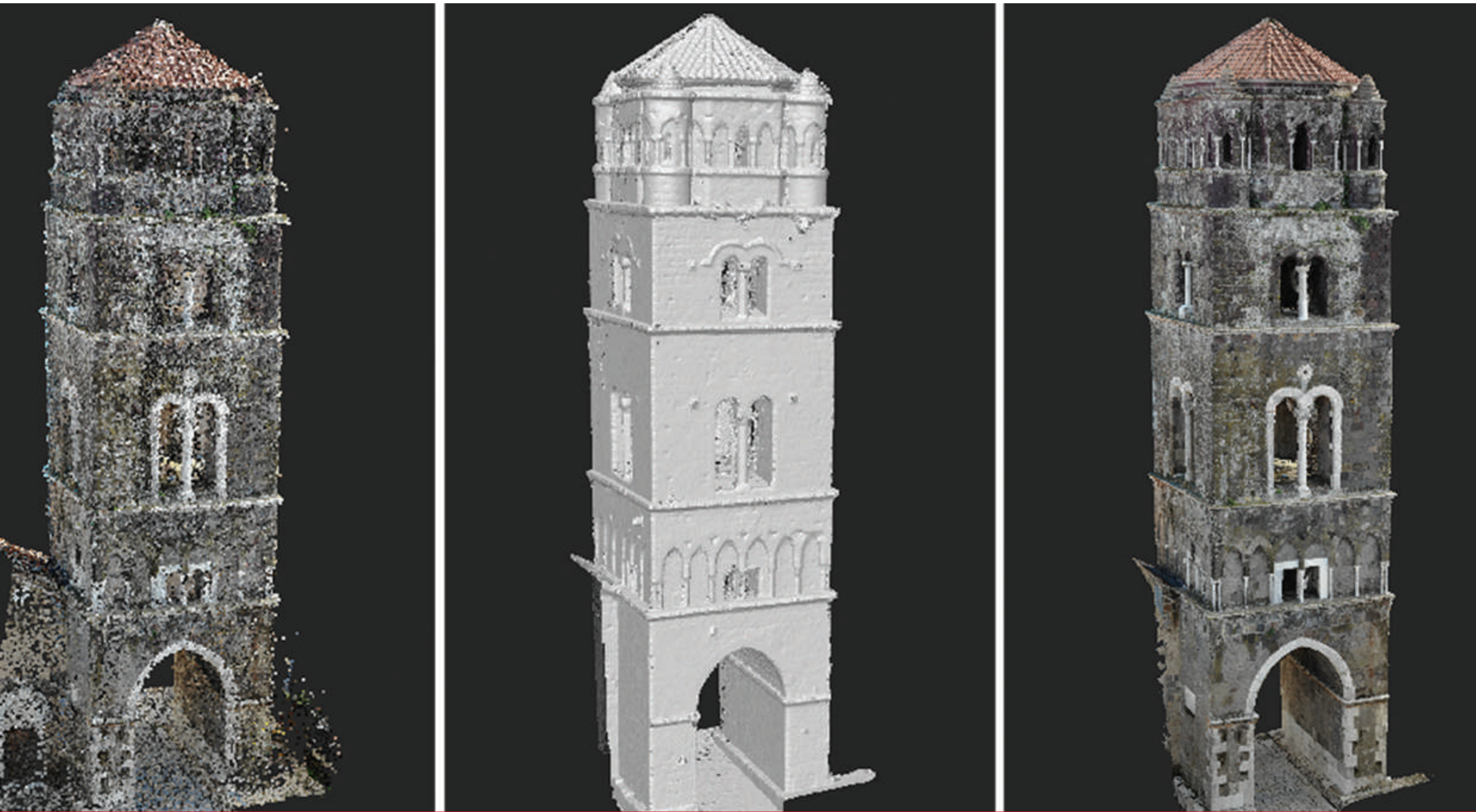

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Keywords:
UAVs, Fast survey, Masonery bell tower, Open-source photogrammetry, Infrared thermography.

ABSTRACT

This study is part of a broader research project aimed at providing a scientific methodology for the structural and conservation assessment and architectural valorization of existing masonry bell towers. In this type of context, the use of UAVs is necessary to obtain an accurate, expeditious and open-source digital architectural survey, also coupling infrared thermographic measurements of the less reachable areas of the artifacts. These measurements are fundamental to the predictive and multidisciplinary analyzes of these peculiar structure.

Open source procedure for UAV-based photogrammetry and infrared thermography in the survey of masonry bell towers

1. Introduction

The study is part of a larger on-going interdisciplinary research project on the valorization of historical bell towers, financed on an intra/Athenian competitive basis (PI: Gianfranco De Matteis. Scientific coordinators: Sergio Sibilio and Ornella Zerlenga).

The main objective of the project, entitled PREVENT, is to provide a scientific methodology aimed at the study and valorization of Cultural Heritage through the disciplines of drawing, technical physics and structural engineering.

A large sample of bell towers with different typological characteristics was taken as a reference and a scientific procedure was outlined for using UAVs in the expeditious survey needed to the realization of the three-dimensional models, the basis for the next multidisciplinary analyzes.

In this work, the results for the architectural and thermography survey of the bell tower of the Cathedral of *San Michele Arcangelo* are reported. The Cathedral is located in the medieval village of *Caserta Vecchia*, 400 meters above the sea level on the slopes of the *Tifatini* mountains. Because of its size, the bell tower dominates all the surrounding buildings, thus it was necessary to use a light aircraft. The UAV is provided with two optical sensors, a photographic module and a thermographic one.

The frames acquired in the visible field, through *ad hoc* flight procedures, were processed though photogrammetric processes to obtain point clouds and polygonal models. Instead, the thermographic module was used to investigate the surfaces' degradation. All the outputs of the processing were necessary in order to define the conservation state of the bell tower.

2. Methods and material

If a person stands in *Piazza Vescovado* looking at the Cathedral, it is possible to observe the bell tower on its right (Figure 1).

The two buildings are not contemporary, the church dates back to 1113 and the bell tower to 1234 (Schultz 1860, pp 182-189; Teschione 1965). From some considerations, it is evident that the bell tower is posthumous: (i) the right corner of the facade of the Cathedral has been found in the left pillar of the bell tower; (ii) it is possible to see the asymmetry of the parallel lines and some forcing of grafting at the points of union between the two buildings; (iii) the access to the bell tower was achieved to the detriment of the right

Figure 1. Piazza Vescovado. Aerial photograph by UAV. (Acquisition by R. Iaderosa).

Figure 2. Historical photograph of the bell tower before the restoration of 1960-1963. Source: M. D'Onofrio, The cathedral of Caserta Vecchia.

aisle of the church which shows a makeshift solution. The current state of the building is the result of a series of restoration interventions, of which the most significant and copious was realized in 1960-1963 (D'Onofrio 1993). At that time, both the partially walled mullioned windows and the right pillar of the bell tower were freed from a huge barbican that disfigured it (Figure 2).

Also, the structure was consolidated through four prestressed belts and reinforced concrete spurs. All the interventions were hidden by the external cladding in which are evident several references to local tradition, as the use of *chiaroscuro* and the dualism of materials (light areas in travertine and gray areas in tuff).

The bell tower has a quadrangular base and its foundations are partially visible, due to the lowering of the general level of the aforementioned square.

The entire structure rests on a plinth made up of Roman relics and it is divided into five vertical orders.

The 1st order houses the large pointed arch, open at the base and entirely decorated with lacunars.

In the 2nd and 5th order there is the ornamental decorative motif of the intertwined arches: round arches resting on thin white marble columns. In particular, in the 2nd order, rectangular windows were inserted between the intertwined arches, probably made in order to let in as much light as possible; the century of this intervention is unknown.

The 3rd and 4th order are both characterized by mullioned windows, but those of the median order appear slenderer, being the highest of all.

At the 5th order the plan of bell tower becomes octagonal: in the four resulting corners between the base square and the inscribed octagon, as many small cylindrical towers rise (Figure 3).

Both the octagon and the towers are covered in tiles, resulting in a rather squat appearance of the structure. Indeed, the octagon was surmounted by a slender pyramid and the towers by conical pinnacles in the past (Figure 4).

This modification, currently the only datable one, took place in the 18th century (Laudando 1927, p 25).

Figure 3. Aerial photographs of the bell towers. Orders and details. (Acquisition by R. Iaderosa)

2.1 UAV-based photogrammetry

According to the requirements of ATM09, on the entire medieval village applies a maximum overflight height limit of 60 meters. Since the bell tower, the highest structure in the surroundings, is about 30 meters high, it was possible to overlook any reserve of airspace for UAV acquisitions. However, in the planning of the activities, a series of factors had to be taken into account: (i) since the village and the Cathedral are a cultural historical asset, big groups of visitors are quite common, limiting the possibility of carrying out the operations in safety; (ii) the structure is located on a hill with an altitude of about 430 meters above sea level; (iii) the activities were carried out in the winter period. These factors have led to a continuous evaluation of both the atmospheric conditions and the use of the places. In addition, since the frames to be acquired (photogrammetric and thermographic) were many, it was not possible to carry out all the operations in the optimal lighting condition. So it was necessary to proceed gradually acquiring every façade over the day, under no direct solar radiation and paying attention to the management of the aircraft. From the available fleet, it was decided to use a DJI Mavic2 Enterprise Dual, for its excellent wind resistance and the availability of a dual cameras system, visible and infrared (Figure 5).
In the visible spectrum, through the open source DJIPilot app, 2,087 frames were acquired in manual flight mode following the design of several ramps structured according to a horizontal and vertical double grid path for a high degree of frames' overlap.
The ramps were completed by placing the axis of inclination of the camera perpendicular to the bell tower and inclined at 45°-70°-90°. The acquisitions of the top part were thickened through manual flights orbiting around the bell tower. The shots took place in automatic mode and set a shooting interval equal to 1 frame every 2 seconds (Figure 6).

2.2 UAV-based thermography and terrestrial integration

The thermographic acquisitions followed a passive approach. In general, passive thermography consists in measuring the temperature differences under normal thermal conditions, generally solar radiation (American Society for Nondestructive Testing 2001).
In order to get a significant difference between the internal and external wall surfaces' temperatures, a closed indoor environment is required.
However, due to the characteristics of the bell tower (massive walls with full open apertures), this thermal difference was very low and the thermography had to rely entirely on the thermal inertia of the most external wall layers, thus resulting in a short available time frame.

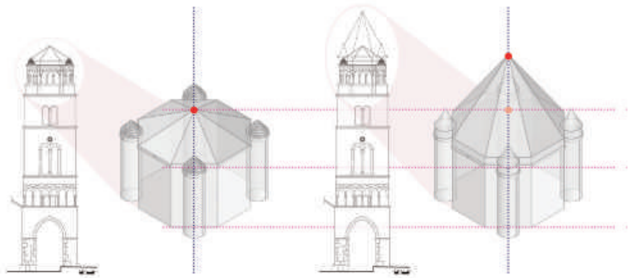
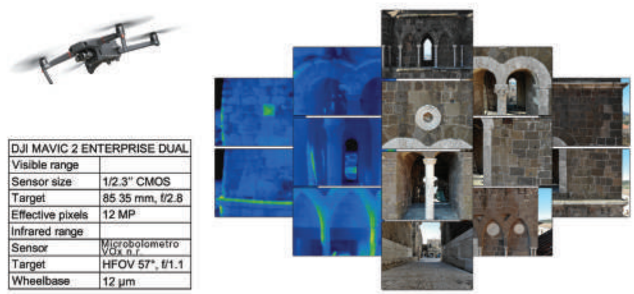


Figure 4. Roofs analysis. From left to right: current status; reconstructive hypothesis of the original state. The hypothesis is based on bibliographic documentation. (Graphic processing by V. Cirillo, R. Iaderosa, R. Miele)



DJI MAVIC 2 ENTERPRISE DUAL	
Visible range	
Sensor size	1/2.3'' CMOS
Target	85 35 mm, f/2.8
Effective pixels	12 MP
Infrared range	
Sensor	Microbolometro VOx n.r.
Target	HFOV 57°, f/1.1
Wheelbase	12 µm

Figure 5. DJI Mavic 2 Enterprise Dual. Technical data of the sensors and acquisitions of the bell tower. (Acquisition and graphic processing by R. Iaderosa)

The *in-situ* measurements were carried out by means of two thermocameras: from the ground, a FLIR A35 (FOV 45°) was used, providing the data for a preliminary assessment of the surfaces, while the aerial measurements were carried out using the thermographic module of the DJI Mavic2 Enterprise Dual (FOV 57°). Both cameras are provided with an uncooled VOX microbolometer sensor: the FLIR A35 sensor (resolution: 320x256 px) is sensible to the 7.5–13 μm spectral range, while the drone sensor (resolution: 160x120 px) has a slightly higher sensitivity range of 8-14 μm. Both devices show some limitations: the FLIR A35 doesn't offer a high-resolution thermography, so the integration with the aerial sensor was necessary in order to get an accurate assessment of the top orders of the bell tower without geometric distortions; the drone sensor doesn't allow for fine adjustments of the thermographic settings and it is not possible to post-process the output files. For these reasons, the DJI thermocamera had to go through a calibration process before the flight, which can be summarized in the following steps:

- preliminary assessment of the surfaces from the ground by means of the FLIR A35, to define the most critical areas and the most useful temperatures' range to be set in the DJIPilot app;
- evaluation of the emissivity of the materials, by comparison between the temperatures measured on a sample area by the FLIR A35 and a TESTO surface temperature probe (type K thermocouple);
- evaluation of the measurement distance for the DJI thermocamera, in order to get the same temperatures measured by the FLIR A35.

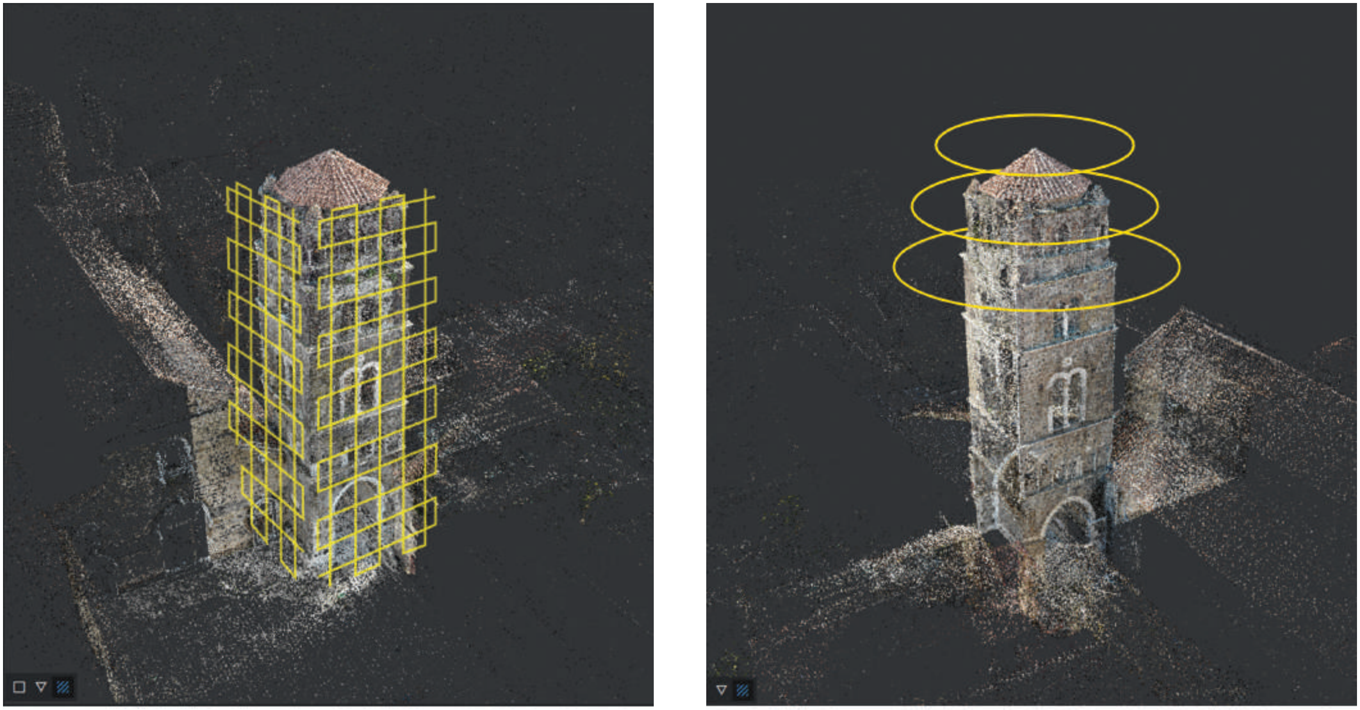


Figure 6. Conceptual schemes of flight trajectories for the photogrammetric acquisitions by UAV. (Acquisition and photogrammetric processing by R. Iaderosa)

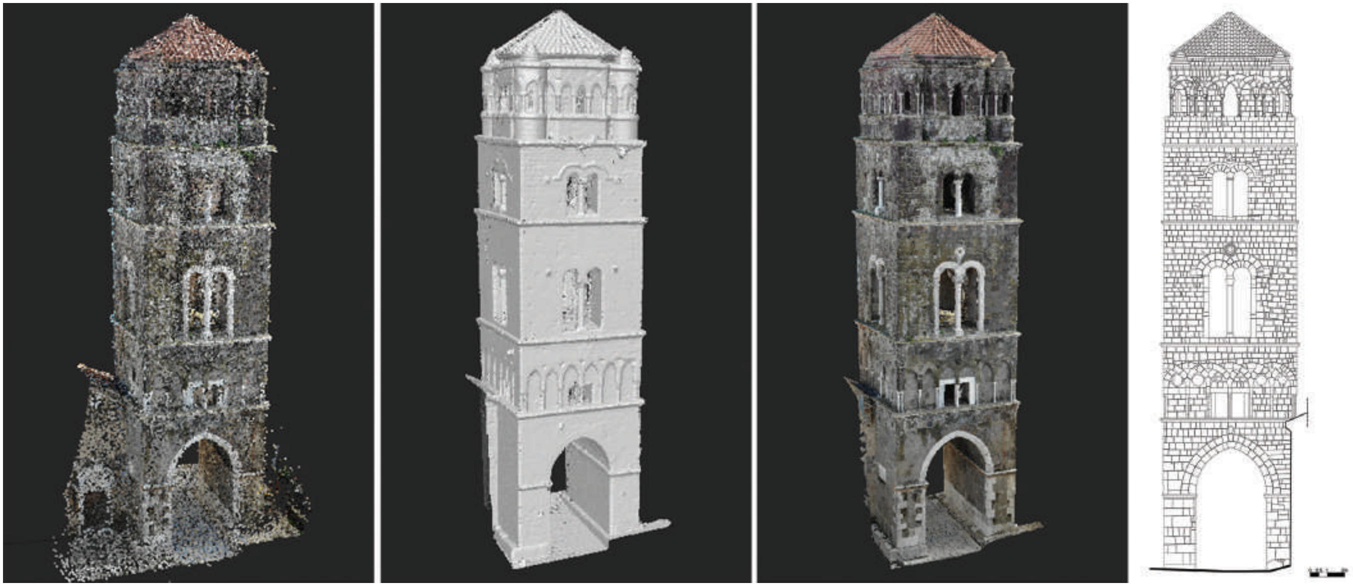


Figure 7. Two-dimensional and three-dimensional graphic processing. From left to right: sparse cloud; mesh model; texture model; geometric facade. (2D and 3D processing by R. Iaderosa)

The last step was necessary as the DJI thermocamera showed a strong shift in measurements upon varying the distance, so the optimal range was defined with the FLIR A35 as reference, and equal to 1.5 m from the analyzed surface. Due to this short distance, it was necessary to fly in manual mode; however, a regular measurement grid was followed along the most critical areas highlighted in the preliminary ground assessment. Both visible and IR images were acquired during the flight with manual timing.

2.3 Post-processing and analysis of the surfaces' deterioration

The post-processing phase started with the generation of the geometrical model of the bell tower. A weighted selection of the acquired data sets was carried out, and 884 photos were processed. To obtain a simple interchange and the repeatability of the protocol (Griwodz et al. 2021, pp 241-247), data processing took place through an open-source software, Meshroom (Verykokou 2021, pp. 228-240). The fundamental steps have allowed to derive a point cloud made up of 642,150 points, and a mesh model of 3,565,244 vertices and 7,129,584 faces (Figures 7 and 8). Through subsequent processing, the four orthomosaics of the bell tower façades were obtained to carry out the appropriate deterioration analyzes.

A preliminary deterioration analysis was carried out on the orthomosaics from the photos, then implementing the information from the thermographic acquisitions. In particular, as the DJI provides for the visible and IR cameras coupled in a single device, the IR image is easily superimposed on the visible one by applying a fixed optical correction (barrel distortion correction, +42 in Adobe Camera RAW) and scaling factor (545%) to the IR one. The architectural survey was returned for a scale of 1:50 representation.

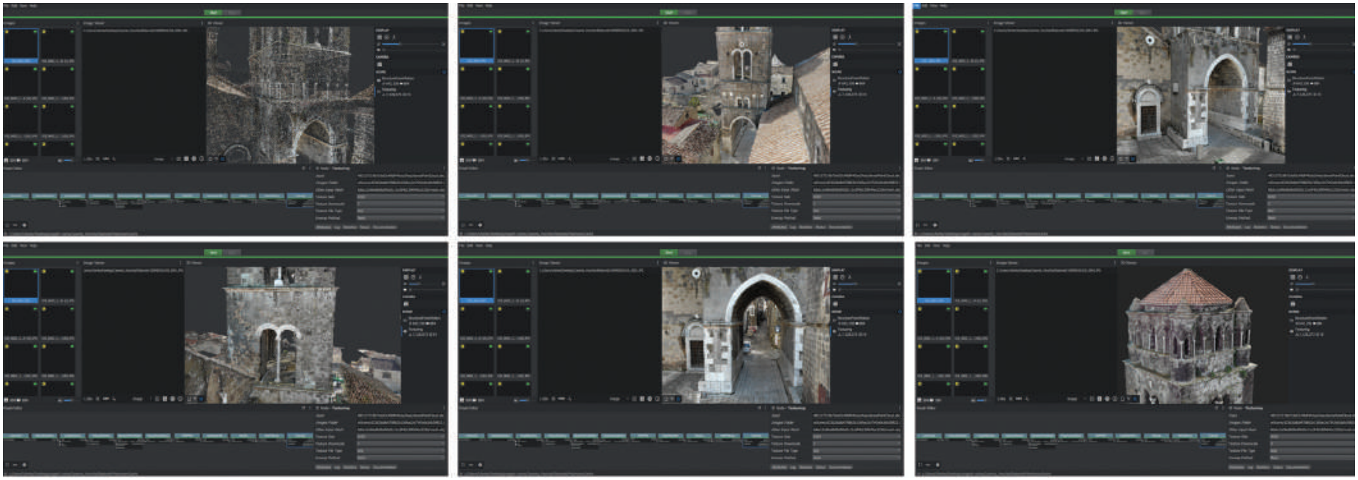


Figure 8. Details of the sparse cloud and texture model within the Meshroom GUI. (Photogrammetric processing by R. Iaderosa)

3. Results and discussions

This section reports the results of the survey carried out following the aforementioned methodology. Figure 9 reports the orthomosaics of the four façades of the bell tower, generated from the mesh model.

Then, the deterioration analysis for the east façade is reported. The IR measurements were started as soon as there was no direct solar radiation on the east façade (around 11:45 am CET).

Figure 10 shows the results of the preliminary thermographic measurements from the ground.

In particular, figure 10a and b show the comparison between the visible and IR images, highlighting: (i) a strong dependence of accuracy and resolution upon varying the angle and distance of measurement; (ii) a hot area (Figure 10c) on the right of the 2nd order of the façade, due to the roof tiles' reflections; (iii) the size of the humidity patch on the right side of the 1st order (Figure 10d); (iv) several deterioration areas, due to biological patina (Figure 10e) and geometrical/material discontinuity (Figure 10f). These material discontinuities could be related to the strong stratification process that occurred over the centuries experienced by both the bell tower and the entire church. Thus, the presence of masonry units of different materials (e.g. limestone) within the tuff walls of the tower cannot be excluded (partially testified by ongoing structural in-situ investigations).

Lastly, figg. 10g and h report the temperature trends along the profile lines on the left (in black) and on the right (in red): these trends show a rising gradient in temperature, mainly due to the effects of the surroundings: indeed, the bottom order fell in shadows sooner than the top orders, which were also more affected by the winds.

The preliminary assessment allowed to define the most critical areas to be evaluated, along with the temperature measurement range (4-24 °C) and the emissivity of the gray tuff (e = 0.93) to be set in the DJIPilot app. After the take-off, several long-distance IR images were captured, and reported in Figure 11.

While these IR images are not valid in terms of absolute temperature values (due to the influence of the measurement distance, as stated previously), they accurately show the surface temperatures' differences. In particular, Figure 11a shows, more in detail, the area of the humidity patch on the right side of the 1st

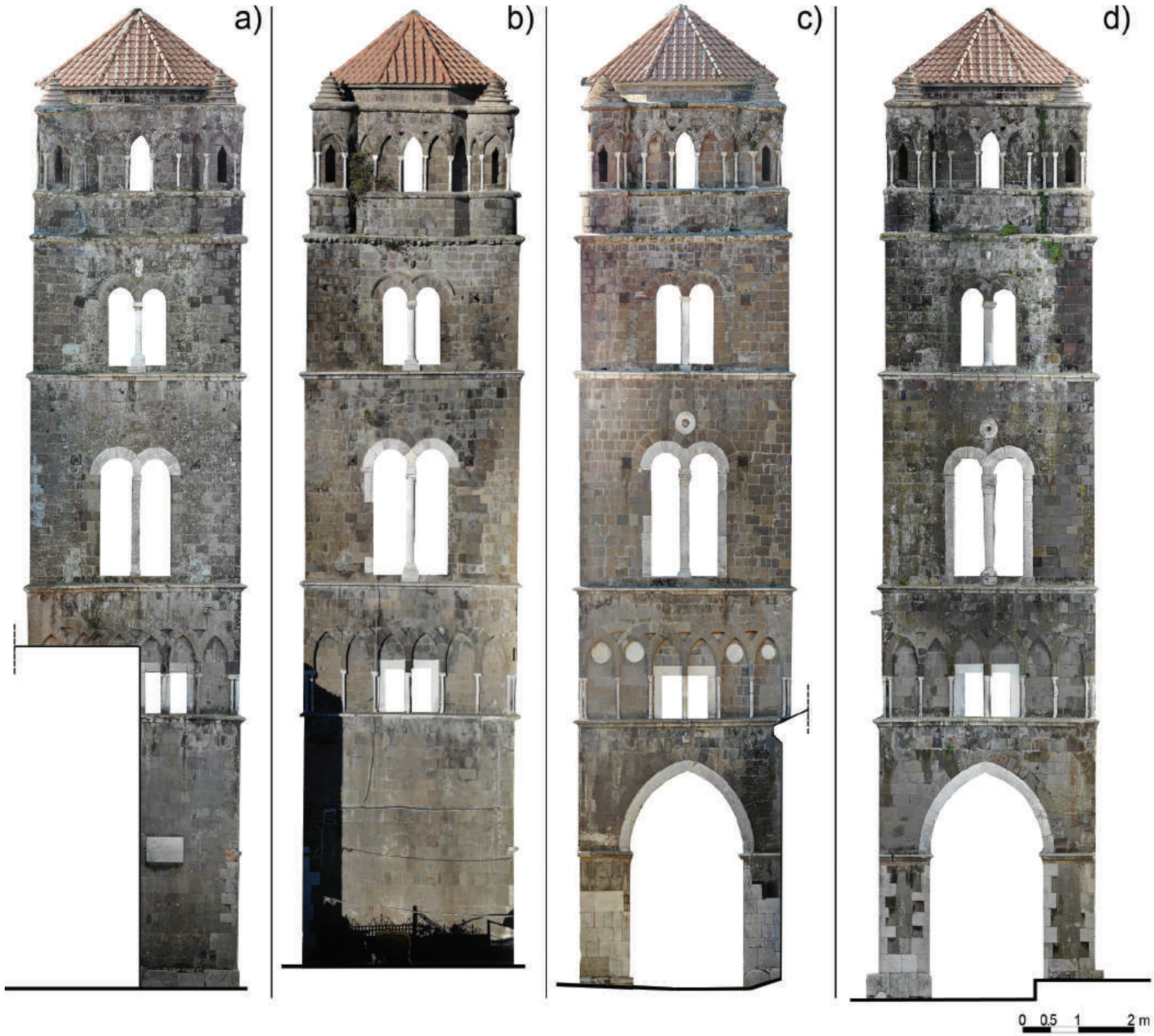


Figure 9. The orthomosaics of the four façades of the bell tower: a) north, b) south, c) east, and d) west. (Processing by R. Iaderosa)

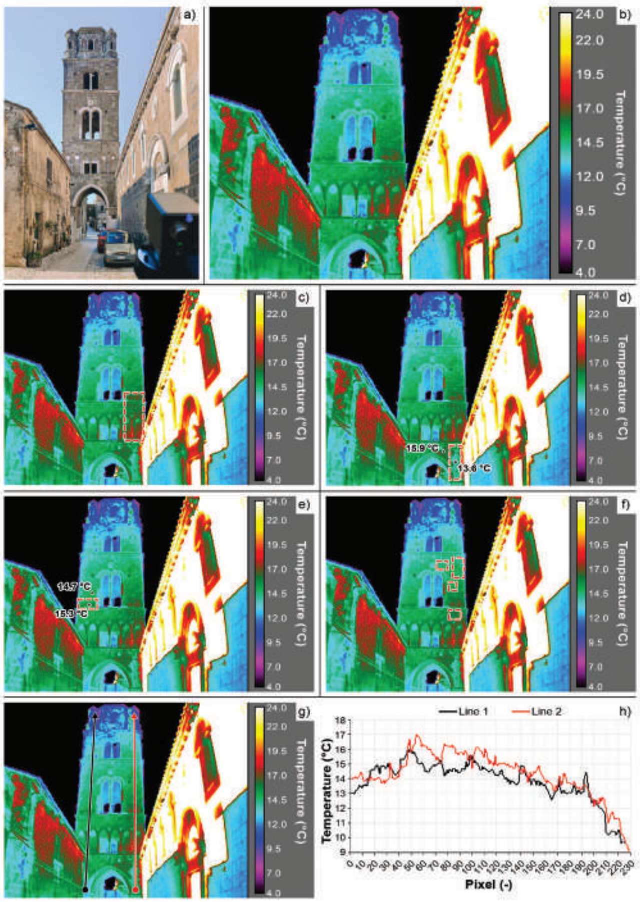


Figure 10. Results of the preliminary thermographic measurements from the ground associated to the east façade of the bell tower: a) visible image, b) IR image, c) detail highlighting a hot area on the 2nd order, d) extension of the humidity area on the 1st order, e) detail highlighting biological patina, f) detail highlighting geometrical/material discontinuity, g) profile lines for temperature trends and h) temperature trends upon varying the pixels of the IR image and the profile lines. (Processing by G. Ciampi, Y. Spanodimitriou)

order (highlighted in red), and possibly the presence of different masonry materials. Moreover, Figure11b and c show the temperatures inhomogeneities (in deep blue) due to the crusts and biological patina on the 4th (Figure11b) and 5th (Figure 11c) orders. Finally, Figure

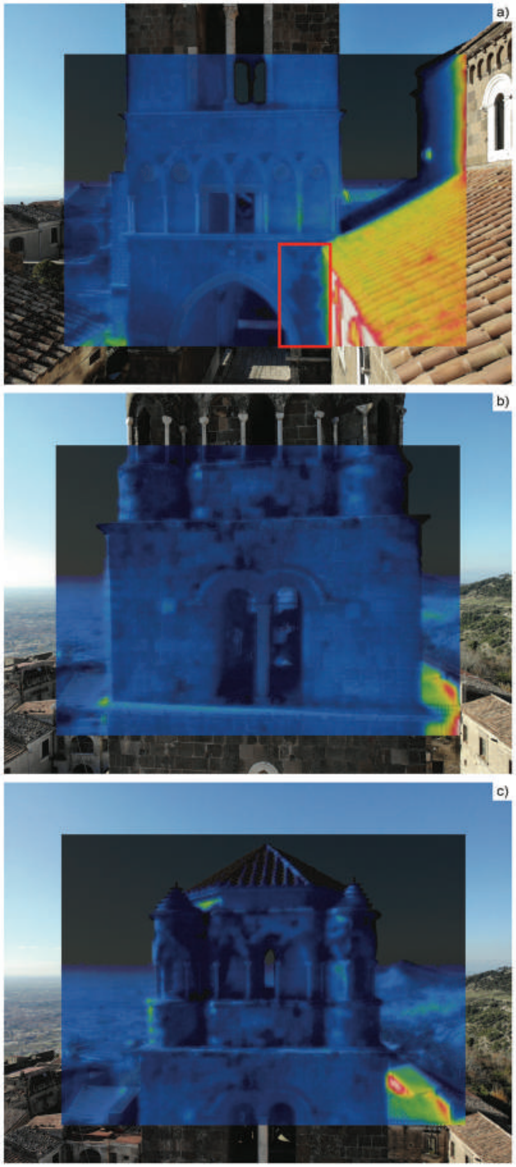


Figure 11. Overlap of the visible and IR images acquired by means of the DJI Mavic2 Enterprise Dual drone: a) extension of the humidity area on the right side of the 1st order, temperatures inhomogeneities due to crusts and biological patina on the b) 4th and c) 5th order. (Acquisition by R. Iaderosa and graphic processing by G. Ciampi, Y. Spanodimitriou)

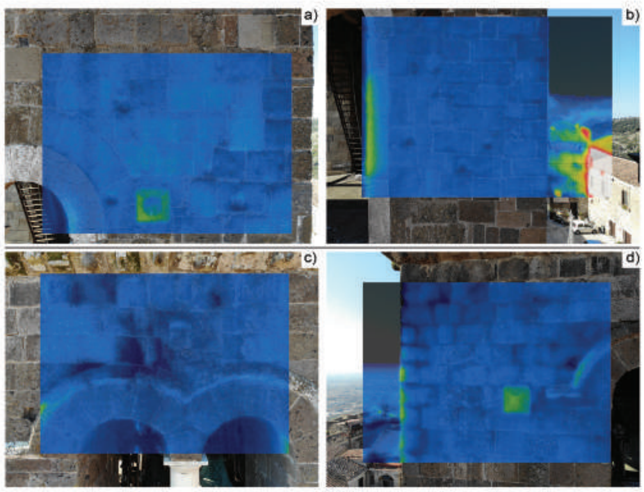


Figure 12. Overlap of the visible and IR images acquired through the DJI Mavic2 Enterprise Dual drone for the most critical areas: inhomogeneities in the gray tuff bricks used at a) the center and b) angle of the masonry of the 3rd order, c) deterioration due to crusts and biological patina on the mullioned windows of the 4th order and d) temperatures inhomogeneities between the angle and center bricks on the left side of the 4th order. (Acquisition by R. Iaderosa and graphic processing by G. Ciampi, Y. Spanodimitriou)

12 reports the IR images acquired at 1.5 m, showing: (i) in Figures 12a and b, the inhomogeneities in the gray tuff bricks used at the center and angle of the masonry of the 3rd order, along with some scaling and fissuring, undetectable in the photos due to their shallow depth; (ii) in Figure 12c, an area of deep deterioration due to crusts and biological patina on the gray tuff bricks of the arches at the 4th order; (iii) in Figure 12d, a strong temperature variation in the gaps between the angle and center bricks on the left side of the 4th order, due to the pulverization of mortar joints. The deterioration assessment of the east façade of the bell tower of the Cathedral of *San Michele Arcangelo* returned a scenario where defects afflict about 27.6% of the total façade area: the main ones were chromatic alteration (44.5 m^2), biological patina/crusts (23.7 m^2), erosion (1.26 m^2), and omissions (0.12 m^2).

4. Conclusion

Nowadays, the idea that UAVs technologies are necessary for the survey of architectures in not accessible and/or not visible areas is widespread in the scientific community. The study shows the fundamental role of UAVs in obtaining an accurate and fast digital survey for multidisciplinary predictive analysis and decision-making processes. In this work, the survey on the bell tower of the Cathedral of *San Michele Arcangelo* was performed using a UAV provided with a coupled visible and IR camera system, returning a more precise scenario of the conservation state of the external surfaces.

Acknowledgments

All UAV acquisitions are by R. Iaderosa. Paragraphs 1, 2, 2.1 and 2.3 are edited by O. Zerlenga, V. Cirillo, R. Iaderosa and R. Miele. Paragaphs 2.2 and 3 are edited by G. De Matteis, S. Sibilio, G. Ciampi and Y. Spanodimitriou.

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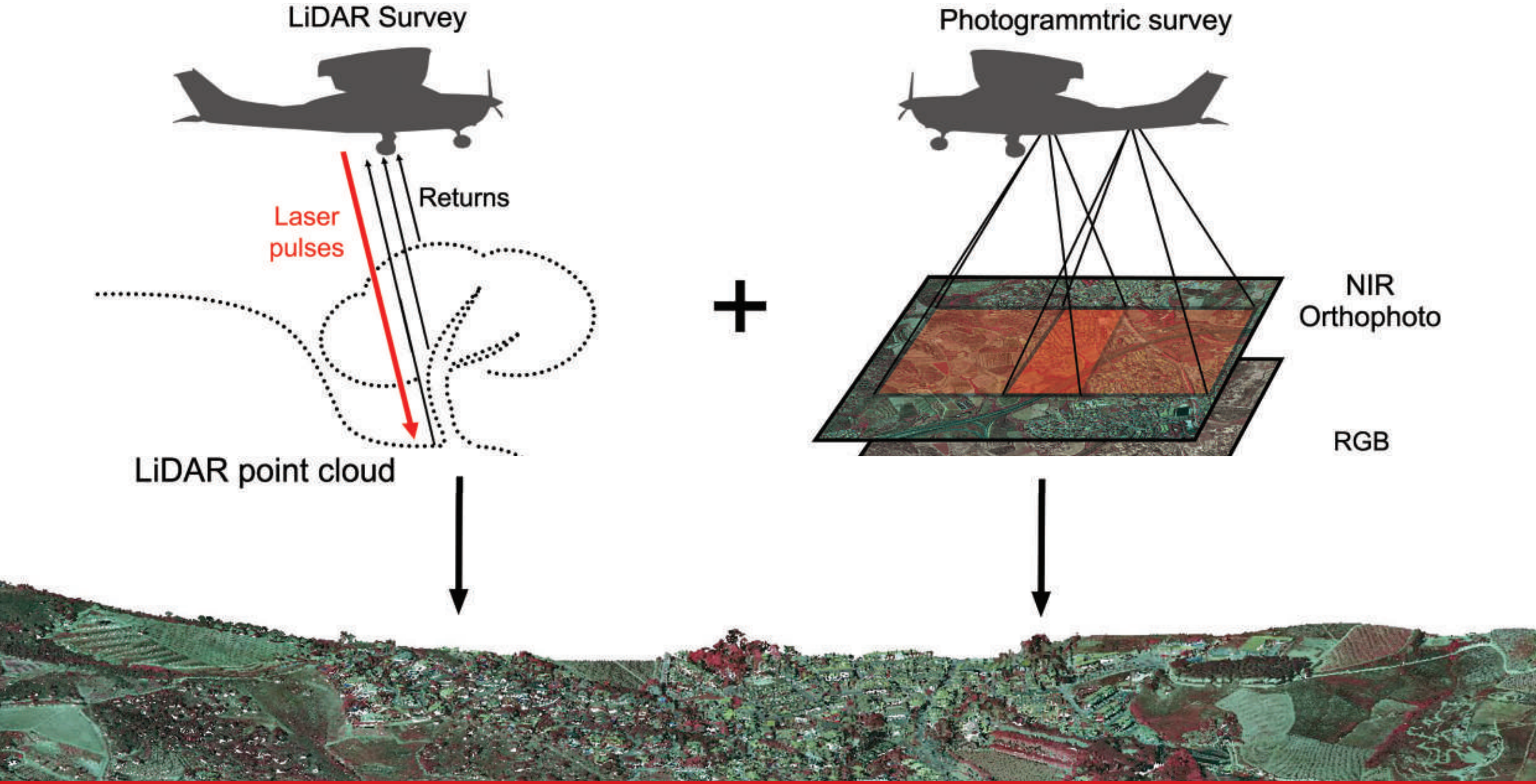

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Keywords:

Survey, LiDAR data, Segmentation, Model analysis, Information systems.

ABSTRACT

The current state of information and the physical conditions of agricultural-territorial zones, with re-spect to the inclusion, security and sustainability of these settlements is, up to date, fragmentary and lacking details. As a result of this, and thanks to open-source software which allow access, easier as time goes by, to data with high precision, a methodology for the analysis of terraced areas was proposed, by classifying LiDAR data to obtain the state of vegetation and the cultivable areas from them. The results allow updating the informative databases for the acquisition, visualization and geolocation of cultivable terraced areas for the surveillance of their state of conservation and recovery.

Image-based segmentation and modelling of terraced landscapes

1. Introduction

In the past decade we have witnessed a growing awareness of the necessity to preserve the cultural landscape of the agricultural-terraced areas, in the context of policies for the conservation and enhancement of the rural landscape, due to its recognized economic and environmental value. Each terracement, like each site, has its own particularity, as it is the expression of the different ways in which the relationship between man and nature manifests itself over time; it constitutes a unicum with spatial-typological characteristics, today, at high risk of irreversible damage due to the progressive abandonment of local production and the lack of maintenance activities of the territory, which motivates the greater attention of the scientific community to the theme of its valorization, especially with respect to the current international scenario. In matter of fact, institutions such as UNESCO, in particular with the World Heritage List and the MAB Program of Biosphere Reserves (UNESCO 2016), and FAO through the GIAHS (Globally Important AgriCultural Heritage Systems) program (Santoro et al. 2020), include many terraced territories in Asia, Africa, Europe and the Americas among those destined for specific protection. The overall picture that emerges, although largely underestimated and in need of further verification and investigation, reveals the impressiveness and widespread distribution of these terraced systems, their exceptional nature in terms of landscape and historical-cultural value, and their environmental value, now marginal, especially in Mediterranean areas sensitive to climate change. In this scenario, the state of knowledge and the information systematization of these areas still appears fragmentary and incomplete, with reference to the context of Campania and in general along the Mediterranean coastal strip where the landscape value of terraced territories attracts the attention of scholars. Therefore, the protection and enhancement of this extraordinary landscape heritage is still one of the major challenges for the territorial regeneration policies that push, also under the impulse of the Agenda 2030 action program for sustainable development and national and regional agricultural policies (Unite Nations 2020), to the recognition and preservation of the elements that characterize the anthropic terraced landscape (such as dry stone walls, interpodal roads and water conveyance systems) in favor of the improvement of inclusiveness, safety and sustainability and recovery of these settlements. To achieve these goals, proven digital integrated survey techniques (Antuono et al. 2020) and smart development techniques for Industry 4.0. (Vaidya, Ambad, Bhosle 2018) can contribute to quantify and qualify the morphology, the spaces and the characteristic elements of the anthropic environment, defining a methodology that overcomes the information deficit of the open-source cartography, in order to acquire useful indicators to orient the projects of valorization of the terraced areas along the Mediterranean coastal strip. The evolution of the techniques leads to an integration of LiDAR (Light Detection and Ranging) data acquired by different approaches with data acquired by photogrammetric surveys with the aim of fusing the best of both techniques, therefore obtaining LiDAR

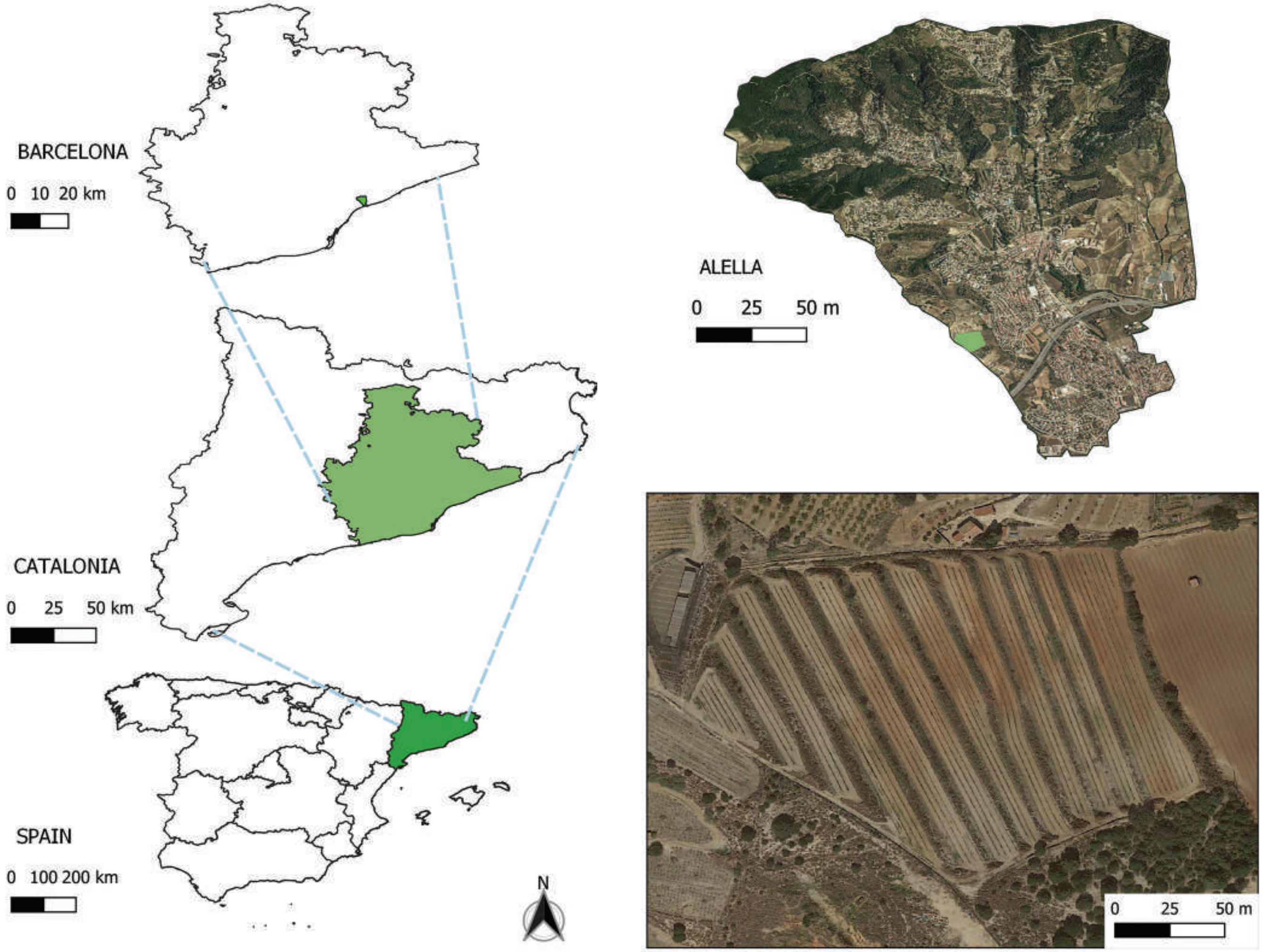

Figure 2. Location of the study area: Alella, Barcelona, Spain.

point clouds with multispectral and RGB values (Figure 1). This type of merging allows, as in this case, to analyze the characteristics present in the cultivable areas, but with the ability to extrapolate them depending on their spectral response (soil, vegetation, buildings, etc.) (Martínez et al. 2013; pp. 3-7). This methodological approach, in this case implemented to take the possibilities of open data even further, can also be used to achieve more accurate and detailed results by carrying out the survey using drones with multispectral cameras. At the same time, the georeferenced altimetric data obtained from the surveys, allows deeper analysis, oriented to extract the functional characteristics of the cultivable areas of terraces (D'Agostino et al. 2021), its control and time monitoring, which would allow with the right tools to recover much of these key areas for the economy and heritage.

2. The pilot area and experimental methodology

The experimentation was conducted with reference to a sample area of about 2000 m^2 of the coastal strip of Alella de Mar near Barcelona in Spain, which shows in its predominantly hilly and mountainous character clear similarities with the Italian territory and more specifically with Campania and Naples, with crops extention that, although profoundly affecting the landscape, adapt to the conformation of the places becoming icons of the productive dynamics of the landscape context (Figure 2). This area has terraces mainly dedicated to the cultivation of vine for wine production, adjacent to other areas destined to the cultivation of ornamental flowers. The choice is motivated, among other things, by a number of other factors: first of all, its proximity to the Mediterranean coast and the use of the land for the planting of specific types of cultivation, are key factors when making comparative analyses with similar contexts in the Italian regions; moreover, the Spanish areas allocated to plantations present a shape and distribution similar to those of the Neapolitan areas, adapting to the conformation of the land; last but not least, Spain makes available a public geospatial and

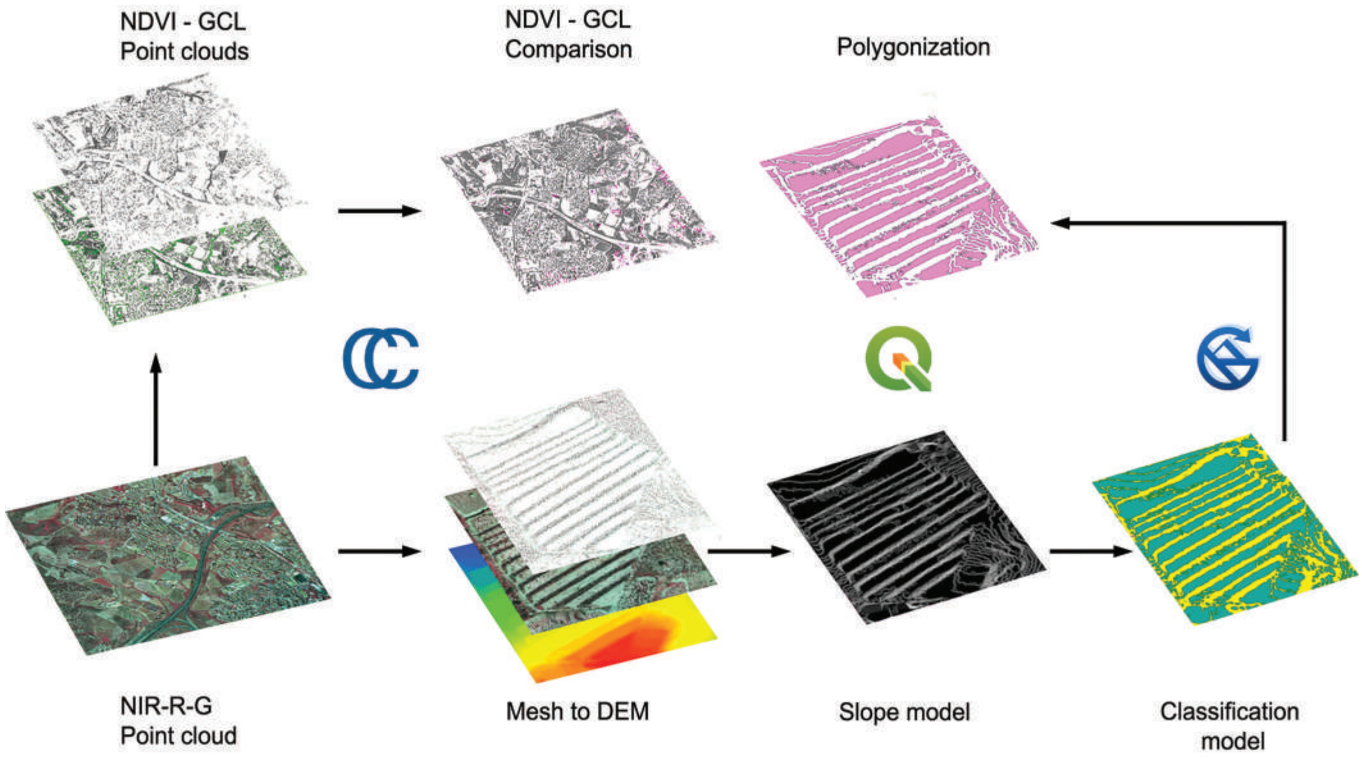

Figure 3. Methodological scheme adopted in the research: from the NDVI -GCL classification to the vectori-zation of the terraced areas.

cartographic database (IGN 2022), where to access to obtain satellite images, cadastral data and LiDAR point clouds with RGB and NIR (Near Infrared) values obtained through two survey campaigns carried out from 2009 to 2015 and from 2015 to date, in collaboration with the PNOA (National Air Orthophotography Plan) project from which to derive high-precision digital elevation models with a maximum level of detail of geographic information of 0.25 points/m^2 in the first coverage and 0.50 points/m^2 in the second, and altimetric accuracy with an approximate mean square error of 20 cm. From the foregoing data, the proposed methodological approach exemplifies the application of classification algorithms based on the spectral response of points (Niemeyer, Rottensteiner, Soergel 2014) to derive the spatial distribution and quantify the plan-volume sequences of the terraced cultivated area. In the extraction of geometric data, the elevation data of the land allow to reconstruct the digital elevation model (DEM), which is analyzed as a slope model to classify the areas according to different gradients by defining the cultivable area and the area of relevance of the retaining walls of terraces and extracting the type and status of crops present, through the analysis of the index (Figure 3).

3. The approach to classifying LiDAR data

With the objective of extracting the points corresponding to the bare terrain, a procedure of classification and analysis of LiDAR data was initially developed, verifying the resolution degree of the extracted data in descriptive levels of the terrain models, vegetation and buildings models by means of the NDVI (Normalized difference vegetation index) (equation.1) (Pettorelli 2005). With the data corresponding to the vegetation, an analysis of the state of the vegetation was carried out through the GCL (Geen chlorophyll index) (Nevalainen 2014) (equation 2), that allows determining from a phenological point of view the amount of chlorophylls existing in the vegetation, this pattern varies according to the time of the year but also to the level of stress to which the plant is subjected, which can be identified through the reddening of the plant structure as a defense mechanism against the excess of ultraviolet light or by the degradation of chlorophylls during the autumn period. The selection of these vegetation indexes was motivated by the characteristics of the area and the available data. In the case of the NDVI, this is the standard indicator for the classification and separation of vegetated areas from built-up areas or bare soil, while the GCL works with two bands, near infrared and green, data that were available, since the blue band was replaced by infrared in the elaboration of the LiDAR point clouds. Analyses were performed with other indices such as RGR (Red Green Ratio), SAVI (Soil Adjusted Vegetation Index) or GNDVI (Green Normalized Difference Vegetation Index), but the results were not as promising as those obtained with the indices selected for this research. The general analysis was carried out for the two periods (2008 and 2016) in order to achieve a more precise value of the areas and to be able to assume that the cause is not due to the time of the year, but to internal factors of the area where they are located (Figure 4).

$$NDVI = \frac{NIR - RED}{NIR + RED} \qquad [1]$$

$$GCL = \frac{NIR}{GREEN} - 1 \qquad [2]$$

With the bare soil data, an area of terrain was identified, this area did not present major problems compared to the previously explained analysis, so only the analysis of the conformation of the terrain was continued. Thus, first, the geometric conformation of the terrain was reconstructed in CloudCompare v2.11.3, according to a mesh of irregular triangles sampled to fill the spaces by interpolating the points homogeneously and ensuring total coverage of the entire workspace. Subsequently, a raster matrix was obtained for the discrete representation of the spatial-altimetric distribution of the georeferenced points corresponding to the absolute elevations (DEM), later exported to the structured information system QGis for slope analysis and integrated

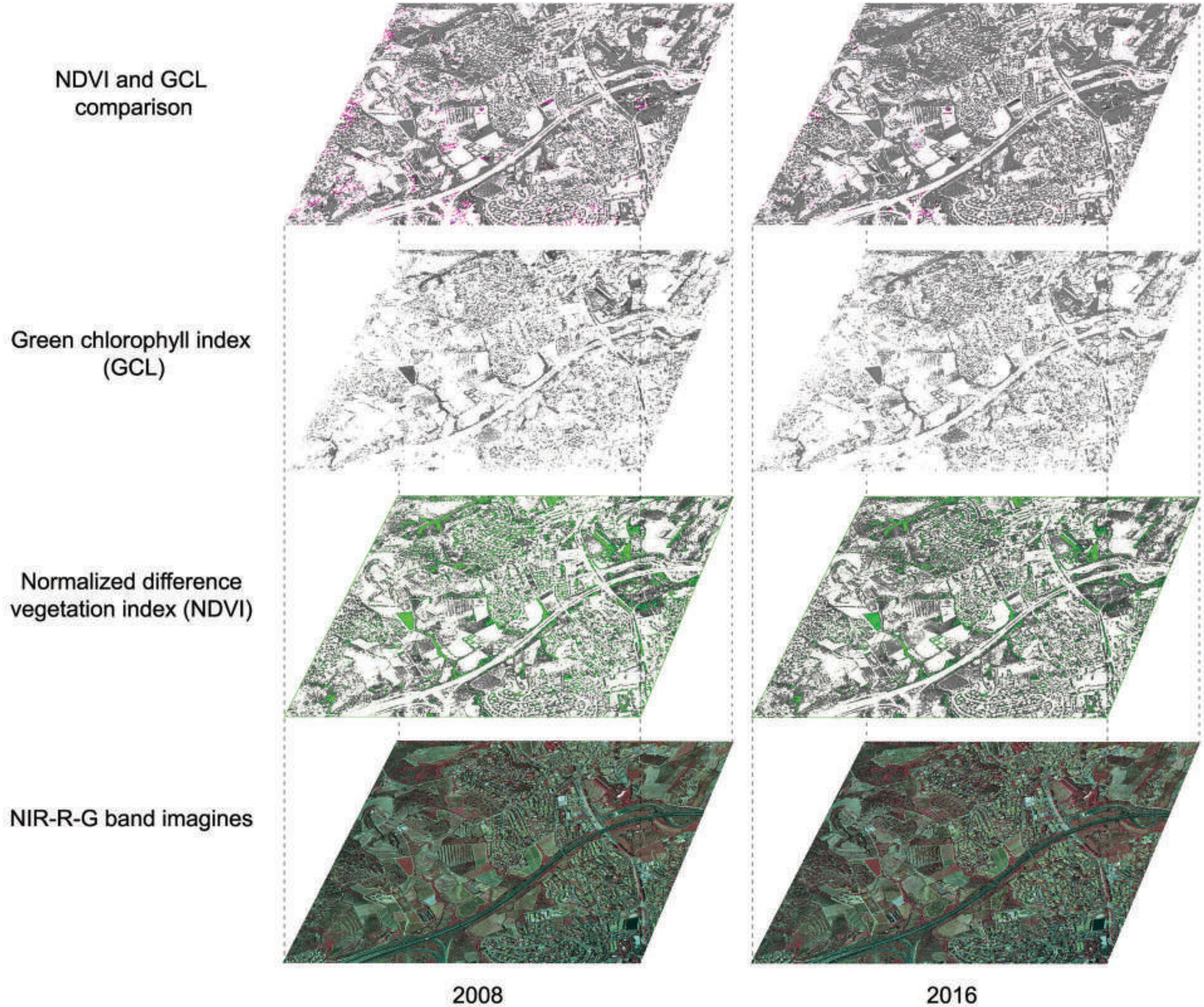

Figure 4. Comparison of NDVI - GCL point clouds between 2008 and 2016.

representation of the height profile data (Figure5). From the height data obtained from the DEM it was analyzed the slope model to determine the geometric characteristics of terraced areas. The calculation model has allowed to extract a raster image of the slopes, from which it was possible to categorize the areas with low and low declivity, defining those areas which characterize the morphology of the territory of the cultivable area and those belonging to the escarpments and retaining walls of the terraces. The unsupervised learning and classification algorithm ISODATA (Interactive Self-Organizing Data Analysis Technique) was used

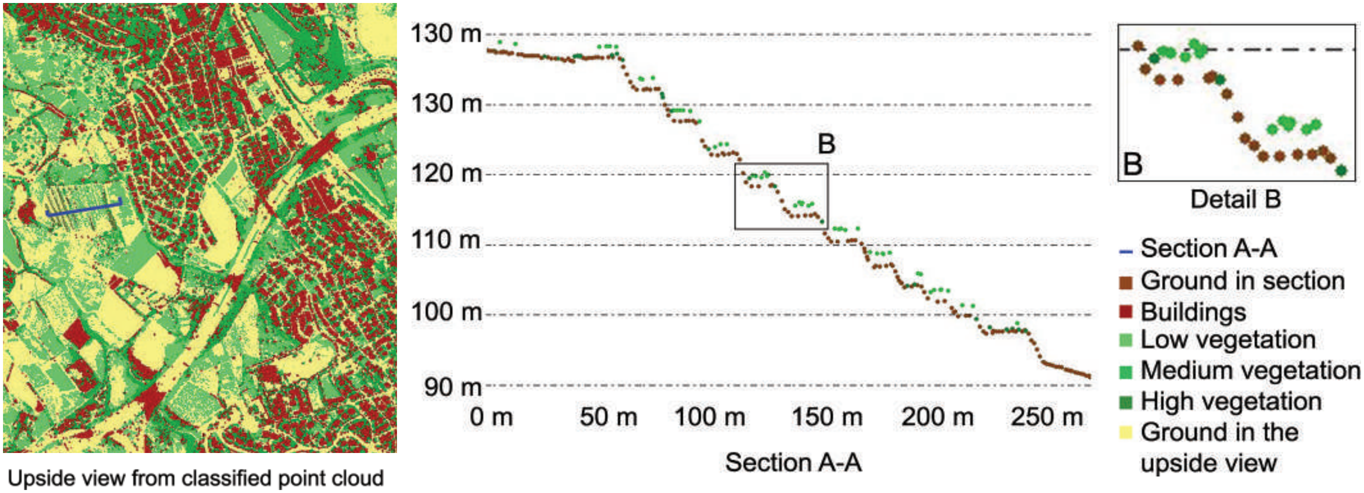

Figure 5. Elevation profile from classified point cloud.

(Ball, Hall 1965) in SAGA QGis, a statistical method of grouping similar pixels into clusters, associating with them by means of the principle of minimum distance the remaining pixels still unclassified (Lillesand, Kiefer 2000). Therefore, two clusters of the raster were defined, a first one with slope values in a range between 3.2 % - 74.0 % and a second one with values in a range between 0.0 % - 3.2 %, through a maximum of 20 iterations (more than enough for convergence) to verify the correspondence of each point to each class. Finally, in order to obtain the geometric data of the cultivated areas, from the previously classified raster, a vectorial transformation was carried out as polygonization, obtaining a layer with two groups of distinct polygons that correspond to the areas that share a common pixel value, thus favoring the quantification of each of the areas of interest, the cultivable one and the one corresponding to the slopes of the terraces (Figure 6). These evaluations are referred only to relatively low resolution clouds derived from open aerial acquisitions, through a rapid estimation method and sufficiently effective to quantify an extensive-altimetric distribution of terraced areas and vegetation conditions, which to achieve the integrative knowledge frameworks of the constituent elements proposed in the research, were satisfactory. This type of analysis allows to update an informative database, which is a useful tool for the authorities to quantify their resources, to orientate the valorization and planning interventions, to monitor the state of conservation of the territory, as well as to study the hydrogeological risks. The aim is a cartographic and informative update of the territorial system, usable also through the web or mobile devices, for the collection, visualization and interactive geolocation of information, which can indicate the quality of the sites and receive public feedback, through geo-referenced crowdmapping (Figure 7), in order to make a census of the conservation status of the terraced areas.

4. Conclusion and future developments

The methodological approach described constitutes a first step in assisting the processes of knowledge regarding the spatial value of anthropized agricultural-rural areas. This process can also be applied in the

Figure 6. Vectorization process for quantifying areas of interest.

landscape contexts of Campania and Italy, where the state of conservation of terraced landscapes is unfortunately precarious, with most terraces and embankments in disuse and forming part of the approximately 11,000,000 hectares of abandoned agricultural areas.

The study of the state of the vegetation through the analysis of the spectral response of the plants with the use of vegetation indices, obtained through multispectral images, acquired with aerial vehicles or satellite images, integrated to the LiDAR point clouds, allowed to obtain a general approach of the vegetation state and the influence that the environment may have on its condition. This, together with the study of the cultivable areas in the terraces, allows to maintain a constant monitoring to provide, in case of unfavorable conditions, the possibility of intervening in time for the optimal growth of the crops.

The control of the cultivable areas and the terrace walls contributes to the decision-making process regarding the recovery of an abandoned cultivation areas, allowing the state to keep control of such areas and individuate available production and cultivation spaces.

The proposed research contributes to cartographic actualization of the territory, which would allow to generate the basis for other types of analysis, such as, for example, the study of hydromorphological factors or the degree of humidity in the areas. These data serve as a source in the implementation of information databases, oriented to improve the knowledge of the cultivated areas, favoring their development and economic-environmental sustainability, as well as the correct planning of exploitation, interventions and the distribution of water resources.

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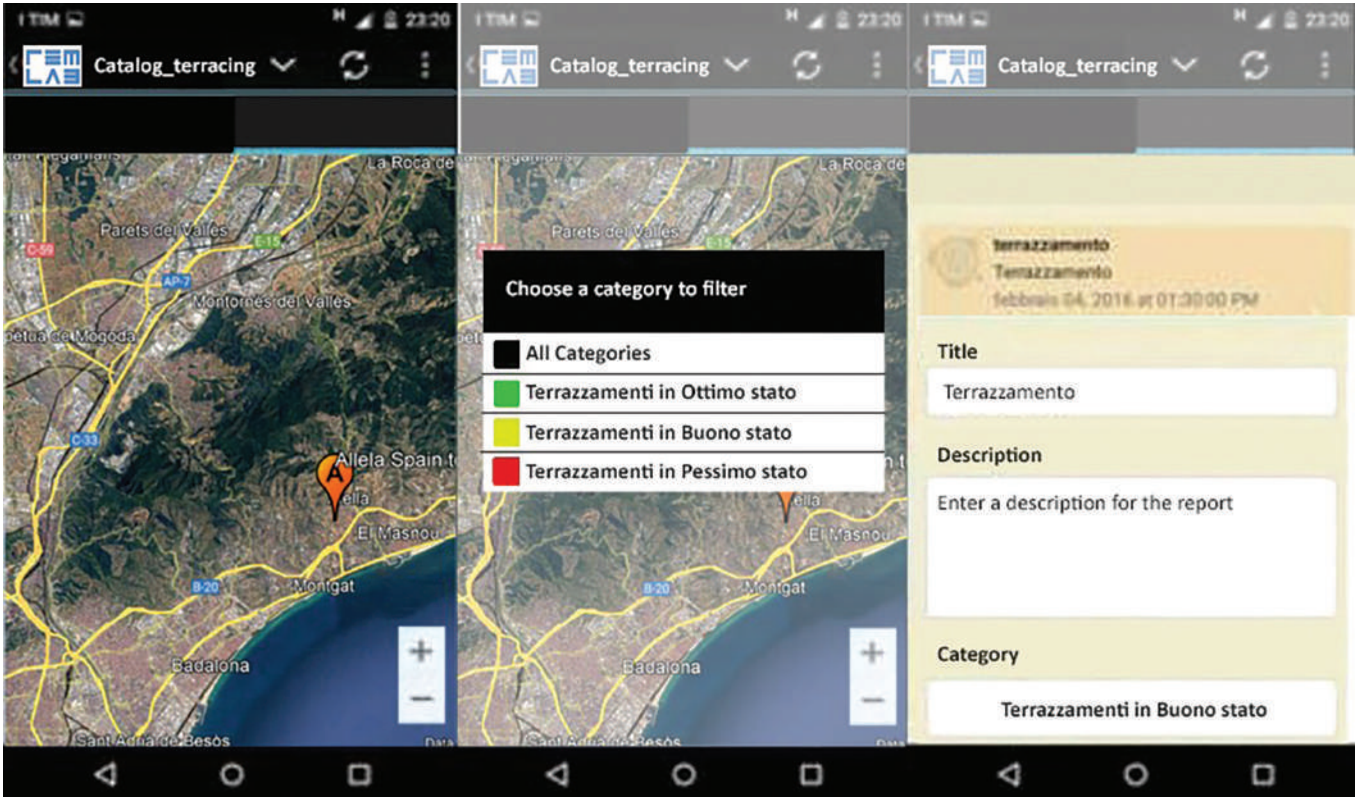

Figure 7. Geo-referenced crowdmapping to make a census of the conservation status of the terraced areas.

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Multispectral photogrammetry, Survey, Biodiversity, Conservation.

ABSTRACT

The Astino Valley maintains the history of biodiversity of the lands of Bergamo. A cultural landscape, which was shaped in medieval times when a Vallombrosan monastery was built there. After a long period of neglect, in 2007 the purchase of the monastery and its agricultural barns by the Misericordia Maggiore Foundation started an important recovery program. In 2021, the Astino valley wins the Landscape Award of the Council of Europe. This has given way to new studies on the territory aimed at its monitoring, conservation and management that have based on advanced survey activities.

The Astino Valley in Bergamo: multispectral aerial photogrammetry for the survey and conservation of the cultural landscape and biodiversity

1. Introduction

The Astino Valley (Val d'Astino) jealously preserves the history of biodiversity of the area of Bergamo: the fruit of centuries of interaction between man and nature. A place with a great personality thanks to its physical (nature of the rocks and soils, presence of water, arrangement and inclination of the slopes, exposure to the sun, vegetation, etc.) and anthropogenic features. A highly valued cultural landscape that is built over time, following the grafting of new territorial elements: the roads, the introduction of crops, the structuring of settlements (Adobati, Lorenzi 1997).

The history of the region experienced its most important episode in the Middle Ages. The construction of the monastery to which it is mainly linked probably dates to the beginning of the 11th century. The building was erected by the abbot Bertario belonging to the *Congregatio Vallis Umbrosae Ordinis Sancti Benedicti* founded by San Giovanni Gualberto, which takes its name from the locality of Vallombrosa, near Florence. A community of monks who have always been very sensitive to the protection of the universe and the rational culture of forests and fields (Cherubini 2009; Ciancio, Nocentini 2016).

The presence of the monastery determines the renewal of the valley as well as its components. It creates new hierarchies and impresses new signs on the territory. Although located on the edge of the city, the monastery soon assumes a role of marked centrality and converts the socio-economic interests of the entire area towards it (Figure 1).

The architectural body models its natural surroundings. From the convent, situated at the foot of the slope, the communication routes open and the network of trails along the hills of Bergamo radiate. Agricultural land is organized in the flat area as well as on the slopes, and rural homes are erected. It thus becomes the structuring element of the organization of a society and its space, preserving this role for centuries (VV. AA. 2018).

Despite a thousand difficulties, the activity of the convent continued flourishing until the first half of the 17th century: the industrious monks cultivate the lands with mulberry and white vine plants. Following the ecclesiastical reforms issued by the Venetian Republic, the monastic community is, however, deprived of autonomy and its separation from the Congregation of Vallombrosa is declared (1769).

With the wave of the Napoleonic suppression of Italian religious orders, on July 4, 1797, the convent was abandoned (Figures 2-4). It became a psychiatric hospital in 1830 and was sold to the Ospedale Maggiore in 1896. At the beginning of the 20th century, it is therefore in poor condition while the surrounding land continues to be cultivated, based on a lease contract, which also includes the adjoining farm.

Over the following decades, the deterioration of the architectural complex was compounded by the total lack of maintenance. The tenant is also granted the use of the monastery and with a new contract, it is decided to implement the project drawn up by the engineer Roberto Fuzier for its transformation into both a dwelling and service areas for agricultural activities. The project involves the demolition of the eastern side of the cloister,

which is implemented even though the building had already been included in the list of monuments subject to protection restrictions. In 1923, it was finally sold to private individuals who would retain the property for agricultural purposes for approximately half a century.
It is only with the transfer of ownership to a real estate company that the local institutions, understanding the peculiarities of the area, place orders to preserve the Astino site from the strong urban expansion linked to the industrialization of the region. The 1969 town plan of Bergamo (PRG), by recognizing the indissoluble link between the architectural organism and the surrounding natural environment, strengthens the maintenance of the gardens around the building and the agricultural use of the land south of it. In addition, behind the old monastery, it submits the existing greenery to a landscape safeguard (Figure 5).
In 1977, the valley was integrated into the Parco dei Colli di Bergamo, created to preserve and enhance the balance between nature and human presence. The territorial coordination plan emphasizes the need to ensure the protection of agricultural soils and the continuity of forest activity. As for the monastic building and the adjacent farmhouse, it provides for public acquisition. Subsequent planning confirms the public interest in the monument, the great landscape value of its surroundings and the agricultural use of the valley. However, this will not limit depopulation and degradation of buildings and land, which was only exploited for maize production.
In 2007, the purchase of the monastery and its agricultural outbuildings by the Misericordia Maggiore Foundation of Bergamo (MIA), and the creation of a collaborative network between the public institutions and the surviving farms, started a program aimed at both the restoration of rural complexes and the landscape recovery of the Astino valley (Civai 2016).

Figure 1. The Astino Valley: the relationship between architecture and nature.

Figure 2. The map of the census unit of the Holy Corps of Bergamo with the Astino Valley: Lombardy Veneto Cadastre, 1808 (© State Archives of Milan)

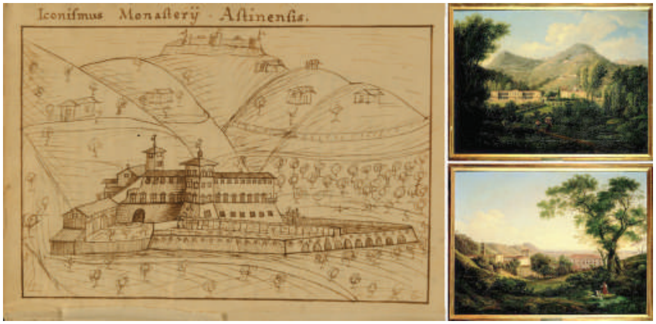

Figure 3. The drawing of the monastery of Astino by the monk P. Mazzoleni (1704) and the project for the Ospedale dei Pazzi and the monastic complex in the paintings of Pietro Ronzoni (1833).

A broad and multidisciplinary project based on the study of the architectural structures, the historical paths, the morphology of agricultural lands, the ancient farming practices, which aimed at the reuse of the former convent and the farmhouses, at the enhancement of the Astino and Allegrezza woods (identified as SCI, Site of Community Importance) and the protected fauna of the pre-hilly area. The project also included the establishment of a separate seat of the Lorenzo Rota botanical garden of Bergamo (called the Valley of Biodiversity due to the presence of over twelve hundred varieties of plants) within a broader context aimed at the rediscovery of the monastic tradition with the reintroduction of the original essences: vines, olive trees, apple trees, pear trees, aromatic herbs, medicinal herbs, hops, flax, hemp for fibre production (Rinaldi 2015, Ferlinghetti 2019).
This plurality of actions has allowed the Astino Valley to receive in 2021 the Council of Europe Landscape Award for exemplary initiatives aimed at safeguarding, managing, and sustainable planning of the territory. A recognition that has given way to new and necessary studies on the territory aimed at its monitoring, conservation and management that have been set up on advanced cyclical and dynamic survey activities.

2. Survey and representation for rural architecture and natural landscape

The study and representation of the landscape are two indissoluble and interconnected processes, oriented towards the understanding of natural areas and the urban

Figure 4. The Astino valley, the medieval tower, and the monastery: comparisons between early 20th century images and today.

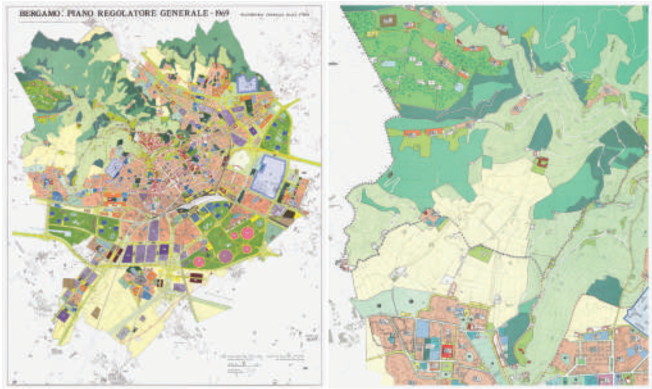

Figure 5. The General Town Plan of the city of Bergamo by Giovanni Astengo and Luigi Dodi (1969)

environment. They allow a preliminary, but essential analysis of the impact of cultural and environmental phenomena on a given territory, aimed at understanding the diachronic transformations for conservation and enhancement (Rossi 2004). The landscape survey is a generic term that considers measuring large areas for the collection and study of elements of the natural environment and human settlement. Data rendering has progressively evolved from the traditional redesign of simple thematic maps towards 3D restitution and image analysis, to be able to rapidly monitor changes in both the built and green spaces, to obtain quantitative data of vegetation and tree species, to investigate spontaneous mutations and biodiversity (Zhang 2018).

Territorial survey today is confronted, on the one hand, with the profound change brought about by innovation and the use of integrated digital documentation systems, and on the other with the need for a multidisciplinary dialogue capable of promoting in-depth studies in specialized sectors. A complete and complex investigation that combines historical research with the most up-to-date tools for multidimensional acquisition and restitution with the use of information from the documentary, cartographic, historical-iconographic sources in synergy with survey instruments (3D laser scanning and photogrammetry), modelling, rendering and virtual landscaping.

A 'logical project' - programmatic and systematic - organized by non-rigid but flexible phases capable of allowing a critical selection of choices; not a strictly mathematical-scientific approach, but also a perceptive-emotional approach capable of restoring the essence of a place (Marotta et. al. 2008).

The best 'observer' is not always who evaluates the metric aspects with great accuracy, but who recognizes the distinctive signs of territory, both in the present through the reading of reality, and of the past thanks to the testimony of ancient prints, of sketches of designers, of old photographs. The representation of the landscape thus extends and becomes richer, developing at different levels, so that the result of the restitution is always more detailed and comprehensive.

The capacity to "know how to see" is expressed by grasping the essential elements and characteristics of the place, for which deep sensitivity and capacity to perceive are required. The representation of reality is filtered according to the personality of the operator and moves in the difficult relation between architecture and environment. Restitutions are not just metric images, but virtual representations of the environment that

respond, therefore, both to the need for a metric survey and to the opportunity of communicating its quality and beauty. This is also possible thanks to distorted images (aberrated perspectives, anamorphic maps, etc.) chosen appropriately to best represent reality.
The combined use of traditional survey techniques with new technologies, in this case RPAS (remotely piloted aircraft system), has opened new scenarios. Today, it is possible to capture images from the zenith and/or from a bird's eye view, not possible with classical photogrammetry with aeroplanes and helicopters and/or with satellite remote sensing. Aerial frames of great sharpness and high resolution were acquired - thanks to the several sensors installed on new drones - not only in the spectrum of visible light (RGB) but also in infrared-thermal and multispectral bands (Monti & Selvini 2015).
The survey of the Astino Valley began in the first decade of the new millennium as part of the restoration and archaeological study of the old monastery. An exploration of the sole building undertaken by traditional terrestrial techniques and aimed at understanding its construction phases and to the cleaning, consolidation and protection of the plasters and frescoes (Figure 6). A first cognitive study, which was followed by more accurate as-built detection activities carried out by unmanned aircraft: in 2015 with Dronica® MAP-1 quadcopter and data processing with Pix4D® Mapper, while in 2019 with DJI® Mavic systems -2 PRO and data processing with Agisoft® Metashape and CapturingReality® Reality Capture (figg. 7,8).
A series of surveys dictated by needs linked more to the communication of the monument than to its actual metric-material understanding; surveys based on approximate measurements (because they lack a topographic network and error control), limited only to external volumes, not aimed at reading the territory and analysing data.
For this reason, a more rigorous survey campaign has been carried out since the summer of 2021 with both aerial and terrestrial (laser scanning and close-range photogrammetry) measurements. The data were georeferenced in one reference system, using a network

Figure 6. The exhibition at the end of the restoration and archaeological works in the former monastery. The reconstruction of the historical phases of the complex can be noticed. (®Giulio Bassi photographer, ®StudioRusso designer)

Figure 7. The as-built survey of the convent carried out in 2015: Dronica® MAP-1 quadrotor drone with Canon Eos M03 and 24 mm/1.4, processing with Pix4D® Mapper with @Dronica srl.

of measured points on the ground with forced centering devices (GNSS receivers and total station). A single reference system for the full integration of terrain and building models operated with both 3D laser scanning and digital close-range photogrammetry techniques.

The survey activities of the wooded areas and crops were repeated in several temporal periods and concentrated in the more delicate phenological phases, to evaluate the physiological state of the vegetation with non-destructive and contactless measures (Shafi et. al. 2019). The DJI® Phantom 4 Multispectral has been used, particularly adapted to monitor biodiversity and vegetation conditions. Thanks to six 2.08 MegaPixel 1/2.9 "CMOS sensors (five monochromatic for multispectral acquisition and one tri-band for acquisition in the visible spectrum), it can provide information in the Red-Edge (RE: 730 ± 16 nm), Near Infrared (NIR: 840 ± 26 nm), Green (G: 560 ± 16 nm), Red (R: 650 ± 16 nm), Blue (B: 450 ± 16 nm) and in the colour space perceptible to the human eye (RGB: 380 - 780 nm). For RGB information, however, the DJI® Phantom 4 PRO with a 20 MegaPixel 1" CMOS sensor was preferred, while having significantly lower quality and resolution. The survey not only produced Normalized Difference Vegetation Index (NDVI) images, orthographic projection of the floor plan and elevations, DTM and DSM, but also perspective glimpses of the point clouds to both evoke emotional sensations and convey the sense of place and the landscape (figg. 9-12).

Figure 8. The as-built survey of the convent undertaken in 2019: DJI® Mavic-2 PRO drone, processing with CapturingReality® Reality Capture. (with @Skycrab Academy)

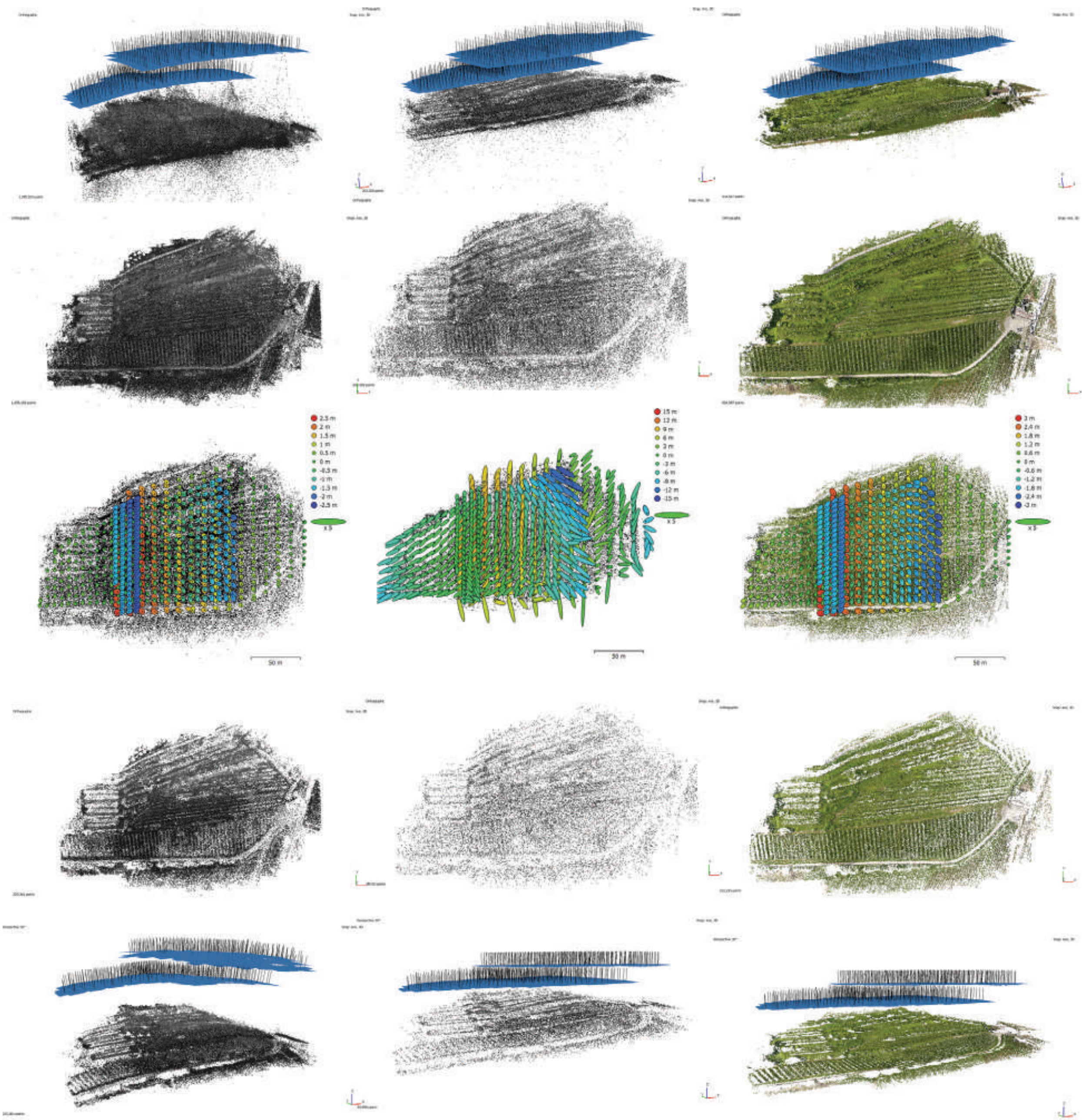

Figure 9. The survey of the crops in the valley: scattered cloud, error ellipse and dense cloud: processing of multispectral images with RTK data, multispectral images without RTK data and RGB images. DJI® Phantom 4 Multispectral drone, processing with Agisoft @ Metashape.

3. Conclusions

The United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro in 1992 has for the first time highlighted the importance of safeguarding biodiversity: the biological insurance of our planet. Since then, biodiversity has been considered critical to the existence of human life and the well-being of societies. A concept that is now very clear after the COVID-19 pandemic has shown its fundamental importance to our health and economic and social stability.

Ensuring the maintenance of biodiversity requires the implementation of a series of mutually integrated measures aimed at the *in situ* and *ex situ* conservation of species and ecosystems, of the cultivated varieties, of the natural and historical agricultural landscapes. Protecting biodiversity and the agricultural landscape means safeguarding traditional crops (also for their protective function under the hydrogeological-erosive aspect), redeveloping agroecosystems of high ecological value, preserving the anthropic/cultural character deriving from natural factors and/or humans and their interactions (Sereni 1961; UNESCO WHC 2013).

As underlined by the European Landscape Convention (Florence Convention) of 2000, it is now crucial to manage the latter in a sustainable development perspective, to guide and harmonize its transformations caused by development

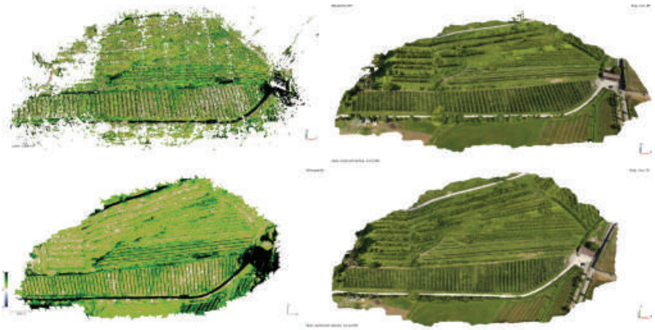

Figure 10. The crops of the valley, the NDRI model of the conditions of the vegetation and the RGB model: bird's eye view and orthographic projection. (Agisoft @ Metashape)

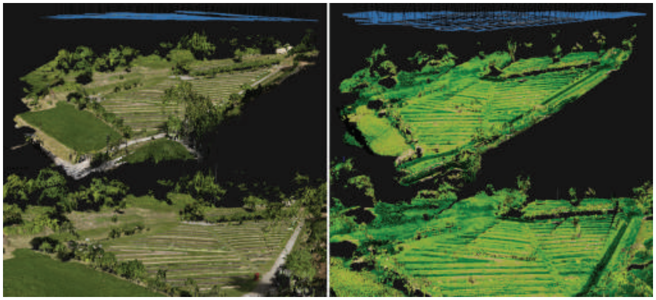

Figure 11. The valley of biodiversity of the Lorenzo Rota Botanical Garden in Bergamo, the NDRI model of the conditions of the vegetation and the RGB model. (Agisoft @ Metashape)

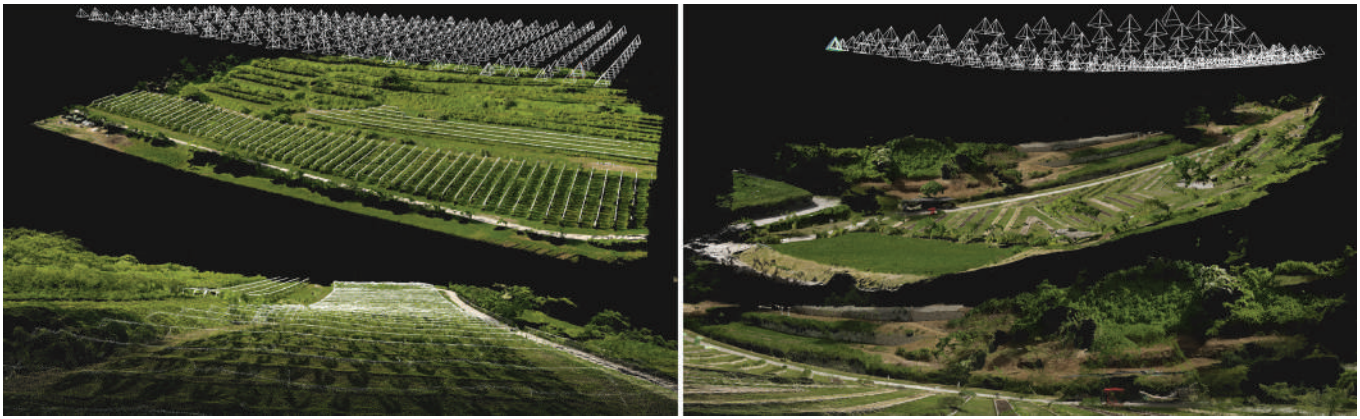

Figure 12. The perceptual-emotional survey: the orchard and the biodiversity valley of the Lorenzo Rota Botanical Garden in Bergamo. (CapturingReality® Reality Capture).

processes and to promote its protection through "strong forward-looking action to enhance, restore or create landscapes" (CoE 2000). To ensure the sustainability of these 'treasures of memory", places where the 'non-renewable' material and cultural sources of the communities are collected (Montanari 2014) a multidisciplinary and cross-scale approach must be followed (Breda & Zerbi 2002). A methodology that must necessarily rely on knowledge and close monitoring processes to evaluate the best backup interventions. In this sense, the use of UAV systems with RGB, Lidar, thermographic-multispectral sensors (integrated with traditional instruments) can contribute to study the landscape in a holistic way, allowing understanding both the built elements and the natural environment. An analysis which can easily be repeated according to predefined programs in a specially created routine.

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Keywords:
Survey, Cultural Heritage, UAV, Cloud of points.

ABSTRACT

The village of Fiskardo lies to the north of the island of Kefalonia, the largest of the Ionian Islands. Called the "Venice of the South" because the coloured elevations of the houses are reminiscent of Venetian buildings, Fiskardo owes its name to Robert of Altavilla who founded a Frankish colony in this bay.

The study carried out with the aid of the photogrammetric technique supported by a four-person drone allowed the documentation of the Cultural Heritage. This activity is configured as a search for identity characteristics through actions of knowledge of the places.

The port of Fiskardo: architecture, history and innovation

1. Introduction

The research deals with the study of historical sources and the drone survey of the structures in the harbour of the village of Fiskardo at the present time. Commonly referred to as the Heptanese or 'seven islands', the archipelago includes several smaller islands in addition to the seven larger ones. An analysis of the few historical documents found, such as Portolans, paintings, nautical charts, travellers' notebooks, shows that they have been inhabited since 1800, i.e. from the time when the islands acquired geographical unity through Western European independence achieved from 1204, when at the end of the Fourth Crusade, they became a dependency of the Republic of Venice. The Kingdom of Greece, created as a result of the Greek uprising against the Turks that broke out in 1821, has its current political-geographical boundaries defined only after the Second World War, when Italy's custody of the twelve islands in the eastern Aegean was terminated. In this historical-political context, sources were scarce both for writings and for graphic and topo-graphical maps. The survey, marked as a graphic technique for knowledge and documentation of the sites, made use of drone technology. This instrument allowed a rapid geometric-configurative vision of the port structures currently used for tourism. The activity of surveying the port by drone is configured as a theoretical graphic unicum both for the techniques used, typical of the discipline of drawing, and for the documentary analysis of the sources. The small size of the drone used made it possible to take pictures even when there was a large number of tourists staying in the many places in the port. The images taken underwent the well-known phases of photogrammetric post-production to arrive at digital models of knowledge of the places.

2. Some historical notes on the "Venice of the South"

As is well known, the Ionian Sea, an important communication route, is the deepest basin in the Mediterranean and is important above all as a transit sea, even though in ancient times it designated that stretch of coastline separating the then Illyria from Italy (Angelier J., Lyberis N., Le Pichon X., Barrier E., Huchon P. 1982, pp. 160-161). Due to their geopolitical position, which has always represented a crossroads between East and West, the islands were used as territories to administer and manage important military, cultural and economic exchanges. In the earliest period of archaic Greece, the governors of the cities of Euboea and Corinth decided to establish colonies and resting places on the islands and coasts of mainland Greece, while centuries later, along the same geographical axis, colonies of Emperor Caesar and Augustus were founded on the coast of the western Balkans (Rizakis, A.D. 1996, p. 256). With the subsequent Roman conquest there was a long period of peace and economic development. The islands, with the division of the empire, were assigned to the Eastern kingdom and fell under Byzantine rule, which had not fully established itself, partly because of invasions by barbarian peoples,

Figure 2. Port of Fiskardo, photo from drone, south view.

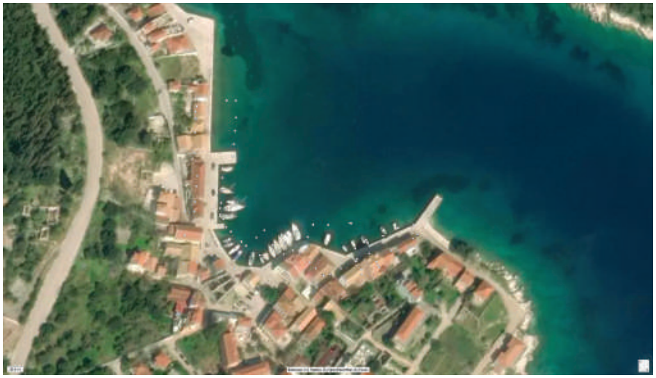

Figure 3. Port of Fiskardo, openstreetmap.

particularly the Ostrogoths. In the 10th century, the islands repelled a Slavic invasion, while two centuries later, especially in the south, the Normans took over, planning to conquer Byzantium itself. New coastal settlements were founded along the channel between Kefalonia and Ithaca, at Kateleios, Hagia Euphemia and Fiskardo.

The site of Fiskardo, in the north of the island of Kefalonia not far from Ithaca, is a Roman settlement, closely linked to Nikopolis, a city of ancient Epirus. Identified with the ancient city of Panormos, mentioned in literary sources by the Greek historian Herodotus in the 5th century BC, it has public buildings, baths, a small theatre and a large cemetery (Isambert É. 1881, p. 394). The village of Fiskardo owes its name to Robert of Altavilla, known as Guiscard, a Norman leader and Duke of Apulia and Calabria, who fought with his brother Roger I of Sicily against the Byzantine Greeks in Italy.

The Norman adventurer occupied the island in 1081, but the Byzantines, with the help of the Venetians, recaptured it at the Battle of Butrint in 1085. Only a year later he died of the plague (A. A. Vasiliev p. 381).

Today, the town is known as the "Venice of the South" because the colourful elevations of the houses are Venetian-style and painted in pastel colours.

3. Drone survey activities

In the analysis of the village of Fiskardo, an initial survey was carried out using an indirect method, i.e. the use of the photogrammetric technique supported by a digital camera and a four-person drone (Figure 1 - Figure 2). This instrument allowed the flight along the port located in the northernmost part of the island in order to create a global image of the village. As is well known, photogrammetry extracts metric information from the evaluation of fixed elements on the scene of the image taken by the operator for research purposes. This method, developed since the mid-19th century, is widely used in various fields, from cartographic survey, carried out with aerial photogrammetry, to architectural survey. The latter allows the survey to be carried out with a field of view from both close up and from medium and long distances. Characteristics of the technique are the graphic capacity not to be influenced by the material and surface characteristics of the object, the low cost and the ease of high-resolution acquisition through a digital drone camera. UAV technologies represent a remarkable innovation as they are used to speed up survey work, but also as an aid to produce three-dimensional models of architectural, urban and landscape heritage (Figure 3). They are extremely versatile, increasingly affordable and constantly improving in terms of performance, range and quality of sensors fitted.

Figure 4. Port of Fiskado, point cloud.

Figure 5. Port of Fiskardo, dense cloud with cameras, top view.

These digital technologies offer the possibility of obtaining specific results not only from survey activities, but also in representation and visualisation, with the effect of obtaining a metrically accurate description of the territory, structures and buildings (Gerke M. 2018, pp. 262-263).
In the case study of Fiskardo, using UAV instrumentation, several photographs were taken at different altitudes. The method used is that of following a grid: in order to obtain a correct reconstruction of the point cloud, sequential photograms are acquired, matching and superimposing the first photo to the next at a rate of no less than 70% in order to combine them with a specific program and then start a processing process that led to the creation of a georeferenced point cloud and an orthophoto of the area of interest.
These drone surveys resulted in point clouds, i.e. digital visions with metric, geographical and colorimetric information (Figure 4). Of considerable importance in surveying activities, in addition to the advantage in terms of time, is the large amount of data that these instruments are able to capture.
The models created with are very close to what is a continuous model, in which the interdistance between the points, when compared to the size of the surveyed object is of considerable precision.
Surface models of the surveyed object were constructed using meshes, which were textured with the images taken during the survey.
This activity provided, for the case study, a three-dimensional model with textures, with the chromatic characteristics of the building and the naturalistic and marine system of the surrounding port. It was possible to extract the contour lines that govern the elevations of the hill behind and the various elevation changes that characterise the port (Figure 5, Figure 6, Figure 7 , Figure 8). In the data processing activities, the technical feature of the program provided the possibility of in-terpolating geometric data with photographic images in order to create textured digital models (Figure 9). The digital elevation model (DEM) (Figure 10) obtained from the fusion of the data, was constructed in geographic projection, planar (Figure 11).
The procedure, from the acquisition of the photographic ma-terial to the generation of the 3D model, was comprised of four phases: alignment, construction of the dense cloud of points, construction of the mesh, and generation of the orthophotos (Figure 12).
The final result shows how it is possible to derive complex surfaces, such as those characteristic of the village of Fiskardo, from drone images and generate digital models for site knowledge.

Figure 6. Port of Fiskardo, dense cloud, seen from above.

Figure 7-8. Port of Fiskardo, dense cloud, southern view - Port of Fiskardo, dense cloud, northern view.

4. Conclusions

The activities highlighted the interpolation of historical data, graphic, iconographic and written sources, with the possibility of geometric verification of structures in the port of Fiskardo. With the help of a UAV instrumentation system, it was possible to survey places and heritages that are not always known and often only used or to welcome tourists and curious people passing through the island.
The contribution attempts to demonstrate how the adoption of aerial survey methodologies and photogrammetric restitution provide an interesting archive of the territory and buildings.
The images obtained highlight the geometric and colorimetric characteristics of the sites and the need to continue studies on the site in order to collect the architectural forms that time and seismic and atmospheric events are erasing. The need to document, starting from the sources, with survey technologies is a great achievement for the knowledge of the places.

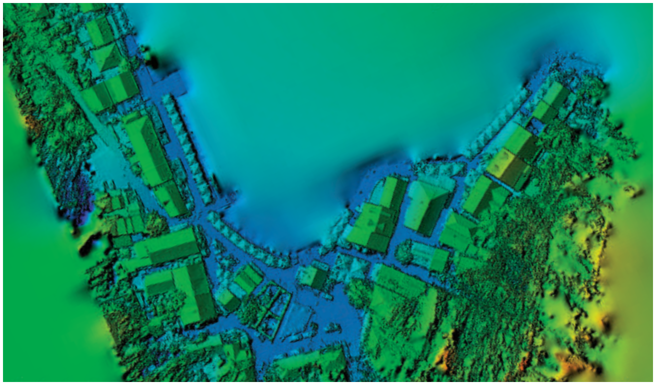

Figure10. Port of Fiskardo, digital elevation-morphology model (dem).

Figure 9. Port of Fiskardo, dense cloud, tiled model.

Figure11. Port of Fiskardo, orthomosaic.

Figure12. Port of Fiskardo, planimetry.

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UAV photogrammetry technology, Architectural heritage Preservation, Protection design.

ABSTRACT

This paper introduces the application of UAV photogrammetry in different stages of architectural heritage protection, such as the investigation of the current situation around the architectural heritage, the acquisition of site information, and the architectural heritage revitalization design. The collected data is processed not only to provide reference data support for cultural relics conservation projects, but also as a reference for long-term heritage monitoring in archives. With continuous development of the field of UAV technology, the working methods and ideas introduced in this paper will become an important scientific and technological protection means in the protection of architectural heritage.

Application of UAV photogrammetry technology in the process of architectural heritage preservation

1. Introduction

With the rapid development of the modern economy, the scale of urban construction has expanded rapidly. Many historic buildings are being destroyed, so the effective measures must be taken to protect them and efficiently repair and utilize them.

The establishment of 3D model archives for historical buildings can better provide protection strategies and guide repair design.Using UAV photogrammetry technology to establish a 3D real scene model can not only greatly reduce the production cost of 3D modeling, but also improve the production efficiency. Compared with traditional manual modeling and 3D laser scanning modeling, The UAV photogrammetry has its own unique advantages, making up for the shortcomings of traditional modeling method.

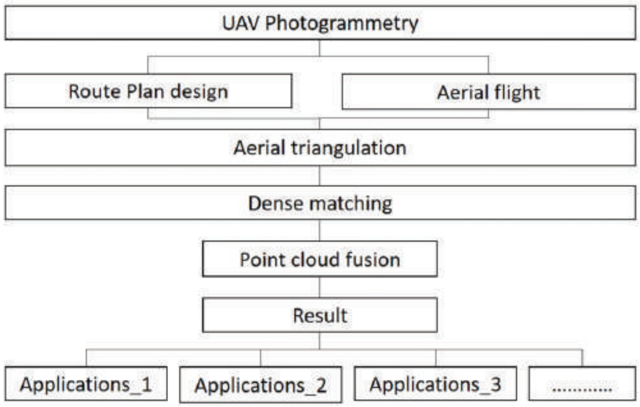

Figure 1. The workflow of UAV photogrammetry for architecture heritage conservation.

It provides more scientific and efficient technical means for the mapping, archiving and protection of historical buildings, which is of great significance to the protection of historical buildings.

In this paper, we mainly discuss the method of using UAV photogrammetry technology to model of historical buildings, and introduce the application of UAV photogrammetry technology in the process of architectural heritage protection based on project cases of different scales. Such as the investigation of the current situation around the architectural heritage, the acquisition of site information, and the architectural heritage revitalization design.

2. The characteristics of UAV photogrammetry technology

Generally, the UAV photogrammetry technology mainly involves three aspects: data collection, data processing and data application. Through the camera lens mounted on the flight platform, the real image information of the ground objects is obtained from different perspectives, and then the vectorized 3D model of the real scene is constructed through the data processing software. UAV photogrammetry technology mainly has the following characteristics.

2.1 The main advantages of UAV photogrammetry technology

Using the drone to collected the data freely in the air and avoiding the limitations of ground operating conditions, field data collection is completed by only one drone controller. Moreover, the data collection process is fully automated without manual control of flight attitude and manual shooting.

During data processing, importing remote sensing data into the corresponding software can realize fully automatic 3D modeling, such as Pix 4D, Photoscan and Smart 3D. The efficiency of modeling speed is greatly improved, comparison of the traditional manual modeling (Lo Brutto et al. 2014).

The point cloud model obtained by UAV photogrammetry obtains directly the plane coordinates, height, slope, area, volume and other attribute information of the objects in the 3D model. It makes up for the limitations of traditional artificial modeling with low simulation degree and unreal geometric spatial data information (Morena et al., 2021).

UAV photogrammetry data is rich in achievements. In addition, the result data also includes Digital Surface Model (DSM), Digital Orthophoto Map (DOM), Digital Line Map (DLGs) and point cloud data, which makes it possible for subsequent applications and multi-technology integration. (Liu et al., 2018)

With the increasing popularity of drone, it is also getting cheaper and more versatile. Compared with expensive instruments such as 3D laser scanners, the economy is significantly improved.

2.2 The main disadvantages of UAV photogrammetry technology

Compared with the traditional measurement technology, the UAV photogrammetry technology has the advantages of low economy, high accuracy and efficiency. Under certain conditions, the following limitations still exist.

The UAV photogrammetry is greatly affected by the intensity of light since it is a measurement technology based on photo images. When the light is dark or changing rapidly, the collected data process cannot be modeling. Thus, it is not suitable to work during the night. And the UAV cannot operate in strong winds or in no-fly zones, while the 3D laser scanners are available in this extreme situation.

The UAVs have high requirements on the technical level and flight experience of UAV operators, since UAV is aerial operations, and there are certain safety hazards in the operation methods. Working in crowded areas should be control risks and ensure safety.

3. Research Strategy

According to the technical characteristics of UAV photogrammetry, combined with the technical characteristics of surveying and mapping of architectural heritage renovation and conservation, the relevant operation flow chart is formulated as follows (Figure 1)

From the above workflow, it can be seen that the 3D modeling based on UAV photogrammetry includes two parts: field work and internal work.

The important work of field work is the data collection. Before the formal operation, it is necessary to collect and sort out the relevant information of the historical building, conduct on-site investigation and confirmation of the surrounding situation, study and select a suitable flight plan for route design, calculation of travel height and determination of overlap. Usually the UAV flight height is set to 20m higher than the building, and pay attention to flight safety (including not exceeding the

Figure 2. The point cloud model of He Xinwu.

local aircraft height limit and not enter no-fly zone), and then carry out parallel flight continuous photo sampling, data sampling from different perspectives, and the photo coincidence should reach more than 60%. The higher the number of photos, the higher the detail.

The internal work can choose different platforms according to the application needs of the project, such as Context Capture, Metashape Pro, Pixe4Dmapper and other mainstream tilt photography modeling software in the industry. And the internal work generally includes steps such as photos import, align photos, build dense cloud, build mesh and so on.

4. Application case studies

4.1 UAV technology in the investigation of the surrounding environment of architectural heritage research

In the process of revitalizing the architectural heritage, it is necessary to investigate the preservation status of the historical building, and specifically express the location, orientation and the surrounding environment, such as original buildings, traffic roads, greening, topography, etc. The operation method uses a total station for field surveying and mapping. When operating in a large area with a complicated environment, there is a problem of low work efficiency, and it is greatly affected by environmental factors. Hence, it is impossible to accurately grasp the layout of the entire building and the surrounding environment. Consequently, there is a lack of data information such as topographic maps and other historical buildings. Since the collected data are always fragmented, there is a lack of spatial layout records for the entire architectural heritage.

He Xinwu is a typical case of Hakka enclosures in Heyuan City, China. It is listed as a historical building protection unit. The 3D reconstruction model of the entire building space is quickly obtained through drone images (Figure 2). This enables the protection staff of cultural relics to have a clearer and more intuitive understanding of the layout and preservation status of the entire historical building. Based on the point cloud model, the corresponding general plane is also accurately drawn, and the surrounding environment is clearly expressed, as shown in Figure 3.

This method digitally documents the entire project, while the digital 3D model contains far more information than a flat photograph. It can be seen from the results that compared with traditional surveying and mapping, UAV has the remarkable achievement of high precision, rich information, intuitive and realistic, quick acquisition and good economy.

At the same time, the use of drone images to build 3D models has low cost and high speed. Moreover, it regularly collects images of historical building. After a period of monitoring, the images collected several times are compared to the models after 3D reconstruction. The development of disease and damage to historical building, the disappearance of traditional villages and ancient dwellings, the development of diseases of soil sites and the protection effect of protective measures, and the governance of

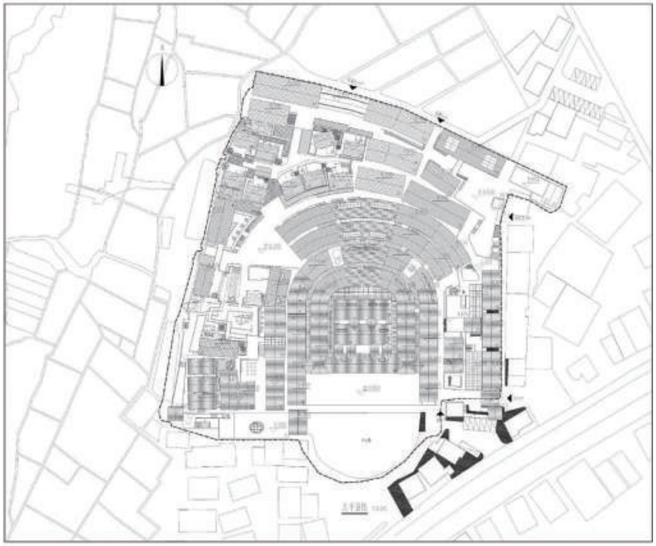

Figure 3. Block diagram of the proposed methodology.

the surrounding environment of the heritage are all clearly reflected, providing a new method for heritage monitoring. Especially for some earthen city wall sites with poor preservation and loose soil, UAV does not require staff to contact the body of the earthen site and avoids secondary damage to the site. Compared with the 3D laser scanning mapping method, it achieves a lower cost, low field workload and fast internal data processing.

4.2 UAV TECHNOLOGY IN THE ANALYSIS OF THE CURRENT SITUATION OF HISTORICAL BUILDING

The analysis of the current situation of the building is an important research topic in the restore process of the historical building, including the presumption of the original state, the evaluation of the complete and damaged condition, etc. Its main workflow is shown in Figure 4.

UAV photogrammetry is able to supplement the appearance data that is difficult to survey. It also analyzes and evaluates the damage status of each facade and the detailed structure of the building. Based on the comparison of the elevation of the 3D model and the survey, it coordinates and investigates the structural problems of the current state of the building, including wall distortion, roof deformation and so on. Therefore, UAV photogrammetry technology is an effective supplement to the current structural damage assessment of the building.

During the surveying process of Chiesa Collegiata di Santa Maria della Scala, due to its large volume and multi-layered sloping roof, the roof areas and wall areas are difficult to survey accurately. However, by using the 3D point cloud model from the UAV photogrammetry, the damage situation of each part of the building is clearly detected, and the three-dimensional visual expression of the disease analysis is realized.

The damage status of the building body is analyzed from various perspectives, including damaged tiles, damaged gutters, severely weathered walls, and damaged waterproof materials. It effectively replaces the on-site climbing survey, and improves the work efficiency of the damage condition assessment. The obtained partial damage analysis diagram is shown in Figure 5.

At the same time, based on the point cloud 3D model, the respective elevations is also exported as a reference for the reconstruction and repair of the later elevations, as shown in Figure 6.

In addition, for the architectural heritage surveying and mapping with complex shapes and high precision requirements, it is necessary to comprehensively use a variety of techniques as follows:

- Global positioning system: It is used to establish a permanent measurement control network as a reference for the comparison of surveying and mapping data in different periods (adding a time dimension to the surveying and mapping data), and to provide data for safety monitoring by changing trends;
- High-precision photogrammetry: it uses for the surveying and mapping of murals and color paintings, and can produce high-definition orthographic projection maps as the base map for

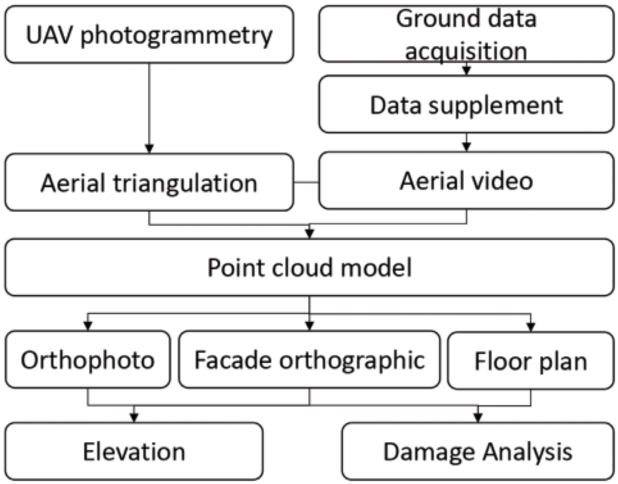

Figure 4. The workflow of UAV photogrammetry for analysis of the historical building.

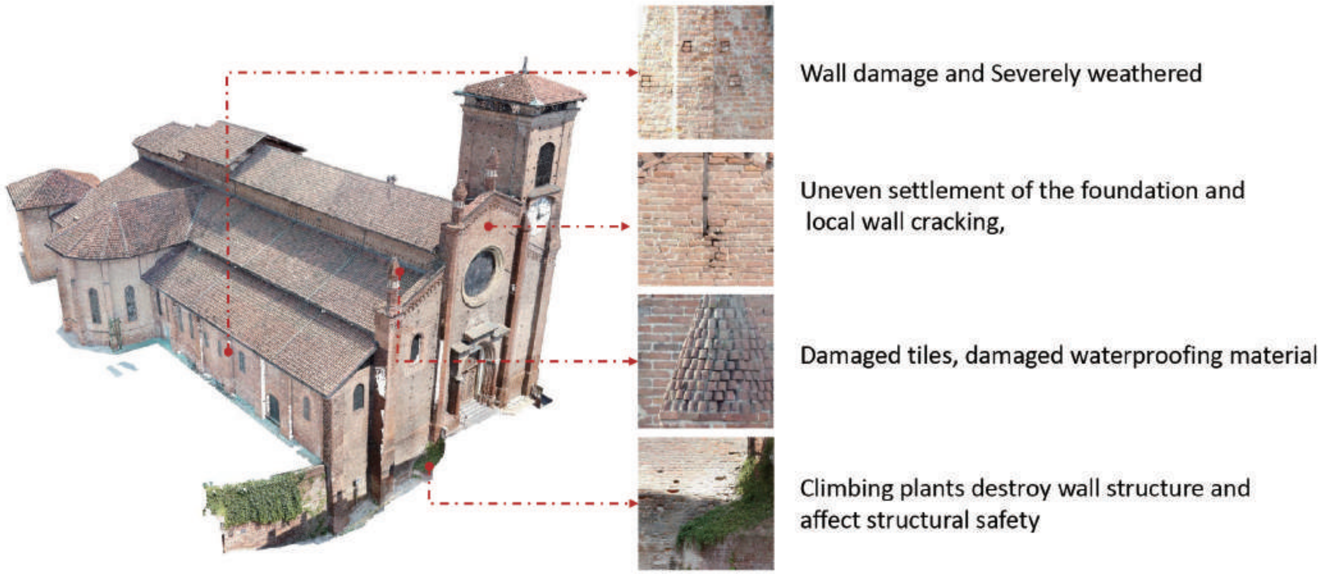

Figure 5. The damage analysis of Chiesa Collegiata di Santa Maria della Scala.

disease analysis;

- Non-destructive testing: using ray, ultrasound, infrared imaging and other technologies to collect information, it is invisible to the naked eye (wall defects, surface strength, foundation conditions, etc.).

4.3 UAV in the revitalization and renovation of architectural heritage

In the process of revitalization and transformation of architectural heritage, the three-dimensional point cloud model obtained by drones technology realizes the actual expression of the design site and design plan. It not only helps designers adjust their plans, but also provides decision-makers with an intuitive and visual presentation of the effects.

In the project of reconstruction of Cantonese residential in Shenzhen, China. In order to create a unique book bar space, which is suitable for young people, without destroying the original building structure, based on the on-site 3D model obtained by the drone technology, the texture relationship between the original building and the surrounding environment is fully presented. The layout relationship between the new and the old buildings, the coordination relationship between materials and colors by importing the plan model into the UAV to construct the 3D point cloud model are detected. At the same time, the newly built space is well integrated into the existing village environment without destroying the original old buildings, which promotes the gradual protection and renewal of the entire building.

In the process of revitalization and reconstruction design of architectural heritage, it is necessary to accurately capture on-site data. Traditional two-dimensional planes and photo records are difficult to precisely express the situation of the site. For some seriously damaged ancient buildings, due to its structural problems, there is the difficulties in building ontology mapping and disease investigation. Generally, scaffolding is erected

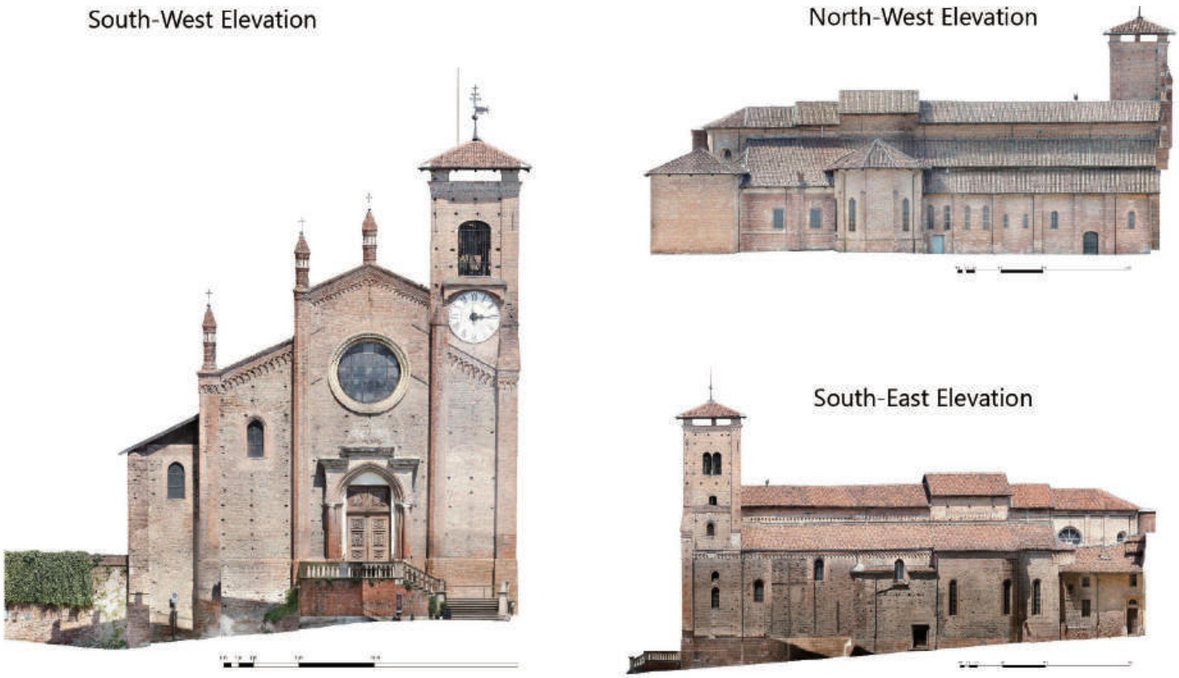

Figure 6. The elevation of Chiesa Collegiata di Santa Maria della Scala from UAV photogrammetry.

before building renovation process. The relevant staff conducts comprehensive surveying and mapping and disease investigation of the renovated buildings. These damaged buildings also have structural safety problems to a certain extent. UAV not only consumes human, material and financial resources, but also poses a threat to the life safety of surveying, mapping and designers. The 3D point cloud model is used for fine mapping of the size of each part of the building to be renovated, and it also measures the foundation settlement and the inclination angle of the building wall to provide accurate data for structural reinforcement. The 3D point cloud model is combined with the scheme design model to assist in the adjustment of the design scheme and realize the real-life expression of the design scheme. It also provides decision-makers with an intuitive and visual effect presentation to accelerate the progress of the design scheme.

In the revitalization and renovation design project of Fenghuang Village in Shenzhen, China, the designer intends to transform one of the severely damaged Cantonese houses into an open book bar that integrates with the original building. In order to preserve the wall texture of the original building to the greatest extent, retain the traces of the years and create an open reading space, on the premise of reinforcing the original wall, the designer builds a new functional module with a light steel structure skeleton, and places the main load-bearing structure on the ground to reduce damage to the wall. By considering the combination and comparison of the point cloud data model and the design scheme model, the relationship between the new structure model and the original site can be clearly mined, which improves the accuracy of the scheme, as show in Figure 7. Based on the real scene expression of the design scheme model in the point cloud model,

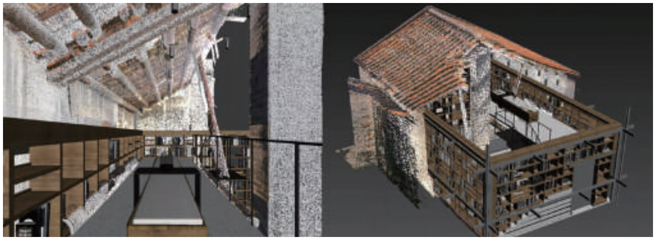

Figure 7. The point cloud model combined with the design model.

the fusion relationship between the design scheme and the surrounding texture, the layout relationship between old and new buildings, and the coordination relationship between materials and colors can be fully presented. The final design scheme is shown in Figure 8.

5. Conclusions

In the application of the protection of historical building, UAV photogrammetry technology not only improves the efficiency of cultural relics protection work, but also provides more accurate building and surrounding environment data. It is a major technical change to the way of mapping work and design renovation of historical buildings, which improves the traditional method of only relying on tape measures, rangefinders, and manual drawing. With the development of drone technology and the continuous progress of related software, UAV photogrammetry technology will be more widely used in the protection of historical buildings. It will become an important role in scientific and technological protection of historical buildings. In the future, the combination of UAV photogrammetry technology and BIM to establish a 3D model of historical buildings with high-precision and all elements. It will provide more complete and abundant information for the protection and revitalization of historical buildings.

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Figure 8. On the cover: The final design scheme of the project.

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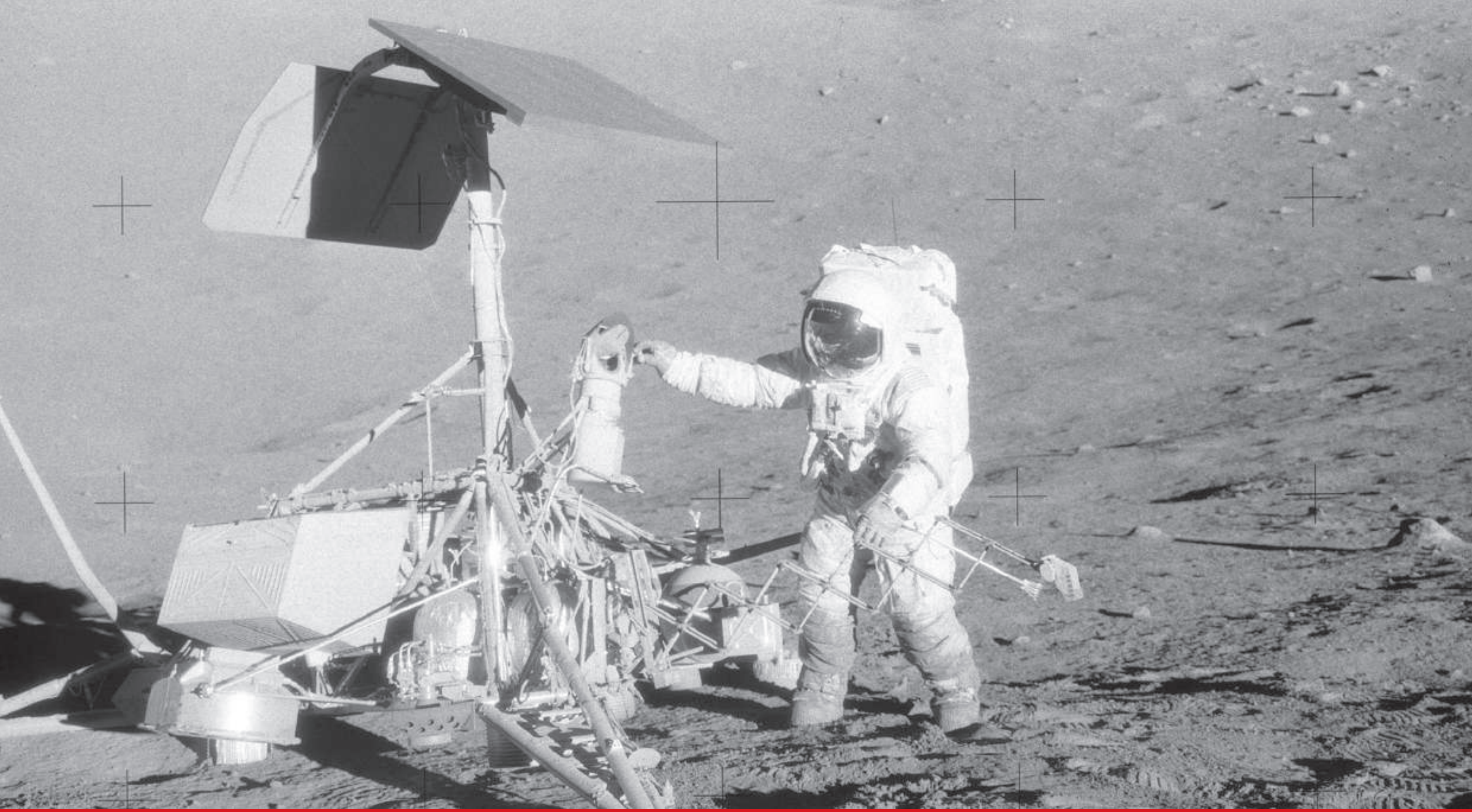

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Visual Studies, Perspective, Perception, Space Probe, Panorama.

ABSTRACT

A phenomenological approach to distant vision products may be useful to understand how some widely used remote control photography techniques are irreducible to a purely technical explanation. Taking into consideration the large graphic and photographic archive of the space missions and in particular that of the lunar probes of the Surveyor program (1966-1968) we realize that some characteristic patterns of the images and the relationship between the observer and the images themselves are already well recognizable in the products of the first remote vision devices.

On phenomenology of remote vision: the panoramas of the first lunar probes

1. Panorama as a form of remote vision

An examination of the extensive collection of images produced by the probes sent to the Moon and other planets of the solar system during the last decades allows to recognize some recurring forms and characteristics of distant vision. For this purpose a phenomenological and topological approach proves more useful than an exclusively morphological one. First satellites placed in orbit around the Earth such as Sputnik, or first probes sent to the Moon by the Soviets, such as Luna 1 and Luna 2, are not equipped to take pictures but are limited to providing data on their position and little more[1]. American probes of Ranger, Surveyor and Orbiter programs transmit to Earth a large number of images of the Moon, taken mainly in three characteristic ways of space shooting: that of the linear sequence, that of the central panorama and that of the orbital mapping[2]. Panorama has become one of the characteristic forms of distant vision. In particular, panoramas obtained from Surveyors' photos are the first views of non-terrestrial landscapes, and can be considered as an elaborate anticipation of the most recent terrestrial and non terrestrial panoramas, and in particular those of Mars.

2. Photographic surveys of Surveyor missions

The first Surveyor was launched on May 30, 1966 and landed on the Moon three days later, on 2 June; the last - Surveyor 7 - was launched on January 7, 1968 and landed on January 10[3]. The overall objective is the acquisition of information in support of Apollo program and mainly the demonstration of the possibility of a soft landing on the Moon. Design scheme of the seven Surveyors is the same: these probes consist of a basic spaceframe with three landing legs and three footpads. On this structure are mounted flight equipment and instruments including a survey television system and a transmission system.

Surveyors are designed to land and rest firmly on the lunar soil. Only twice probes move from their position: the rockets of Surveyor 3 do not stop before touching the ground as expected, and the probe makes two jumps, the first of about 20 meters and the second of a little more than 10 meters. During Surveyor 6's mission, mission control commands rockets to ignite again after the landing and the first period of activity, and causes it to leap 2.5 meters, in order to obtain pairs of stereoscopic photos. The barycenter of the triangular structure is the origin of the probe's reference system. The camera is moved a few tens of centimeters from this origin, and its vertical axis is tilted by 15-16° with respect to the vertical axis of the probe. The camera's horizon does not correspond to the local one: in the panoramas, the local horizon appears as a curved line whose curvature depends on the inclination of the camera with respect to the probe and the probe with respect to the lunar horizon. The camera can rotate almost 360° horizontally and tilt 40° above and 65° below the same plane. The cameras of Surveyor 6 and 7 can tilt more, of 90° above the horizontal plane, and so see the Earth from the Moon. (Figures 1 and 2)

The lens mounted allows a focal length of 100 millimetres and 25 millimetres corresponding to a field of view of 6.43 inches – narrow-angle – and 25.3

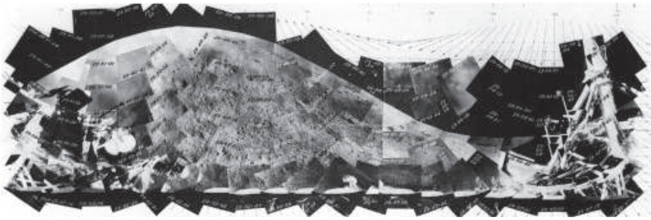

Figure 1. Surveyor 5: landing site panorama from wide-angle mode frames (day 254, survey W-B).

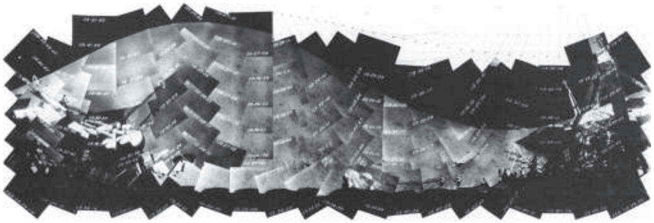

Figure 2. Surveyor 5: landing site panorama from wide-angle mode frames (day 258, survey W-E).

inches – wide-angle. The resolution is 1 millimeter at a distance of 4 meters and the focus can vary from just over a meter to infinity. The characteristic parts of the panoramic images are the horizon, the far ground, the near ground, the probe itself. The edge of the sky ends the panorama but the black sky is not taken. There is never the whole sky in the lunar panoramas and even in the most recent martian ones, even if the sky of Mars is as bright as that of Earth. The images of the high Earth in the Moon sky are single images and are not yet part of any lunar panorama.

The five probes - Surveyor 1, 3, 5, 6, 7 - that completed their mission took a total of almost 90000 photos. In the camera the image is formed at the end of a photosensitive tube and is transformed into a signal transmitted by the antennas of the probe. The first photos considered more urgent and a few others have a resolution of 200 lines, the others a resolution of 600 lines. The first one taken and transmitted by Surveyor 1 is the low-resolution image of his foot resting on the Moon shortly after the moon landing, confirming the sufficient lift of the Moon's soil. The scanning time of an image is 1 second and the interval between scans is 3.6 seconds, while the transmission time is 20 seconds per image. Most of the photos were taken during the first lunar day, but a number of them were taken in the following days after the spacecraft hibernated during the lunar night. The times of shooting and transmission, and the duration of the entire mission, contribute to determine the 'net of rationality' characteristic of these lunar panoramas, together with the parameters of resolution and definition of images[4].

3. Panoramic mountings

The shooting program is aimed at producing almost complete or partial panoramas of the landing site. The pre-ordered scheme of the different photo sessions is characterized by a grid with regular vertical and horizontal gaps, defined in function of a sufficient overlap between frame and frame. The panoramic series cover an angular sector ranging from 65° below the horizontal plane of the camera to that of the local horizon. For a panorama of frames with a narrow field of view of 6.43°, 900-1000 images are needed: the images are taken every 6° horizontal and 5° vertical and the lines are staggered between them by 3°. For a panorama of frames with a wide field of view of 25.3°, approximately 120 images are needed. The images are taken every 18° horizontal and 15° vertical and the lines are not staggered[5]. (Figures 3 and 4) The mounting of the frames is usually done on flat surfaces, but also on curved ones mostly corresponding to half a sphere or a quarter of a sphere: in the case of flat mounting the overall image appears very deformed; in the case of the spherical assembly the image seen and photographed again from the center of the sphere appears as a view from an observer on the Moon. (Figure 5).

Spherical more than plan panoramas intends to satisfy the need of identification and immersion and not only that of knowledge. Both panoramas presuppose an effort of adaptation of the observer: an effort that is greater when one observes the plane one and mentally corrects its deformations, and that is minor – but nevertheless there is – when you observe the spherical one from an incorrect position. In both cases, an effort

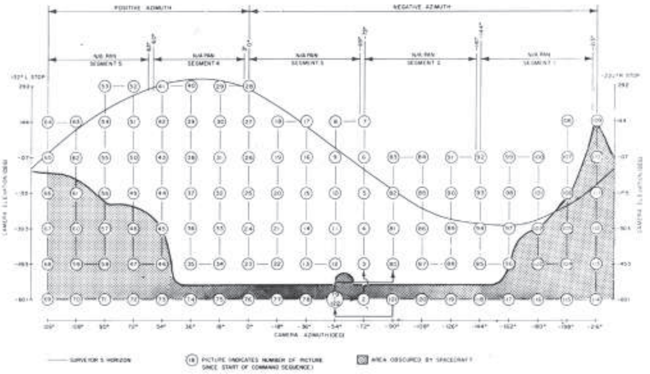

Figure 3. Surveyor 5: wide-angle mode survey panorama sequence. Pictures were taken in the order shown by the circled numbers, at the camera azimuths and elevations shown. The amplitude of the sinusoidal horizon curve is a function of camera tilt.

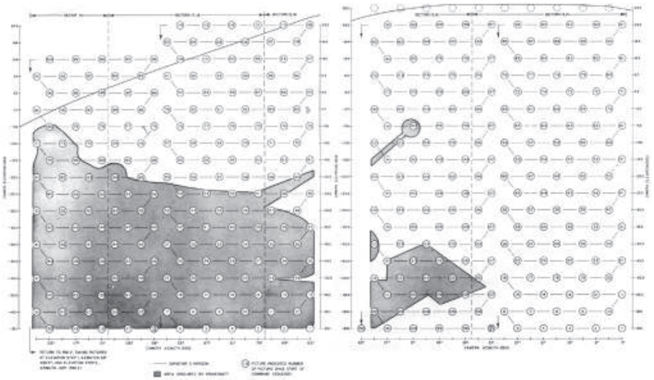

Figure 4. Surveyor 5: two (of five) segments of narrow-angle mode survey panorama sequence.

of adaptation is also required by the imperfection of the junctions between the frames that is gradually reduced to almost disappear in the more recent and perfect mosaics. Imperfect junctions can be found even in the martian panoramas, even if these imperfections remain below the threshold of normal visibility. In the first analogic as well as in the last digital and immersive panoramas, a sort of pact of verisimilitude is established between the observer-spectator and the 'spectacle'.
In the photographic atlas of Surveyor 5 published in

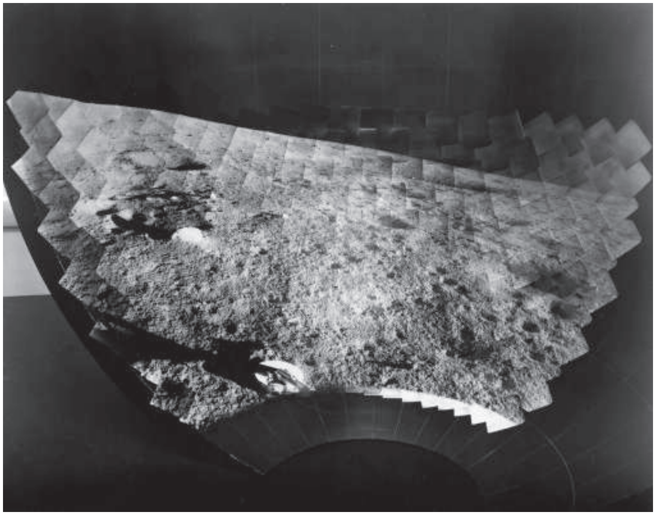

Figure 5. Surveyor 1: narrow-angle mode frames mounted onto the inside of a hollow sphere to preserve the view geometry of the camera.

1974 – a few years after the missions of the Surveyor program and the Apollo program itself – we can see the different types of panoramic montages produced in this first epoch of planetary exploration[6]. There are: the photos of the panoramas obtained from narrow-angle frames mounted on a hollow hemisphere; the photos of the 45° portions of these panoramas taken from the center of the sphere, corresponding to the point of view of the camera; the photos of the complete panoramas taken at different times during the lunar day; the photos from above of a specially manufactured model to verify the morphology of the site. Then there are the photos of the complete and partial panoramas obtained by mounting on a plane of the wide-angle frames of the band between 60° below and 30° above the reference plane of the camera: in these panoramas the horizon is a sinusoidal curve whose curvature is a function of the inclination of the camera. Finally, there is the very long list of all the frames identified by the mission time of the shot, the azimuth angle and the elevation angle and the other parameters of the shot. (Figures 6 and 7).
Images of the same portion of soil taken at different times of the lunar day show the movement of the

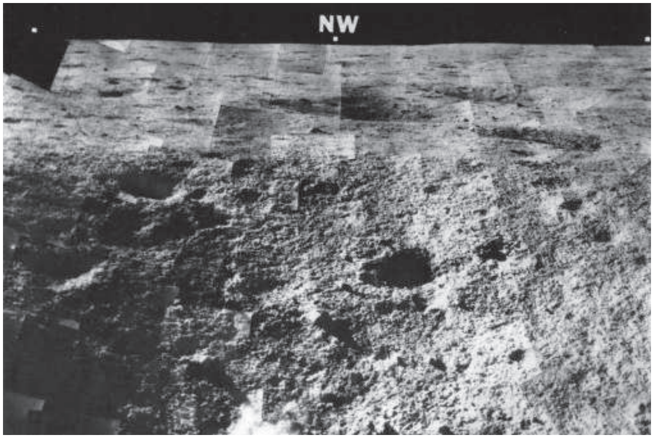

Figure 6. Surveyor 5: segment of narrow-angle mode panorama facing northwest (WNW-NNW).

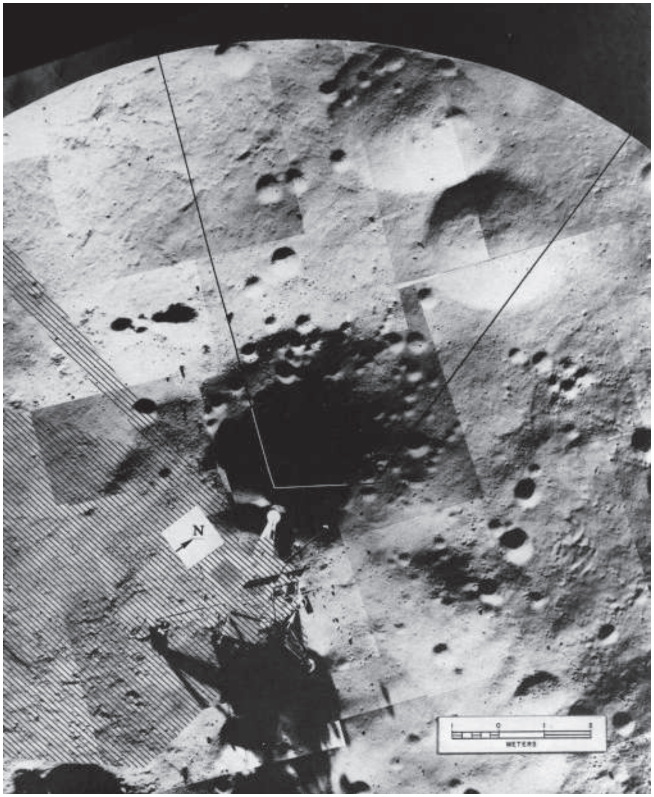

Figure 7. Surveyor 5: physical model of the foreground of figure 6.

shadows: first you see the shadows of the rocks near the probe lengthen, then you see the shadow of the Moon itself reach the rocks and join theirs, and finally you see the edge of the shadow reach the probe, obscure its around and proceed towards the distant horizon. The slow change of the lighting conditions gives a strong impression of presence and confidence with the place 'inhabited' by the Surveyor. (Figures 8 and 9)

The panorama is an intrinsically habitable image and deep. Distant vision always tries to render a depth that would not otherwise be experienced, and stereoscopy is one of the ways to render this depth. The mission command again turns on the rockets of Surveyor 6 and makes him make a leap so as to see the landing site from a second point of view: the distance of 2.5 meters between the first and the second position allows you to get pairs of stereoscopic photos. For the same purpose the Surveyor 7 is equipped with a mirror so that the photos taken directly and those taken indirectly by means of the mirror constitute stereoscopic pairs. Stereoscopic photos are used to derive topographical data and then to map the landing site. Photos taken with variable focal length and those showing the progression of shadows provide additional metric information: shadow measurement contributes to the understanding of local morphological features – rocks, small craters, etc – which differ from the background of the lunar soil. Looking at the shadows and their movement you can imagine the shape of the hidden face of those rocks, as in the past astronomers have deduced the shape and heights of the lunar reliefs observing with the telescope the passage of the terminator, which is the edge of the lunar night.

Already in the missions of the Surveyor program, the perception of the depth 'seen' and the depth 'touched' overlap. Surveyors 3 and 7 mount a remote-controlled mechanical arm to excavate the lunar soil near the spacecraft. The mechanical arm – called also *scratcher arm* – ends with a small scoop and can extend up to

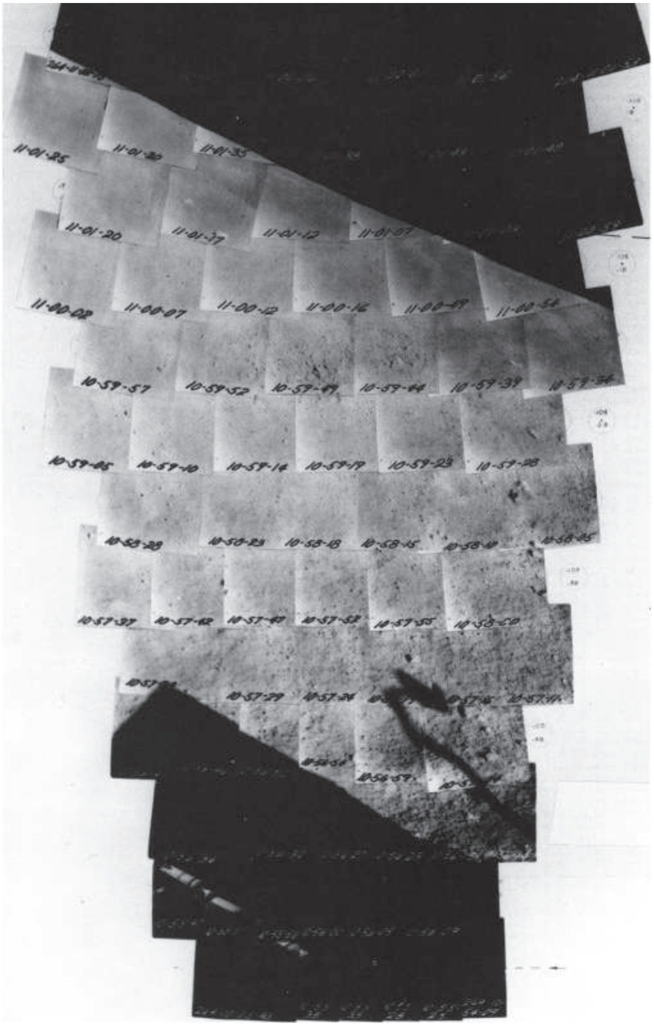

Figure 8. Surveyor 5: sector of narrow-angle mode panorama.

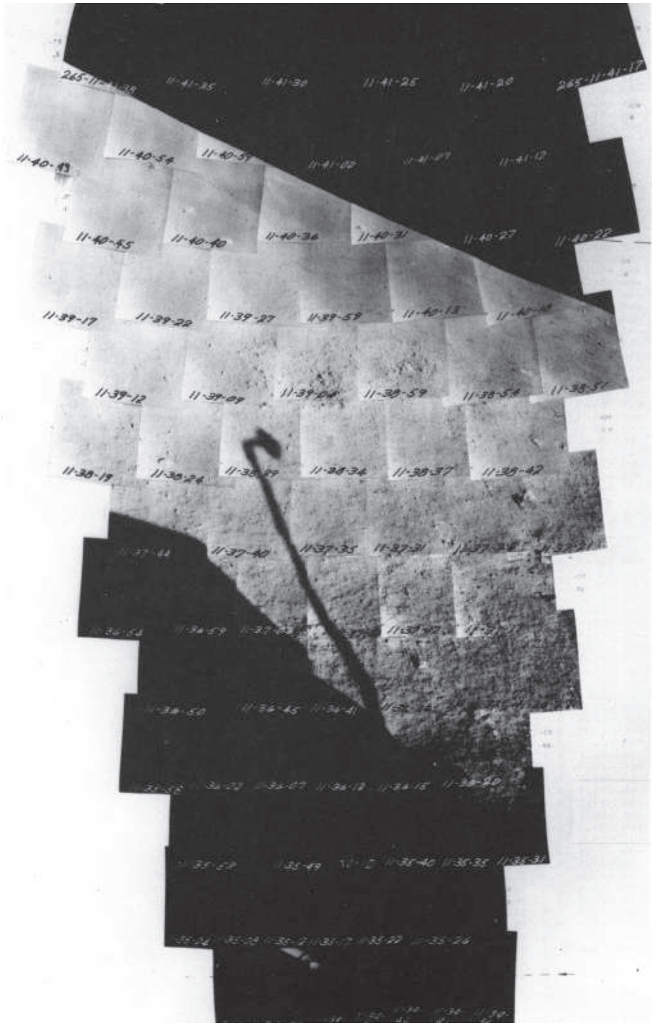

Figure 9. Surveyor 5: the same sector of figure 8 the day after. See the different shadows of the probe and the rocks.

1.5 meters, so the ground dug by this tool and the one photographed by the camera partially overlap. The arm has the function of ‘feeling’ the consistency of the lunar soil: the operators report having ‘felt’ the resistance during the excavation maneuvers, experiencing a particular telepresence effect[7]. (Figure 10).

4. A phenomenological approach

The lunar landscape photographed by Surveyor 3 is also seen in the photos of Orbiter 3 and Apollo 12, and the return of the Apollo 12 astronauts to the site of Surveyor 3 is the only true ‘return’ to the same place on the Moon[8]. In this case, a new continuity of imagination

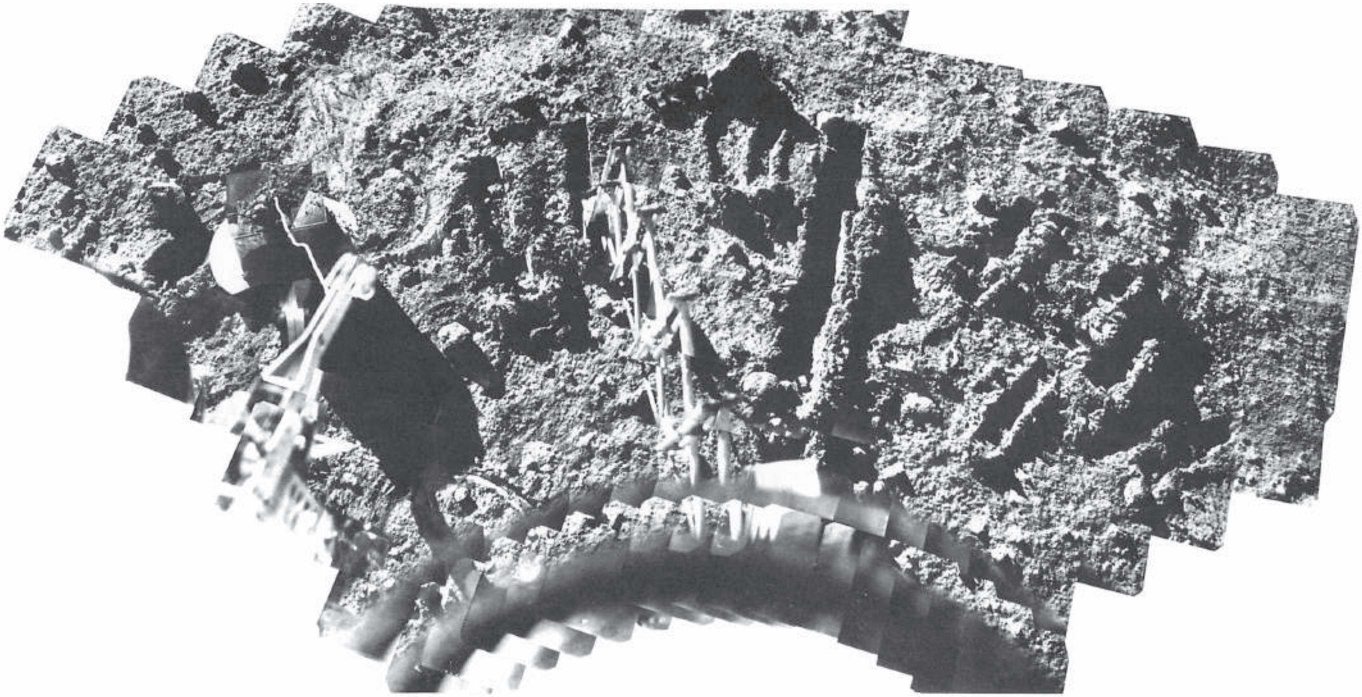

Figure 10. Surveyor 7: photographic mosaic of the sector dug by the mechanical arm.

and identification has been established between the Earth and the Moon. The recognition of common characteristics in different views contributes to the identification and completion imaginative, and to the transformation of a simple position in a place[9]. A place is a relatively stable system of relationships between the different parts of a landscape and between the parts and those who explore them directly or indirectly. The multiplicity of points of view is the premise of the transformation of a new site into a place: the multiplication of sights and therefore of panoramas is the product of the displacements of the probes – and of their possible doubling as in the case of the recent lunar and martian expeditions –, and yet the prolonged stay and the change of lighting conditions in a certain way also multiply the views of the same landscape. (Figures 11 and 12).

The images captured and sent by the probes, and especially the panoramic ones, are the result of decisions shared by a group of scientists[10]. The definition of the program takes a certain amount of time as well as the transmission of commands and the reception and processing of images, and so the interaction with the probes is always a delayed interaction. Despite this delay, however, an impression of effective interaction with lunar probes and even with the most distant martian ones has been produced, and this impression is the consequence of the adaptation of the operator – of his perceptive and intellectual abilities – to the probe. More generally, we can observe a gradual transformation of the way of seeing the non-terrestrial landscapes – and also of the terrestrial ones – as a result of an adaptation to remote vision systems[11].

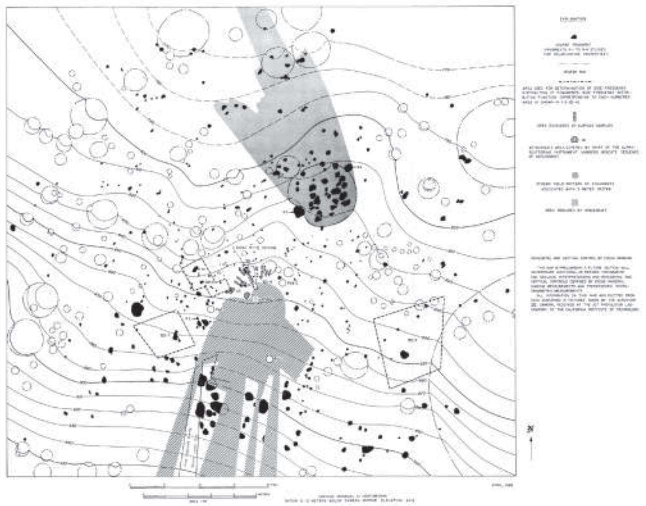

Figure 11. Surveyor 7: landing site map from photos only of Surveyor 7.

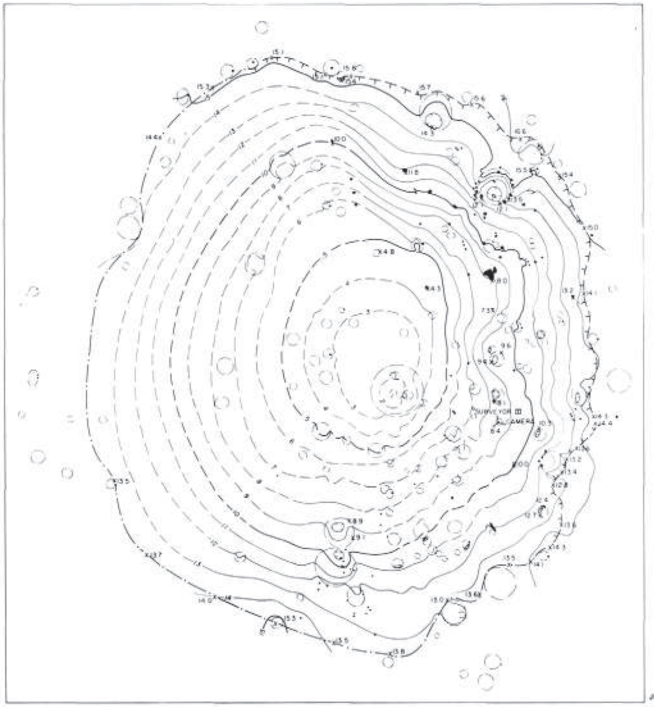

Figure 12. Surveyor 3: landing site map from photos of Surveyor 3 and Orbiter 3.

Surveyors' panoramas show a common feature to the panoramas of all the probes – and not only theirs – which is a constant aspiration to regularity and completeness, and an effective irreducibility of irregularity and incompleteness.

Just as the orbiting mapping tries to complete the image of a spherical planet seen from the outside but there are always gaps or imperfections to prevent it, so the panorama would like to complete a spherical image seen from the inside, and yet even this image is normally imperfect and interrupted. The images sent by the first lunar probes and their subsequent processing show in an exemplary way the overlapping of multiple 'net of rationality' characteristics of the different stages of production of the same images, and which becomes particularly evident in the production of Surveyor panoramas. These nets and their compositions discover and cover at the same time, and for each of their different compositions discover and cover different things. Remote images – as and more than all other images – are always partial images of partial characteristics, produced by a continuous process of processing and interpretation shared between multiple observers and operators.

5. Conclusion

The structure of the Surveyor probes, as well as that of all the probes and all the remote vision devices, necessarily has anthropomorphic settings and tends to assimilate the most diverse landscapes, and yet the images produced always exceed the normal vision and transform and expand the very idea of normal vision. Remote vision is characterized from the beginning as a complex perceptual and imaginative process shared between many human and non-human agents, differently placed spatially and temporally, and irreducible to a merely technical description. A further examination of the extensive documentation declassified and published by space agencies in recent years can give useful insights into future developments of remote vision techniques applied to terrestrial landscapes.

Notes

1 For a list of probes sent into space since the 1950s, see Siddiqi 2018.

2 For an overview of Ranger, Surveyor and Orbiter missions see Hall 1977; NASA 1969; Byers 1977.

3 The full reports of Surveyor missions are NASA JPL-CALTECH 1966-1968.

4 Here the concept of 'net of rationality' of an image is taken up by William Ivins, art historian and curator of the graphics department at the Metropolitan Museum of Art in New York from 1916 to 1946, which uses it in reference to the trait and the hatching of the most common printing techniques. According to Ivins, the engravings would consider only a part of the imagery conceived or imagined, as a consequence of the more or less dense, but always discontinuous, pattern of signs used to reproduce them. See Ivins W. M. (1953), *Prints and Visual Communication*. Cambridge Mass.: Harvard University Press, 1953.

5 See NASA 1969.

6 See Batson Jordan Larson 1974.

7 «[Ronald] Scott and the first actual operator of the sampler, JPL engineer Floyd Roberson, reported that they developed a "feel" for the lunar soil despite the intercession of some 400,000 km, the need to control the sampler electronically in steps, and the camera mirror dirtied by dust raised by the verniers. They compared their vantage point to that of a nearsighted person viewing the soil from four feet away. They could "feel" the increase in resistance about a centimeter below the surface that the Apollo astronauts also later noted». Wilhelms D. E. (1993). *To a Rocky Moon: A Geologist's History of Lunar Exploration*. Tucson-London: The University of Arizona Press, 1993, pp. 141-142.

8 The dialogues between Apollo 12 astronauts Charles Conrad and Alan Bean near the Surveyor 3 are in NASA-MSC 1969.

9 A number of scholars has recently been concerned with the notion of place. Jeff Malpas highlighted how it is a preliminary concept to the experience of any territory, and more generally of the world: «Fundamental to the idea of place would seem to be the idea of an open and yet bounded realm within which the things of the world can appear and within which events can 'take place'. Such a notion of place is, of course, broader than just the idea of place as a narrowly defined point of location, but this latter idea of place as merely a 'point' would seem to be a very limited and perhaps even derivative use of the concept. Indeed, even when we think of a place in very basic terms as just a particular position – the position in which I am now located, here on this spot – that idea typically carries with it some idea of the place, the spot, as nevertheless possessed of enough breadth and space so as to allow us to conceive of ourselves, our very bodies, as located in that place, and as permitting us to view the world from it and so, within it, to move ourselves in order to obtain such views. [...] The delineation of place can only be undertaken by a process that encompasses a variety of sightings from a number of conceptual 'landmarks' and that also undertakes a wide-ranging, criss-crossing set of journeys over the landscape at issue – it is only through such journeying, sighting and re-sighting that place can be understood». Malpas 1999, pp. 33-41.

10 A study of the complex relationships between a remote probe and its control team is Vertesi 2014.

11. Vertesi's arguments concerning Mars rovers may apply to most remote vision and exploration devices: «Team members do not so much use their robots as extensions of human senses; rather, they acquire an embodied sensitivity to the robots' capabilities, mediated through Earthbound visual transformations. Stories that circulate on the mission and shared gestures create a close, even totemic relationship between human team members and the rovers, binding team members to their robots and, through them, to each other». Ivi, p. 22.

Abbreviations

ACIC	Aeronautical Chart Information Center
CALTECH	California Institute of Technology
JPL	Jet Propulsion Laboratory
MSC	Manned Spacecraft Center
NASA	National Aeronautics and Space Administration

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ABSTRACT

The following paper presents a comparison of models obtained from UAV aerial photogrammetry using different SfM programs for the three-dimensional elaboration of the sculptural and decorative apparatus of the facades of the Ark of Mastino II in Verona. Particularly, the paper wants to focus on the methodological process of collection, elaboration and comparison of data, aimed at obtaining metrically and geometrically accurate models enabling the start of investigation procedures for the knowledge and diagnosis of conservation status of the funeral monument.

The documentation of the decorative system of the Ark of Mastino II in Verona. Comparative analysis of photogrammetric data obtained from UAV systems

1. Introduction

In recent years, the production of digital three-dimensional replicas of Cultural Heritage artifacts has seen an exponential growth in relation to technological advancements and information tools. Digital models produced with high levels of detail, can be exploited in different contexts: from the heritage management to the support to conservation, virtual restoration, art cataloguing and, moreover, visual communication.

In particular, the procedures aimed at the conservation require 3D models to be highly detailed, feature that can be achieved by carefully planning acquisition and elaborations, in order to manage information, different analyses and programming the maintenance of the monument.

A particularly debated research topic in this context is the control of levels of precision and accuracy reachable by these models: this topic invites to experiment and compare new tools for the analysis and optimisation of acquired data.

The reliability of material data is one of the key factors towards a comprehensive documentation of architectural heritage, particularly about the output obtained in the post-processing phase of captured data (Jiang et al., 2020; Murtiyoso, Grussenmeyer, 2017).

With these objectives, the research presents the case study of the Ark of Mastino II in the historic core of Verona. Keeping the remains of the lord of Della Scala, the monument represents one of the highest peaks of medieval funerary architecture in Italy, and it stands out for its impressive height and a significant decorative apparatus in its higher portion. It is enriched by trilobed arches and tympans on the four sides, all adorned with leaf decorations and high-relief sculptures representing religious scenes of the Christian tradition (Figure 1).

2. The Ark of Mastino II

The Complex of the Scaliger Arks comprises several Gothic-style funerary monuments built by the Della Scala family, lords of Verona, to conserve the memory of the illustrious dynasty. Among the tombs of the open-air funerary complex (Figure 2), located in the very historic core of the city1, the ark of Mastino II, who ruled from 1329 to 1351 (Allen, 1910) stands out. It constitutes a singularity not only for its remarkable decorative apparatus, but also for its role of powerful communication tool in the urban context.

The Ark becomes a narrative medium where literally every surface is used to express magnificence, power, virtues and christian lessons.

To this purpose, four triangular slabs are fitted over the trilobed arches of the canopy, enriched by sculptural figures laying on projecting corbels.

The sides of the tympanums are decorated with crockets, repeated on the edges of the pyramid-trunk-shaped structure. The four figurations in the tympanums represent episodes of the Old Testament from the Book of Genesis and are similar in arrangement: a tree stands out in the middle and part the scene, completed with statues of the key characters of the various allegories.

Figure 1. The Ark of Mastino II is made of marble and consists of two levels with a rectangular plan (approximately 3.10x3.50m) surrounded by marble columns, with a truncated pyramid roof. On the first floor is the sarcophagus, a remarkable sculptural work (1.25x2.45m) supported by a central pedestal and 8 small pillars at the sides. At the top of the monument is the statue of the deceased in civilian clothes, protected by four saints who are located inside the aediculae at the corners of the monument.

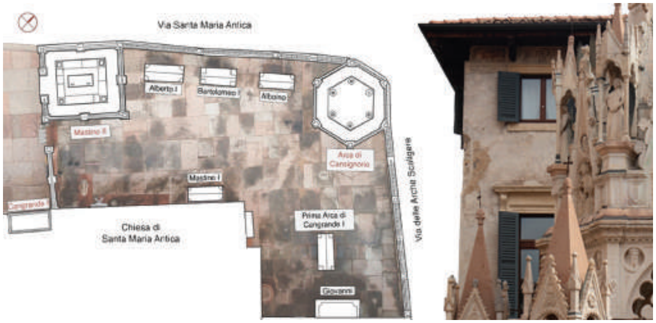

Figure 2. Planimetry of the Scaliger Arches complex. The Arches are protected by a marble fence and a fine wrought-iron gate repeatedly charged, in the flanking quadrilobes, with the emblem of the Lords. About the three arches in the complex, the Ark of Cansignorio and the Ark of Mastino II are the most imposing, with the most exquisite decoration.

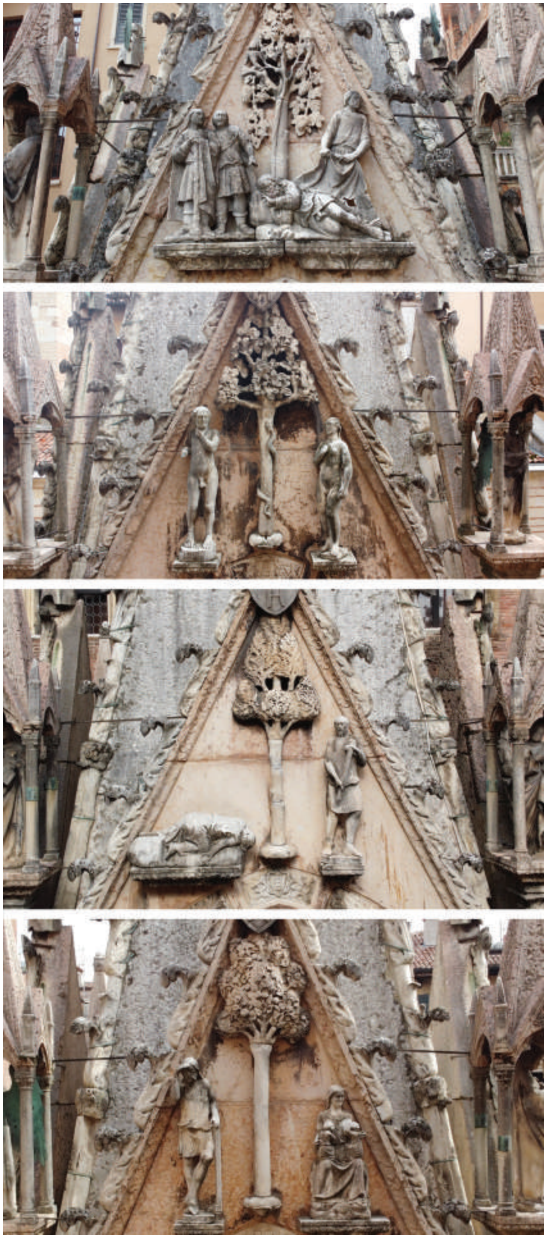

Figure 3. Analysis of scenes from the Old Testament on the tympanums of the Ark of Mastino II. From above: the mockery of Noah, the temptation of Adam and Eve, the killing of Cain, the work of the progenitors.

Figure 4. Data quality of the point cloud registration results.

3. Photogrammetric documentation by UAV of the decoration system of the Ark

The characteristics of the monument, its intrinsic conformation as well as its state of conservation, pose particularly challenging issue in its documentation: large surfaces inaccessible with a terrestrial laser scanning; a prevalent vertical development that brings about inhomogeneity in the resolution of the point cloud (Figure 4); the decorative apparatus consisting of intricate details and high-relief, hard to capture completely; scarcity of high-level stations around the object to carry out laser scanning. Ultimately, the precarious state of conservation of the structure and material surfaces called for a non-invasive documentation and keeping physical contact with the object to the minimum (Parrinello, Miceli, Galasso, 2021). In particular, by using ultra-light drones – in this particular case, a DJI Mavic Mini – it was possible to capture elements at high altitude, obtaining high detail documentation of the decorative apparatus – particularly focusing on the tympanums, the aedicula and the equestrian statue -

Figure 5. Drone acquisition methodology according to convergent axes of the upper portion of Ark of Mastino II.

and access elements otherwise inaccessible such as the back of the tympanums and part the roof covered by the tympanums themselves.
Two flight methodologies have been planned: the first one was focused on the documentation of each elevation of the monument, by using a parallel-axes acquisition path; the second one has been implemented using the the Point of Interest (PoI) flight mode (Figure 5), which is able to produce an extremely accurate and reliable database of images, responding qualitatively to a convincing representation of the object2 (Parrinello, Picchio 2019; Carnevali et al. 2018).

4. Elaboration and analisys of photogrammetric database

The research develops starting from the planning - specifically designed according to the criticalities of the case study - of the methodologies of photogrammetric acquisition using UAV systems. After that, it focuses on data processing using different software dedicated to photogrammetric reconstruction, with the aim of evaluating the levels of accuracy obtainable, according to different approaches of research and data elaboration.
The photos collected have been processed using two different photogrammetry software, Metashape (Agisoft) and Reality Capture (Capturing Reality), aiming at evaluating and comparing the different performances and results.
The objective has been to compare the selected software in terms of (i) systems of data processing, (ii) quality of 3D models obtained from point cloud processing, (iii) their application for documentation purposes.
Within this view, it was possible to evaluate which workflow, among the selected ones, is the most suitable for reaching proper knowledge of the architecture and the decorative system of the monument, integrating an already established measurement reliability with a high level of detail, able to appropriately represent the geometric and expressive complexity of the object.
In line with the standard photogrammetry pipeline, the dataset has been processed in Metashape and the homologue points extracted from the calculation of the orientation parameters have been used to produce,

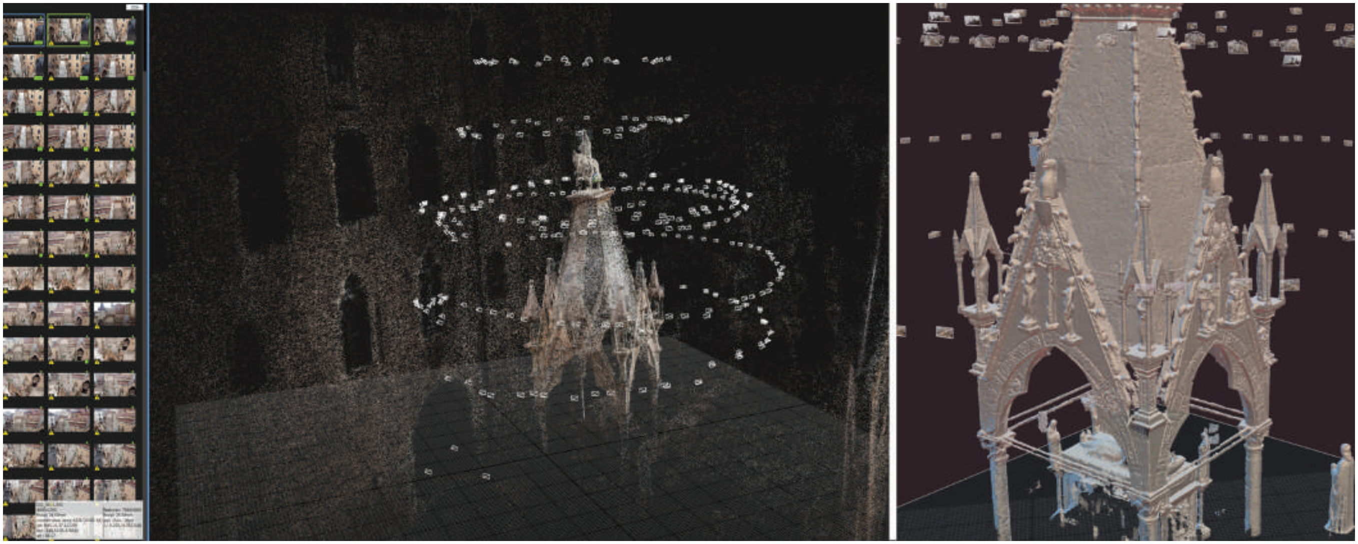

Figure 6. Photographic image processing using Reality Capture software. On the left, a screen from the point cloud construction software. On the right, details of the mesh model resulting from the processing of the point cloud.

using dense image matching algorithms, the textured polygonal model (Repola et al. 2019). For a correct evaluation of the final model, the parameters of the mesh reconstruction have been raised, leading to obtain ultra-detailed models consisting of an extremely high number of polygons.
The same batch of images has been processed in the software Reality Capture (Figure 6), by first performing an initial auto-alignment of the photographs, allowing to correctly place and orient cameras in the scene. As with the previous software, the parameters for the creation of the final mesh model have been set, and the results obtained are synthetised in the following table.

Comparison of photogrammetric data Ark of Mastino II			
	Agisoft Metashape		Reality Capture
Photographic set = 343 images			
Sparse Cloud			
Parameters	High precision		High precision
Number of aligned images	340		343
Processing times	1h		20min
Number of points	3,5 M		1M
Dense Cloud			
Parameters	High		
Processing times	6h 20min		
Number of points	46 M		19,4 M
File Size	609,94 MB		1,62 GB
Mesh model			
Parameters	High	Ultra-High	High
Processing times	50 min	2h 30min	1h 30min
Number of polygons	24,9 M	93,6 M	38,7 M (Divided into 18 parts[3])
File Size	2,3 GB	4,4 GB	2,2 GB

Table 1. Synthesis of data obtained during the different processes in the two photogrammetry programs.

5. Analytical and qualitative data comparison

Reliability checks have been implemented, by comparing SfM models obtained from each software used with a reference model, obtained from the laser scanner point cloud, and measuring the maximum deviation of the portions characterised by a marked morphological complexity, such as the decorations and the statues in the tympanums.
From an analytical point of view, the comparison of the point clouds has been performed in Cloud Compare, by integrating in a single file the accuracy of the laser

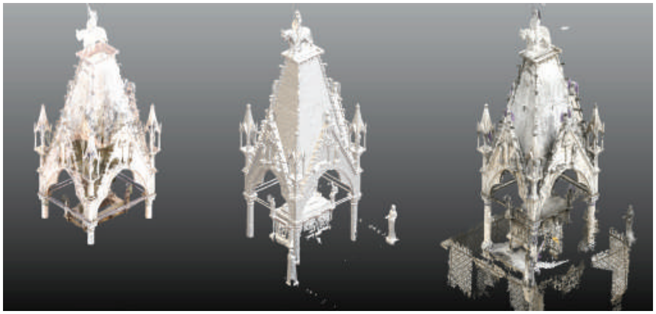

Figure 7. The three databases analysed within the CloudCompare software. From left, point cloud from TLS acquisition, point cloud from Metashape processing, point cloud from Reality Capture processing. The three databases were aligned based on the GPS coordinates of the photographic images.

scanner data and the photogrammetric point clouds obtained from the two selected software (Figure 7).
Analysing the deviation of the models from the point cloud obtained from TLS, we have obtained visual information that could be represented in a chromatic scale starting from blue, representing the lowest deviation, to red, representing the highest deviation. For the case study of the point cloud of the Ark, the deviation values have been set to 10mm and 20mm. In general, the analysis shows a good congruency between the modes, with the maximum error located in close vicinity to the areas where there is lack of data acquired by the laser scanner (Figure 8).
By the same logic, the point clouds obtained from the two software have been compared, to highlight criticalities and differences (Figure 9).
A quality analysis has been performed by comparing the mesh models and their visualisation in the software Geomagic Design X, showing that most of the details and elements characterising the facades appear more evident and distinguishable in the model obtained from Reality Capture, where details of the decorative elements are highlighted, as opposed to the one obtained from Metashape. The presence of a high number of polygons of small size has led to obtain a more discretised and formally detailed model (Figure 10).

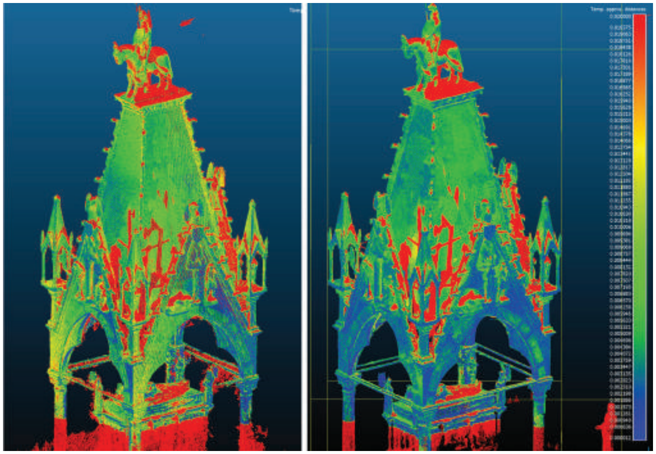

Figure 8. Analytical comparison of point cloud data from TLS processing, Metashape processing (left) and Reality Capture processing (right) with a tolerance range of 20mm. A greater deviation is evident in the areas of the retro-timpanum, where the data from TLS are missing.

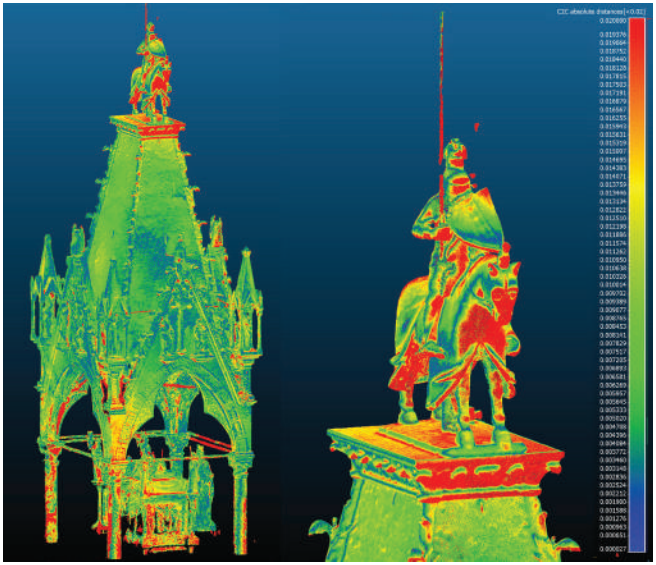

Figure 9. Analytical comparison of point clouds from Metashape and Reality Capture processing with a tolerance range of 20mm. For most of the surfaces, the maximum error found does not exceed 8mm. Misalignments of more than 15mm are found at the top of the monument, at the statue of Mastino II.

6. Conclusions

The quality check performed using the two different software for photogrammetric processing has highlighted a deviation of a few millimetres, proving a considerable quality in terms of data accuracy and reliability. The research allowed to determine a critical-knowledge path, able to achieve a high level of completeness in regard to the specific needs of knowledge and conservation of the monument, without harming its state of conservation, currently precarious. In particular, the modelling process, based on an accurate metric reliability and an ultra-high level of detail, will serve the purpose of experimenting new and more valuable tools for the knowledge, valorisation and maintenance of the Ark: 2d drawings, acknowledgement of structural criticalities through elevation maps and conditions survey with an atlas of the decays will provide with a tool able to support the development of restoration and intervention projects (Figure 11).

Acknowledgement

The documentation research of the Ark of Mastino II has been fostered by the Rotary Club of Verona and the Municipality of Verona, with the cooperation of professors, fellows and Ph.D. students of the laboratory DADA-Lab of University of Pavia, coordinated by Sandro Parrinello and Francesca Picchio.

Notes

1 Among the other tombs, two arches stand out for their complexity and beauty: the tomb of Cangrande I and the tomb of Cansignorio, belonging to the canopied tomb on columns typology, which constitutes the most sumptuous form of 'noble' burial of the time.

2 In this case, the number of images acquired is 343. For the purposes of the following research, only the photographic set resulting from the PoI mode acquisition was processed, to assess the monument in its entirety, without making alignments between separate chunks. Furthermore, to obtain a good resolution of the photographic image and the photogrammetric model to be integrated with the data obtained from ground-based instrumentation application, a GSD of 4 mm was calculated.

3 Unlike Agisoft's software, Reality Capture processes the final model by dividing it into several parts, ensuring maximum interpolation of the data for each of them.

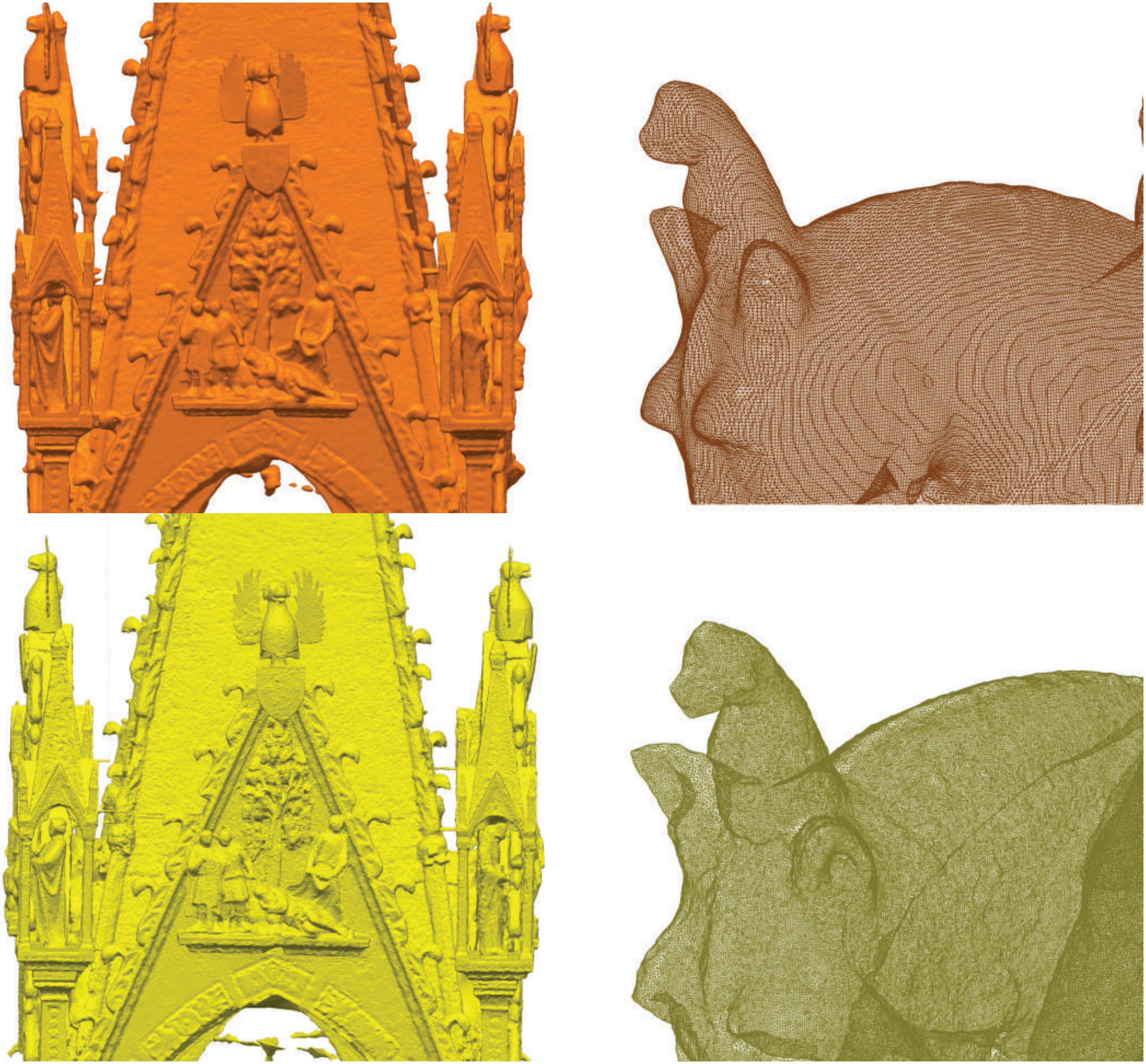

Figure 10. Qualitative comparison of mesh models. Above, the model from Metashape processing, below the model from Reality Capture. On the right, a detail of the triangular mesh of the Mastino II statue on top of the Ark from the two softwares. Although the number of polygons does not differ too much (as seen in Table 1), the resolution of the model processed by Reality Capture appears to be of higher quality.

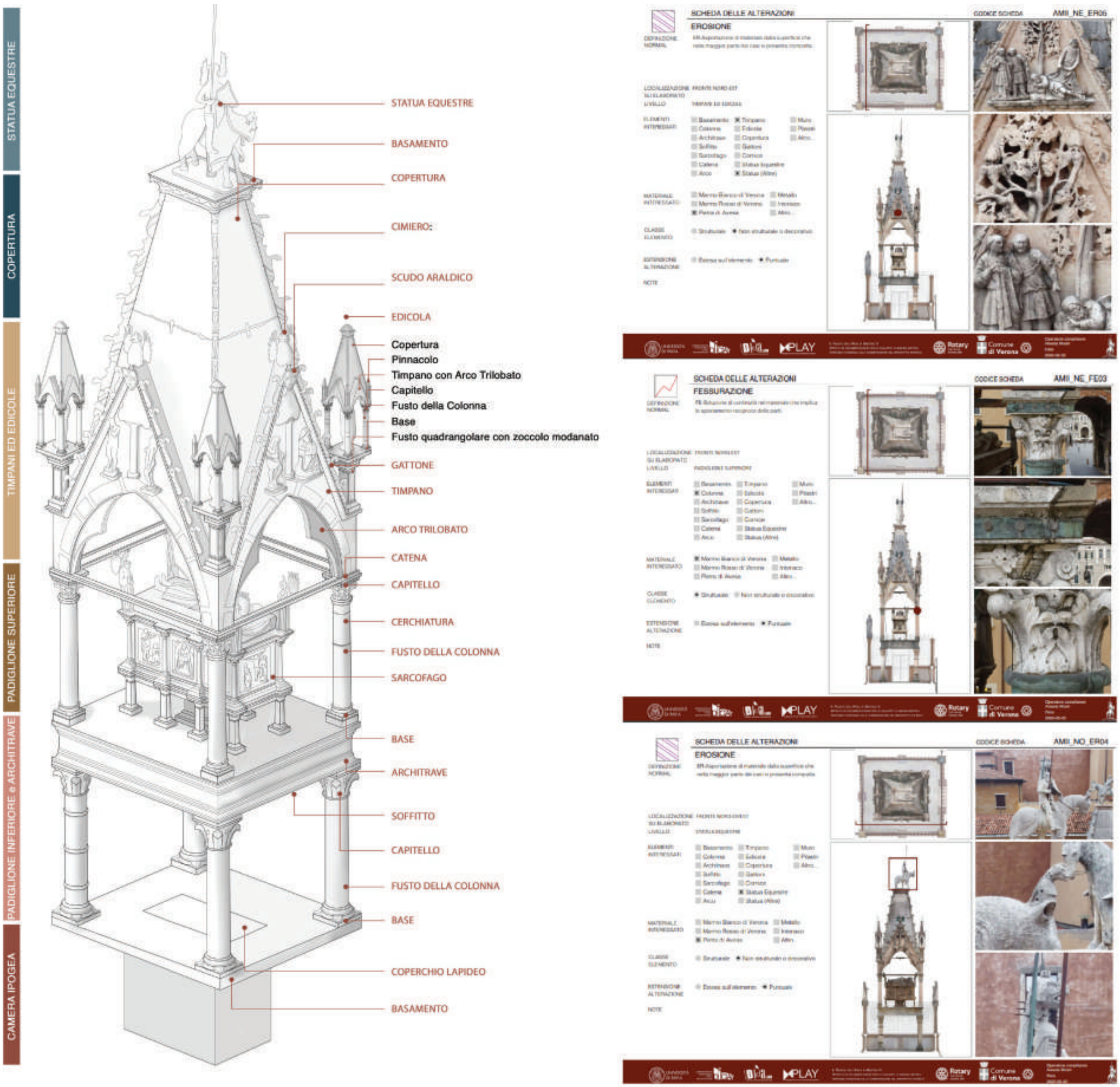

Figure 11. To determine a correct methodology aimed at the restoration, conservation and monitoring of the monument, with particular attention to the valuable decorative system on the façade, a census and cataloguing system was developed for the elements making up the Ark. A mapping of degradation was developed for each element, with particular attention to episodes of cracking and evidence of consolidation work. The mapping was organised within a database, whose characteristics of manageability, updatability, and integrability lean towards the objective of an aware management of the artefact (Parrinello, Miceli, Galasso, 2021).

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ABSTRACT

In 1911 the Cathedral of Conversano was damaged by fire and a project for the reconstruction of the presumed medieval structure was drawn up, based on studies whose methods are explained in a rich archive documentation. The paper aims to overcome the visual limits of the observation of the monument and the physical limits of the communication of its construction history. The experimentation proposes the use of UAV's and virtual reality to observe, measure and analyse the artefact in detail and, by simulating the museum experience, to connect the memory to the current architectural form.

Immersive environments and heritage digitization. The virtual image of a medieval cathedral

1. Conversano Cathedral in the project drawings and surveys by Sante Simone and Angelo Pantaleo

The medieval appearance of the Cathedral of the Conversano city in Apulia is not entirely original because it is due to a restoration in style carried out following a fire in 1911 that deeply damaged the monument (Dicarlo 2017, p. 9 and 26; Pepe 1996, p. 169). When Sante Simone was commissioned to carry out work on the interior of the cathedral in 1877, he undertook an investigation to find the original structures of an Apulian cathedral «with a Lombard appearance» (Simone 1878, p. 18). The aim is to restore a "supposed original unity of style", guided in the design process for its restoration "by the principles of stylistic restoration based on the writings and examples of Viollet-Le-Duc" (Pepe 1996, p. 179). The investigations, conducted through introspection and accompanied by a rich repertoire of drawings, allowed him to formulate hypotheses on the chronological succession of the structures and to draw up an accurate reading and description of the Cathedral. The documentation it produces consists of a report and a corpus of plates in which the graphic reconstruction of the old factory is presented in plan, main elevation and longitudinal section (Figure 1). These drawings do not represent the real monument, but an architecture devoid of what is not considered "original". These "virtual" representations are accompanied by a detailed graphic documentation of the existing ornamentation surveys, consisting of drawings of capitals, friezes, and cornices (Figure 2).

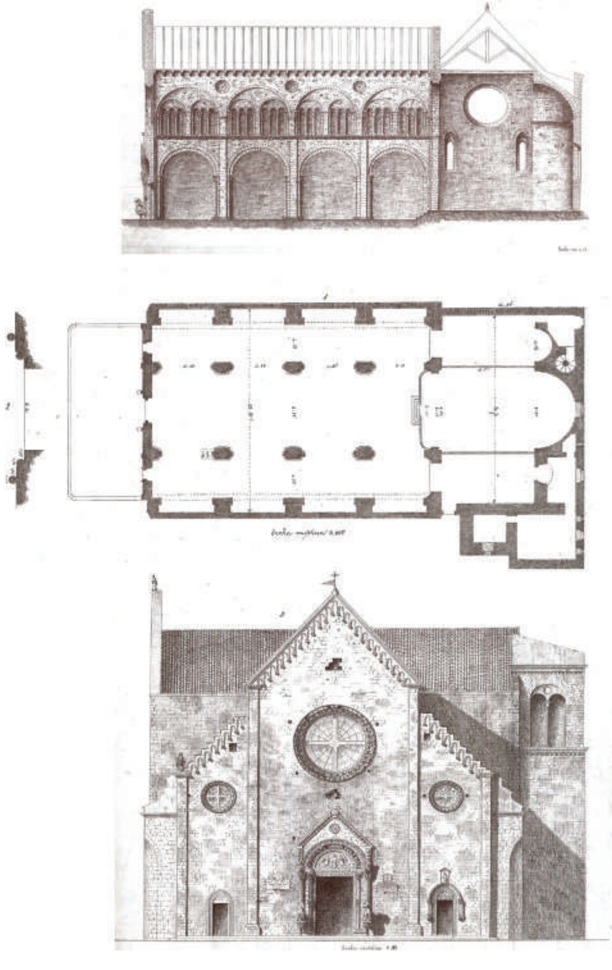

Figure 1. The Cathedral of Conversano according to Sante Simone: longitudinal section, plan, main front.

Figure 2. The Cathedral of Conversano according to Sante Simone: decorative elements.

Simone's investigations document important parts of the monument as they appeared in the second half of the 19th century, and form the basis on which architect Angelo Pantaleo, a few years later, built the path of knowledge that he undertook when, in 1907, he was entrusted with the consolidation of some of structures of the Cathedral (Dicarlo 2017, p. 28). In 1912, the need to restore the monument compromised by the fire became the pretext for planning the stylistic restoration that Sante Simone had been unable to carry out. Pantaleo's project (Fanelli 2009; Fanelli 2017; Colaleo 2017) made use of the reconstructions carried out by his predecessor, as well as his scientific surveys. In Pantaleo's work, in addition to the project drawings, of construction and decorative details drawings (Figure 3), reports and photographs, there are preparatory tables, notes, calculations and reasoning about the work. The detailed documentation produced in support of the two projects now makes it possible to delimit almost with certainty the interventions carried out, distinguishing recent interventions, albeit in style, from the original structures. Today, visitors to Conversano Cathedral are unable to distinguish what is original from what was styled, let alone what role the two designers played in the history of the monument.

This is why we believe that today we can go beyond a value judgement on their work, and that it is necessary to look at the work behind the current image of the Cathedral, making the survey, study and design drawings of the two architects known, usable and directly comparable with the existing one.

2. Preliminary stage, the morphological components

The survey operations focused on investigating the loggias located along the north and south walls and on the main west side elevation.

Figure 3. I° South Door and II° South Door: Project drawing of the decorative apparatus of the doors of the south front drawn up by arch. Angelo Pabntaleo (courtesy Mr. Donato Posa).

Particular attention has been paid to the analysis of the decorative apparatus.
The side elevations are developed along streets slightly under 5 meters narrow, making partially visible some of the interventions made by the architect Angelo Pantaleo after the fire of 1911 (La Viola 2017).
The lateral fronts are characterized by four blind arcades that surmount piers leaning against pilasters and that mark the prospectus in four vertical bands. In the first and in the third band, starting from the square in front of the churchyard, there are two portals that host inside lunettes and bas-reliefs. The upper part of the body of the building is divided into two parts: the first one crowning the side nave and a second one, set back, corresponding to the main nave.
The upper frieze that runs along the entire elevation of the outer nave, is composed of an alternation of small rose windows and single lancet windows that follow each other regularly.
Walking along the streets leading to the cathedral yard, it is possible to observe the facade in all its parts, except for the upper ones, because of the strong foreshortening and the limited size of the streets.Whyle in front of the main front, the *Largo Cattedrale* square opens, a wide space that allows an overall vision.
The facade is tripartite with two slightly projecting pilasters, three entrance portals and has a gabled roof. Above there are the central rose window (14th century), compromised after the fire of 1911, composed of a double frame, and two smaller rose windows, coeval and reworked during the restoration of the 20th century, like the main one. (Figure 4).
The present analysis is the result of an initial reading of the morphological components of the areas of the monument involved in the enhancement project. This analysis constitutes the fundamental preliminary phase for the planning of the instrumental survey operations, for which an integrated methodology between aerophotogrammetry and celerimensuration was used.

Figure 4. Outside photo of the Cathedral.

3. Operational phase, aerial survey and data processing

The aerial operations were conducted through the use of a Mavic 2 Pro drone equipped with a 35mm camera with 77° field of view, 1 inch and 20 Megapixel CMOS sensor, GPS - GLONASS system with vertical positioning accuracy +/- 0.5m and horizontal +/-1.5m, through which, it was possible to create a dataset related to the lateral and main elevations. In the survey phases, that have involved the main elevation, defined by large maneuvering spaces, flights between 3 and 20 meters were made with a bustrophed trajectory and camera orientation perpendicular to the facade planes, with the aim of finding photographic data as free as possible of perspective aberrations and shadow cones derived from the projection of architectural and decorative elements (Figure 5).

Different orientation, but with similar trajectories, was used for the datasets involving the side elevations. The flights were carried out at altitudes between 4 and 17 meters on 9 trajectories of uniform height. Greater precautions have been taken in the vicinity of the roofing pitches where sequences of shots have been taken with the camera inclined at 45° with respect to the axis of rotation of the gimbal, but with an incident angle of less than 15° with the surface to be detected, so as not to affect the quality of the data (Barba 2016) (Figure 6).
All operations were conducted in manual flight mode, ensuring safe control of the aircraft and allowing the avoidance of obstacles present at altitude.
The data were subsequently processed with the Agisoft Metashape software and scaled following the interpolation of celerimetric data acquired with a Leica TCR805 total station, with which the spatial coordinates of GCP (Ground Control Points) located on the ground and on the elevations were collimated. Six markers were respectively allocated on each elevation.
The photographic dataset referred to the main elevation, consists of 107 photos and was produced a point cloud dense 12,804,640 points and a textured mesh of 745,783 polygons with error degree of 4 mm, from these was processed an orthophore with a resolution of 2.67 mm/pix (Figure 7). The datasets of the North and South elevations consisted of 182 and 194 photos, respectively, which produced dense clouds of 43,814,863 points and 52,645,265 points and textured meshes of 2,920,985 polygons and 3,154,621 polygons and average error degrees of 6 mm and 5 mm. Subsequently, the corresponding photoplans were processed with resolutions of 2.83 mm/pix and 2.41 mm/pix (Figure 8).

Figure 5. Extract of photogrammetry and dense cloud with location of main elevation photos.

Figure 6. Photogrammetry excerpt and dense cloud with photo locations of the north side elevation.

Figure 7. Photogrammetry of the main front Ovest.

Figure 8. North elevation photogrammetry.

4. From the photogrammetric database to the virtual tour

The research aims to overcome the human perceptive and visual limits, finding a possible solution in the new technologies applied to the architectural survey. The use of UAV (Unmanned Aerial Vehicle), applied in the field of aerial photography, and virtual reality have made it possible to observe, analyze and study the artifact as a whole and in decorative detail, producing not only conservative results, but also allowing you to enjoy the asset in a digital way.

Photogrammetry, allows to realize a documentation composed by dense clouds, textured models and orthophotoplans, a set of data that compose a digital database useful to technicians and administrations not only *"to investigate and document the artifact in order to identify strategies for monitoring and maintenance"* (De Marco, Miceli, Parrinello 2020), but also to use it for popular purposes, given the strong communicative value that it has.

"Digital transposition of the artifact manifests additional dffusion potential" (Parrinello, Miceli, Galasso 2021). In fact, the data produced lend themselves to alternative dissemination, and suggest their digital consultation, diversifying and overcoming the constraints of *in situ* use if we change their form into a new, more interactive product. A virtual tour can be configured as a container that can keep together the entire database produced. The integration with a textual information apparatus allows both the visitor in situ and the digital visitor to enjoy the artifact at 360°. The tour was realized through a terrestrial photographic beating with Insta360 One R camera with 18 MP - 4K resolution and 1 inch sensor. The spherical panoramas obtained, placed at a distance of 5 meters from each other and 1.70 meters from the ground, have composed the skeleton of the composition of the virtual tour that simulates a walk through the streets of the historic center (Figure 9). The views were interlaced with each other with bidirectional hyperlinks, offering a fruition according to two opposite directions (forward and backward) within the Theasys software. The infographics implemented in the tour allow to interrogate the architecture and its elements. In proximity of the decorative apparatus, pop-ups have been inserted containing the data emerged from the research, study and comparison between the historical drawings

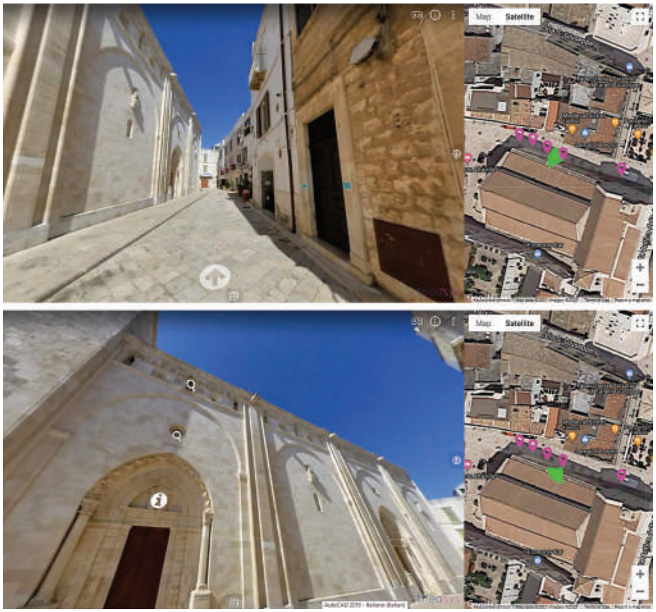

Figure 9. Images from the virtual tour.

and the photogrammetric data. The tour also offers the possibility to visualize the textured models, so that the user can observe both the decorative apparatus from close up and have the cultural tools to understand some historical phases of the life of the Cathedral (Figure 10).

5. Analogue and digital. The image in the survey of Conversano Cathedral

The visualisation of the artefact in a digital environment, which makes it possible to observe the dense system of data distributed over the surface of the support, penetrating the physical material and absorbing the memory from it, is at the same time an absence and a presence: «it is an absence because it testifies to the distance and diversity of the real object of which it is a virtual projection; it is a presence because it is a real object that refers back to itself» (Purini 2007, p. 35). The large amount of data collected during the survey generates a hyper-real, hyper-structured model in which the observer, going beyond the limits of his point of view, accesses the numerous architectural elements, forming a credible and suggestive idea of Apulian architecture in the medieval period. The study of the iconographic material relating to Pantaleo's drawings for the north façade of the Cathedral suggests a reflection on images in the architectural survey. In particular, Table n. 15 (Figure 11), a technical study[1], traces a working method that, from the survey drawing of the existing building, passes through the analysis, interpretation and selection of material and immaterial data, to arrive at a complex but recognisable image of religious architecture in the ideal reconstruction. The line drawings in the upper part of the book describe the construction system of the roof, with diagrams and measurements. At the bottom are drawings of the side elevation, the longitudinal section and the roof frame, through which, in transparency, the interior can be read. In the centre is the interior, with the three-mullioned windows of the women's gallery, framed in the sequence of arches between whose piers is the supporting pillar of the roof structure. On the left-hand side, the small arches are schematically outlined, while on the right-hand side they have hinted decorations. Among these, a single-light window is represented in more detail, strictly in style. The whole is equipped with written notes, measurements, calculations indicating the existing parts, the project parts, the system of relations, the functioning of the elements. The image is interesting precisely because of the way it is composed, because it is able to show the architect's design thinking, clarifying the sense of the link between the survey of the existing and the design of the new. The image produced by the survey of the north façade is the result of a mosaic of data selected and recomposed in a digital environment, integrating different techniques and tools capable of accessing the spatial, dimensional and figurative values of the building. Apparently a photographic image with a high visual content, the orthophoto plan is able to

Figure 10. Pop-up example. Orthophoto plan and detail visualization of the architectural elements of the north side.

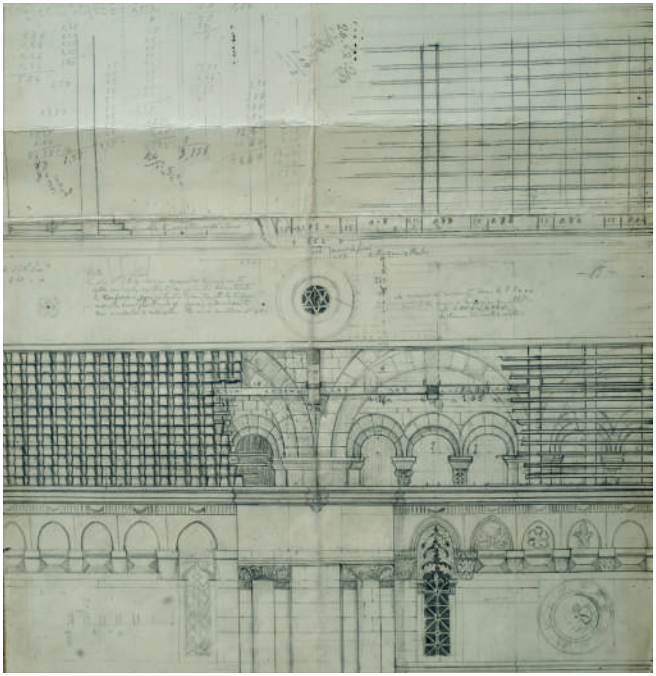

Figure 11. Table 15: Comparison between the north side elevation and the longitudinal section, for the structural and linguistic verification between inside and outside of the Cathedral drawn up by arch. Angelo Pantaleo (courtesy Mr. Donato Posa).

provide a series of coordinates through which the observer can frame and order his visual experience.
By placing Pantaleo's drawings and the orthophotoplan in continuity (Figure on the cover), the two images converse in a particular tension between the representation of existing reality and that of the future and desired reality. The drawing of the form and the geometry of the elements are reflected on the real architectural surface, finding the object of representation and its meaning. Through images constructed in this way, in which the technical datum is intertwined with the figurative, the monument will continue to survive despite the passage of time. Architecture, which must be «experienced, inhabited, so that it can be said to have been fully experienced» (Marconi 1993, p. 2), will be «materially evoked, re-produced in front of the user, to be truly perceived» (Marconi 1993, p. 28). It therefore requires a dedicated space, capable of responding to the doubts and questions posed at the basis of the investigation. This space, constructed through survey operations, defined and measurable in a digital environment, simulates the museum experience by expanding the boundaries and connecting drawing to model, image to reality, memory to architectural form[2].

Notes

1 The table is owned by Mr Donato Posa.

2 The paragraph "Conversano Cathedral in the project drawings and su rveys by Sante Simone and Angelo Pantaleo" is by Valentina Castagnolo, the paragraphs "Preliminary stage, the morphological components", "Operational phase, aerial survey and data processing" and "From the photogrammetric database to the virtual tour" is by Remo Pavone, the paragraph "Analogue and digital. The image in the survey of Conversano Cathedral" is by Anna Christiana Maiorano.

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ABSTRACT

Drone-aided digital photogrammetry (SFM) has rapidly become a widespread tool for the materic and morphological characterization of architectural fronts. The opportunity to use the 3D mesh, textured with an adaptive ortophoto, as a primary tool for further elaboration through various software calls for a versatile use of the 3D textured surface, which is today underused in the professional field preferring the classic 2D orthophoto. The intent of this contribution is to illustrate the workflow that, based on the textured mesh, allows a real-time visualisation and control of the planned restoration operations.

Towards an "allround" control of the restoration project: 3D modelling as a real-time monitoring system for the design outcome

1. Introduction

The rapid development of the drone market, with specific reference to the use of APRs for technical services (aerophotogrammetry, building surveys, etc.), has launched digital photogrammetry (SFM) as a privileged tool for the material and morphological characterization of architectural fronts of valuable historical buildings, making the previous methods of bidimensional photomosaic in orthographic projection practically obsolete. Surprisingly, however, the expected output in the professional sphere continues to be the orthophoto[1], as if the "intermediate product" - the textured mesh - was not a fundamental tool itself in the field of conservation.

In spite, therefore, of the legislative[2] and technological[3] evolution that places the object in its three-dimensionality at the centre of the restoration process, historical architecture is often evaluated in its two-dimensionality. The restoration works still neglect the third dimension which, in front of an apparently minor extension in geometrical terms, represents instead one of the critical nodes in terms of definition of the conservational interventions, of materic yield and of economic evaluation.

The numerous disciplinary needs of conservation, ranging from the analysis of the totality of surfaces to the 3D verification of conservational and reintegrative interventions, from the control of natural and artificial lighting to the simulation of the behaviour of fluids on the surface, as well as the structural verification of particular elements (sculptures, overhangs, etc.), can and should be supported by a versatile and convenient use of 3D textured surfaces[4]. In this view, the commonly operated workflow starting from the acquisition by aerial photogrammetry can then be implemented to fully express all the potentialities related to the realization of 3D textured surfaces, without this being an additional effort in terms of process to the operations already implemented. (Figure 1)

2. Photogrammetric survey: operational setup

The surfaces of architectural facades undoubtedly have a prevalent spatial development on two dimensions against a third one, that of the overhangs, with an apparently marginal extension. However, it is these surfaces in particular that require greater attention and specific interventions during restoration. They are in fact less resistant to mechanical actions, more exposed to atmospheric agents and more subject to the deposit of sediments. At the same time though, they are the means whereby the architectural and figurative values of the buildings are conveyed. The understanding and evaluation of this peculiarity must therefore be at the centre of the 3D architectural survey project, which for this reason must include the definition of non-vertical surfaces, paying a special attention to them.

Nowadays a survey project that sets up an image capture grid for the characterization of architectural fronts is an integral part of the aerophotogrammetric survey techniques in architecture. This is carried out observing the following principle, especially when using ultra-light UAV: a good overlap between the photos and

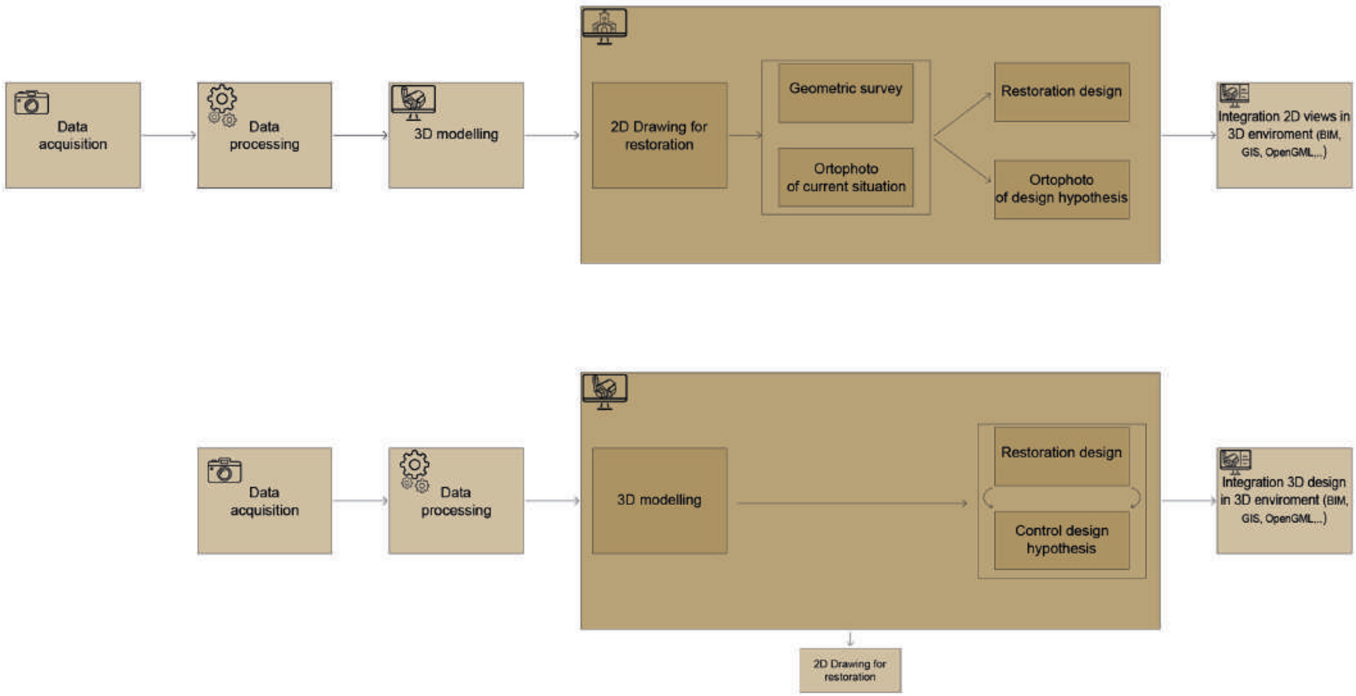

Figure 1. Above: the commonly used workflow in the aerophotogrammetric survey process generating a 2D output. Below: the proposed workflow remaining in a 3D environment.

a complete coverage of the surface in question, while keeping the camera direction perpendicular to the facade's main surface[5]. This operation, which has the undoubted advantage of allowing a rapid and effective[6] scanning with a good definition of the vertical surfaces, however, neglects the characterization of all the surfaces that are not perpendicular to the grid. In the case of historical architecture, these areas can display different levels of complexity and value.

To achieve a homogeneous characterization of the surfaces, it is essential to consider certain factors during the field survey. First, with the purpose of acquiring all the dimensions of an architectural artifact with the same accuracy, it is not sufficient to conduct a single sequence of photos perpendicular to the front, but it becomes necessary to shoot with a different angle[7] all the surfaces such as cornices, windowsills, friezes or sculptural elements, etc. In this regard, while maintaining a grid flight pattern, it is of great help the ability to tilt the camera to capture the best even the surfaces of overhangs. This feature is offered by those drone models with a camera gimbal separated from the body, such as all the latest models of the well-known manufacturer DJI.

At the same time, an extra attention is needed when tilting the camera on both horizontal and vertical axes as framing objects on too different depth ranges may result in parts of the image being out of focus, something that must absolutely be avoided for a successful texture outcome. (Figure 2)
A further reflection should be made on the obstacle detection and avoidance functions. In fact, if it is true that urban fronts tend to have a linear development, in the architectural field, and in particular in the historical one, internal courts or the presence of edges are rather frequent. In these cases, in order to produce a clean mesh in the photogrammetric processing phase, it becomes important to be able to de-activate the obstacle detection so as to flank the building as much as possible in the corners. This possibility, missing for example in the DJI Spark, is now an integrated feature of the new models of the same manufacturer such as the DJI Mini2.
Clearly a process requiring such a systematic control of the photographic acquisition, with multiple sets of takes at different angles relatively to the vertical, cannot be performed by an automatic flight program. Not only, in fact, the possibilities of flight planning with variable altitude are scarce in terms of applications for average level drones, but even when possible, it would be necessary to carefully control the progress of the UAV. A slight inaccuracy of the GPS or the altimeter - instruments that may have excellent precision at the topographic scale but not at the architectural one - or even due to a slight variation in wind speed, there is the risk of no longer guaranteeing the minimum overlap rate between photos, potentially affecting the success of the photogrammetric process.
At present, the control of the systematic acquisition of the data must be carried out manually and the planning of the photography operations must be designed for each case according to the characteristics of the site and of the survey object. While it is necessary to ensure an even quality and density of photographic data on all three dimensions, it is still possible to generate a good model with a high-definition texture without producing

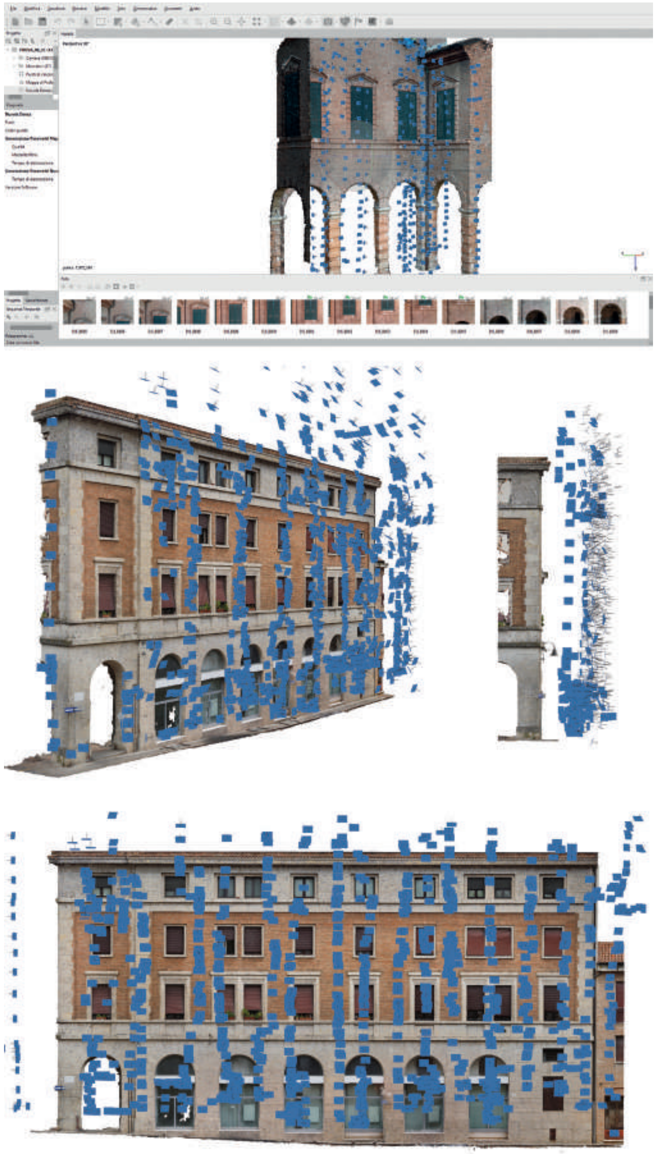

Figure 2. Top: Avogli Trotti Palace, Ferrara (Developed by Luca Cei). Bottom: INA headquarters, Ferrara (Developed by Marco Zuppiroli). Scheme of the drone photographic takes: the grid layout is enriched with shots from different angles, especially in coincidence with overhangs and sculptural elements.

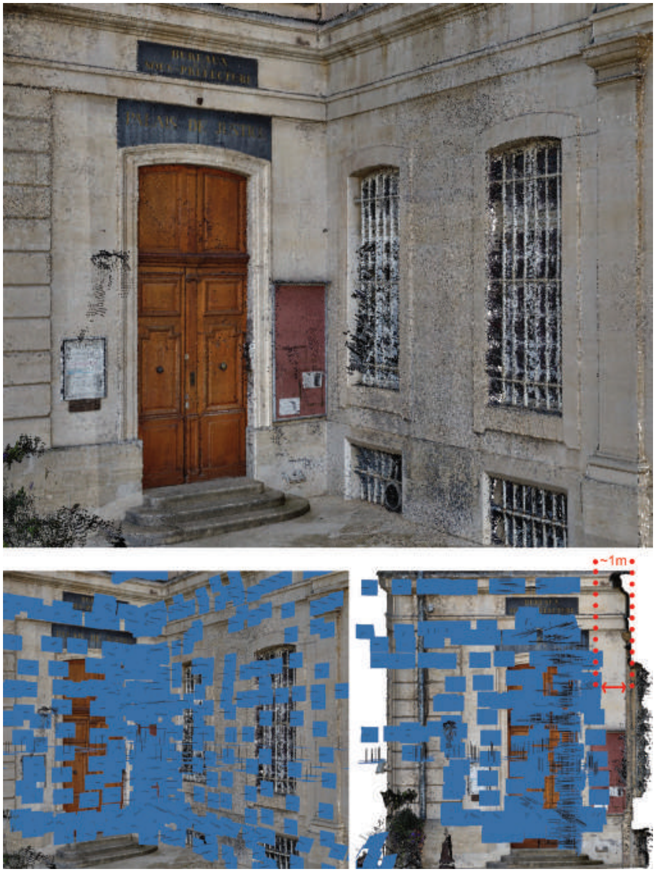

Figure 3. Subprefecture Palace, Apt. Noise in the point cloud generated by an incorrect drone flight capture.

excess data. This is possible by implementing some strategies to minimize the field capture and processing times, as well as to generate a lighter output. In this regard it is important that some parameters are well calibrated. One of these is the distance of the camera from the architectural surface: in most cases a distance of 2 - 3 meters is sufficient to obtain a detailed texture. Such a range, both for safety reasons and for flight ease, is problematic to manage with drones above 500g. In fact, the excessive detail of the images often generates defects in the processing of the point cloud and, consequently, of the 3D mesh. Moreover, it is a good rule not to process photos whose distance from the surface is too far from the average, as to obtain a good texture the density of the data must be as homogeneous as possible.

A further evaluation should be made regarding the overlap parameter between photos. The acquisition of photos only in orthogonal orientation requires indeed a high overlapping of frames, between 60% and 80%[8]. A photographic acquisition conducted both with orthogonal and tilted camera reduces the minimum necessary overlap rate closer to the 60%. It is sufficient, in fact, that most of the points of the surface are visible in five or six images, while the excess of overlap does not bring added improvement in the final result making, on the contrary, the processing more complex. (Figure 3)

3. Data processing: from the ortophoto to the adaptive ortophoto

Among the software that today operates in the field of photogrammetry, Agisoft Metashape is undoubtedly one of the best known for data processing[9]. Starting from the images, which are aligned and converted first into a sparse point cloud and then into a dense cloud, the program generates a 3D mesh that can then be mapped and textured[10]. (Figure 4)

It is precisely in this last texturing phase that, even with a highly accurate photogrammetric survey and surface characterization, the workflow for the restoration project starts to lose its three-dimensional connotations in favour of two-dimensional ones. In fact, Agisoft Metashape provides several solutions in terms of surface mapping that are however underutilized, focusing the attention on the production of the classic bidimensional “orthophoto”. However, among the different proposed methods, the most interesting solution for the following display and control of the restoration project is the adaptive orthophoto mapping mode. Unlike a simple orthophoto, which neglects the surfaces perpendicular to the respective projection plane and thus significantly reduces the information quality, the adaptive orthophoto projects the texture on all surfaces, whichever the orientation, maintaining their quality and orthogonality to their own projection plane. It operates projecting the texture on the mesh always in an orthogonal direction, maintaining the density of the data and its quality in every point of the model. The texture generated by

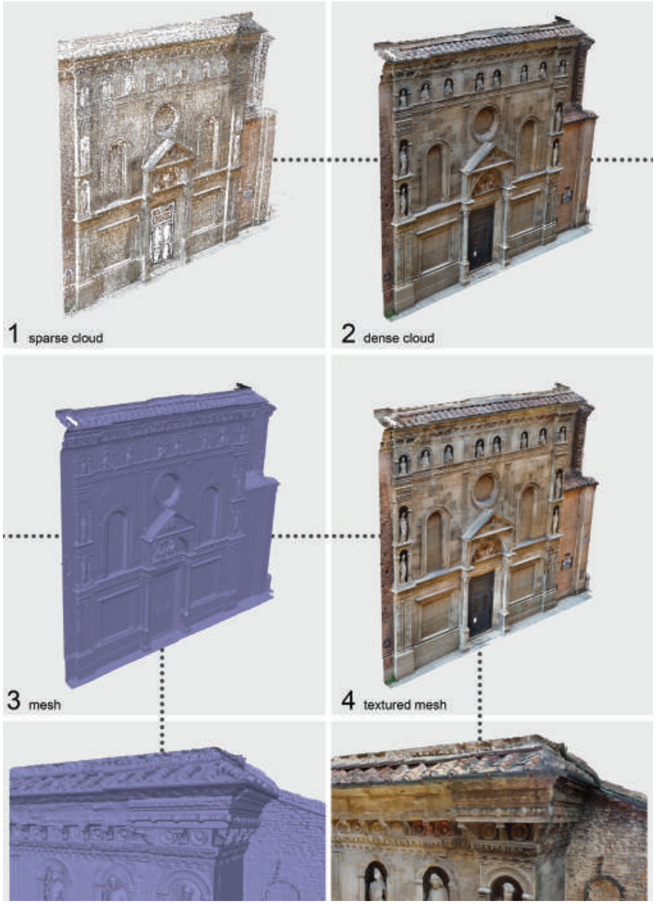

Figure 4. Madonna di Galliera Church, Bologna. The intermediate and final products of the photogrammetric process: sparse point cloud, dense point cloud, mesh and textured mesh. (Postgraduate School thesis; students: Samanta Fortini, Anna Volinia)

Figure 5. S. Salvatore dei Fieschi Church, Cogorno. Differences between texture types. Left: an adaptive orthophoto. Right: a simple orthophoto. (Postgraduate School thesis; students: Luca Formigari, Davide Felici).

this method, once exported, looks like a mosaic of all the surfaces of the model deconstructed according to their orientation in space: in the centre of the image are placed the largest planar surfaces, while moving towards the edges are arranged all the other surfaces as compactly as possible, strictly in orthogonal view and sorted by size. If the result appears to be a fragmented, intricate texture, on the other hand it allows an optimal control when the workflow is carried out mainly in a 3D environment. (Figure 5)

4. Use of data: the adaptive orthophoto as key tool for the 3D control of the restoration project

The model textured with adaptive orthophotos finds its natural application no longer for the production of classic photomaps, which are still widely used by professionals, but within software that allows the control and evaluation of the result of the restoration process in three dimensions.

In order to draw up the project status to verify the planned restoration interventions, coherently with the normally adopted workflow, the adaptive orthophoto must be initially modified through the use of bidimensional image processing software

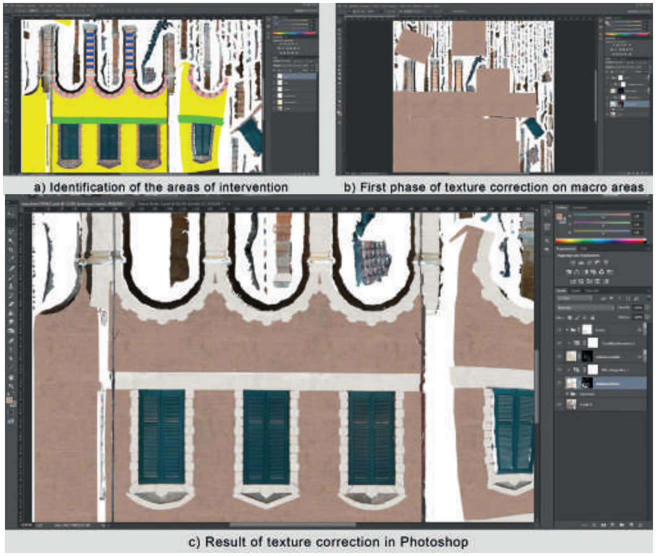

Figure 6. Avogli Trotti Palace, Ferrara. First stage of the texture editing on Photoshop: the larger surfaces are classified according to the areas of intervention that will be treated with the same type of correction. (Developed by Luca Cei).

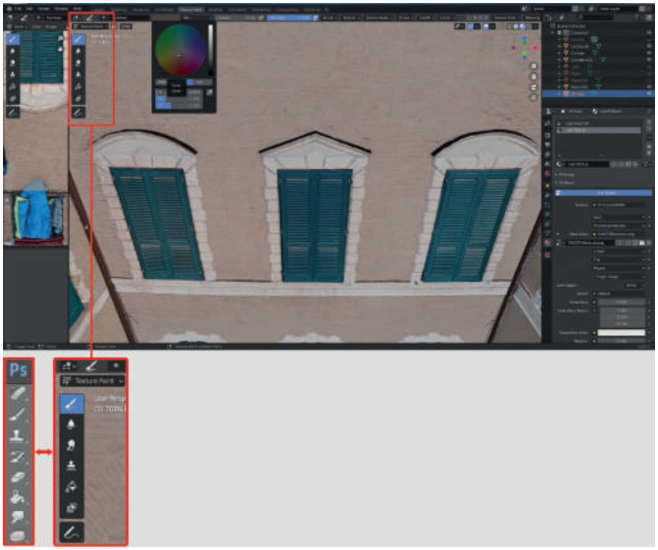

Figure 7. Avogli Trotti Palace, Ferrara. Second stage of the texture editing on Blender: use of the clone stamp directly on the 3D model. (Developed by Luca Cei).

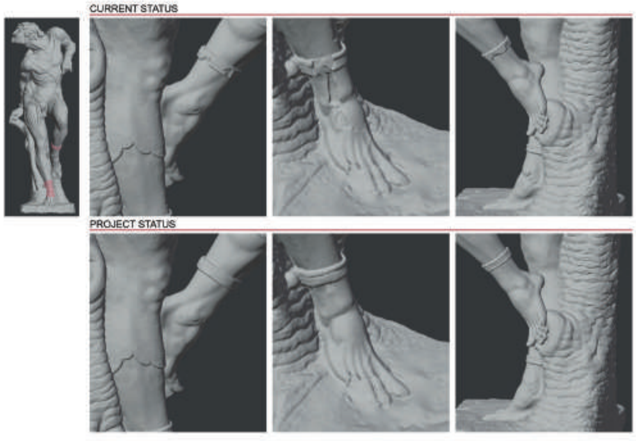

Figure 8. Statue from the Boboli Gardens, Florence. Example of digital sculpting through the use of Blender. The command was used to assess the result of the reintegration process.

(Photoshop). The prevailing surface of the texture, located in the centre of the image, is in fact editable also using this kind of tool, well known even to professionals, which contributes to define the initial restoration parameters for the larger surfaces. (Figure 6)

Following, to coherently modify the texture of all the minor surfaces that are located within the adaptive orthophoto, the textured model must be imported into a software that enables the user to operate both on the mesh and on the texture. One of the possible tools is Blender, an Open Source software able to combine modelling and image processing with an excellent rendering engine. Key point of this workflow is the integration of the result of the aerophotogrammetry inside a 3D environment through which it is possible to perform a number of processes commonly carried out using various software.

In fact, the software allows the processing and correction of the texture even on the more complex sculptural surfaces (statues, frames, ornamental elements, etc.) allowing the processing of the texture directly on the 3D object using tools like the well-known “clone stamp”

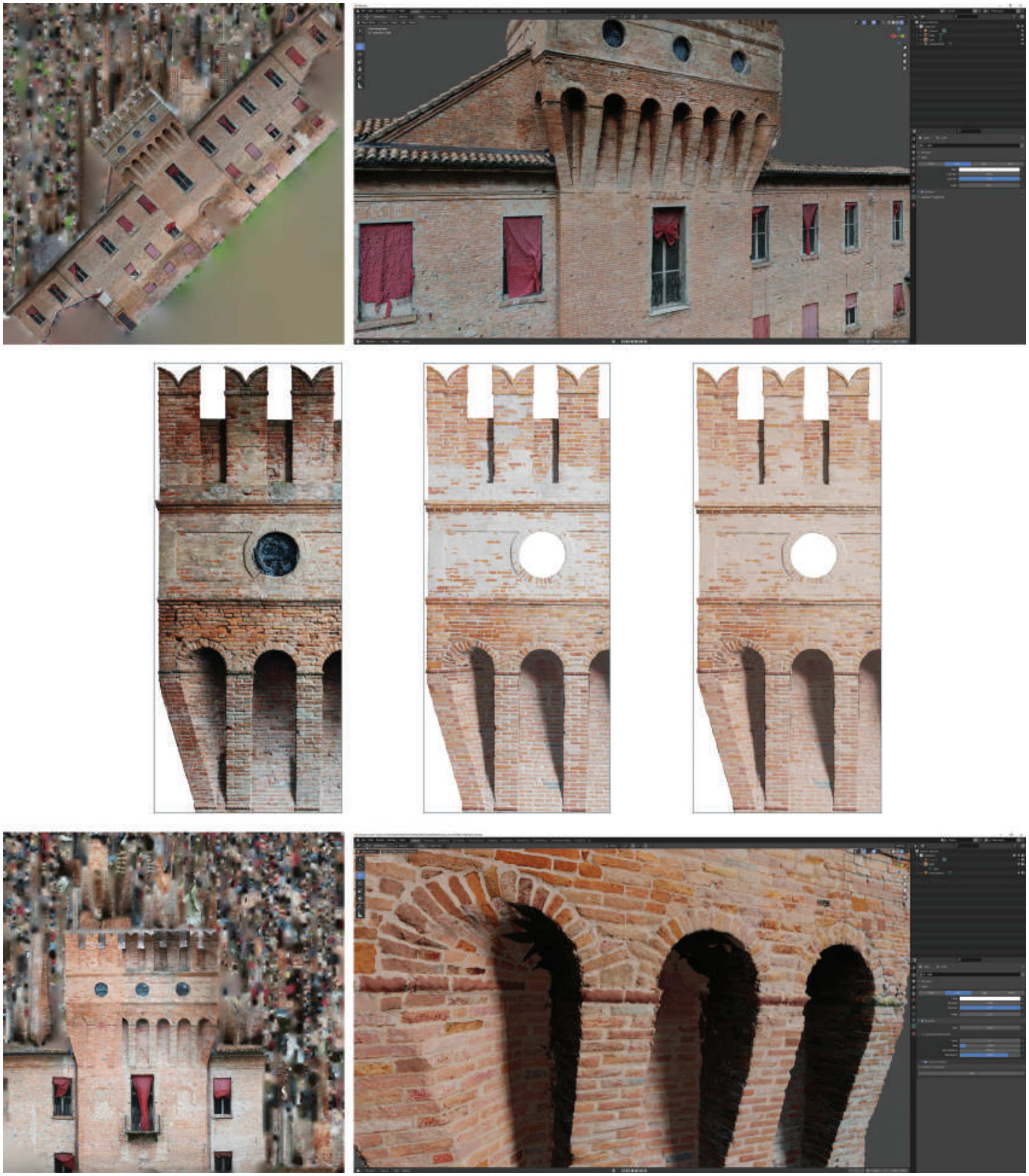

Figure 9. Delizia di Benvignante Villa, Argenta. Management of the restoration process in a 3D environment and hypotheses of intervention. (Master degree thesis; students: Marianna De Pascale, Ilaria Venturin).

Figure 10. Bagni Ducali Palace, Ferrara. Current status (left) and project status (right). (Master degree thesis; students: Emily Bosi, Alessandro Contucci).

or "filler" found in bidimensional software. (Figure 7) Moreover, being a modelling software itself, it is also possible to edit the mesh in order to preventively assess the result of the reintegration, reconstruction and restoration operations of the surface finishes. (Figure 8, Figure 9) Finally, as a rendering tool, the software allows to evaluate the result of the interventions in a global three-dimensional representation with the opportunity to verify the design choices also regarding the effect of light given by the different surface roughness. (Figure 10, Figure 11)

5. Conclusions

The problem of representing technical information within the restoration project seems to be more topical than ever. The rapid evolution of digital management and information processing systems within the construction industry, particularly marked in the last decade by the strong expansion of the BIM methodology, has led to an increasingly widespread use of the project through the various electronic devices available on the market. The concurrent progress in the portability of the devices themselves, which with their reduced dimensions are now able to offer interesting opportunities for visualization, makes it possible to have complex elaborations available in contexts that are not particularly favourable such as building sites or inspections.

Even in the field of restoration, therefore, it appears necessary to consider all the opportunities offered by the recent evolution of the digital usability modalities of the project.

Nevertheless, it should be always considered that, when necessary, the elaborations produced must be referable, at least in their essential contents, to "static" elaborations reproducible also on paper[11].

The de-materialisation process ongoing and the chance to deviate from the logic of the sole bidimensional elaboration has had multiple consequences on the gradual transformation of the entire design process: from the representation of the technical information (current status and/or project status) to the assessment of the potential outcomes of the intervention, from the digital usability of the project within the construction site to the communication of virtual spaces through VR - AR - MR devices.

It seems therefore necessary to be able to guarantee along the whole process the maintenance of a 3D characterisation of all the project outcome.

In this sense, the adaptive orientation of BIM technologies (Heritage BIM) is external to the discipline of restoration and has essentially no impact on real operational practice. Through the coding of new objects of a parametric nature that are functional for the reproduction of complex elements (architectural orders, capitals, etc.) and the texturing of stereometric 3D elements, this orientation claims to offer - so far with negative results - a 3D tool suitable for the collection and management of information at the different Levels of Detail (LoD). (Figure 12)

In light of this, without expecting to be exhaustive, in this contribution it is intended to highlight the value

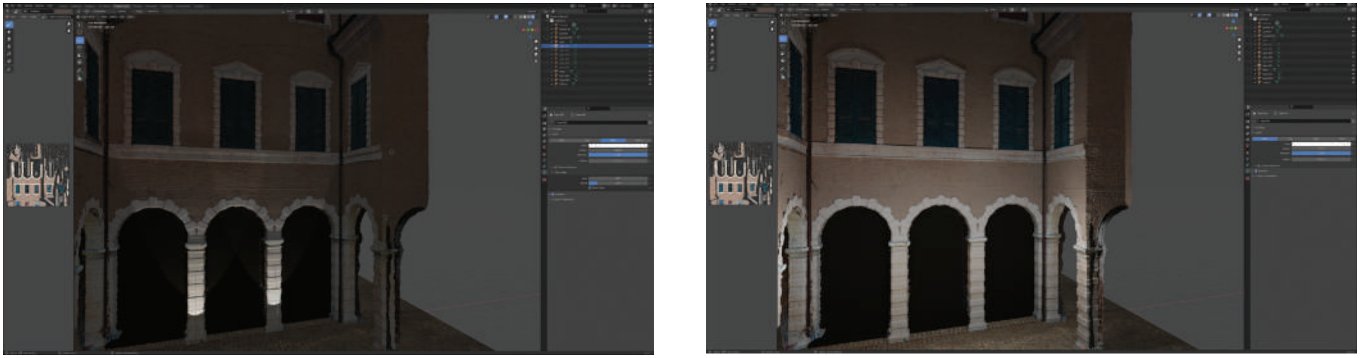

Figure 11. Avogli Trotti Palace, Ferrara. Lighting design hypothesis. (Work by Luca Cei).

of a critical and open management of information, which is always adaptable to the peculiarities of each historical artefact. In order to plan the restoration, the direct use of 3D models resulting from drone-aided photographic acquisitions is proposed as a matrix and aggregative unit of information of materic-constructive and technical nature (mesh with texture and 3D information system), which are aspects closely related to the outcome of the restoration project (project status).

Notes

1 Although some experimentations are carried out in the field of crack analysis on 3d surfaces obtained by digital photogrammetry (Galantucci, Fatiguso 2019), to date the orthophoto is presented as the main result of architectural photogrammetric survey (Adami et al. 2019; Empler, Valenti 2020).

2 When mentioning monumental buildings, this is mainly referring to public buildings for which the Italian New Procurement Code (D.lgs 50/2016) and the Baratono Decree (DM 560/2017) regulate the introduction and mandatory design management through 3D software.
3 An evolution that, on the one hand, pursues an increasingly efficient and valid integration of new tools (Fiorillo et al. 2021) and, on the other hand, attempts a semantic structuring of acquired data oriented to the operational interventions (Micel et al. 2020).

4 The topic of the representation of restoration projects is a complex issue that has been always moving in the close relationship existing between survey (Marino, 1990; Docci, 2003; Cardaci & Versaci,2018) and restoration (Carbonara 1990; Fiorani 2004; Galli 2009; Dalla Negra, Nuzzo 2008).

5 The theme of camera orientation has been widely investigated: see some recent paper as, for example, Multiyroso, Grussenmeyer 2017; Carnevali et al. 2018, Adami et al. 2019 or Picchio, 2020.

6 The development of these tools is shifting its focus to increasingly expeditious and functional protocols. See, as an example, Kunii Y. 2018
7 The relationship between orthogonal or tilted camera acquisition has already been investigated in experiments such as Aicardi et al. 2016.

8 See Carnevali et al. 2018.

9 Should be recalled that that, in addition to Metashape, in the current panorama there are many software whose workflow and results have been analysed and compared (as example see Aicardi et al. 2018; Rahaman, Champion 2019; Kingsland 2020).

10 The result of the photogrammetric model in architecture finds its application today in countless contexts ranging from the urban environment (see for example Foschi 2015) to the details of fine elements within historical architecture (see for example Russo 2021).

11 The drawing also remains in its digital dimension and is still an element of technical reliability.

Figure 12. Bagni Ducali Palace, Ferrara. Surface degradation mapping in 3D environment. (Master degree thesis; students: Emily Bosi, Alessandro Contucci)

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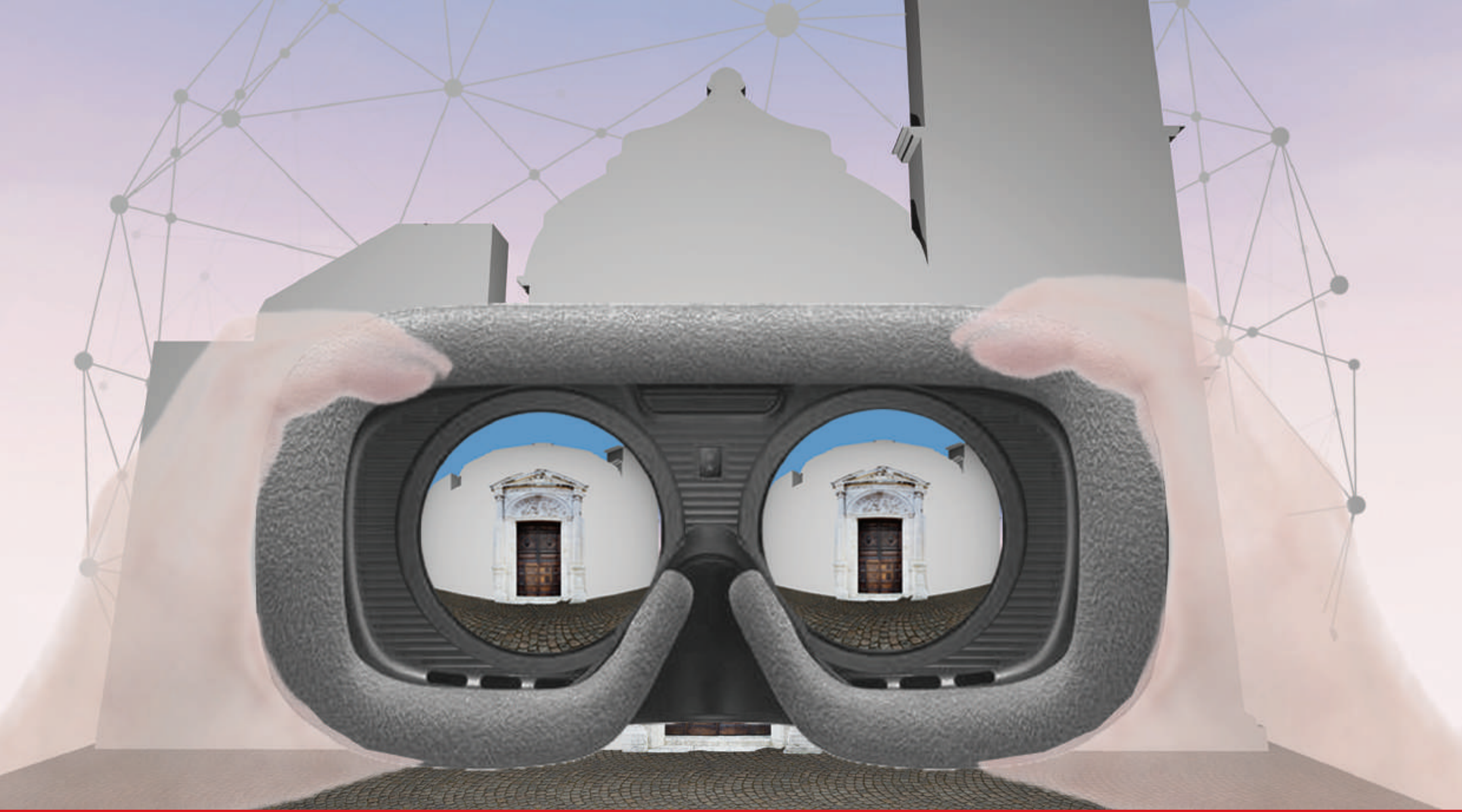

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Digital photogrammetry, Drone, Visual accuracy, Architectural details, Virtual reality.

ABSTRACT

In this research, photogrammetry is coupled with Virtual Reality to model a complex architecture case with the aim to assess the correlation between the dense point clouds and the quality of the immersive virtual scenarios upon varying the number of the points of the clouds. The visual quality of the virtual reality scenarios was evaluated by subjective assessment. The results underline that the higher the number of points is and better is the visual quality of the virtual model perceived by people.

Immersive virtual model accuracy and user perception: preliminary results of a case study with low cost photogrammetric survey method by drone

1. Introduction

Multisensory design tools, such as Virtual Reality (VR), allow taking into account different factors (objective and subjective) during the design process (Narasimha et al., 2019; Ruotolo et al., 2013; Scorpio et al., 2020). VR, especially if coupled with head mounted displays (HMDs), allows showing people virtual environments with high levels of presence, realism and "feeling of being" as if they were in the real world.

Nevertheless, virtual reality environments have to ensure the reproduction of perceptions that people experience in the real spaces and correct light distributions. For lighting research purposes, virtual environments are mainly modelled through photographs, 360° panoramas, and geometric modelling, which do not allow detailed reconstruction of complex architectural elements. Unfortunately, the higher the model accuracy, the longer it takes. For this reason, methodologies aim at obtaining accurate complex virtual models in a reasonable time are necessary.

According to various studies, photogrammetry has been proved as a reliable, lowcost method for a faithful and accurate reconstruction of complex threedimensional (3D) architectural elements with high surface detail (Pavlidis et al., 2007; Remondino et al., 2012; S. Gonizzi Barsanti F. Remondino, 2013).

Then, using photogrammetrically reconstructed complex architectural models into VR could provide accurate scenarios that allow not only visualisation, but also immersive and interactive experience (Webb et al., 2016). In this research, photogrammetry was used as low-cost instrument for building a 3D model of a complex architecture into VR. The portal of the Church SS. Annunziata di Sant'Agata de' Goti, Benevento (Southern Italy) was used as a case study. Four scenarios, with different 3D model accuracy, were obtained performing photogrammetric acquisitions at four distances (1.5 m, 3.0 m, 6.0 m and 12.0 m) from the portal of the Church. The four dense point clouds derived by photogrammetric surveys were imported into Unreal Engine 4 (UE4) (Https://Www.Unrealengine.Com/En-US/, 2021) to obtain four 3D immersive virtual models with different detail accuracy levels.

Figure 1. Church of SS. Annunziata of Sant'Agata de'Goti, Benevento (Italy): a) overall view and b) detailed view of the portal.

The four models were submitted to subjects to assess the correlation between the accuracy of the dense point cloud and the quality of the immersive virtual scenarios. With this aim, the research focused mainly on the visual quality of the virtual reality scenarios, rather than on their geometrical accuracy.

2. Materials and methods

The research has been conducted on the portal of the Church of SS. Annunziata di Sant'Agata de'Goti, built by the Bishop Giovanni in 1238. It was rebuilt and enlarged in the XVI century, following the Gothic style and focusing the attention on the portal of the main façade. The latter was built in 1563 by the school of Annibale Caccavello, it joins sixteenthcentury and baroque features, with many friezes, a wooden main door and a lunette with a basrelief depicting the mystery to which the Church is dedicated: the announcement to Maria and the Incarnation of the God's Son. The picture of the portal is shown in Figure 1. The portal survey was conducted using digital photogrammetry; in particular, it was used the technique of the "convergent photogrammetric socket" (Docci M., 2020).

This technique provides that photographs converge in a point and the shooting axes are slanting compared with the surface. In this way, it is possible to detect both the concave and the convex parts of the portal. A DJI mini 2 drone (Https://Www.Dji.Com/It/Mini-2/Specs, n.d.) was used, with the camera sensor of 1/2,3" CMOS, 12 MP, a lens of 24 mm., a camera angle FOV of 83° and the opening of f/2.8.

The surveys were carried out by positioning the drone at four different distances from the portal: 1.5 m., 3.0 m., 6.0 m., 12.0 m (Figure 2). The pictures were taken to ensure a percentage of overlapping equal to 70% and 80% in horizontal and vertical directions, respectively. For each survey's distance, images were imported in the "3DF Zephyr" (Https://Www.3dflow.Net/It/Software-Di-Fotogrammetria-3df-Zephyr/, n.d.) software to get the dense point clouds.

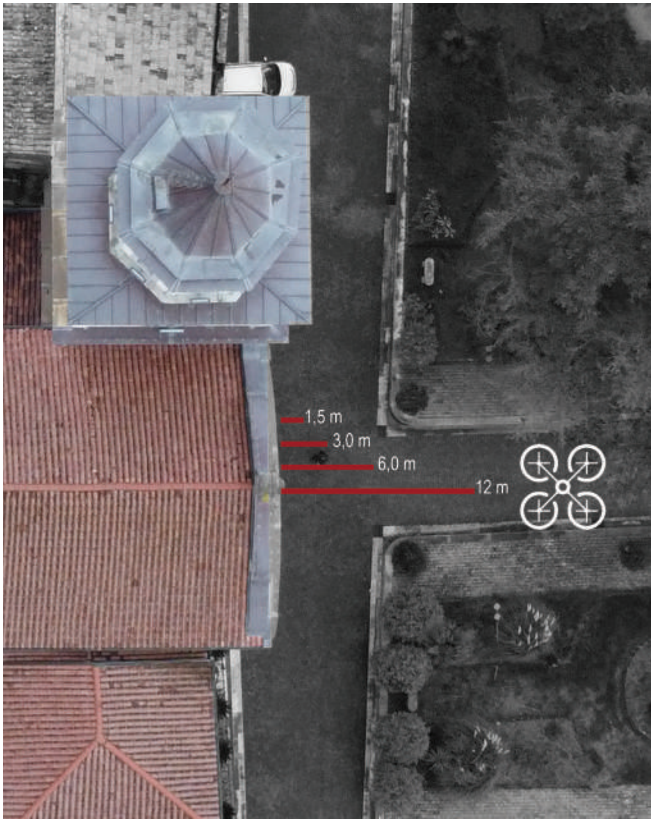


Figure 2. Church of SS. Annunziata of Sant'Agata de'Goti, Benevento, roof plan and identification of the distances from the portal.

Control points were used to ensure that the orientation and size of the dense point clouds correspond to the physical artifact. Each point of the dense point clouds is associated with a position in the space (by three Cartesian coordinates) and colour (by RGB coordinates).

Then, the four dense point clouds were imported in UE4 through the "LiDAR Point Cloud" plug-in (Https://Docs.Unrealengine.Com/4.26/En-US/, 2020). For each dense point cloud, a virtual scenario was created. Only contours of the remaining façade were rebuilt to contextualize the portal, avoiding at the same time to influence the subjects.

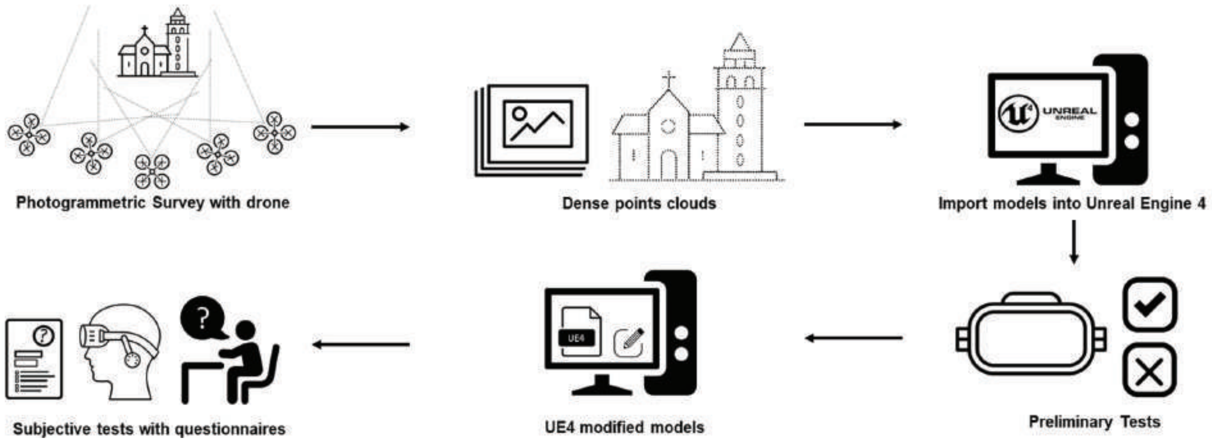


Figure 3. Block diagram of the methodology used in this research.

The scenarios were shown to the users using a pc with an “NVIDIA GeForce” video card and a head mounted display (HMD) “HTC Vive pro Eye”. Before the start of the assessment campaign, preliminary tests were conducted to evaluate the efficacy of scenarios, questionnaires, and administration methods. The scenarios were modified according to the preliminary tests results.
The final version of the scenarios were administered to the subjects. The methodology applied is reported in the Figure 3. Figure 4 reports the subjective test administered to each subject for each shown scenario. In particular, the virtual scenarios were compared according to the following dependent variables: i) perceptual impressions (PI), ii) presentation ability rating (PAR), iii) reported presence (RP), iv) emotional attributes rating and v) overall satisfaction rating (OSR). The 5-point Likert scale was used for the questions, where 1 corresponds to “not at all” and 5 to “very much”. The questionnaire was prepared both in Italian and English and used according to the most familiar language to the subjects. Scenarios were randomly presented to exclude errors related to the presentation order of the scenarios. In order to avoid that boundary conditions could influence the execution of the experiment, subjective tests were led

Perceptual Impressions	
PI.1	How pleasant are these architectural elements?
PI.2	How complex are the architectural elements?
PI.3	How satisfied are you with the view of these architectural elements?
PI.4	How discernible are the details of the architectural elements?
Presentation - ability rating	
PAR.1	How much do you feel present in the virtual space?
PAR.2	How do you perceive the field depth of architectural elements?
PAR.3	How recognisable do you evaluate the architectural elements?
PAR.4	How comfortable is this scenario?
Reported Presence	
RP.1	How much did the virtual space look like the reality for you?
RP.2	When you think back about your experience, do you think of the architectural elements more as images that you saw, or more as somewhere that you visited?
RP.3	During the time of the experience, did you often think to yourself that you were actually in front of an architectural element?
RP.4	How are you captivated by the virtual representation of these architectural elements?
Emotional attributes rating	
	Nervous
	Relaxed
	Unrestrained
	Restrained
	Noisy
	Quiet
Overall satisfaction rating	
OSR.1	Which is your overall satisfaction level in this scenario?

Figure 4. Overview of questionnaire items used in the study.

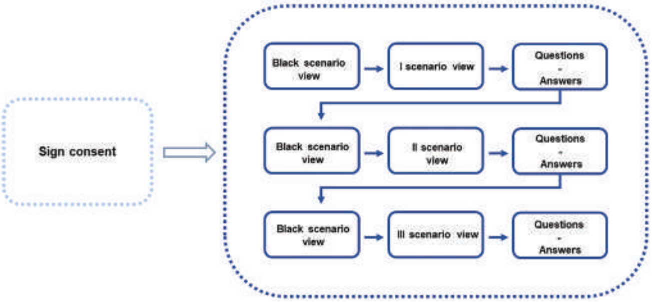


Figure 5. Block diagram of the procedure followed to administer the questionnaires.

Distance from the portal	Percentage of images overlapping (horizontal/vertical)	N° of taken photos	Number of points	Name of Virtual scenario in UE4	GSD (mm/pixel)
1.5 m.	70 / 80 %	206	27,000,000	Scenario #1	0.1
3.0 m.	70 / 80 %	73	412,000	Scenario #2	0.2
6.0 m.	70 / 80 %	24	121,000	Scenario #3	0.4
12.0 m.	70 / 80 %	20	37,000	Scenario #4	0.8

Table 1. Characteristics and results of the photogrammetric survey.

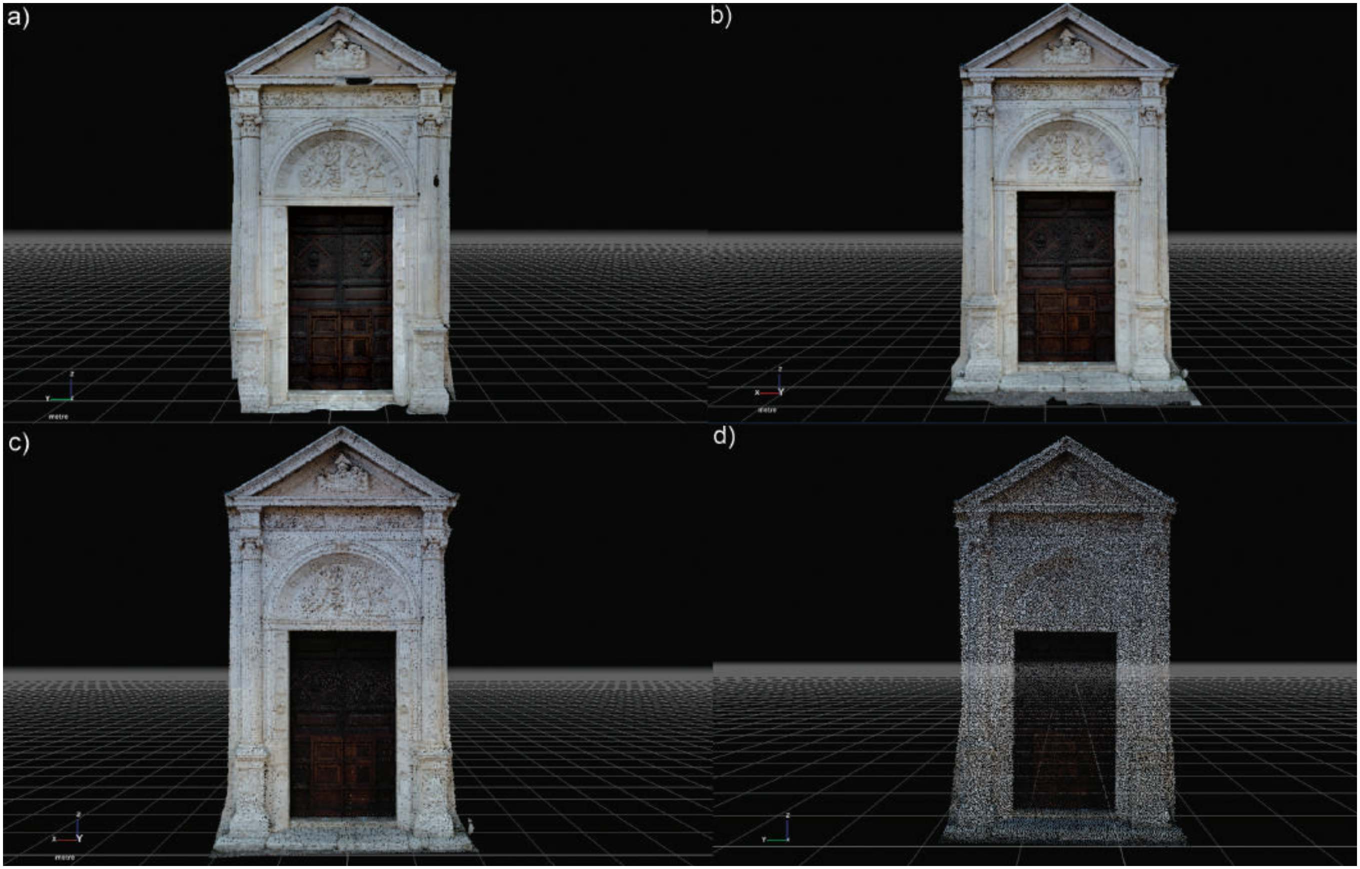
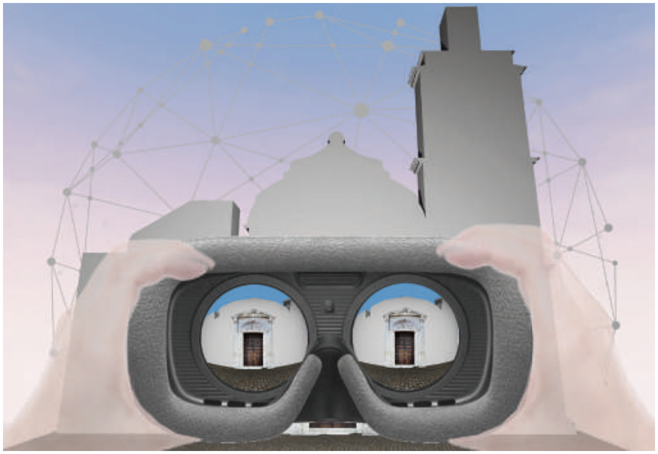


Figure 6. Virtual model of the Church's portal based on the four dense point clouds.



in the "Sens i-Lab" of the Department of Architecture and Industrial Design at the University "Luigi Vanvitelli"(Https://Www.Architettura.Unicampania.It/Images/Ricerca/Laboratori/SENS-I_Lab_2021_ITA.Pdf, n.d.). Both noise levels and air temperature were monitored during subjective tests, to verify that subjects carried out the test in similar conditions.

Figure 7. Virtual model of the Church's portal based on the four dense point clouds.

Figure 8. Virtual model of the Church's portal based on the four dense point clouds.

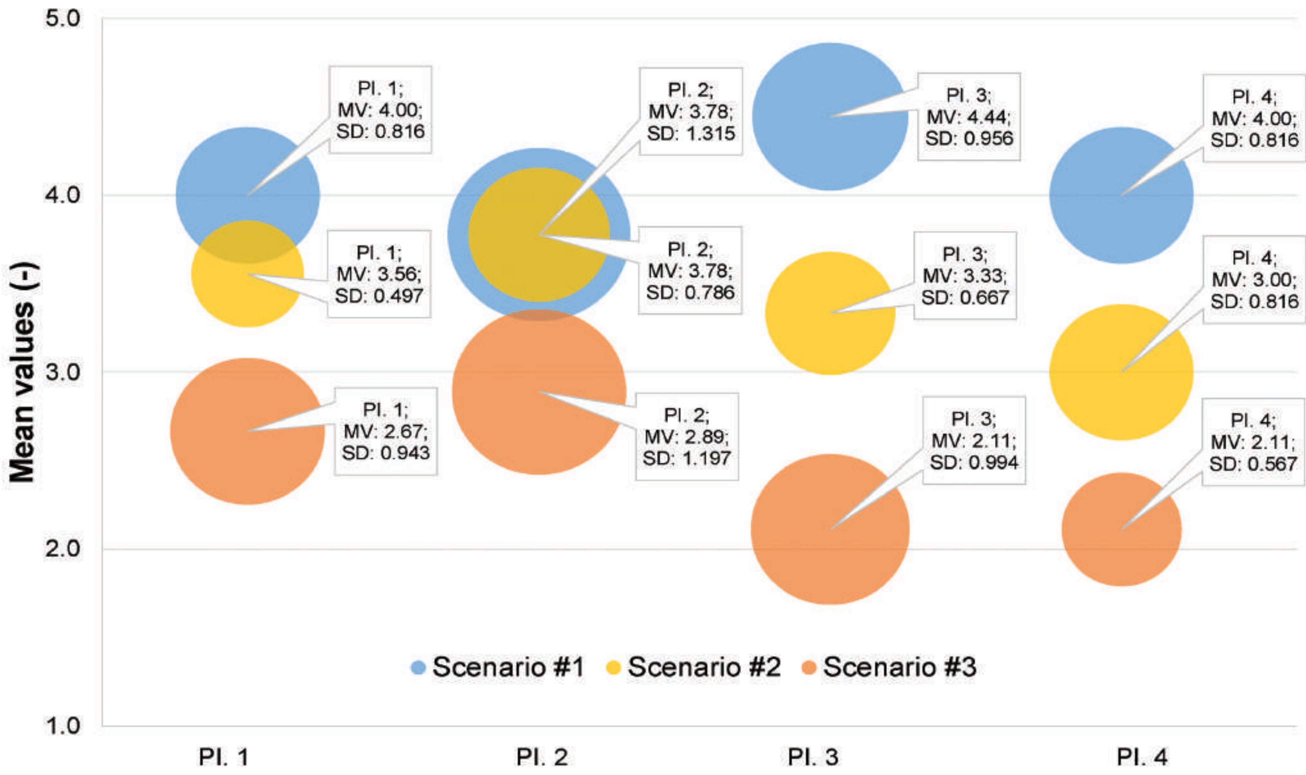


Figure 9. Questionnaires results upon varying the virtual scenario, for perceptual impressions (PI).

The volunteers were asked to sign the informed consent and the Covid- 19 informative on the adopted security measures.
Then, personal information, such as age, gender and potential visual problems, were asked.
In order to avoid that visual problems could influence the results of tests, participants were invited to use glasses during the subjective tests. S
ubjects took place at a desk at the center of the room and were helped to wear the HMD. For each scenario, the user was invited to visualize for at least a minute and then answer the questionnaire verbally while he continued to observe the scenario.

Passing from one scenario to another, a completely black scenario was shown to the users to avoid judging a scenario that was influenced by the memory of the previous one.
The procedure was repeated for the other scenarios.
The subjective answers were elaborated considering the mean value (MV), to understand the direction in which the barycenter of the distribution of the answers to each question moves for every scenario, and the standard deviation (SD), to know how far are the statistical units from the mean value.
The questionnaires administration procedure is reported in Figure 5.

3. Results and discussions

Photogrammetry surveys were used to obtain four dense point clouds with different attention to portal's details. Tab. 1 lists: (i) the distance from the portal to the Church, (ii) the percentage of overlapping of images (horizontal/vertical), (iii) the number of taken photos and (iv) numbers of points of each dense cloud, (v) name of virtual scenario in UE4 and (vi) the ground sample distance (GSD). The GSD is the distance between pixel centers measured on the façade and was obtained according to the formula proposed in (Pinto & Sona, 2010), considering the distance between the camera and object, camera focal length as well as pixel size. Figure 6 shows the four dense clouds points obtained as the photo elaboration software 3DF Zephyr output. As it can be inferred from the image, as the distance of image acquisition decreases, the number of points of dense cloud increases and, with it, the quality and perceptible details of the artefact. From Figure 7, it is possible to see the virtual scenario created in UE4, in which contours of the Church, the paving and the portal areà distinguishable. Figure 8 ad shows the virtual scenarios in UE4 realized using the four dense point clouds, obtained from the elaboration of photos taken at 1.5 m, 3.0 m, 6.0 m and 12.0 m from the manufact, respectively.

Results of preliminary tests have highlighted a low detected quality of Scenario #4 (Figure 8d), which was, for this reason, excluded from the subsequent phases of the research.

Moreover, limitations in the capacity of the hardware in the immediate rendering of dense point clouds have come out, in particular for Scenarios #1 and #2. To overcome these limitations, the subjects were asked to move their head slowly during the vision of the scenarios. Scenarios #1, #2 and #3 were presented to nine volunteers (2 women and 7 men) aged between 26 and 36 (average age 31.6).

Figure 9 reports the questionnaire results as the virtual scenario changes for the perceptual impressions (PI), Figure 10 those ones relative to the capacity of the

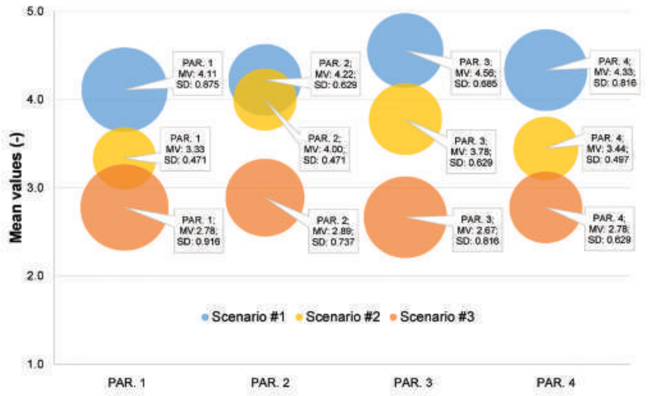


Figure 10. Questionnaires results upon varying the virtual scenario for presentation-ability rating (PAR).

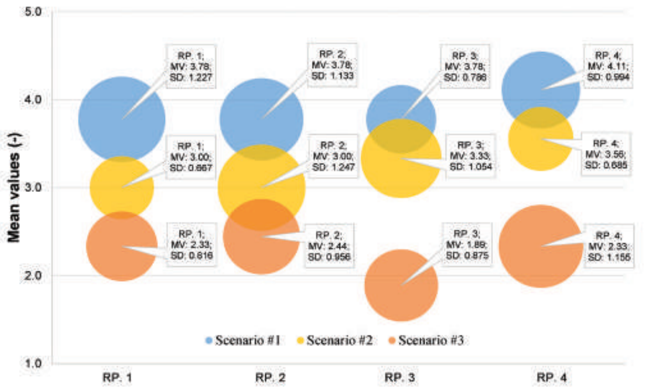


Figure 11. Questionnaires results upon varying the virtual scenario for reported presence (RP).

virtual model of presentation ability rating (PAR) and Figure 11 those ones relative to the reported presence (RP). In these diagrams, the center of each bubble indicates the mean value (MV), while the diameter indicates the standard deviation (SD); small diameters correspond to low values of standard deviation. For each bubble, the "data callout" reports the acronyms of the question as well as the values of MV and SD. These figures highlight that whatever the question is, Scenario #1 and Scenario #3 are those able to collect higher and lower MVs, respectively.

On the contrary, it is not possible to identify a univocal trend for MVs relative to Scenario #2. In particular, for question PI.2, the MV for Scenario #2 (MV=3.78) is equal to that one of Scenario #1 (MV=3.78), while for the question PAR.1, the result of Scenario #2 (MV=3.33) is that one closer to Scenario #3 (MV=2.78). For the remaining questions, the MVs obtained with Scenario #2 are between those ones obtained for Scenarios #1 and #3, even if in most cases, they are closer to results obtained with Scenario #1. Figure 12 shows the results linked to the dependent variable relative to emotional attributes rating (EAR), as the virtual scenario changes. This figure underlines as the best MVs are always linked to Scenario #1, while the worst are always linked to Scenario #3. The last examined parameter was the overall satisfaction rating (OSR), for which Scenario #1 confirms as the best (MV=4.22; SD=0.629), Scenario #3 is the worst (MV=2.44; SD=0.956), while Scenario #2 has intermediate values (MV=3.44; SD=0.497).

4. Conclusions

The research aimed to assess the visual perception of the virtual model of an architectural element in VR, starting from dense point clouds obtained through photogrammetry with lowcost systems, as the distance of image acquisition changes.

The three virtual scenarios obtained were compared through the administration of questionnaires at subjects who offer voluntarily for tests. Through the questionnaire, different dependent variables were examined: perceptual impressions (PI), presentationability rating (PAR), reported presence (RP), emotional attributes rating (EAR) and overall satisfaction rating (OSR). The results underline that smaller is the distance of image acquisition and better is the acceptance of the relative virtual model for users. However, the increase in the number of the dense cloud's points implicates visualization criticism of the cloud in VR. The research highlights how Scenario #2 can be considered as the optimal solution to ensure good visual quality and, at the same time to limit visualization problems of the point cloud in VR. Therefore, the research suggests it is not possible to provide a univocal indication of the optimal distance to be used during a photogrammetric survey designed to obtain dense point clouds to import in VR to create virtual models of external architectonical elements. In fact, the photogrammetric survey at a distance of 3.0 m may be considered the most effective one to identify and distinguish the principal elements of architecture. In comparison, the survey at a distance of 1.5 m allows high the visual accuracy in reproducing of details of architectural particulars.

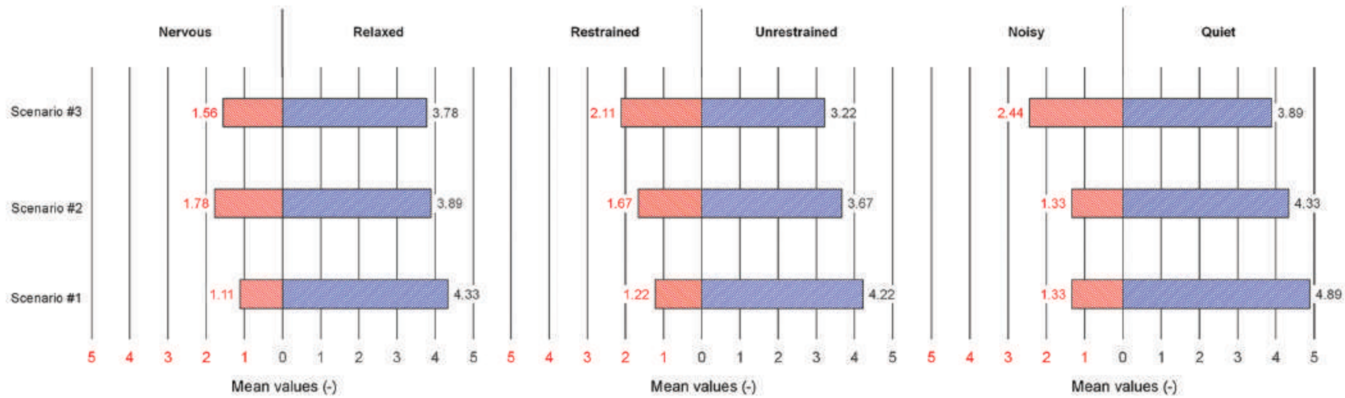


Figure 12. Results linked to emotional attributes rating (EAR), as the virtual scenario changes.

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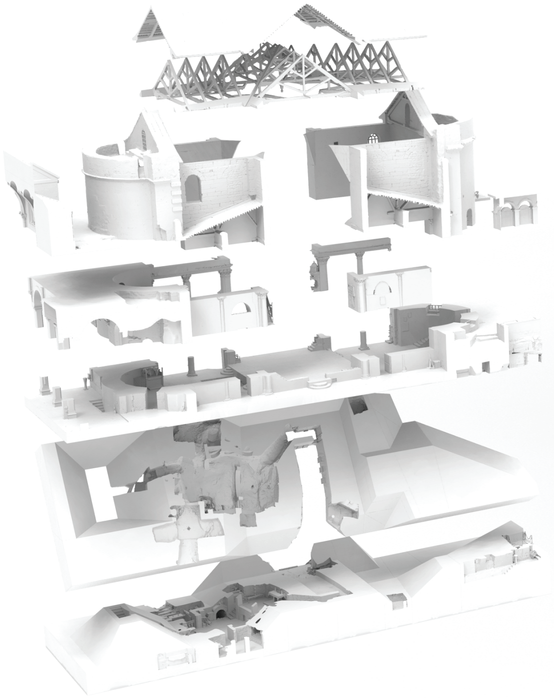 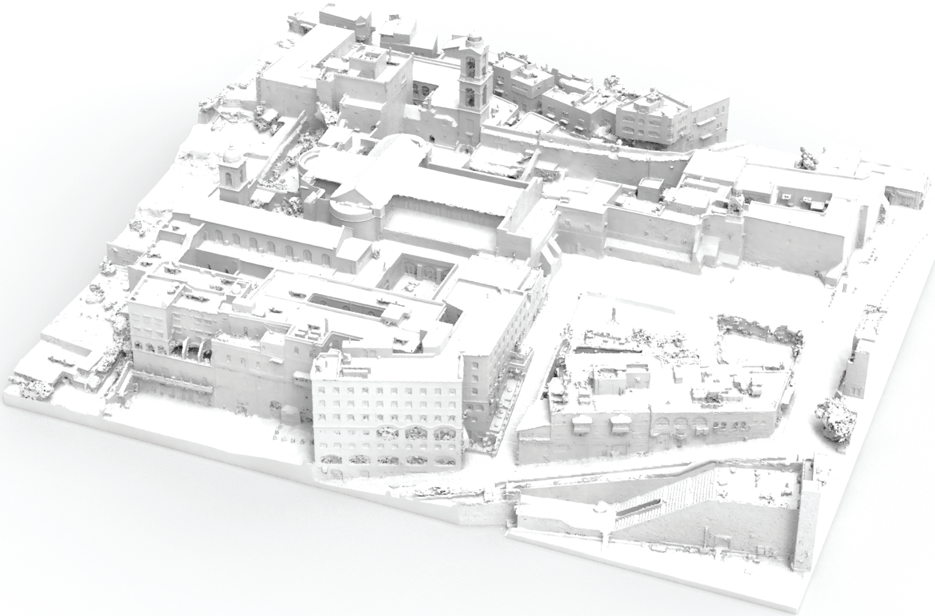

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Keywords:
3D Printing, UAV Survey, Scan to Mesh, Cultural Heritage.

ABSTRACT

The physical model replicated is certainly one of the most effective and accessible representation tools for the morphological and cognitive reading of architecture and Cultural Heritage. The miniature model allows the user to read and experience visually the composition and complexity of the built heritage. Moreover, 3D-printed models make it possible to tactile read heritage, thus enhancing their accessibility for those with reduced eyesight (blind or visually impaired). Using a small drone is essential for surveying of the urban center and for integrating data of areas not easily reachable to perform terrestrial laser scanning.

UAV survey for 3D printing digital modeling for the representation and enhancement of Nativity Church on the urban and architectural scales

1. Introduction

The development of digital technologies has seen, in recent years, an exponential growth in the number of products related to the field of representation, including new tools and updated methodologies aimed at understanding and transmitting historical-cultural values relating to the archaeological and architectural heritage. This instrumental and methodological evolution is also the result of the wide dissemination and adoption of innovative techniques applied to the survey; in particular, 3D scanning, carried out by means of highly metrically and geometrically precise instruments, is used to achieve three-dimensional representations of complex morphologies that are difficult to obtain with traditional 2D or 3D acquisition and restitution methods. or drone photogrammetry for the survey and documentation of the rather large area such as the land, urban center, road systems, aqueducts, etc; dangerous or difficult to access spaces, where scanning from the sky is the most suitable solution. Innovation in the documentation of Cultural Heritage with 3D scanning tools finds its greatest communicative expression when it is associated with the solid prototyping of the scanned objects. Three-dimensional printing offers the possibility of producing faithful copies of elements by mathematically processing the 3D model obtained from scanning and physically duplicating them in a relatively short time and often without excessive costs. The recent market proliferation of desktop 3D printers, with their small size and low cost, has quickly made them affordable objects for everyone to use. Developments related to the world of prototyping everyday objects and the fast growth of 3D printers for 'commercial' purposes has also made it possible to create a community of 'makers', thereby propelling 3D-printed designs into the world of drawing and representation(Balletti et al, 2017). However, in the context of the application of 3D printing to Cultural Heritage, the need to ensure reliability and conformity in terms of the physical characteristics of the printed object should be taken into account. The scaled reproduction of a decorative artifact, a portion of a historical building or a monument requires a degree of sensitivity and experience with regard to the acquisition and management of morphometric data, as their representation will depend on the level of accuracy that the three-dimensional printing wants to achieve. Thus, the preparation of the 3D model, the choice of the printing material and the scale to which the object will be printed are complex operations that require a long time and numerous tests and evaluations, especially since these are relatively new topics, lacking a real reference literature. In the field of architectural and archaeological heritage, 3D printing finds its most specific application within museums and museum collections. The reproduction of entire artifacts, or the reconstruction of portions of them, guides the user into the knowledge of that object and therefore of the collection to which it belongs. These

3D-printed reproductions thus become those objects, now missing, beneficial to the understanding of the exhibition itinerary, usable at a tactile level, diversified in appearance with respect to the original goods they contain, and capable of catalyzing the visitor's attention, making the tour more stimulating(Scopigno, et al, 2015).

2. Case Study

The Church of the Nativity, located in the city of Bethlehem, is known as the birthplace of Jesus, a sacred place with more than 2000 years of history in the background, frequented by tourists, visitors and pilgrims of different religions, consecrating its importance also from an economic point of view, as a result of which the entire city benefits from and is built around it.

The church has recently been renovated to consolidate the structure and restore or rather uncover some precious mosaics hidden in its interior.

The objective of this research[1] is to digitally reconstruct and then physically reproduce two reliable models: the historic center at an urban scale and the Church of the Nativity at an architectural scale, including the interior and the caves below. The proposed operation involves the management and processing of a database consisting

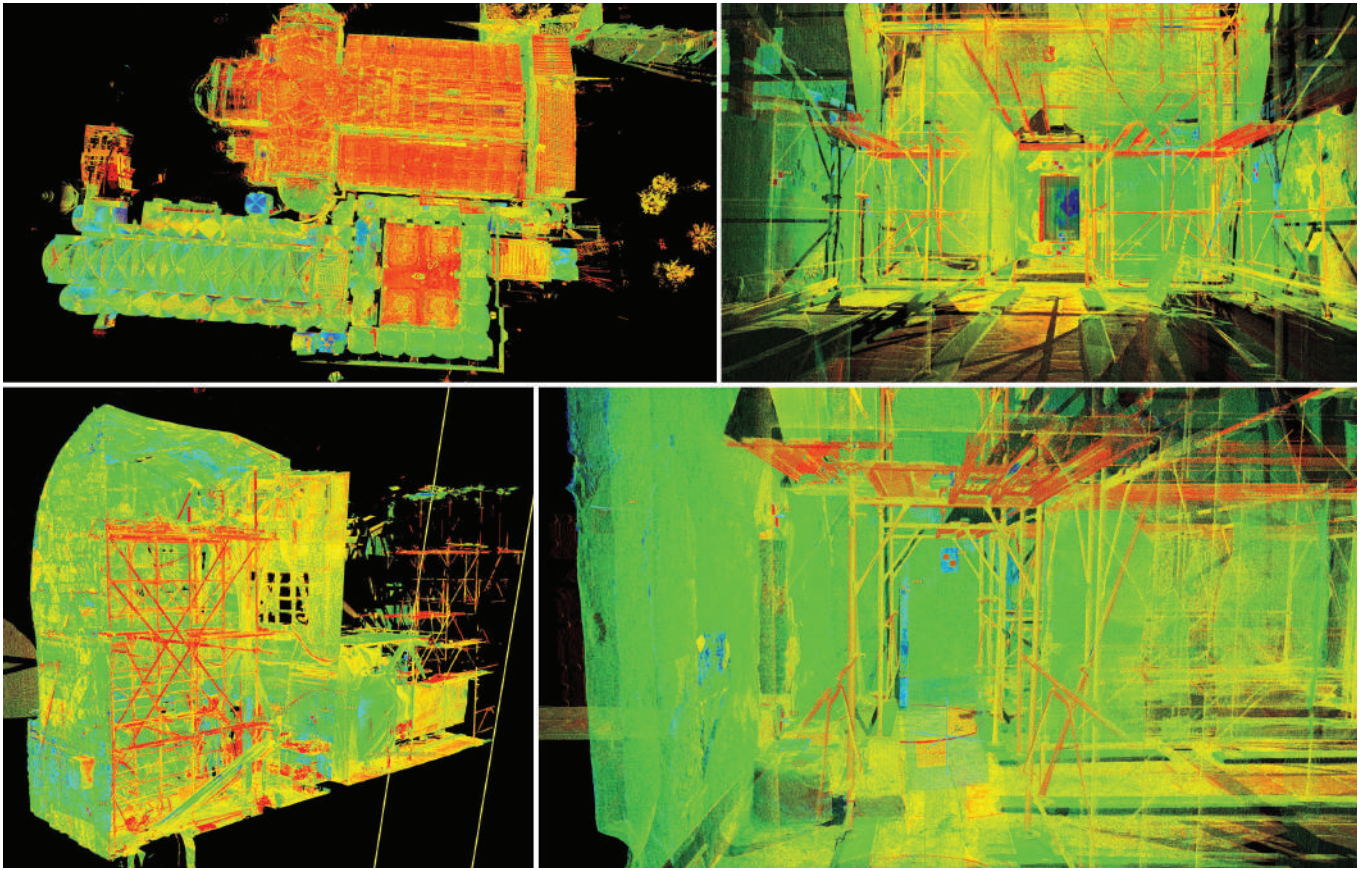

Figure 1. TLS Point Cloud database; interior space of nativity church with scaffolding and noises to be cleaned.

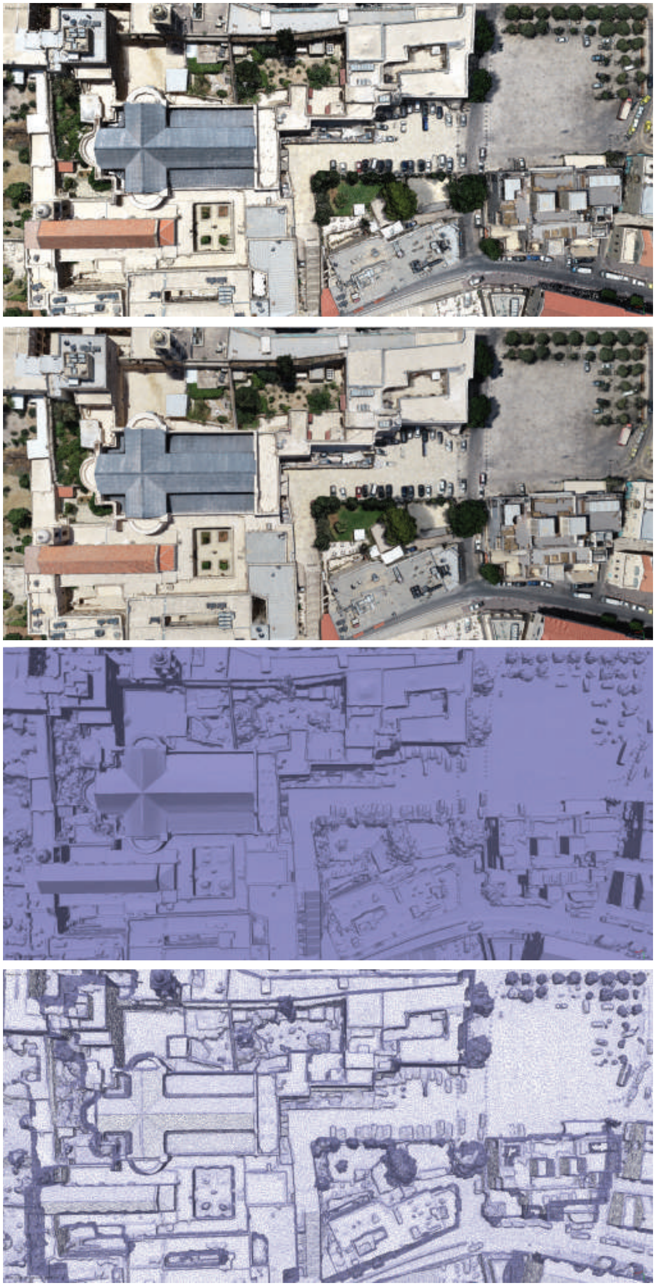

Figure 2. Metashape views, from up to down: Dense cloud; Textured Mesh; Mesh model; Wireframe view.

of multiple integrated digital surveys conducted during several missions, from 2018 to the most recent one in April 2022; different types of instruments were used for this purpose, including: terrestrial laser scanner (TLS) - Faro Cam2; LiDAR mobile laser scanner (SLAM) - BLK2GO; and Unmanned Aerial Vehicle (UAV) for photogrammetric applications - DJI Phantom 4 Pro.

In particular, a small drone proved to be essential in surveying the city center and integrating data from areas not easily accessible for terrestrial laser scanning, such as rooftops.

The objective of the drone survey campaigns was to obtain a point cloud with the maximum data quality and density, from which to generate a 3D model of the old town center, the area around the Church of the Nativity serving as the main database to produce the urban scale model and as a data integration for the roofs, where it is not possible to carry out a survey with the terrestrial laser scanner.

For various safety problems it was not possible to get too close with the drone to the church, the photos, even if they are in high resolution, were taken from afar, consequently the level of detail of the model is not at the maximum. The quality obtained for the urban scale model is more than good, while it is a bit poor for the 1:50 scale model.

The post-production phase is divided into two further applications. The first one aims at the production of the model of the historic center (scale 1:700) and concerns only the data acquired by the drone. The result is a mesh model optimized for 3D printing of the church and its urban context. The second is aimed at producing the model of the Church of the Nativity on an architectural scale (1:50). In this case, the data acquired from the drone mainly contributes to the integration of the missing parts from the laser survey. Here, the quality of the UAV data is slightly lower, but it is still crucial to complete the model.

In the first application of the post-production, the 3D model is processed with the Agisoft Metashape software, presenting numerous defects and holes to be corrected.

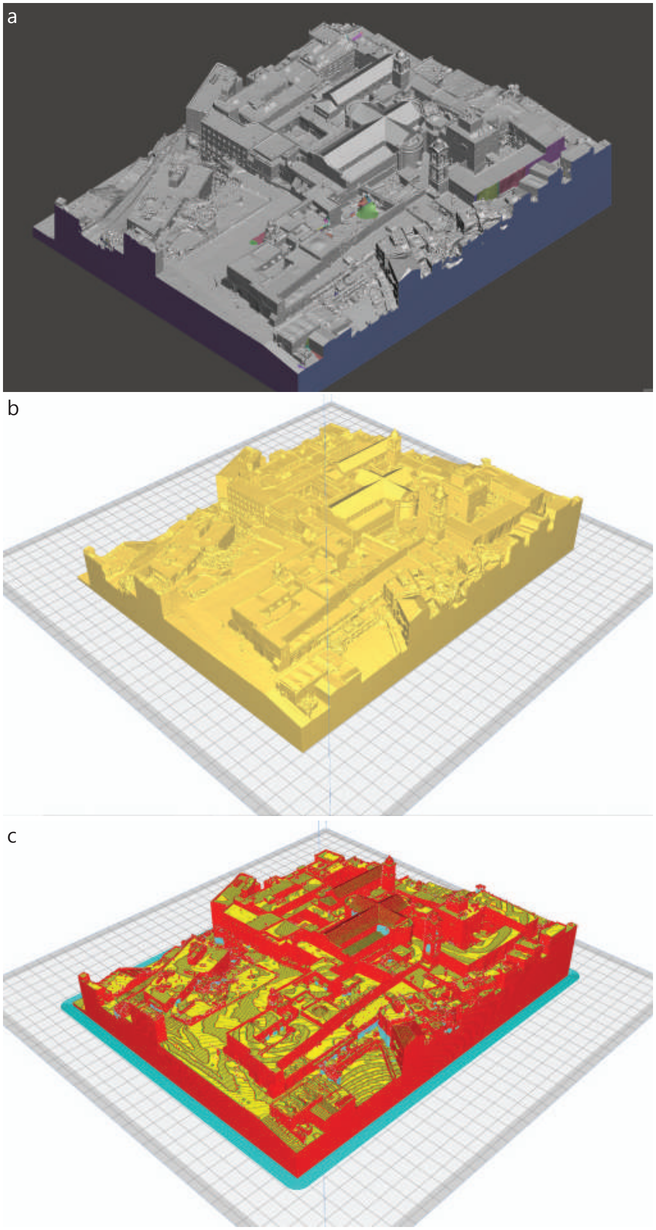

Figure 3. a. Mesh model after post production processes on meshmixer. b. Mesh model imported in Cura slicer to prepare Pringting G-code. c. Preview of printed Mesh model.

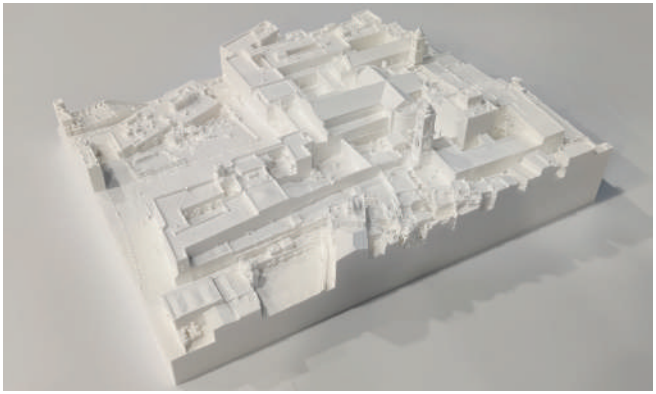

Figure 4. Printed Urban Scale model (1:700), Material: PLA.

The photogrammetric output is then imported into the Autodesk Meshmixer software to perform a series of optimisation and accommodation steps on the model before finally printing it (Figure 3,4).

In the second application, i.e., the architectural model of the Church of the Nativity, the exterior and interior spaces of the church were accurately acquired with the Terrestrial Laser Scanner and the LiDAR mobile laser, producing a database of 465GB. It would be unrealistic to manage a database with such a large size at the same time, hence the whole site was divided into different portions: the underground cave, the roof, and the central body, which itself was divided into 6 strips each consisting of 4 blocks(Figure 5). The starting data, i.e., the point cloud, are registered and exported using the Leica Cyclone software, and grouped according to the portions defined in the previous step. A scan-to-mesh post-production process is then initiated, consisting of a set of semi-automatic steps employing several pieces of software (3Dreshaper; MeshLab; MeshMixer), in order to transform the point clouds into a mesh model that can actually be used for 3D printing. The main sequential steps are:

- Point cloud cleaning;
- Generation of the raw mesh model;
- Integration of missing parts from other sources;
- Optimisation of the mesh model and defect removal.

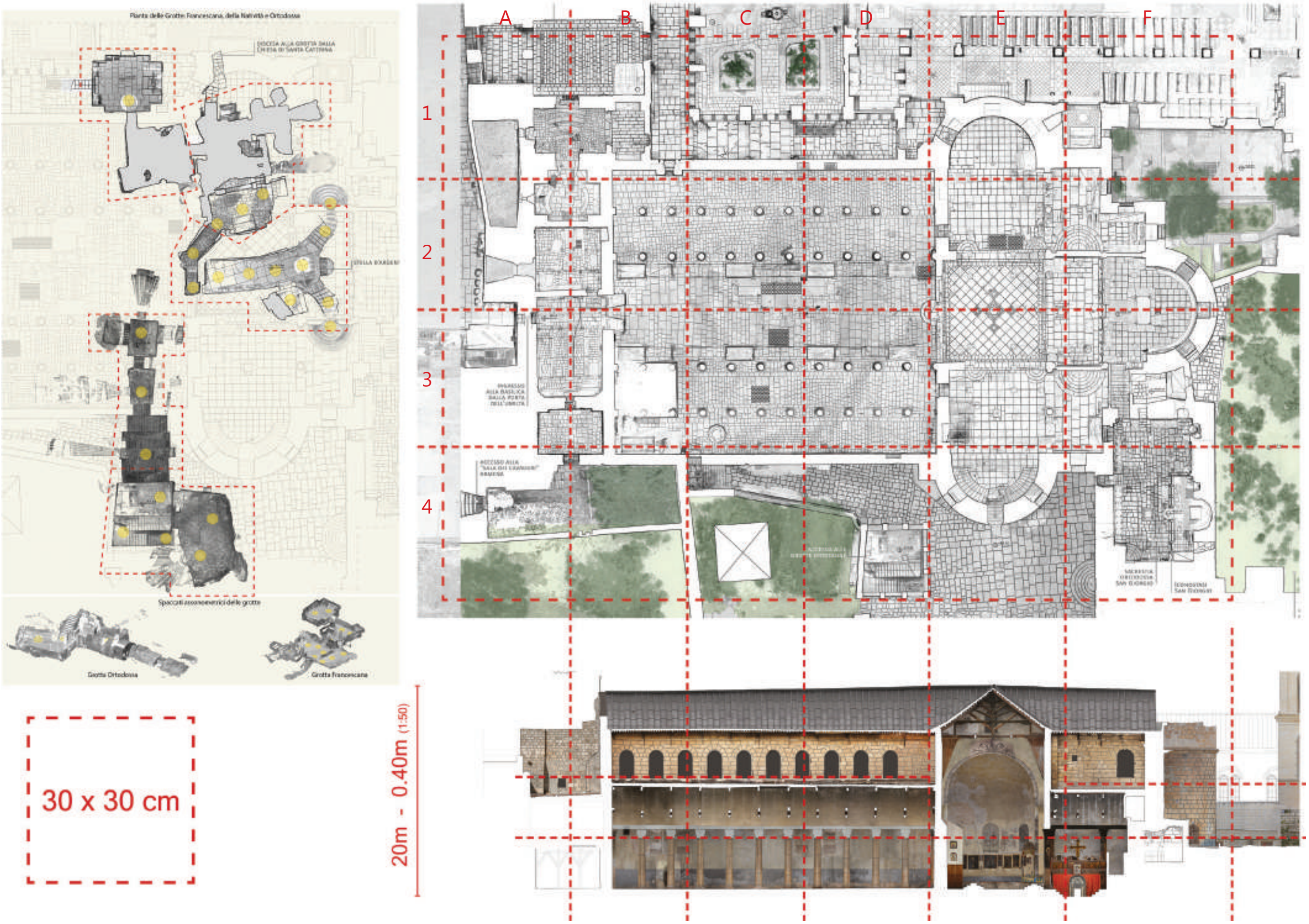

Figure 5. Database division and coding. (Plan and section by Pietro Becherini)

In particular, the point cloud cleaning phase took much longer than expected due to the presence of scaffolding and decking inside the church during the survey, which also caused noise and imperfections in the raw mesh model, resulting in an even longer time for the mesh model optimization and defect removal phase.

Integration refers to the replacement of modified parts or surfaces between the different moments of the survey, such as the excavation to uncover the mosaic, the restoration of the vault, the removal of scaffolding, etc. In particular, for the integration of the roof, photogrammetric images acquired by drone were used to produce a mesh model of the roof, which was then aligned with the main model and divided into portions to complete the individual model parts.

the drone data has a much lower level of detail than the data acquired by the laser scanner, to make the most of the data, the dense cloud calculated with

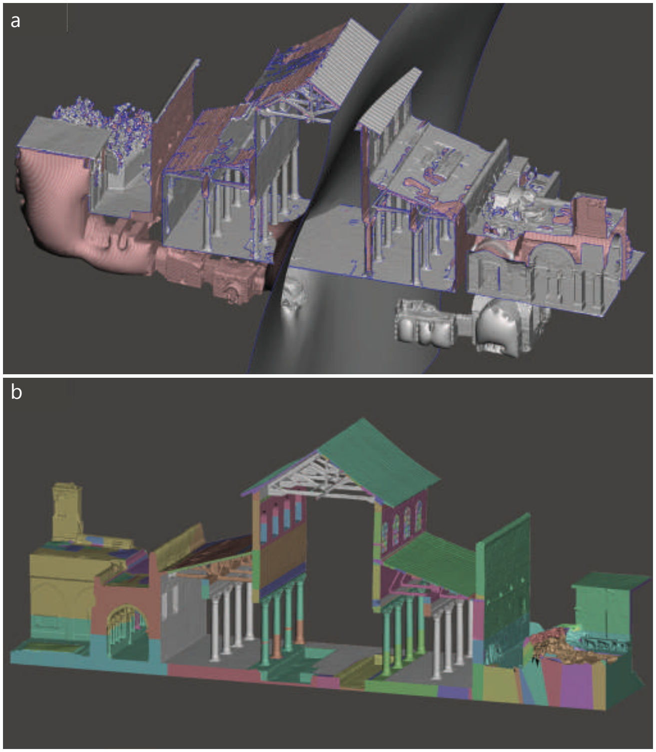

Figure 6. a. Raw architectural scale Mesh imported into software Meshmixer.
b. Architectural scale Mesh Model after post production processes.

maximum performance by the metashape software was exported and transformed into a mesh model using the meshlab software. the quality of the mesh obtained by meshlab is slightly higher than that calculated directly by metashape, precisely because the process of approximating the points of the dense cloud is not carried out, which cannot be controlled within the metashape software.

At the end, several solid Mesh models were created, with a good overlap between one piece and another, to be subsequently trimmed with a clean cut in order to create the perfect joint, with a neglectable micro error (+/- 0, 1 mm) (Figure 6).

Once the models are finished, they are divided into portions to generate the print file in G-code format (Figure 7). The model will be printed at a scale of 1:50, so it is advisable to check from the very beginning that the maximum measurements of the individual portions do not exceed the maximum measurements supported by the 3D printer, of 35x35 cm.

Furthermore, having to divide the model into many small portions also makes it possible to use several printers at the same time, reducing the total printing time and at the same time the risk of errors and therefore having to reprint the entire model or a part of it from scratch.

Digital reconstruction combined with 3D printing in the field of Cultural Heritage offers museums and researchers in general the dual advantage of carrying out a non-invasive analysis of the built environment (based on laser and photogrammetric technologies) and of benefiting from reliable, easy-to-handle and reproducible copies. In particular, the possibility of obtaining a physical restitution makes it possible to deepen knowledge of the existing building or to make inaccessible spaces tangible. Working with these technologies, it is possible to model and produce copies of the originals at different metric scales, maintaining the correct proportions and textures of the physical component.

In the case of a monument or an extended urban area, the model printed at a smaller scale than the real one allows for a global view, facilitating the understanding of the space, its accesses, elevations and centralities. This flexibility makes 3D printing products adaptable for different educational purposes, attractive, interactive, and inclusive forms of museumization. By working to the right scale, it is also possible to produce printed objects that allow the visually impaired to approach heritage through tactile fruition.

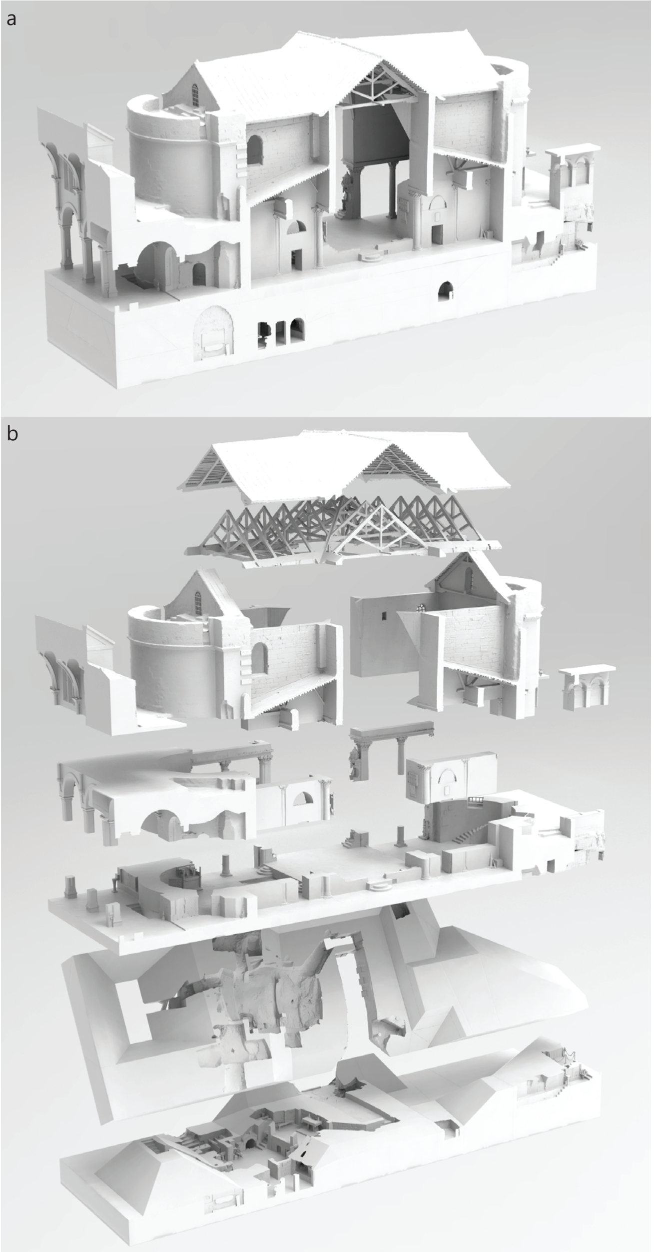

Figure 7. a. View of strip E, finished printable model. b. View of strip E, finnished printable model broken down into blocks.

3. Conclusions

Despite all the potential aspects related to the use of UAVs for data acquisition for 3D printing purposes, it still has some limitations related to data acquisition. Among these the constraint for the distance between the UAV and the detected object; the lignt variation during the day; the limited battery autonomy. To these are added the limits of 3D printing such as the limited size of the printing plate (however variable depending on the model of printer used), long prototyping and finishing times and, sometimes, also the difficulty in simulating the rough surface of particularly porous objects. However, these limits are believed to be overcome in a short time, given the growth of the sector and the continuous advancement of technology, which uses UAVs, materials and increasingly performing printers. The road to a plausible three-dimensional tactile representation is still under development, but it is certainly laying the foundations for a new way of using the digital product, more and more reliable, playful and inclusive.

Notes

1 The documentation activities of nativity church of Bethlehem are carried out from May 2014 to May 2015, thanks to an agreement between DICAr-University of Pavia, DIDA-University of Florence and Piacenti S.p.a. Scientific managers of this project: Prof. Stefano Bertocci (University of Florence); Prof. Sandro Parrinello (University of Pavia).

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ABSTRACT

The need to achieve a complete three-dimensional database has seen an increasing use of UAV systems in architectural surveying. In particular, special types of drones -mini-UAVs- are increasingly being used for surveys within historical centres or in critical areas. Through the case study of the documentation of Donatello's Pulpit at Cathedral of Santo Stefano in Prato, the paper aims to evalu-ate the acquisition's reliability by mini-UAV of an architectural element characterized by a high level of detail. The evaluation is carried out comparing the results obtained by drone with those obtained by proven techniques of terrestrial laser scanner and photogrammetric survey.

Testing the reliability of mini-UAVs acquisition campaign on detailed bas-reliefs. The case study of sculpturing elements of Donatello's Pulpit

1. Introduction

One of the main objectives behind an integrated three-dimensional survey is the reliability of the results obtained from the management and processing of the collected data. For this reason, surveyors tend to use digital surveying tools of well-established reliability and geometric-morphological accuracy - TLS[1] - which, however, alone do not provide all the data needed to describe the surveyed object (Carnevali et al. 2018). This problem has led to the increasing use of UAVs[2] in architectural surveying for Cultural Heritage conservation. In particular, among the different remotely piloted instruments used in surveying campaigns, mini - UAVs, characterized by ease of manoeuvrability, low weight and low cost, have enjoyed considerable success in recent years; these characteristics allow mini - UAVs to be used in contexts that are often prohibitive for other drones and within historic centres (Parrinello, Picchio 2019). The versatility that characterizes these tools, however, must reckon with the reliability of the database derived from them, particularly with regard to architectural objects characterized by considerable formal and decorative complexity.

This contribution aims to verify the reliability of 3D databases from mini-UAVs - DJI Mavic Mini - comparing them with those from survey tools considered reliable - TLS and digital cameras-. The point clouds and mesh models on which the comparison is made concern the case study of Donatello's Pulpit of Santo Stefano's Cathedral in Prato.

2. Case study: Donatello's Pulpit

Donatello's Pulpit is a particular architectural element located at the intersection of the West and South elevations of Prato Cathedral at a height of approximately 3 metres above the ground; for this reason, it is the ideal case study to test the validity of using mini-UAVs as an integration to a survey carried out with TLS instruments (Figure 1). Using drones, it is indeed possible to perceive

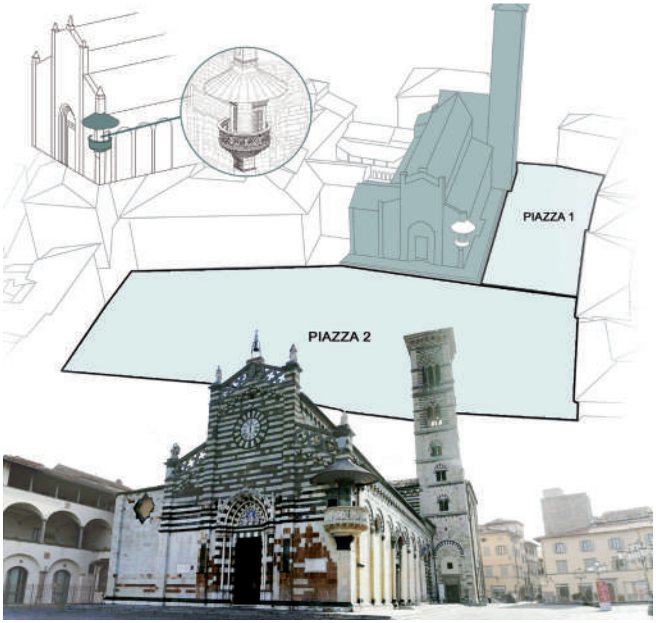

Figure 1. Contextualization of Donatello's Pulpit and Cathedral of Santo Stefano within the urban context of Piazza Duomo in Prato.

the morphological and material complexity of the surveyed object in its entirety (Galasso, La Placa 2020).
Donatello's Pulpit (1428 - 1434) is a sculptural masterpiece composed of several elements, each richly decorated. Shelves with volutes and concentric finials, decorated in classical style and with mouldings, support a circular balustrade; this is divided into seven panels alternating with paired pilasters depicting a dance of angels (Guasti 1887)[3]. The balustrade is covered by an umbrella canopy, placed at a height of about 6 metres from the ground. The pulpit visible today on the facade is actually a copy of the original, preserved in the Museo dell'Opera del Duomo (Figure 2).
The presence of a rich decorative apparatus that characterises the morphology of the pulpit made it necessary to use photogrammetry techniques to supplement the data obtained from the terrestrial laser scanner in order to study and accurately survey the entire sculptural apparatus. The acquisition of the metric and photogrammetric data for the creation of a three-dimensional database is carried out during a survey campaign in the first week of August 2021. In addition to the laser and photogrammetric instruments on the ground, the documentation activities involve

Figure 2. Donatello's Pulpit and detail of balustrade's decorative apparatus.

the use of two different types of drones, all from the company DJI. (Figure 3) In particular, the use of a mini-UAV allows the detailed photogrammetric acquisition of the object, while the UAV instrumentation provides a general restitution of the entire complex's exterior of Prato Cathedral and the Piazza del Duomo, allowing the pulpit to be placed in the historical and architectural context of the public space in front of it.
The use of drones in the survey stems from the need to integrate not only the decorative apparatus of the pulpit, but also the canopy and church roofs respectively, in order to obtain a single integrated three-dimensional database.

3. Documentation and post-production of the decorative system

3.1 Range-based and image-based acquisition methodology

The detailed acquisition phase of the decorative devices of the external pulpit involves the use of the DJI Mavic Mini[4] drone which, thanks to its light weight and small size, allows the operator to safely approach the object and obtain high-resolution images. The planning of the acquisition phase sees the use of an 's'-shaped flight plan, dividing the balustrade and the decorative rings below into three horizontal bands with a certain margin of overlap between them (Figure 4). This scheme allows the complex decorative apparatus to be acquired from all perspectives, trying to obtain as complete an image database as possible. At each position, a single image is acquired while keeping the inclination of the camera axis perpendicular to the element. Within the same horizontal acquisition band, a certain percentage of overlap between contiguous images is considered, in accordance with the general principles of photogrammetry (Aicardi et al. 2016).
Photogrammetric acquisition also involves the use of a telescopic rod, the 3D - EYE. This, given the possibility of extension up to 9 metres, makes it possible to obtain

Figure 3. The Different types of instruments used by the Dada-Lab Research Laboratory during the acquisition campaign. From left: FARO CAM2 S150 terrestrial laser scanner, 3D-EYE, DJI Mavic 2 and Mavic Mini.

close-up images of the decorative elements (but without the possibility of reaching the highest parts or the umbrella roof). The acquisition phase with this tool again involves the use of an 's' pattern, dividing the decorative complex into 3 horizontal bands (Figure 5). In addition, for each position, the camera takes 4 types of photos: the first keeping the axis of the camera perpendicular to the element, while for the others the entire pole is rotated to the right and then to the left and finally the camera is tilted downwards.

A more general photogrammetric acquisition of the pulpit and roof portions of the cathedral is carried out using the DJI Mavic 2[5] drone. The spiral flight plan allows the acquisition of all necessary data that cannot be detected with laser scanners (Figure 6).

On the other hand, the range-based acquisition is carried out with a terrestrial laser scanner[6]. In particular, nine colour and high-density scans are carried out for the pulpit alone.

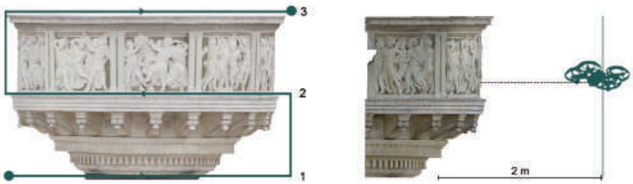

Figure 4. Acquisition scheme of the balustrade with DJI Mavic Mini.

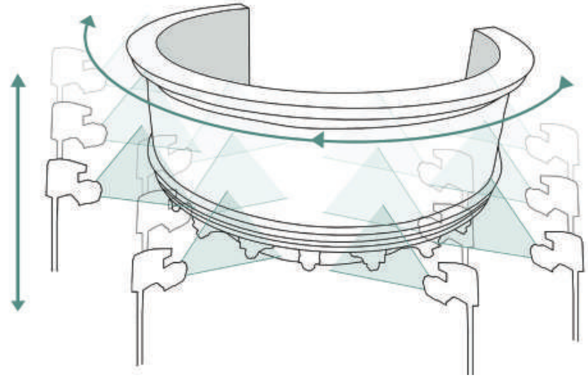

Figure 5. Acquisition scheme of the balustrade with 3D-EYE.

3.2 Processing of photogrammetric data

The data management and processing operations, with the aim of obtaining textured three-dimensional models of Donatello's pulpit, are conducted using Agisoft Metashape software for photogrammetric processes. The software is based on the sequence of several processes in succession. The first step consists in the alignment of the images, guaranteed by the overlapping margin between contiguous shots; then, a sparse point cloud is generated, which defines the volumetry of the surveyed object. From the sparse cloud is created a dense cloud on which the mesh and final texture are elaborated (Figures 7 and 8). For the

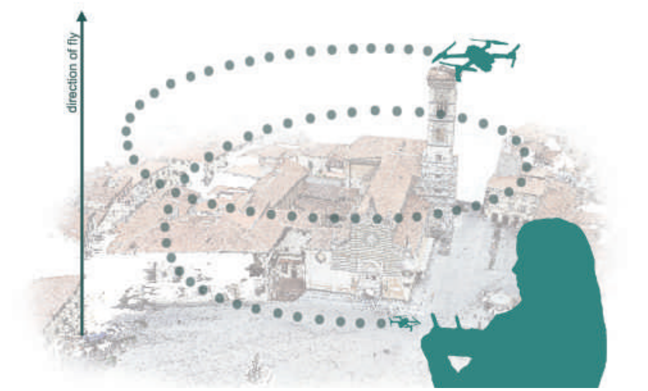

Figure 6. Spiral acquisition scheme of the Prato Cathedral complex and square with DJI Mavic 2.

present case study, 70 photographs from the DJI Mavic Mini, 360 photographs from 3D - EYE and 394 images from the DJI Mavic 2 are processed. In particular, the images coming from the DJI Mavic Mini are treated obtaining a model composed of 3,470,574 points and a mesh of 694,144 faces, those coming from 3D - EYE generated a model composed of 29,004,034 points and a mesh of 5,806,545 faces and finally those coming from the Mavic 2 141,432,585 points and 28,286,481 faces. All point clouds are aligned using morphological and architectural homologous points to those derived from the TLS point cloud. The model of the DJI Mavic Mini has an alignment error of 0.005 metres, that of the 3D - EYE of 0.002 metres and finally that of the Mavic 2 of 0.017 metres (Figure 9).

3.3 Comparison of models

Due to the decorative complexity that distinguishes Donatello's pulpit, it is decided to focus attention on the low-relief decorated surfaces of the balustrade and the decorative rings, making comparisons between the three-dimensional photogrammetric models obtained from the different instruments and those obtained by drone (Figure 10). In particular, the comparisons carried out are of different types: a first qualitative comparison within the Agisoft Metashape software, which allows us to understand the decorative reliability of the models generated by the data obtained from the mini-UAV; at the same time, a second comparison is carried out in the Geomagic Design X software, which permits to calculate the average standard deviation of the meshes. Finally, a metric comparison is carried out within the Leica Cyclone software, which allows to understand if the point clouds obtained from mini-UAV are metrically reliable compared to those obtained from the TLS.

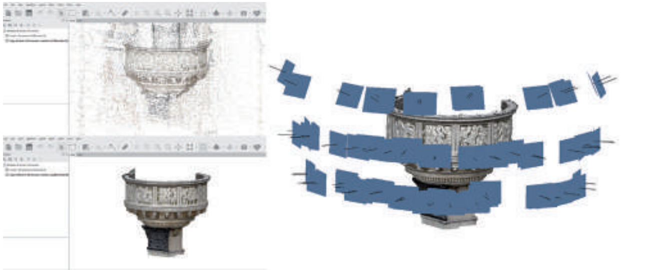

Figure 7. Point cloud processing through Agisoft Metashape software of the data acquired by Mavic Mini. On the left, the processing phase starting from the creation of sparse cloud to the dense cloud on which to build the mesh model. On the right, the acquisition positions of the images.

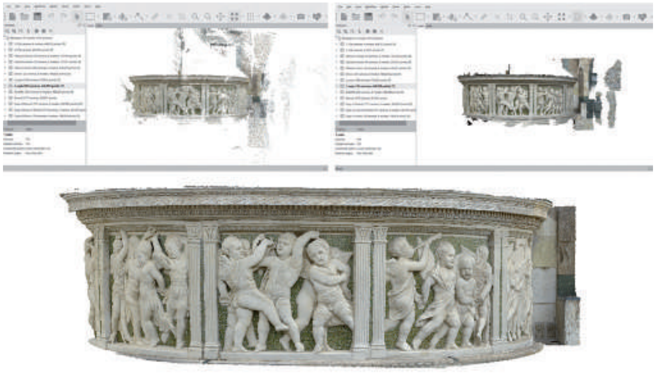

Figure 8. Point cloud processing through Agisoft Metashape software of the data acquired by 3D-EYE. Above, data processing from the sparse cloud to dense one; below, the final textured model.

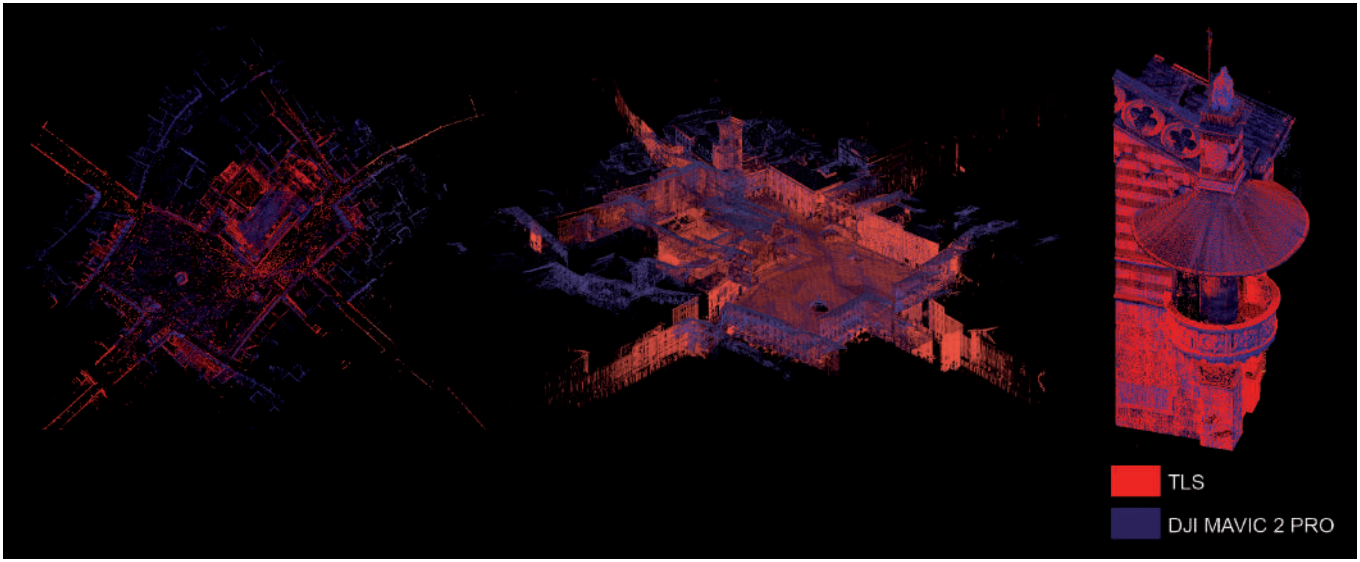

Figure 9. Overlay of point clouds generated from data acquired by FARO CAM2 S150 terrestrial laser scanner (red) and DJI Mavic 2 UAV (blue).

3.3.1 Visual comparison: 3D - EYE versus DJI Mavic Mini

A first visual and qualitative comparison is made by comparing the mesh model obtained from the photos taken by 3D - EYE and that obtained from the data acquired by the DJI Mavic Mini. The comparison permits considerations to be made on the level of detail of the mouldings detected. In particular, the decorative elements are clearer and more readable in their shapes in the model obtained from the 3D - EYE than that obtained from the mini drone. However, the floral decorations between the scrolling shelves of the mesh model obtained from 3D - EYE reveal some problems - e.g., lack of data - (Figure 11). The difference in accuracy is due to the fact that with the telescopic pole it is possible to observe the decorative details more closely; in fact, the drone acquisitions are taken from a more distant position, in order to avoid excessive proximity between the mini-UAV and the decorative apparatus of the pulpit. However, the chosen distance ensures that a good level of GSD[7] is maintained (Draeyer, Strecha 2014). Furthermore, the final image of the models depends on the number of polygons that compose the mesh: 5,806,545 faces of the 3D model - EYE versus 694,144 faces of the drone model. A high number of polygon faces corresponds to a greater possibility of obtaining models with a high degree of detail.

A second type of comparison is carried out within Geomagic Design X software. In this case, the two mesh models are aligned by points and then compared using the Mesh Deviation tool, which permits analysis of how far the surfaces deviate by setting different ranges of tolerance values.

The deviation study is done on visual information interpreted by a colorimetric scale where adhesion areas are in green, out-of-plane deformations in red and inward displacements in blue (Figure 12). The

analysis shows good congruence between the models in the capital portion, while areas of inaccuracy are concentrated within the concentric volutes and corbels, with a maximum error between 5 mm and 15 mm.

Figure 10. Composition obtained by merging three-dimensional databases coming from different instruments.

3.3.2 Metric comparison: TLS versus DJI Mavic Mini

In addition to the visual comparison, a metric one is made by comparing point clouds obtained from ground-based laser scanners and DJI Mavic Mini.
The analysis of the deviation between the two clouds is conducted with the Leica Cyclone 9 software.
In particular, the point cloud of the mini-UAV is aligned considering the one obtained from the TLS as a reference. Then a section plane is inserted into it; in the frontal view, it is possible to calculate the distance between the two clouds at different points and thus understand how reliable the cloud from the data obtained with UAV systems is. In general, the analysis shows a good congruence between point clouds; the verification allows us to assess the deviation by measuring the distance between them by defining two points and using the measuring instrument.
It is verified that the error tends to increase close to architectural elements characterised by more complex shapes, where the drone cloud discretizes the information more. The error also increases near the decorative rings of the pulpit, where a loss of geometry is visible. In addition, the cloud obtained by drone in these areas generates "swipes" of points, creating noise (Figure 13).
The inconsistency error interval is instead due to a previous error of cloud drone's reference to that coming from TLS.

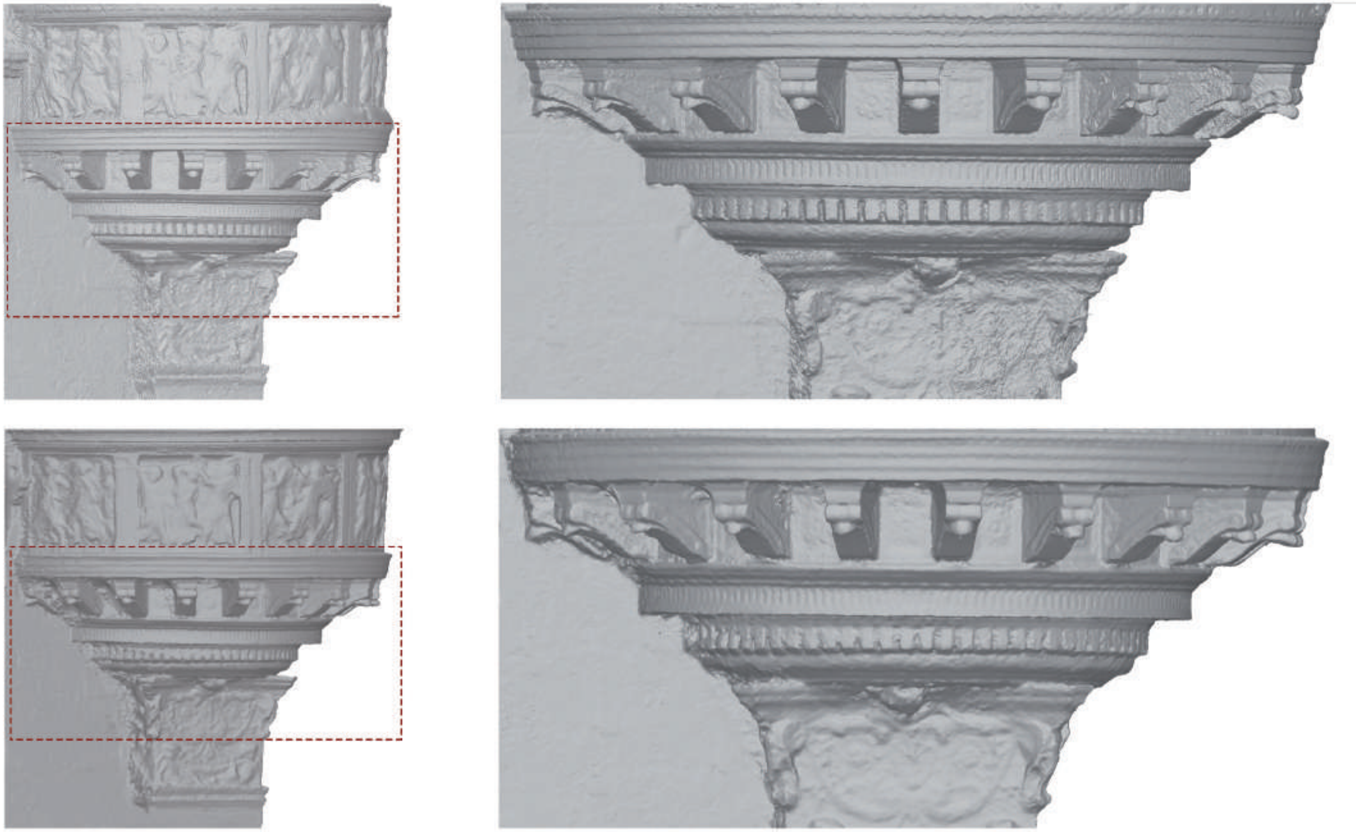

Figure 11 . Visual comparison between photogrammetric models. Above, the model obtained from Metashape software by processing data obtained from 3D-EYE. Below, the model from Mavic Mini.

4. Conclusions

The article analyses the reliability of the use of mini-UAVs in the context of an integrated investigation aimed at the knowledge and documentation of an architectural element characterised by a complex decorative apparatus.

The results obtained highlight two fundamental aspects of the use of mini-UAVs in the documentation of Cultural Heritage. Firstly, the work carried out on the case study demonstrates how the use of the drone within a survey allows us to obtain a complete database focusing on the decorative and plastic aspects, especially if positioned at heights where ground-based instrumentation alone (range and image-based) cannot be effective. On the other hand, the work emphasises the potential of using mini-UAVs in architectural surveys, especially in areas where flight regulations are restrictive. The visual comparison, but especially the metric one, highlights the qualities of these drones in terms of reliability and accuracy of measurements.

Figure 12. The model deviation coming from data acquired with 3D-EYE compared with that from DJI Mavic Mini acquired data. The tolerance value is set at 5 mm on a maximum deviation of 30 mm. It can be observed that the surfaces are fitted in the lower part, while the deviation values increase in the upper one.

Future research developments see the possibility of implementing acquisition methods with these particular instruments at altitude, in order to obtain final results that better match the goals set by the documentation.

Credits

The research project on Donatello's pulpit in the Cathedral of Santo Stefano in Prato, scientific responsible Prof. Francesca Picchio, has been developed within the research laboratory DAda-Lab of the University of Pavia (responsible Prof. Sandro Parrinello) within a joint activity with the Department of Architecture – DIDA - of the University of Florence, and the Museo dell' Opera del Duomo of Prato.

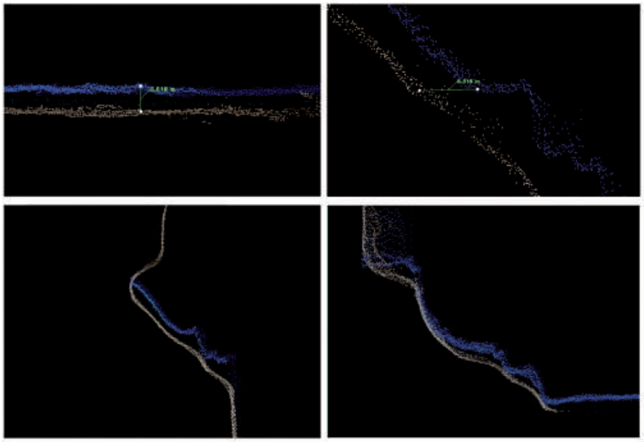

Figure 13. Above, metric comparison between point clouds obtained from TLS and Mavic Mini. Below, geometric deviation of the point cloud obtained by drone to that obtained by terrestrial laser scanner. The discretization of information obtained from drone is relevant.

Notes

1 Terrestrial Laser Scanner.

2 Unmanned Aerial Vehicle.

3 For an in-depth reading on the historical and constructive aspects of Donatello's pulpit, see Bonsanti, Giorgio (2000). Il pulpito di Donatello. In Donatello restaurato. I marmi del pulpito di Prato, pp. 11-30. Pistoia: maschietto&musolino, 2000.

4 The main features of the DJI Mavic Mini: weight less than 249 grams, open dimensions with propellers 245×289×55 mm, upward speed 1.5 m/s - 4 m/s, downward speed 3 m/s, flight time 31 minutes, 20 MP camera, 35 mm lens, f/2.8 aperture, shutter speed 4 - 1/8000 s (for additional information see https://www.dji.com/it/mavic-mini/specs).

5 The main features of the DJI Mavic 2: weight 907 grams, open dimensions with propellers 322×242×84 mm, upward speed 4 m/s - 5 m/s, downward speed 1 m/s - 3 m/s, flight time 30 minutes, 12 MP camera, 35 mm lens, aperture f/2.8-f/11, shutter speed 8 - 1/8000 s (for additional information see https://www.dji.com/it/mavic-2/info).

6 The range-based acquisition is carried out using a FARO CAM2 FOCUS S150 terrestrial laser scanner. The point clouds obtained from this instrumentation are aligned and recorded through the use of SCENE software, produced by the same manufacturer of the laser scanner. In particular, the maximum referencing error obtained in the registration phase of the total cloud is 0.0042 metres.

7 Ground Sample Distance.

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Keywords:
UAVs, Shanghai, Lilong, Photogrammetry.

ABSTRACT

In the last decade, the concept of historical preservation and the gradual improvement of protection regulations have been leading Shanghai government to discuss more and more on the safeguard of the traditional model of low-rise houses called Lilong. The available data on these neighborhoods are now extremely limited because of the uncontrolled demolitions and the little value unfairly given to them.

UAV-technologies represent an effective photogrammetric survey tool in a contest where the extremely dense urban space makes complicated the use of traditional tools.

Documenting the evolution of a Lilong neighborhood in contemporary Shanghai through mini-UAV-based photogrammetry surveys

1. Background

The *Lilong* embodies the essence of Shanghai history and culture. It represents an extraordinary mix of architecture, born from the merger between the "*English working-class homes and the fundamental principles of traditional Chinese houses, siheyuan, constructed of brick and wood*" (Gustin, 2016). This typology has characterized the city for more than 100 years, from 1840 to 1949, and has represented most of the housing stock in the city center until the end of the 20th century. Nevertheless, the great economic boom that China has been experiencing in the last 35 years has required an ever-increasing number of lands. Therefore, the shanghainese historic neighborhoods have been affected by several and uncontrolled demolitions, reconstructions and resettlements: «*millions of square meters of old houses have been taken down and replaced by new buildings. Millions of local residents have been displaced with the disappearance of former neighborhoods*» (Zhong, Chen, 2017).

Although the demolition of the *Lilongs* which were in a pitiful condition was an obvious and necessary choice, the disappearance of the communities that lived in those neighborhoods and embodied the true strength of the spaces points out the true importance of heritage preservation. In this regard, the American anthropologist Jane Jacobs highlights the strong relationship between small-scaled dense urban neighborhoods and community lifestyle. Denouncing the activities of the bulldozers, she writes: «*Some who are fortunate enough to have communities still do fight to keep them, but they have seldom prevailed. While people possess a community, they usually understand that they can't afford to lose it; but after it is lost, gradually even the memory of what was lost is lost*» (Jacobs, 2004).

Moreover, it is important to point out that the Cultural Heritage of a city lies in its neighborhoods and historic centers (in the case of Shanghai in the Shikumen districts) and the initiatives to be implemented should aim at protecting not only famous monuments, buildings and natural landscapes, but also construction and work techniques, buildings and objects reflecting the history of various countries and the different ways of life. (Kilburn, 2006) In fact, the Venice Charter, a fundamental document for the theory of conservation and restoration of monuments and architectural sites (1964), states in its first article: «*The notion of a historical monument includes not only the single architectural work but also the urban or rural context in which there is the testimony of the existence of a civilization, an important development or a historical event. This is true not only for the great works of art, but also for more modest historical works that have acquired a cultural meaning over time*».

A planning that recognizes all of this provides an opportunity for the city to grow and contribute to the progress of humanity. For these reasons it is necessary to define shared rules on how to work in the field of *Lilong* architecture, otherwise the inexorable consequence is the loss of heritage and identity of places.

The French historian Françoise Choay was the first one to highlight how the transformations of the historical heritage during the industrial revolution and the false rehabilitation projects implemented in several historical centers of Europe between the 70s and 80s generated the so-called "Disneyland towns", reproductions exclusively tourist-orientated of original cities, with the consequent loss of the authenticity of those urban places. (Colletta, 2005) The same approach was used in Shanghai, during the recovery of the *Lilong* districts called *Xintiandi* and *Tianzifang*, where the restoration intervened only in appearance, recreating the facades and not the social structure, and like Disneyland, returning only an artificial product created just for fun. The destruction of the authenticity, of the sense of community and belonging to a place, of that intangible Cultural Heritage, of the *genius loci*, through an economy and a tourism mostly interested in profit and fake folklore, risks over time to cause the degradation of these districts. Nevertheless, focusing on the environmental and social aspects of the sustainable development does not automatically mean neglecting the economic feasibility, which must therefore be understood in the sense of a correct protection and management of the cultural asset resource.

2. Research questions

The actions to be implemented to reverse the demolition trend and stop the process must proceed in two directions: on one hand it is necessary to demonstrate the social value that the Lilong can still represent for the contemporary Shanghai as space of cohabitation; on the other hand, it is necessary to document the characteristics of these neighborhoods through architectural surveys, in order to increase the available data that are now extremely limited because of the little value unfairly given to them.

Figure 2. Shanghai simplified 3d-model aerial view

Yong'an Mill district, within the French concession[1] has been identified as the case study for this double investigation, thanks to its geographical location and its recognition by the Shanghai Municipality as a historic block to be protected in the future development of the city. (Figure 2) In fact, in the last decade, the concept of historical preservation and the gradual improvement of protection regulations have been leading to discuss more and more on *Lilong* safeguard. Now, in Shanghai, a new opposite road has been tested, in which the government's huge monetary investments are aimed at a restoration finalized, contrary to the cases of *Xintiandi* and *Tianzifang*, to a historical-cultural safeguard focused on the

Figure 3. Xintiandi neighborhood.

Figure 4. Tianzifang neighborhood.

Figure 5. Lilong key issues.

Although *Yong'an Mill* presents the same common problems of many other *Lilong* that keep the inhabitants in very poor and shameful conditions, in general its current state of conservation can be considered acceptable and therefore worthy of a restoration work that preserves the general characteristics of the building typology, consolidates the dwellings and provides them of the basic living facilities, as kitchens and private bathrooms. (Figure 5)

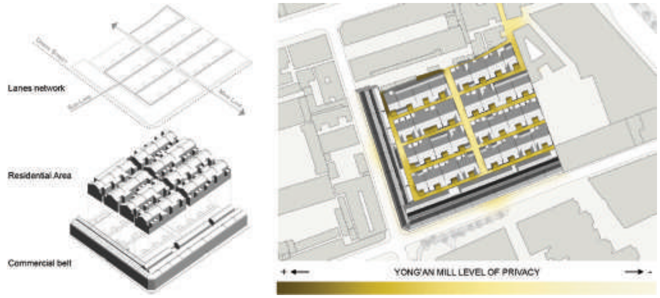

Figure 6. Yong'an Mill layout and level of privacy diagram.

3. Survey campaign

3.1 Introduction to the survey

The *Lilong* is a very challenging context for a technician who is planning an architectural survey. In fact, as the term indicates, it is a model of low-rise neighborhood (*Li*) organized along a grid of narrow alleys (*Long*), a feature that makes traditional survey techniques (like standard photogrammetry) not very convenient. In particular, *Yong'an Mill* district dates back to 1912 and it is built according to the Old Shikumen style [2] with some evolutions (e.g., organization of the plans) typical of the New Shikumen style[3], developed a few years later. Regarding the general layout of the neighborhood, to the south and west *Yong'an Mill* is delimited by a row of buildings placed on the perimeter of the neighborhood and interrupted only at the ground floor in the two access points. The block is distributed on three or four levels almost entirely residential. The only commercial activities are located on the ground floor on the side facing the streets.

To the north and east, the neighborhood is instead bordered by a wall. The interior space of *Yong'an Mill* is characterized by a main lane along north-south direction, that divides the neighborhood in half, and by six secondary alleys (one along north-south direction and five along the west-east direction. (Figure 6) Thus, considering the narrow geometry of the neighborhood, the most suitable technology for the survey campaign is that of UAVs, such as the DJI *Mavic Air*, chosen for its quality-price ratio and its impressive portability. In fact, the aerial-photogrammetric survey allows to take hundreds of photos through which a complete model of the neighborhood can be generated.

In particular, the shots acquired flying parallel to the ground have returned precise 3d data of roofs, terraces, alleys, and just partially of the facades, whose data have been integrated making the drone fly perpendicular to the ground.

3.2 Flight parameters

Before defining the flight mission, it is necessary to verify the Chinese legislation regarding drones, issued by the Civil Aviation Administration of China (CAAC). The main restrictions to follow in order to complete the mission safely are listed below[4]:

Maximum Altitude: 120 meters; to flight higher it is necessary a commercial license from the CAAC. Most drones automatically set this limit and warn the operator in case of passing it;

Maximum Distance: it is required a “Visual Line of Sight” with the drone; that means that the operator needs to fly with the drone in sight;

Maximum Weight: if the drone weighs more than 250 grams it is required the real-name drone registration (DJI Mavic Air weighs 430 grams);

No-Fly Zones: it is forbidden to use drones in China’s NFZs, such as airports, military areas, specified cities (Beijing) and sensitive areas (Xinjiang and Tibet). Through CAAC, it is possible to request special permission to fly in NFZs (DJI drones automatically don’t take off in NFZs).

Considering the aforementioned regulations, the parameters of the mission were then defined:

Camera angle: given the complexity of the Lilong and the narrowness of its alleys, the camera was tilted 50° from vertical;

Flight height: 30 meters. Each camera is able to distinguish a particular dimension of a detail based on the distance from the subject. Through the flight height (H) and three camera values, sensor width (Sw), focal length (Fr) and image width (W_{im}), the Ground Sampling Distance (GSD) is calculated, which relates pixels of the final model with the real size (cm) of the object, according to the following formula:

$GSD=(Sw \cdot H \cdot 100)/(Fr \cdot Wim)$.

In accordance with DJI Mavic Air camera features (Sw = 6,17 mm; Fr = 4,5 mm; Wim = 4056 px), flying at a height of 30 meters above the ground, GSD is equal to 1.01 centimeters, meaning that the details on the ground smaller than 1.01 centimeters cannot be discriminated. (Figure 7). Once the flight parameters are defined, in order that the photogrammetric survey falls within the parameters of precision and metric accuracy, it is also

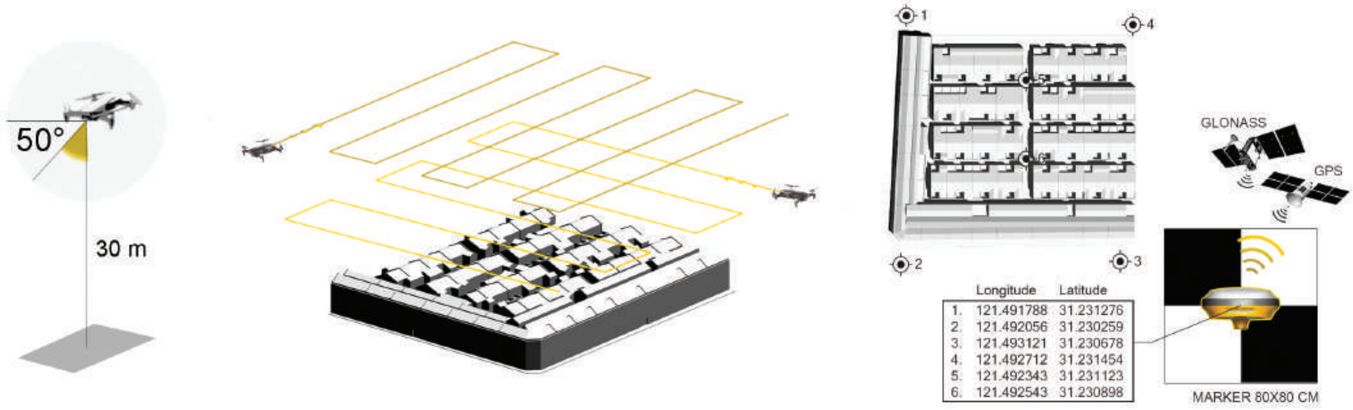

Figure 7. UAV-based survey diagram.

necessary to introduce a phase of survey of coordinates on the ground. In fact, photogrammetry is a passive light technique and the size of the shot scene cannot be established a priori, as in the case with active light techniques (total station, laser scanner, etc.), but is only approximated.
The materialization on the ground of the points to be converted into markers, Ground Control Point, is made using simple black and white squares sufficiently large (80x80 cm) to be identified by the drone. Four markers are placed at the corners of the neighborhood and two along the interior alleys.
Their placing occurres before the images are acquired, so that they are perfectly visible and recognizable in the photographs.
In order to be able to define their position with respect to a given reference system, it was possible to proceed with different instruments, such as the total station, the laser scanner or devices equipped with differential Global Navigation Satellite System (GNSS), that is able to geo-locate a point through the combination of data observed simultaneously from two or more satellite receivers.
Without the first two instruments, which would return a more precise datum (error within 5 mm), but referring to a local coordinate system, the position of the Ground Control Points is defined through a GNSS receiver, such as the DJI *D-RTK Mobile Station* that supports all major GNSS (GPS, GLONASS, BeiDou and GALILEO signals [5]) and provides real-time differential corrections that generate centimeter-level geographical coordinates (error 1-3 cm).

3.3 UAV-based photogrammetry surveys

Before taking off, the path that the drone must follow is established, considering that each photograph should capture an area that must overlap at least 60% with that of the adjacent photographs: this is necessary to successfully match photographs in the processing phase. Shooting options are set in RAW format, which allows a great post-processing power able to take shots almost perfect for photogrammetric purposes.

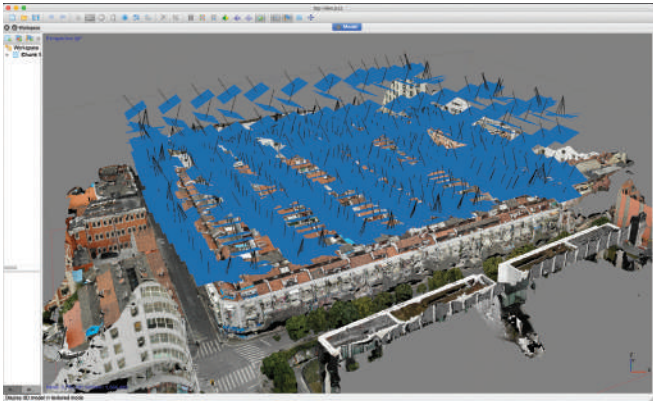

Figure 8. Photographic acquisition flight path.

The focal point of the *Mavic Air* camera is fixed, but it is possible to vary some shooting parameters, such as the ISO, in order to make shots conform to the ambient light.
Thanks to some applications for smartphones and tablets, such as “Pix4D Capture”, it is possible to plan the route in automatic-flight mode.
However, in order to have greater control, it has been decided to pilot the drone manually by the supplied remote control connected to an iPhone 8 provided with DJI “GO 4” app. Through the smartphone, all the flight parameters can constantly be monitored.
To cover the entire area, about 600 photographs have been taken. (Figure 8) In the post-production phase, it has been highlighted that the 3d model, obtained from the points cloud generated by the *Agisoft Photoscan* software, combined with the data collected by traditional surveys and Ground Control Points position, is qualitatively very satisfactory, rich in details, geolocated and suitably accurate for the aims of the research. (Figure 9)

Figure 9. Yong'an Mill south elevation.

4. Conclusion

It should not be the nostalgia for the past to justify the use of the living model of the Shikumen Lilong, but rather an approach that defines how the space is traditionally used and how it can be justified or reinterpreted today. Through the case study of *Yong'an Mill* it has been demonstrated how UAV-technologies represent an effective photogrammetric survey tool, in particular in those contests where the morphology of the space (extremely dense urban spaces) makes the use of traditional tools complicated. Finally, the UAV-based photogrammetry survey has given a complete 3d model of the outdoor parts of the neighborhood, necessary to go on with the design phase, which has to take into account place-making and co-living principles, in order to preserve the strong sense of community that characterizes *Lilong*. (Figure 10)

Figure 10. Survey results example: CAD drawing, orthophoto and 3D model (software: Rhinoceros).

Notes

1 In 1844 the Treaty of Whampoa, also known as the treaty of Huangpu, was signed in Shanghai: China granted the French Empire the same privileges offered to Great Britain with the treaty of Nanjing, as for example it was guaranteed to the French trade the opening of the five ports of Canton, Fuzhou, Ningbo, Xiamen and Shanghai. Following the treaty of 1844, in 1849, the governor of Shanghai assigned to France an area of 66 hectares located north of the old Chinese city: the French concession.

2 The first typology of Lilong was called Old Shikumen and, given its large dimensions, was designed to accommodate the traditional Chinese extended families, which generally came from the provinces around Shanghai. It consisted of terraced housing units made of bricks and with a sloping, double-pitched roof (not curved) aligned and equipped with a private courtyard onto which most of the rooms faced.

3 At the end of the 19th century, following the constant industrialization and continuous demographic increase that affected Shanghai and its foreign concessions, it was necessary to define a new housing proposal, an adaptation of the Old Shikumen Lilong typology to modern times.

Thus, the New Shikumen Lilong was introduced, which foresaw a decrease in living spaces (a small courtyard is symbolically maintained).

4 www.caac.gov.cn
5 GPS (Global Positioning System), GLONASS (GLObal NAvigation Satellite System), BeiDou and Galileo are GNSS managed respectively by the Government of the United States of America, by the Russian Space Forces (VKS), by the Government of the People's Republic of China and by the European Union Agency for the Space Programme (EUSPA).

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Keywords:
3D modelling, Survey, Structure from motion, Drone, Cultural Heritage.

ABSTRACT

Low-cost Unmanned Aerial Vehicles and Structure from Motion algorithms are well-established and satisfactory tools for surveying architectural Cultural Heritage.

The case study discussed here concerns the survey of an object of particulate morphology: a 23-sail dome, the abandoned Woodpecker discotheque located in central-northern Italy.

In order to digitize this complex, it was necessary to use a network of cameras capable of creating nadir and oblique images.

The proposed method has proven convincing in a real-world application for its feasibility, ease of implementation, and surface coverage; it can be used in a wide range of applications on artifacts of various morphologies.

The Woodpecker: Virtual reconstruction of an abandoned discotheque in the Adriatic Coast

1. Introduction

This paper presents the digital geometric survey of a specific case study located in the Adriatic Coast (Riviera Romagnola), in the heart of Milano Marittima (Cervia, Ravenna), namely the Woodpecker nightclub (Figure 1). This building was built in 1968 as a discotheque and was soon abandoned in 1970, due to a fire that devastated the structure. The nightclub, wanted by the De Maria family, was designed by architect Filippo Monti (Bertoni 2003). Passionate about painting and drawing, between 1947 and 1948, he attended courses in graphic design and painting at the School of Arts and Crafts in Faenza (Monti 1967). Later, he enrolled in the Faculty of Architecture in Florence (Bertoni Rava 2009).

Back in Faenza, he developed his qualities as a designer of plastic architecture, creating several works, including the Woodpecker in Milano Marittima, the subject of this study (Mantovani Ricci 2012).

The Woodpecker, abstract and minimal, represents a seal to the continuity between earth and sky, open and closed, visible and invisible (Dantzig 1954) (Figure 2).

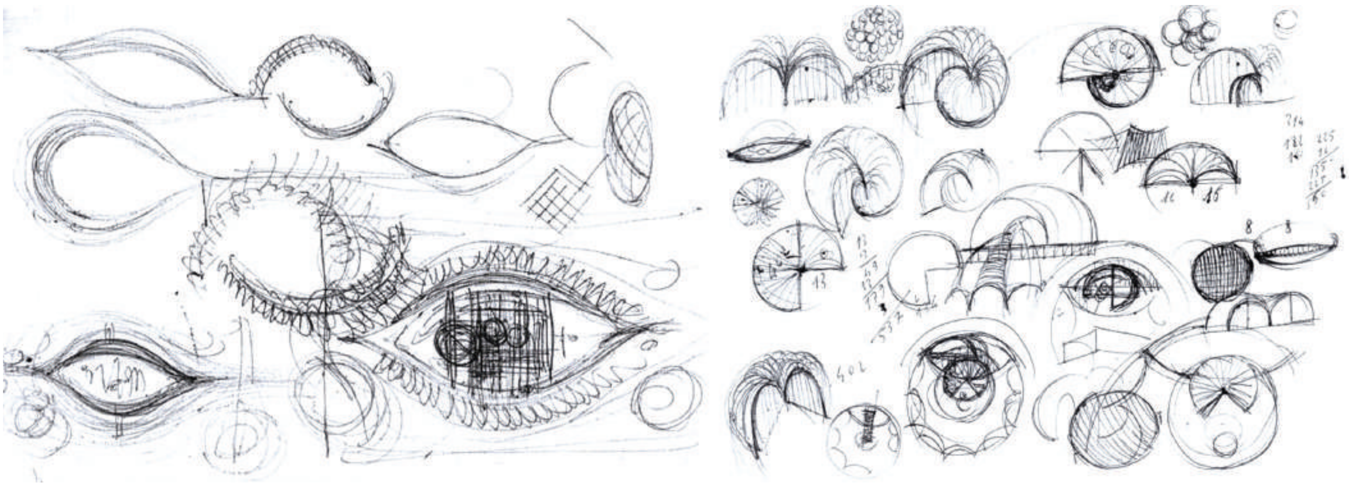

Figure 2. Above, some sketches by the architect Filippo Monti.

2. Survey procedure

The 3D data acquisition of the nightclub was carried out by means of a photogrammetric survey, with terrestrial and drone images acquisition.

The integration of low-cost unmanned aerial vehicles (UAVs) and structure from motion (SfM) algorithms simplify the documentation of buildings and architectural heritage by providing greater flexibility and more extensive coverage (Aicardi Chiabrando Grasso Lingua Noardo Spanó 2016).

Although a UAV system installed with multiple cameras is more efficient in acquiring images, it is also much more expensive and cannot be used in most countries, such as Italy, without permission (Trizzino Caprioli Mazzone Scarano 2017).

Low-cost UAVs, such as the one used in this case, make low-altitude image acquisition accessible and manageable for users with limited budgets (Blais 2004).

The combined use of UAV and SfM enables 3D modeling of large-scale and complex architectural heritage sites using low-cost, highly flexible collections of acquired imagery (Chiabrando Lo Turco Rinaudo 2017). Mainly when surveying architectural heritage sites, three factors most influence ac-curacy: the camera's calibration, the camera's network, and ground control points with known geographic locations (Murtiyoso Grussenmeyer 2017).

Camera calibration is a very important factor in image acquisition; among the most relevant internal camera parameters are principal points, principal distance, and radial distortion of the lens.

Depending on the case study analyzed and according to the research objective, it is possible to calibrate the camera in different modes (Nocerino Menna Remondino Saleri 2013).

By conducting a procedure for independent calibration before orienting the image, higher accuracy can be achieved. However, it is often preferred to use autocalibration, i.e., simultaneous calibration of the camera and an image orientation for automated applications (Zhihua Lixin Yonglin Fashuai Qiuling Ran 2014). In architectural heritage detection, feature-based camera calibration is the favored mode because it speeds up the field measurement process and avoids the need to place tar-gets in inaccessible areas.

The camera network is concerned with the geometric relationships of the detected objects and the image block. It exerts a decisive influence on the accuracy of the feature-based calibration.

Currently, most software applications used to process images acquired by UAVs are based on the SfM approach. As opposed to traditional digital photogrammetry, this approach solves the collineari-ty equations without the need for any control points providing a sparse cloud of points over an arbitrary coordinate system and a complete camera calibration. This is made possible by image matching algorithms that automatically search for similar image objects, called "key points", by analyzing image features' correspondence, similarity, and consistency. Structure from Motion is coupled with multiview stereopsis (MVS) techniques that apply an expansion procedure to the sparse set of matched key points in order to obtain a dense point cloud.

Ground control points (GCP) are usually used in the photogrammetric process to georeference the 3D point cloud generated; these control points can be permanent ground features or reference targets scattered on the ground prior to flight, which must be surveyed to obtain their precise coordinates and ensure that they are clearly identifiable on the raw images. To perform the georeferencing process, the minimum number of GCPs required is three, although increasing the number of GCPs is highly recommended to improve the accuracy of the photogrammetric products.

The influence of the number of GCPs on the DSM and the accuracy of the orthoimage obtained with UAV photogrammetry were studied, and it was concluded that more accurate results were achieved by combining GCPs located around the study area and a stratified distribution within that area, for these reasons, there were 40 uniformly distributed grounded points in the study area. The use of NADIR images, an image just

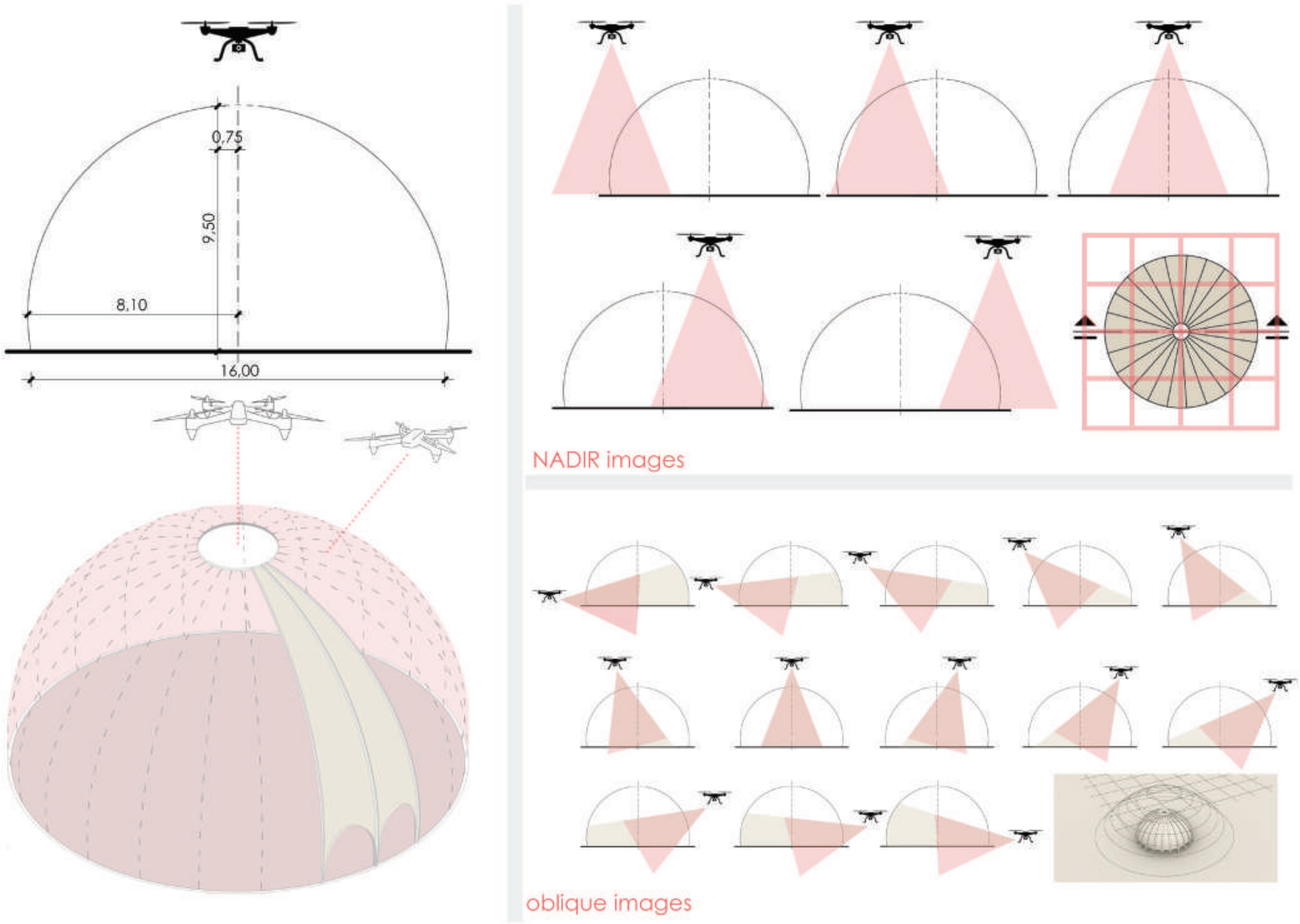

Figure 3. Explanatory schemes for the photographic-drone acquisition of the dome.

means that the camera is facing directly beneath the camera/drone at the time of the exposure, for 2D objects such as facades or roofs to plan a camera network is quite simple (Bolognesi Furini Russo Pellegrinelli Russo 2015), because two factors have to be considered: the image overlap and the ground sample distance (GSD) (Figure 3).
In the present case where it is necessary to detect a dome and arches or objects of particular morphology, the survey becomes much more complex since it is necessary to use a network of converging cameras with oblique images (Petrie 2009). This is because image scale, lens tilt, and illumination transitions can affect metric quality. Today, many applied case studies on architectural heritage in the literature are UAVSfM based surveys that have employed only NADIR images (Robertson Cipolla 2008). In the case of the Woodpecker, this approach is not practical given the complexity of the object. An allin-one

Figure 5. DJI Phantom 4 quadcopter drone - camera specifications.

Figure 4. Data set and data acquisition.

camera network capable of producing a complete 3D model is the most common requirement. In order to minimize possible deformation of the camera network during beam adjustment, in aerial image-based surveys, external constraints such as Global Navigation Satellite Systems/ Inertial Navigation Systems (GNSS/INS) data and GCPs are used to geo-reference the 3D results. GCPs are used to achieve higher accuracy and can be measured using a total station on manually placed targets or natural features on the object to be surveyed. Ground Control Points, or GCPs, are marked points on the ground with a known geographic location. In aerial surveying, a drone can be used to collect photos of the survey area autonomously. If used, GCPs must be visible in these aerial photos (Themistocleous Agapiou Hadjimitsis 2016). The photos are then processed in the cloud using drone mapping software. The total station could measure the target with an accuracy of about 1.5 mm, but instrument performance, distance to the target, and human error can lead to different results. The terrestrial acquisition was realized to generate a whole coverage of the dome, while the drone acquisition was performed to acquire images of the upper part of the dome and the geometry of the water bodies. In this way, using images captured from different viewpoints, it was possible to obtain complete images coverage of this mystical architecture. The survey was measured by employing the Canon EOS600d camera and the Mavic Pro-DJI drone (Figure 4). The UAV used was a DJI Phantom 4 quadcopter drone equipped with a camera with the features shown in the figure (Figure 5). The rotating wing equipment allows for takeoffs and landings in confined spaces and a single-operator photo capture campaign. The battery allows a maximum flight time of 30 minutes. With the point clouds obtained by processing the images acquired by these instruments, it is possible to get geometric and colorimetric information, thus being able to have a model that defines the state of the structure to be used as a basis for design or maintenance of the work (Gaiani Remondino Apollonio Ballabeni 2016). In this way, it is possible to constantly update all the information concerning the structure and oper-ate according to the needs.

3. Data processing

The images acquired by drone and terrestrial acquisition were processed through the new release of the Photoscan software: Agisoft Metashape. The alignment of the terrestrial and aerial photo-graphic set within the agisoft Methashape software was carried out by working on separate chunks with common targets.

Thanks to this software, it was possible to obtain polygonal models and a model composed of Tie Points. First, the sparse cloud was generated, then the dense cloud.

Then the reference and scaling of the model were done using measurements or known points rec-ollected in the field, with the creation of mesh and the projection of HD oriented image onto the ob-tained mesh model.

The number of images that have been processed in Metashape for the creation of the dome is 82 terrestrial photographs and 143 aerial photographs (Figure 6).

This experience shows that terrestrial and drone acquisition and 3D image modeling represent an effective way to obtain fast and accurate results.

4. Conclusion

This study is the starting point for creating a helpful model as a basis for elaborating a project to give new life to this abandoned discotheque. In conclusion, this paper evaluates the accuracy of the UAV-SfM method for surveying a dome structure, illustrates the steps performed to obtain the three-dimensional model, and presents how the results could be processed in subsequent analysis and used for artifact management purposes (Vacanas Themistocleous Agapiou Hadjimitsis 2015). Ultimately, the accuracy and resolution of this approach support efficient and robust data acquisition under varying light conditions and difficult access to the area where the discotheque is located and confirm the great potential of UAV systems to serve the survey and cataloging of abandoned artifacts. The use of photographs obtained from drone surveys makes it possible to document situations lo-cated in difficult to explore contexts, even at considerable distances and with a level of detail that would escape the classic aerial or helicopter shots (Anderson Gaston 2013).The versatility and speed with which large

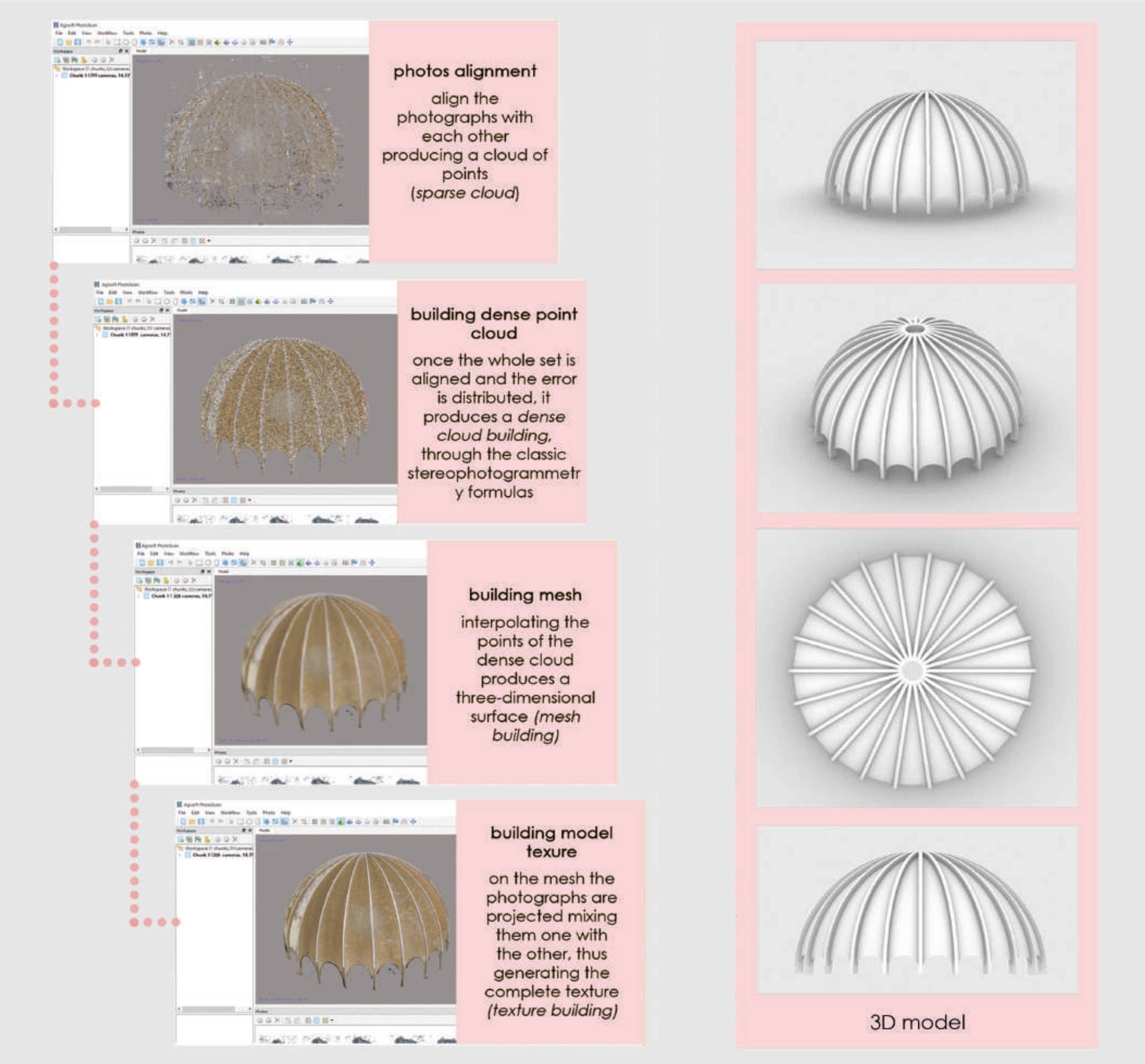

Figure 6. Modelling process.

amounts of visual information can be retrieved, make the images at high altitude an ideal graphic index to communicate with immediacy the configuration and location of architectural elements, decorations, states of deterioration, temporal stratifications, and superfetation, even for project interventions (Pizzigatti Franzoni 2021). The fronts of development for this process of acquisition and cataloging of information are also aimed at the easily modeling of architecture for which you can generate virtual urban scenarios ex-plorable from above and from different angles that would allow the design of virtual itineraries, to disclose and enjoy the good in a virtual way (Vosselman Maas 2010).

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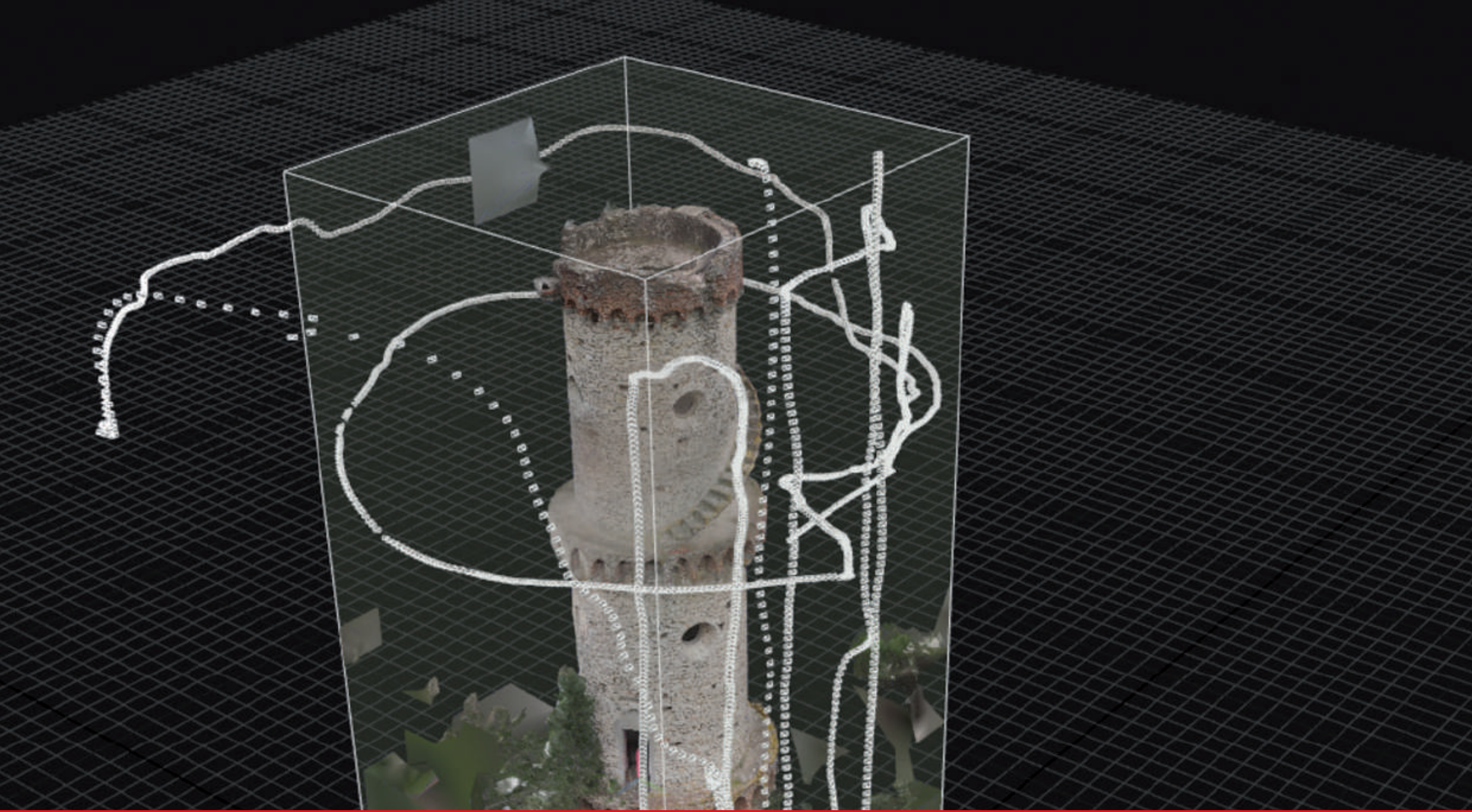

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Keywords:
Photogrammetry from UAV, 3D Modeling, Virtual environment, Digital reconstruction. Cultural Heritage.

ABSTRACT

The observation underlying the study arises from the issues encountered during the period of global lockdown caused by the covid-19 epidemic. The emergencies evidenced, on which we reasoned, were two: the need to perform dimensional and material surveys with operating teams of few components, to ensure social distancing; and the desire to obtain digital products rapidly, ensuring a wide use referred to a general user base. The generic answer to these cues has been satisfied by the use of digital photogrammetry, the core of this presented contribution.

From UAV photogrammetry to digital restitution, new process for the preservation of Cultural Heritage

1. Introduction

The paper presented here aims to investigate the relationship between the use of the aerial drone for photogrammetry and the use of digital output in virtual environments. The elaboration phase by means of digital photogrammetry, the restitution of the survey, is preceded by the methodology of data acquisition, filmed by aerial drone, and followed by methodologies of management on the virtual environment of 3D digital models as a strategy of restitution and fruition of the data.

2. Workflow

The paper presents a workflow applied to an architectural and landscape heritage. The objective of the text is to share the method applied to the survey and digital restitution, demonstrating the possibility of performing the operations of data acquisition in autonomy of a single operator.

The focus of the study is to reduce the time of digitization, survey and restitution, in order to make the architectural and artistic object easily available on web platforms. The strategy to achieve this goal is the application of two digital means.

The aerial drone (UAV) and software for the management of virtual environments (VR). The data acquired from the aerial photographic campaign will reach the 3D world, thus structuring a navigable environment.

The object will be so viable and investigable as a digital copy, available through web browser. Being in the field of Cultural Heritage, it will be with the help of digital photogrammetry that we will maintain a level of scientific attention in the process of digitization of the architectural and artistic heritage.

The processing of digital photogrammetry represents the link between the phase of data acquisition (survey) and that of importation and structuring of the virtual environment (restitution). This highlights how the photogrammetry is the step of digitization of the subject.

This step can be performed with two methodologies: the first is the modeling of the object "from scratch", using the survey data to derive information through the reading and study of the images.

Or, the second methodology, the inverse modeling, developed by processing the images to obtain a 3D model with a presence of error and approximations highly reduced. This second method is structured through the use of digital photogrammetry.

Figure 1. Villa Le Falle.

Figure 2. Round Tower "La Ragnaia".

3. The subject of the survey - Torre Tonda della Ragnaia di villa le Falle

The subject selected for the proposed study was the Round Tower of the wood of Villa le Falle (Figure 1) or Torre della Ragnaia. Architectural and Landscape object furnishing the wood of the Villa located in Ellera di Fiesole - Florence.

The history of the park is linked to that of Villa Le Falle (name given for its position near the small village of Le Falle). News about this residence dates back to the 13th century. At that time it belonged to the Gubertini family, but then it passed to the Pazzi family (known at that time as "il Palagio"). Following the "Pazzi Conspiracy" the property was confiscated by the Medici and the house ended up in the hands of Guadagni, who, thanks to the architect Gherardo Silvani, transformed it into a beautiful residence. In the nineteenth century it was purchased by Enrico Danti who led the organization of the Ragnaia Park. The Park is located to the north of the Villa inside the woods, on the hill once called "Poggio de'Pazzi". Its realization took 50 years. Enrico Danti was inspired by the project of the set designer Giovanni Gianni. The idea was to create an English-style park, without following a geometric scheme, where the vegetal elements mixed with the artificial ones in a natural way. Inside, Danti had a series of architectural elements built, which can be visited freely today, even if they are in a real state of abandonment and covered by nature. In the landscaping system we find: the Belvedere, the Obelisk, the Tabernacle, the Bridge, the Square Tower, the Medieval Village, the Neoclassical Temple and the Round Tower (Figure 2). The Round Tower is 25 meters high. It is ideally divided into three sections marked by external circular balconies, the first two with an internal helicoidal staircase (which can be found today for some remains but most of which have collapsed) and the last section with external stairs leading to the top. The position at the top of the wood makes the Tower in the landscape as a lookout.

The Torre Tonda was chosen for several reasons. The main one is the state of decay that makes the property in structural emergency and therefore calls for a registration of its state for a concrete future testimony. The tower's position at the top of the park's organization, both altimetrically and in the hierarchy of the route, makes it dominant in the landscape and in the park system. The difficult access by means of transport and mediumsized equipment completes the scenario making the Torre Tonda an ideal subject for the proposed study.

4. Photographic survey from UAV and photogrammetric restitution

The ideal work path presented is structured on a photographic survey performed by drone. This practice, framed in the methodology of indirect survey, necessary for the safeguard of the Cultural Heritage, offers the possibility to perform operations with a single operator, the drone pilot, minimizing the team involved in the field. To this must be added another reasoning useful to our prerequisite, i.e. the possibility of minimizing the time of the operations through the planning of flight missions with dedicated software; this operation can be performed upstream of the in situ visit and is useful to estimate the time of flight and, in general, to approximate the period of stay in the field. The survey phase was carried out by data acquisition with an aerial UAV drone. A DJI Mavic Mini was used for the operations. The model is of low professional level, it is considered entry level for the flight characteristics, for the level of control in the maneuvers and safety systems.

These features, although not ideal for the survey of Cultural Heritage are balanced by the ease of transport (given the size and weight contained). Besides that, in the development of a work process, the application of a lowlevel instrument provides a sufficient result. It constitutes a minimum framework, which can be implemented and improved in future projects. The preliminary phase, functional to the study of the flight

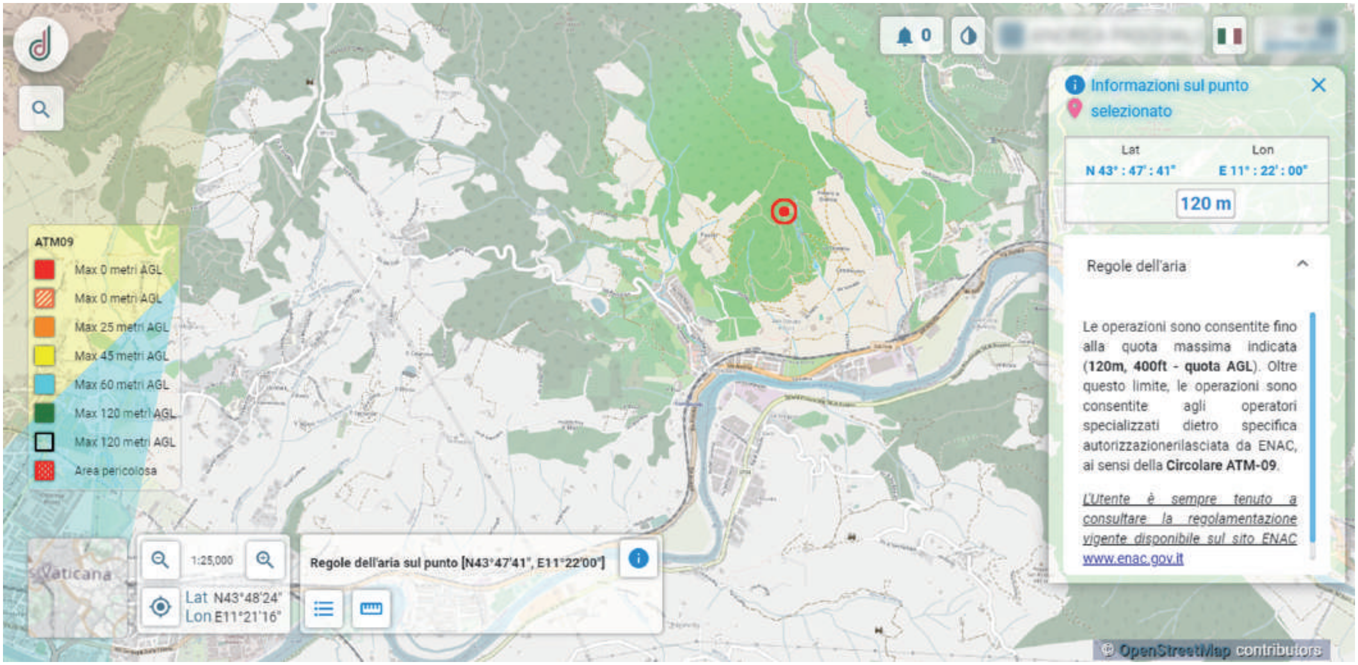

Figure 3. ENAC, d-flight website page.

area, has allowed to plan the operations, in order to optimize the result and the time spent in the place. The flight area has been identified on the dfight web portal (Figure 3).
The Enac web portal provided the general indications, that is, the tower site is in the ATM-09 area free to fly, with basic limitations (from the regulations directly referring to the weight of the drone at take-off) and the only limitation of flight at a maximum altitude of 120 m.
This verification has allowed to declare the feasibility of the operations and to exclude authorization procedures and production of paperwork necessary to fly in restricted areas. The next step of the preliminary phase is the assessment of flight path automation. This is done by means of dedicated third party software (APP) and the DJI flight APP. It should be pointed out that the choice is forced, since DJI Mavic Mini does not support in its flight APP an advanced route tracking system, nor flight plan programming possibilities. Tools present in the resident APPs of more advanced UAV models. The flight mission study was performed with the Dronelink APP for DJI (Figure 4). The software allows to configure the affected areas and program the level of photo coverage. To these data, the software response is the indication of the required battery charge and the time of the operation.

Figure 4. DJI Mavic MINI and Dronelink APP.

The final evaluation opted to exclude the use of the flight mission and opt for a manual flight. This choice, in this case, is imposed by the strong presence of vegetation around the Torre Tonda.
Since the drone does not have lateral anticollision sensors and the flight mission is more useful for the coverage of portions of the surface discretely extended but difficult to control on casi of limited size, the choice to fly manually to adapt the route according to peculiarities and obstacles was considered the safest.
The conclusion of the preliminary phase is the control of the aircraft, its components and the charging of all batteries for operation.
Although trivial and obvious, we emphasize this phase to ensure the success of the operations and, above all, the safety of the flight phases.
The survey consisted of three flights of 15 minutes each. Two types of routes were alternated in order to enhance the coverage.
One with vertical ascents and descents of altitude (constant thrust), organized in a circle with respect to the center of the Torre Tonda. The other was a constant altitude loop, climbing along the height of the tower and keeping the tower as the subject of the shot (controlling the roll and yaw constantly).
The flights covered the entire surface of the tower with some insufficiencies in the part topped with vegetation but the entirety of the asset was recorded.
Two shooting methods were applied.
The first one was with photo shots programmed on the DJI APP automatism with 1 shot every 2s, which allowed to concentrate on the flight.
The second method, chosen to detect the portions closest to the tree branches, was the use of video capture.
The choice of this acquisition method is due to the need for a slower and more careful flight, with less control over the framing of the subject. The video, recorded at 24 FPS, allowed for continuous capture, allowing for the selection of useful images from the frames in later processing.

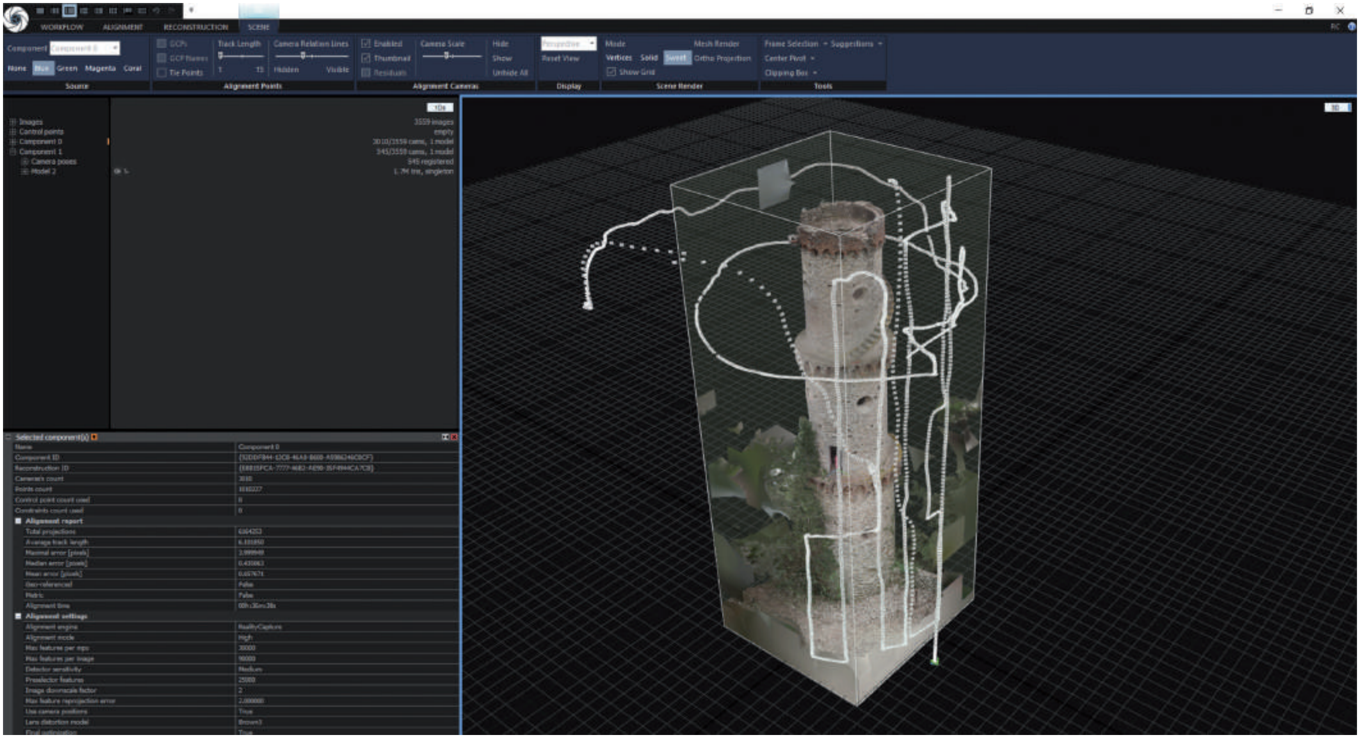

Figure 5. Epic Games Reality Capture screenshot, Round Tower.

5. Digital Photogrammetry

Once the photographic survey campaign has been carried out, the rest of the workflow moves entirely to the studio and calls for the use of software to achieve the usable and distributable product. First step, preliminary, is the control on the quality of the executed shots. Possible post-production operations to obtain a uniformity of exposure between the individual shots. Then through the use of software for digital photogrammetry is built the final mesh model, appropriately decimated in preparation for subsequent steps, with associated texture. The images and photo frames used for the reconstruction were 3560 in resolution 1920x1080 px, saved in JPG format. Not an optimal format but the only one available on DJI Mavic Mini.

The images processed with the software Epic Games Reality Capture, obtaining a final mesh model (Figure 5) of 6.660.000 polygons with associated texture of 16400x16400 px (Figure 6). In the context of the photogrammetric process steps, two not negligible peculiarities are highlighted. The model obtained was initially more extended (Figure 7) compared to the single Round Tower, it has been reducted and cleaned of the vegetation in order to obtain an optimized object of useless polygonations and, not ordered, cause of unnecessary weighting of the topology. The second peculiarity is due to the lack of a decimation phase of the mesh obtained. In fact, the model consisting of 6660000 polygons is already usable, after export, on VR software. Therefore, no backing processes have been applied. The last step, related to the photogrammetric reconstruction phase, was the export. The OBJ format was chosen with associated MTL and PNG textures.

Figure 6. Epic Games Reality Capture screenshot, site of Round Tower.

6. Virtual Reality

The export phase of the digital model has been conducted taking into account the requirements for the fruition of the data through tools such as Virtual Reality. The data obtained was converted into .fbx format and then imported into the software Epic Games Unreal Engine 4.27, allowing the modification of some basic settings proposed by the software at the time of importing mesh, such as the possibility of deciding to create a new material and associate it directly to the imported mesh or whether to keep the information regarding the lighting of the object. Subsequently the process continues with the creation of a new material to which the texture exported at the end of the processing of the data acquired during the digital photogrammetry is associated.
It is a texture already mapped and therefore it will cover the mesh perfectly.

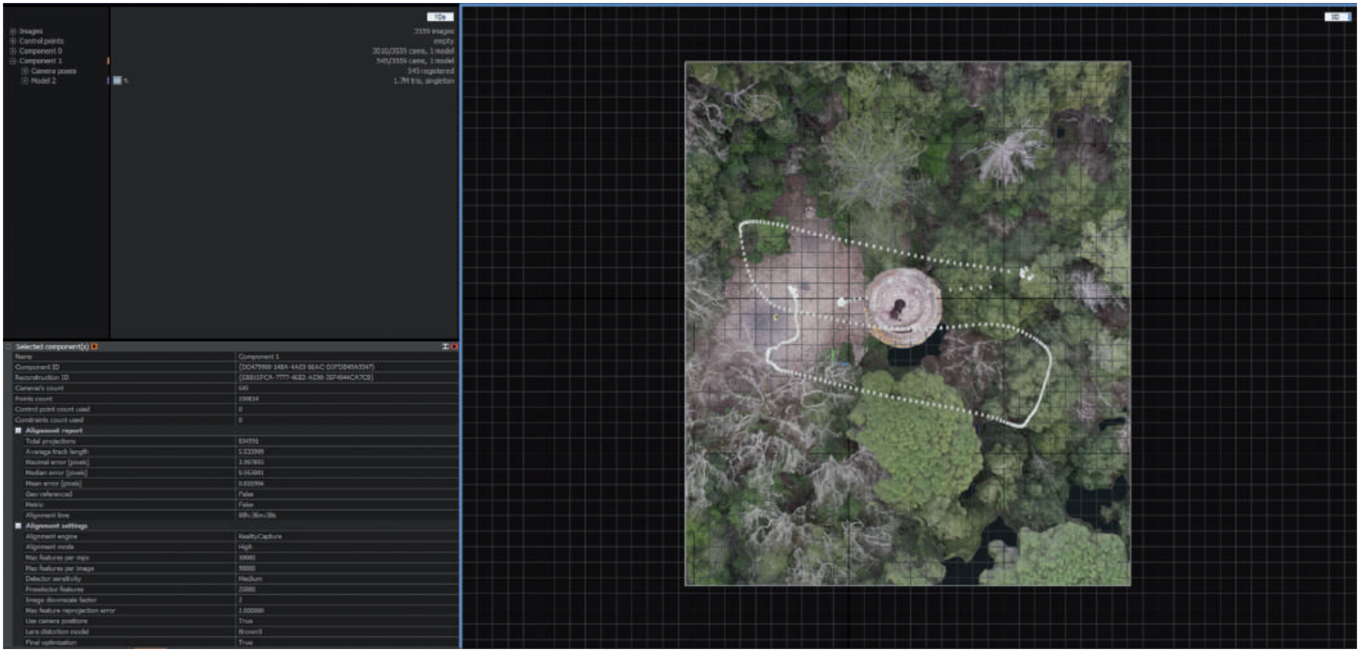

Figure 7. Epic Games Reality Capture screenshot, detail.

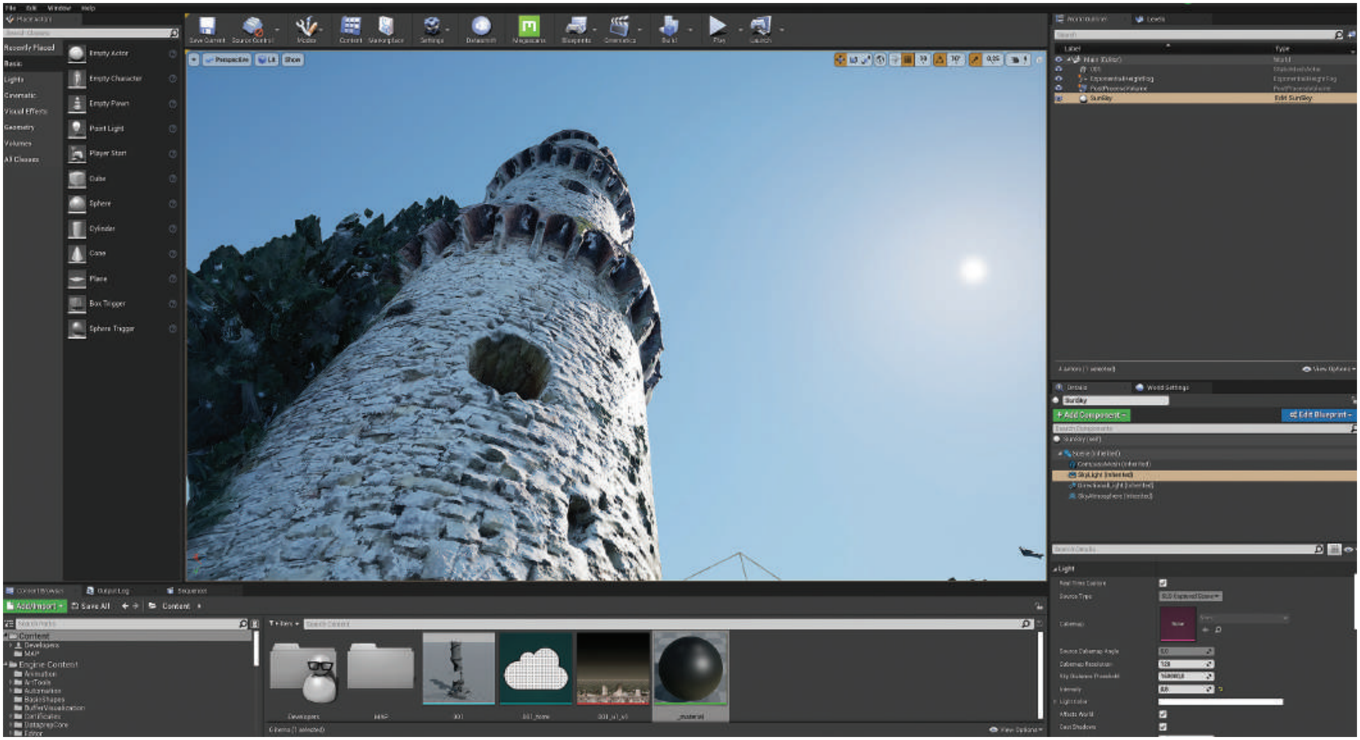

Figure 9. Epic Games Unreal Engine screenshot, Round Tower.

The last step consists in the setting of the blueprint and its functions in order to enjoy the virtual space through interactions that are transmitted using the visors dedicated to VR and their joysticks.
This process, in its simplicity, allows to reach a great result, that is the fruition of the good in question through means that go beyond the 2D representation, and that allow a more detailed analysis of the object, exploiting not so much a new technology, but a new awareness that is behind the use of these tools. The use of software for the management of virtual environments allows to obtain the restitution of the survey with the digital environment usable and transmissible through the network or spread with application packages or loadable on a server for direct use.

7. Conclusion

The contribution is structured through the presentation of a real theme, related to Cultural Heritage, on which the operational choices have been applied.
As mentioned, the paper wants to adapt to the emergency period, recent procedures clearly rooted in the practice of study and preservation of Cultural Heritage.
All this in order to ensure dissemination and facilitate dialogue between scholars of different subjects engaged in the topic.
In addition to the above, there is the will to build a parallel digital world open to the crowds interested in visiting places and objects of great identity value.

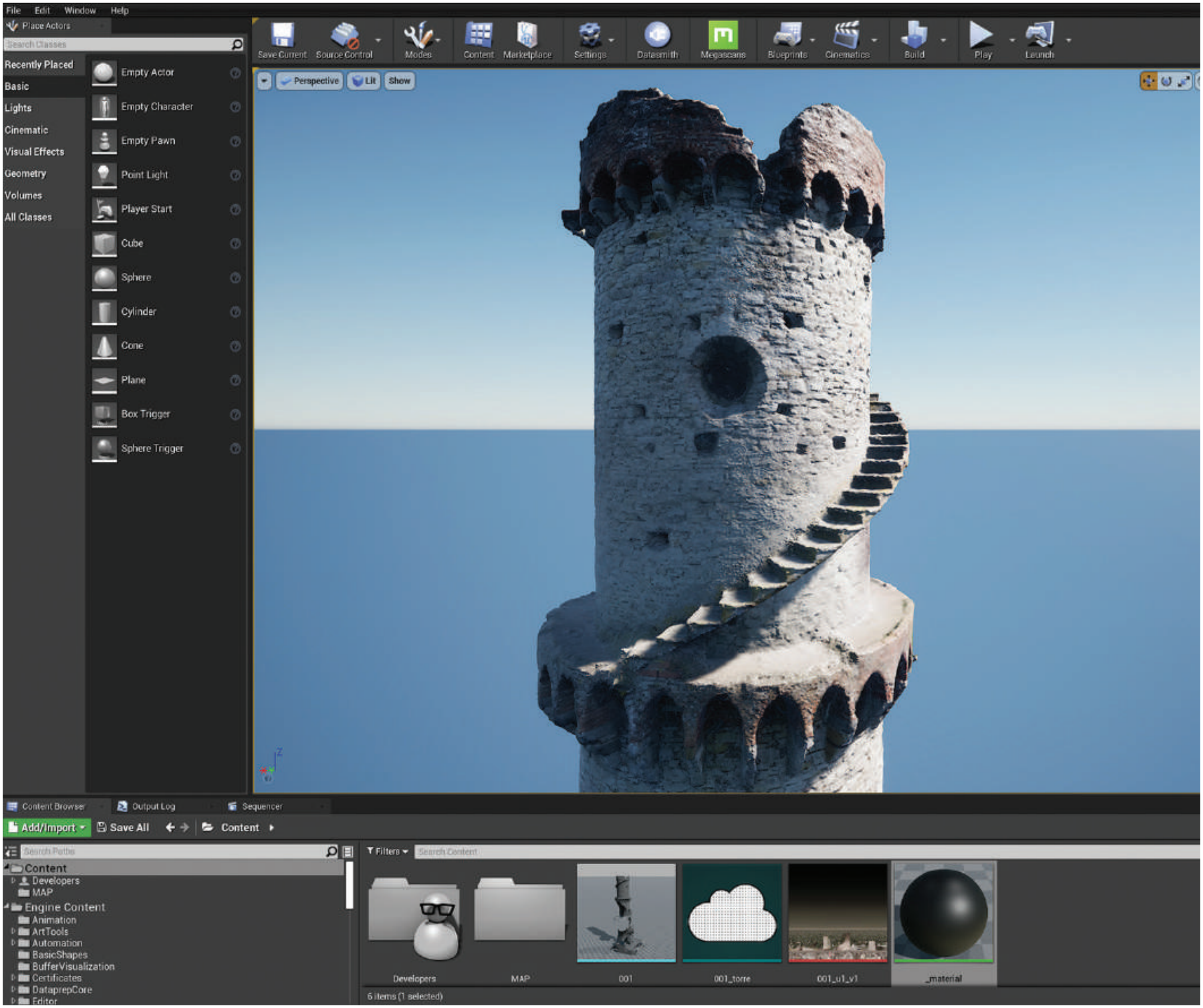

Figure 10. Epic Games Unreal Engine screenshot, Round Tower, detail.

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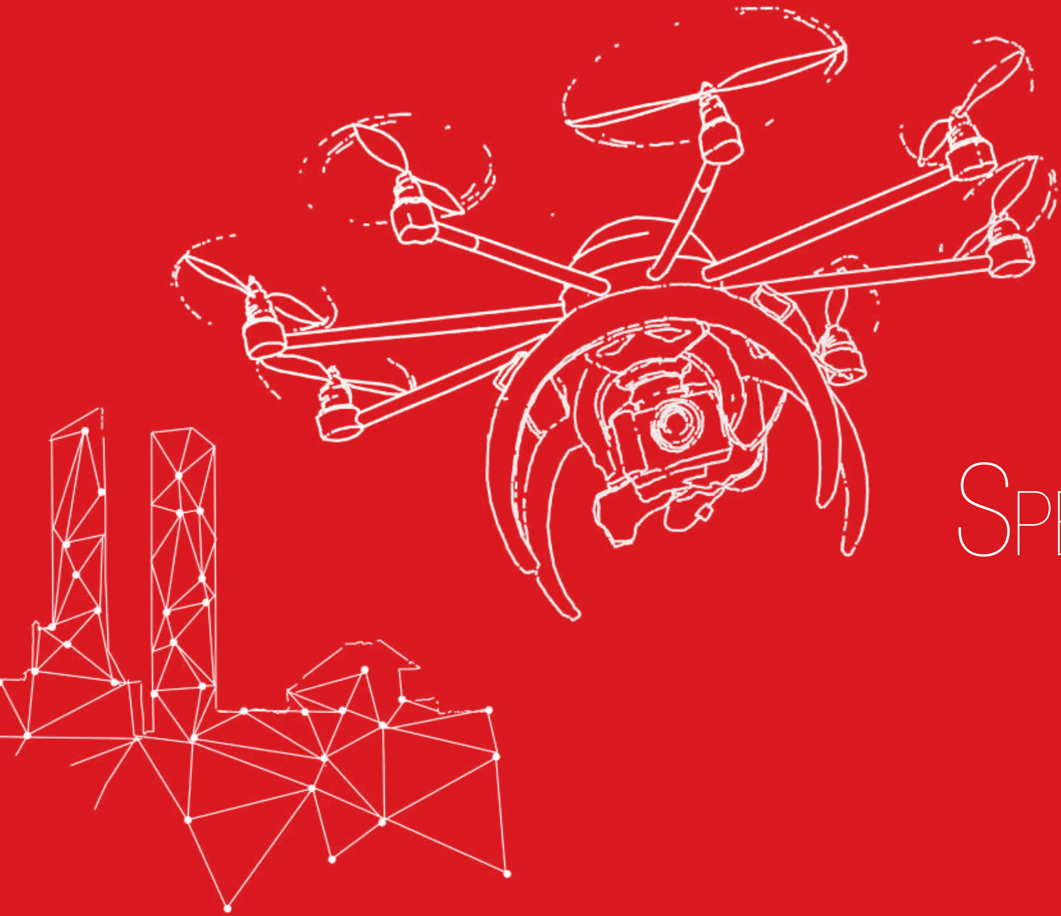


Special Session

Remote Sensing in Agriculture and Forestry

Chair

Mirco Boschetti

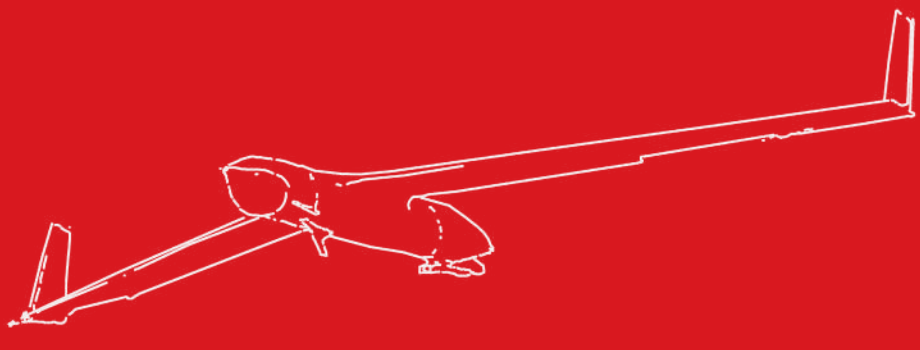
IREA-CNR

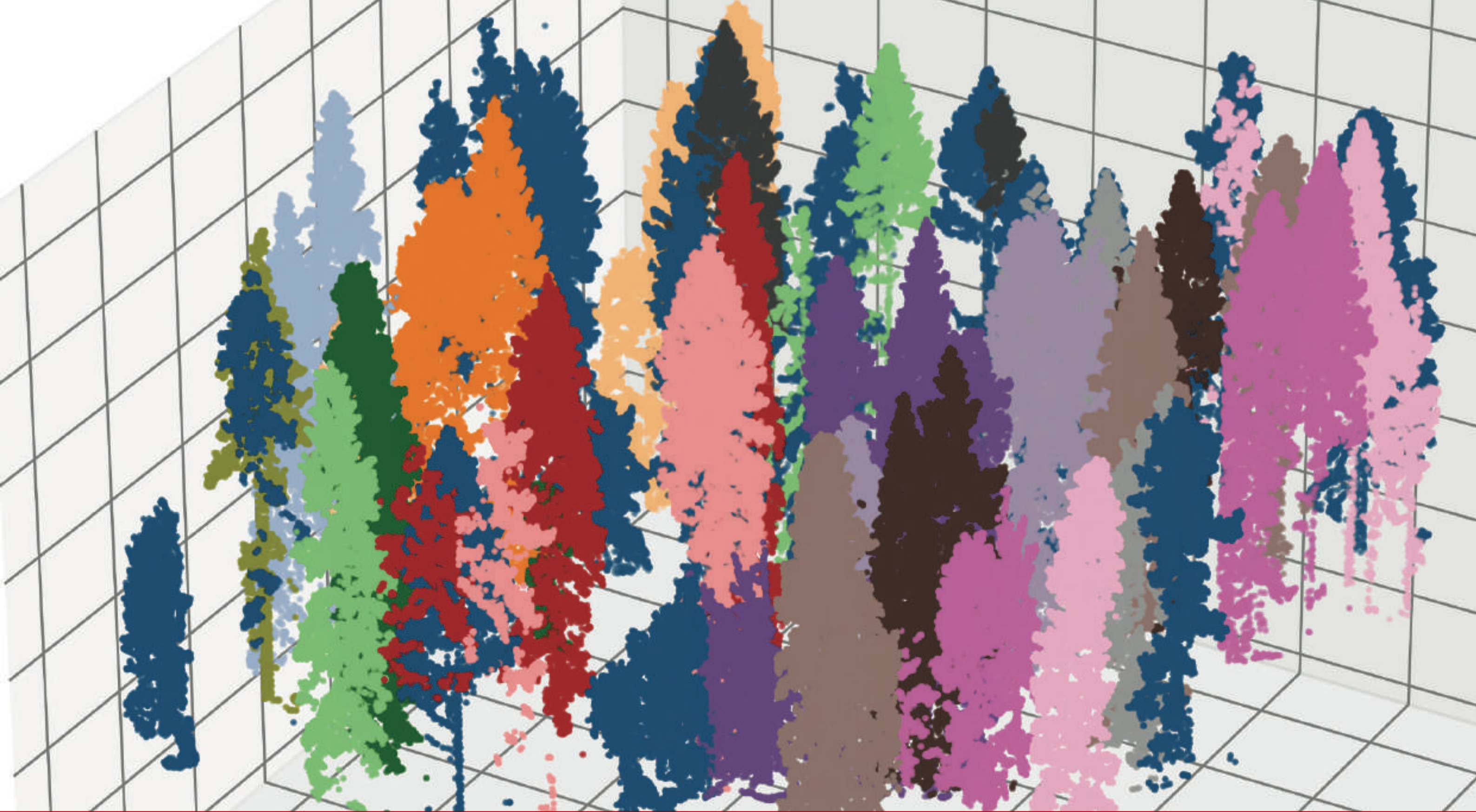
Co-Chair

Enrico Borgogno Mondino

University of Turin, Department of Agricultural, Forestry and Food Sciences (DISAFA)

The integration of the agriculture and forestry domain into the Copernicus users community is fur- ther increasing the possibility to address the needs of this sector with new remote-sensing based services and information.
The aforementioned services are also enabling dedicated platforms for the integrated management of multi-scale and multi-sensors (satellite, aerial, UAV) data and other information sources from public and private entities.
A significant acceleration has occurred in recent months due to the COVID-19 emergency, pushing further the use of Remote Sensing to minimize field activities and increase the remote exchange of data between farmers and agro-forest technicians, through dedicated digital and web applications (e.g. Regulation EU No 2020/532).
In this innovative context, spatial data and geoinformation play a key role in facilitating the "digital transformation" of the agronomic and forestry domain, providing operational services to users characterized by a higher level of accessibility, usability, and understanding.
This session will provide insights into the state of the art of Remote Sensing techniques, focusing on challenges and perspectives of the sector.





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Keywords:
Point clouds, Automatic detection, Multitemporal analysis.

Forest change detection using multi-temporal aerial point clouds

1. Introduction

Optimal management of the forest resource from an economic, environmental and sustainable perspective is a primary need, and it requires innovative approaches (Fardusi et al, 2017), such as LiDAR technology, which supports a wide range of research fields.
It can be used in precision forestry (Akay A.E et al, 2009), combined with aerial supports (i.e., helicopters, drones). LiDAR can facilitate surveys and helps to understand the effects of climate change (CC) (Kirilenko A.P et al, 2007) and anthropogenic disturbance through analysis over time.
The purpose of the current study is to define an automatic and innovative method of multi-temporal point cloud change detection in uneven-aged ad mixed forests, based on identifying and monitoring the same trees over time and detecting the trees damaged (e.g., broken, uprooted) due to CC-induced disturbances.

2. Case study and materials

The study was conducted in the Dinaric Mountains in southwest Slovenia in Dinaric silver fir – European beech forest with main tree species of silver fir (Abies alba Mill.), Norway spruce (Picea abies Karst.) and European beech (Fagus sylvatica L.) (Figure 1). In January–February 2014, an extreme ice storm caused damage to more than half a million hectares of forests across Slovenia (Nagel T.A et al, 2016). As part of a Life+ ManFor C.BD. project, LiDAR acquisitions and in-situ measurements were collected during November 2013 (pre-ice-break) and April 2014 (post-ice-break). Laser scans were acquired with a helicopter equipped with a Riegl LM5600 (point clouds density of about 250 pts/m2, Figure 2).
In-situ measurements on 0.4 ha circular plots (radius = 35.7 m) were realized in November 2013 during which the locations of trees, the DBH (Diameter at Breast Height) and the social status of a tree (relative to the surrounding trees) were collected; moreover, during a post-ice-break survey, the felled trees have been identified.

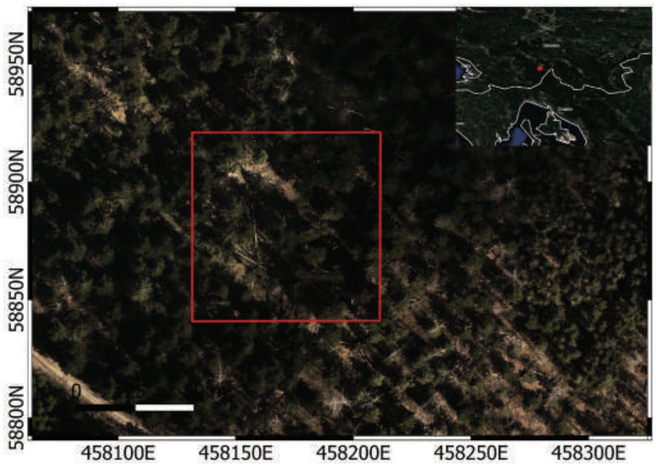

Figure 1. Study area.

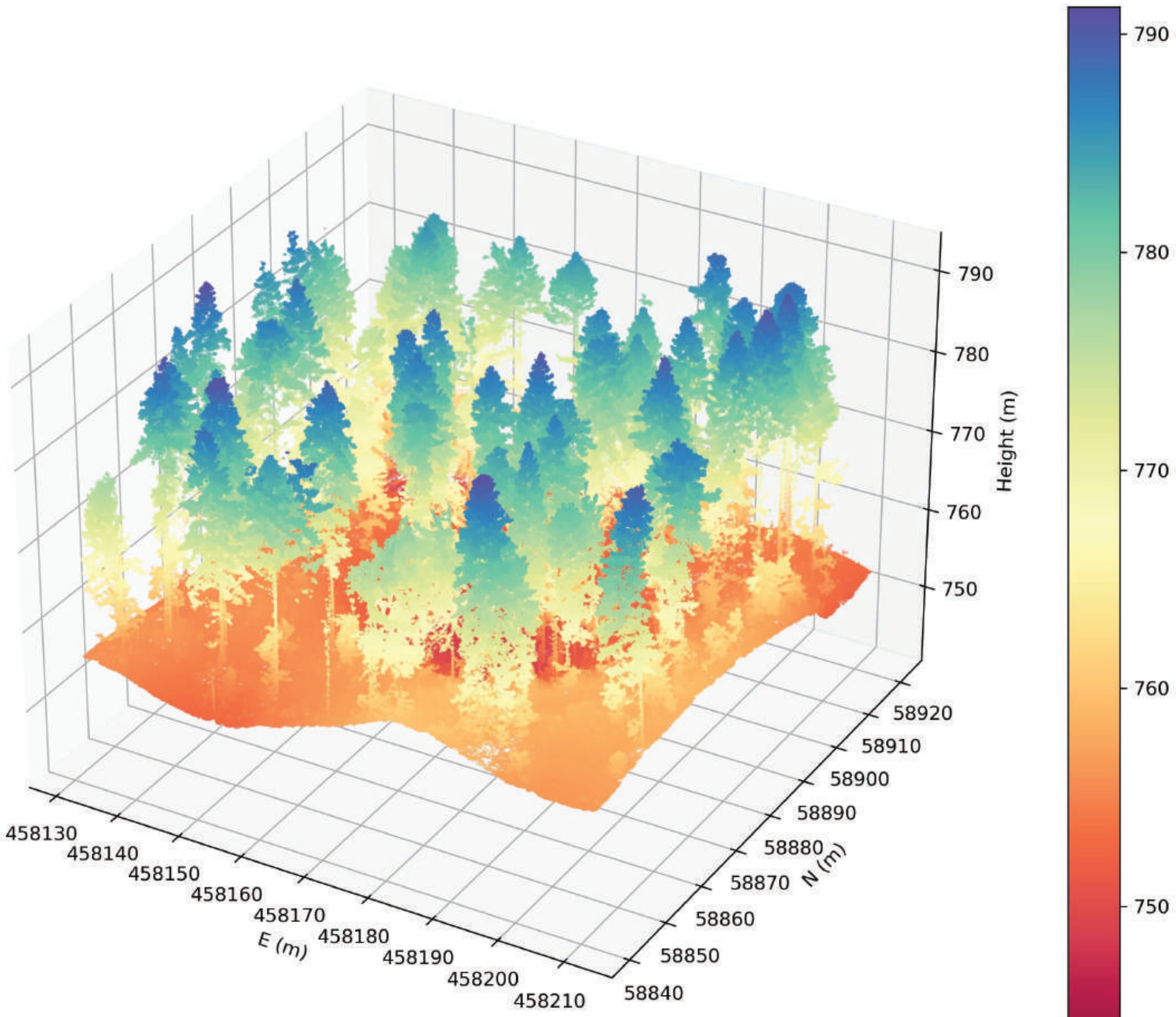

Figure 2. Point cloud acquisition. EPSG:3912.

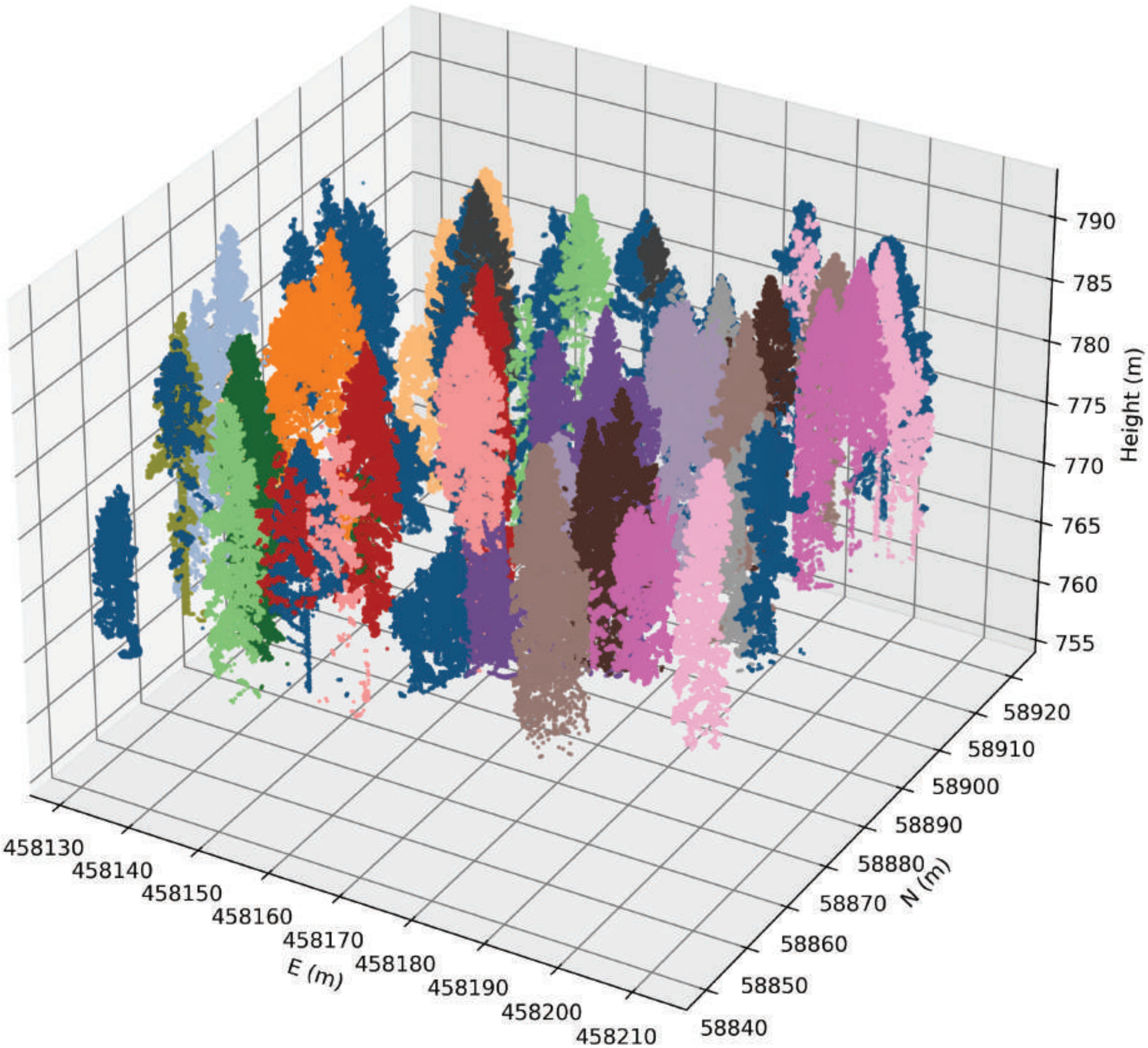

Figure 3. On the Cover: Segmented point clouds: matched trees in colors, felled trees in blue.

3 Methods

A ground point classification was carried out applying the CSF filtering method (Zhang W. et al, 2016); subsequently, the DTM (Digital Terrain Model) and the DSM (Digital Surface Model) were obtained through 'Whitebox' Python package, and the CHM (Canopy Height Model) was calculated as the difference between them.

The individual treetops were detected by a local maxima investigation over the CHM, and then the crowns were segmented by region growing algorithm with treetops as input seeds (Zörner J. et al, 2020) using 'PyCrown' package. For the parameters tuning, several tests were performed, and the best outputs were obtained with standard parameters and the maximum value of the crown radius equal to 7 m. These parameters can be considered efficient for coniferous forests with the same characteristics; further test should be performed in order to optimize results in deciduous forests for which treetop identification is more complex. The algorithm returns the segmented point cloud, the treetops locations and height, and crown boundaries.

After processing both point clouds (pre- and post-ice-break), change detection of the trees were carried out considering the treetop positions, assuming that if a tree was only minor damaged, its position does not vary significantly. The method considers a circular area around the treetops of the pre-event scenario with variable radius according to the crowns' size; then, it selects post-event treetops laying in the circular regions. If several points lay into the circular areas, the closest treetop is matched; the tree was uprooted if no point is selected. In this way, it is possible to assign the same label to the matched trees and detect changes in forest stand before and after ice-break. The novelty lies in the use of treetops as a discriminating factor for the multitemporal match, since it is easy to be identified and it is meaningful to discriminate unscathed trees from those both uprooted and severely damaged (e.g., broken trees).

The validation process of the segmentation was carried out comparing the outcomes with reference crowns defined by visual interpretation supported by the data of the in-situ survey. Similarly, the validation of the change detection algorithm is performed comparing the resulting matching trees with a visual interpretation of the input point clouds, supported by in-situ data.

4. Results and discussion

The accuracy assessment has been evaluated with PA (Producer's Accuracy), UA (User's Accuracy) and F1 score parameters (Belcore E. et al, 2020) related as follows:

$$Producer's\ Accuracy = \frac{Nr.\ of\ matches}{Reference\ Crowns}$$

$$User's\ Accuracy = \frac{Nr.\ of\ matches}{Defined\ Crowns}$$

$$F1\ score = \frac{2*PA*UA}{PA+UA}$$

The validation of both the segmentation and the matching procedure was performed with respect to the F1 score. Table 1 summarizes the results. The segmentation accuracies of the two datasets are considered acceptable in natural scenarios (70% and 68%), consistent with other studies (Ma K. et al, 2022) and coherent with each other. Moreover, no cases of simple omission were recorded, which means that all the trees where detected; the discrepancy between the number of trees identified by the algorithm (Defined Crowns) and the real one (Reference Crowns) is due to the under-segmentation (two or more trees detected as one) and the over-segmentation (a single tree segmentated in multiple trees).

The change detection accuracy assumes values entirely consistent with those of the segmentation (69% and 63%) since the segmentation performance strongly limits them. In fact, several matchings are not valid because trees are affected by under- or over-segmentation. An additional indicator of this relationship is that the F1 score in 2013 scenario increases up to 80% if matches between over-segmented trees are considered valid ("2013, No over-segment" column of Table 1).

	Segmentation		Trees match		
	2013	2014	2013	2014	2013, No over-segments
M	58	39	34	31	39
RC	87	56	56	56	56
PA	0.67	0.70	0.61	0.55	0.70
DC	79	58	42	42	42
UA	0.73	0.67	0.81	0.74	0.93
F1	70%	68%	69%	63%	80%

Table 1. Accuracy assessment results. M = Matched; RC = Reference Crowns; PA = Producer Accuracy; DC = Defined Crowns; UA = User Accuracy.

5. Conclusions

This study presents an automatic change detection method for segmenting multitemporal tree point clouds identifying trees over time and locating the up-rooted ones.

The results are promising, and they emphasize the validity of the algorithm; however, this study should be considered the first step of a broader analysis. Firstly, This approach was tested on a relatively small area of interest; further areas with ground truth data will be considered to improve the statistically meaningful of results. it is also necessary to evaluate the method's accuracy under different forest stand conditions, such as various tree species and forest densities, which can considerably influence the proposed method's performance. Subsequently, further tests on treetop detection algorithms should be implemented.From the forest management point of view, the proposed approach can be very supportive, allowing the acquisition of information on large areas quickly. Moreover, implementing the latest LiDAR technologies on drones would increase the point density and the overall accuracy in smaller areas. Laser scanner equipped on elicopters can be still used in order to manage larger areas with a good accuracy, providing a greater quantity of information than other processing (e.g., photogrammetric analysis) thanks to the multiple returns of laser pulses.

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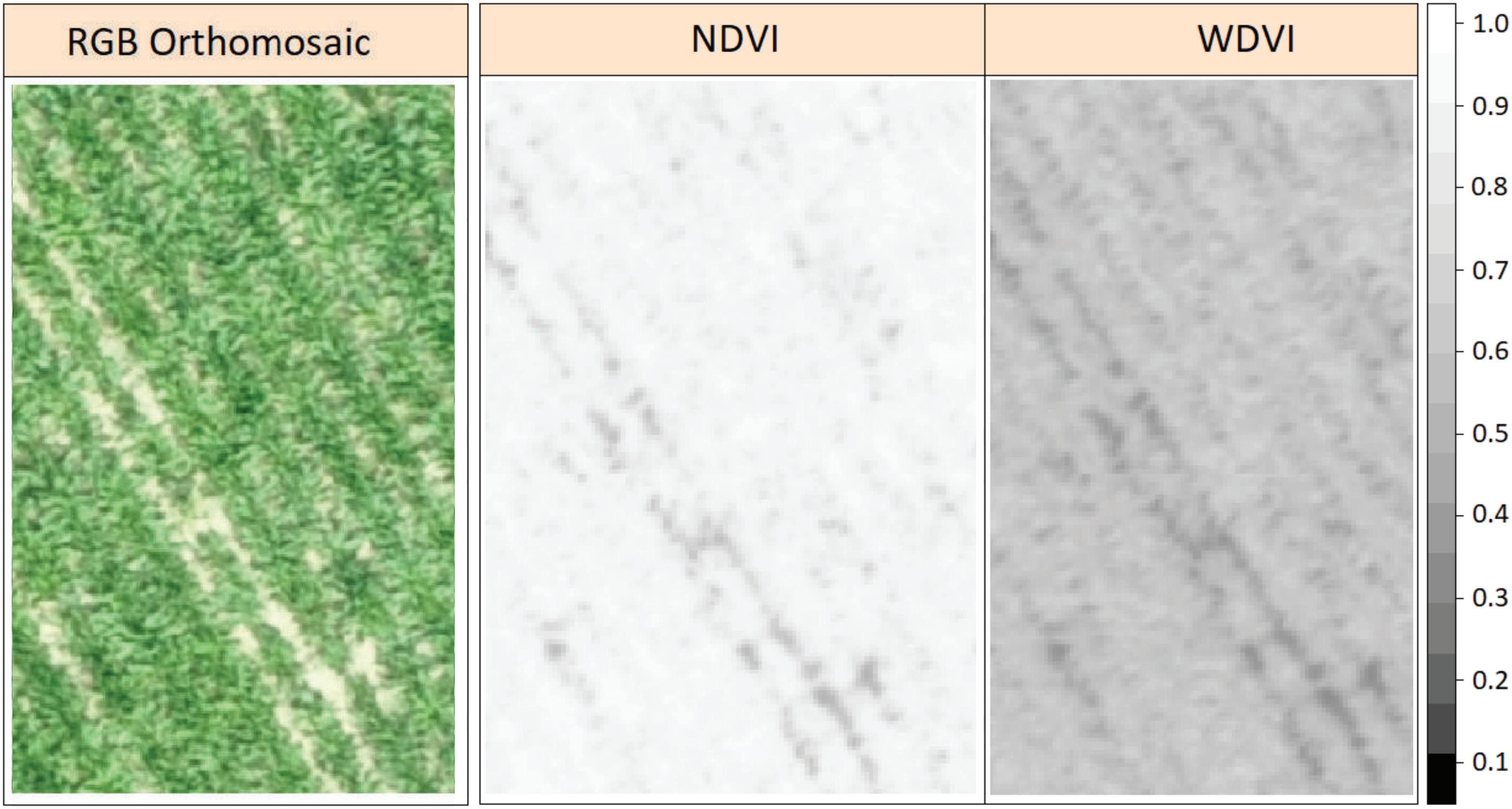

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Keywords:
UAV, Soil organic carbon, Crop water stress.

Exploring the relationship between soil organic carbon and crop water stress across century-old biochar patches within agricultural fields by combining UAV thermal, multispectral, and RGB images

1. Introduction

In the context of climate-smart agriculture, biochar (the black carbon residue of biomass pyrolysis) amendment has gained increasing attention thanks to its ability to improve soil quality, and in particular, water holding capacity (e.g. Glaser et al. 2002). Hence, biochar use can help in reducing crop water stress by increasing plant available water content (Fischer et al. 2019).
UAV thermal imagery can meet the necessities of precision agriculture to accurately map crop water stress (Zarco-Tejada et al. 2013). The usage of hyperspectral sensors to monitor soil organic carbon (SOC) has been widely studied. However, deploying multispectral sensors for similar purpose has yet to be evaluated. Heidarian Dehkordi et al. (2022) showed that biochar strongly affects surface spectral status such as surface albedo (SA) derived from UAV multispectral images.
The primary objective of this study was to map SOC variability for a field with patches of buried biochar by relating UAV multispectral images to in-field SOC values; with an overarching goal of evaluating biochar impact on crop water stress.

2. Materials and Methods

UAV images were acquired over a winter wheat field located in the Namur province of Belgium (NW corner: 50°31'N 4°44'E; SE corner: 50°31'N 4°45'E) in which several century-old biochar patches were present (Heidarian Dehkordi et al. 2020). Plots of 10 by 10 m, labelled from 1 to 10, were considered within the biochar and the adjacent reference patches.
RGB dataset was acquired using a DJI Phantom 4 Pro operating at 65 m altitude with 35 min endurance, resulting in two UAV flights to map the whole field. Multispectral and thermal datasets were collected using MicaSense RedEdge-M and FLIR Vue Pro R 640 sensors, respectively, on board of a DJI Matrice 100 flying at 60 m. Two TB48D batteries were used to increase the flight endurance to 30 min, and hence, the entire site was captured in two consecutive flights. The resulted ground sampling distance was 1.8 cm, 3.7 cm, and 7 cm for RGB, multispectral, and thermal images, respectively. UAV images were processed in Pix4Dmapper. The geometric accuracy was enhanced using ground control points with known coordinates measured by an RTK-GNSS.
A reflectance calibration panel was captured to radiometrically process the multispectral images. Within-flight irradiance was recorded by a downwelling light sensor attached to the multispectral camera. This data was used to aid the radiometric calibration.
FLIR brightness temperature values were converted to surface temperature values using reference targets with known ground temperature values measured by a hand-held thermal imager.
SA was retrieved from the multispectral images when the field was bare soil as:

$$SA = \frac{[0.356\,R_{\mathrm{blue}} + 0.130\,R_{\mathrm{red}} + 0.373\,R_{\mathrm{NIR}} - 0.0018]}{[0.356 + 0.130 + 0.373]} \quad (1)$$

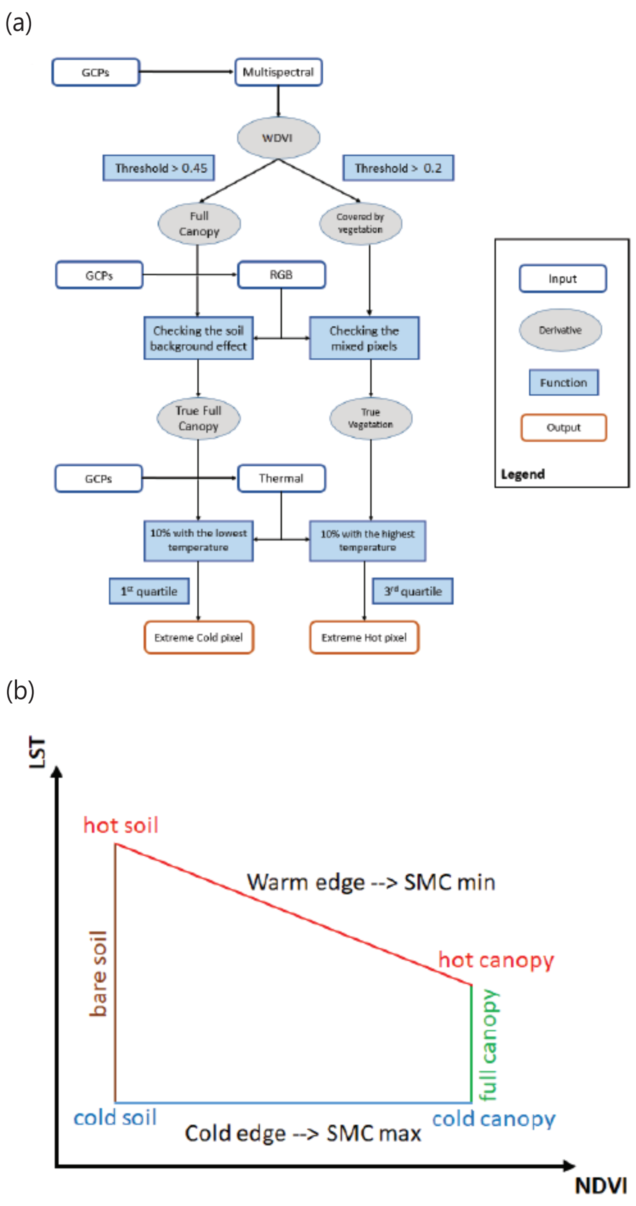

Figure 1. Flowchart of the proposed algorithm used to retrieve the extreme pixels for UAV-based CWSI modelling in the present study (a). NDVI/LST trapezoidal space to identify extreme pixels as well as the limiting edges to predict the soil moisture content (b).

where R_{blue}, R_{red}, and R_{NIR} are the reflectance values of the blue, red, and near-infrared bands, respectively.

For each investigated plot, SOC was determined based on dry combustion. SOC values were then correlated with the corresponding UAV SA values to generate a spatially explicit map of SOC across the experimental site.

Gago et al. (2015) initially designed crop water stress index (CWSI) for irrigated crops. We developed a relative CWSI (r-CWSI) that represents a relative pattern of CWSI across our rainfed study site as:

$$r - CWSI = \frac{[T_{canopy} - T_{cold}]}{[T_{hot} - T_{cold}]} \quad (2)$$

where T_{canopy}, T_{cold}, and T_{hot} are the temperature of canopy surface, a thoroughly vegetation-covered pixel with maximum leaf transpiration rate, and a reference surface covered by vegetation which claims the highest rate of water stress.

Our methodology (Figure 1a) is similar to trapezoid algorithm (Long, Singh 2012) which identifies four extreme pixels (cold/hot soil and cold/hot vegetation) based on the combination of the vegetation coverage and land surface temperature (LST) defining a trapezoidal space (Figure 1b).

The normalized difference vegetation index (NDVI) and the weighted difference vegetation index (WDVI; Clevers et al. 1989) were determined to represent the vegetation coverage in LST/VI trapezoidal space. WDVI was found to be less saturated and exhibited a better soil-vegetation separation as compared to NDVI (Figure 2).

The hot pixel should not be attained from a pure bare soil area since T_{hot} in Eq. (2) reveals the minimum leaf transpiration and should be covered by a minimum level of vegetation. The identified pixels from areas where the vegetation exists (by thresholding the WDVI image; Figure 1a) were evaluated by overlaying WDVI map on the higher resolution RGB image to ensure vegetation presence for the selected pixels prior to the creation of the vegetation cover mask layer. Finally, 10% of the selected pixels with the highest temperature values

(Veysi et al., 2017) were extracted and the third quartile was calculated to identify the extreme hot pixel. The same procedure was adopted to identify the extreme cold pixel (Figure 1a).

3 Results and Discussion

There was a negative relationship (R^2 = 0.65) between in-field SOC values and UAV-based SA (Figure 3a). The average (standard deviation) SA was 0.12 (0.01) in the reference plots as compared to 0.09 (0.02) for the biochar plots. Such negative relationship can be explained by the aggravated dark color soil across the biochar patches (Heidarian Dehkordi et al., 2022) that decreases the reflectance values in the computation of SA (see Equation 1).

By fitting the attained regression line between SOC and SA, a map of SOC was predicted over the entire field with SOC values ranging from 0.7% to 3.1% (Figure 3b). Footprints of biochar patches within the study field were clearly discerned. The latter is most likely attributable to the significantly higher SOC values across the biochar patches as compared to the reference ones (Heidarian Dehkordi et al. 2020).

The modelled r-CWSI map (Figure 4a) exhibits a condition of less water stress in the western part of the field (r-CWSI < 0.4) due to the shadow of the forest area next to this side. There was a moderately-stressed zone (0.4 < r-CWSI <0.6) in the upper left part of the field, and also a severely-stressed zone (r-CWSI > 0.6) in the middle of the field in which the crop suffered from water deficit (Figure 4a).

The overall accuracy of crop water stress map was investigated by a visual interpretation of all the 22 experimental plots comparing the r-CWSI result and the corresponding RGB imagery. The identified severely-stressed spots (red-colored pixels in r-CWSI image) correspond to yellowish wheat leaves in the RGB image. As an example Figure 4b shows plot 9 comparison.

Higher SOC values across the biochar patches were found to significantly decrease r-CWSI in these areas (Figure 4a). The average (standard deviation) r-CWSI was 0.62 (0.22) in the reference plots versus 0.38 (0.21) for the biochar plots. This finding is in accordance with the literature reported higher soil water holding capacity and also higher plant available water content across the biochar patches (de la Rosa et al. 2014; Jeffery et al. 2015).

We encourage future experiments to assess our approach across various crop types using unprecedented multispectral satellite images (e.g. Sentinel-2) in combination with high-resolution thermal images captured by aerial platforms.

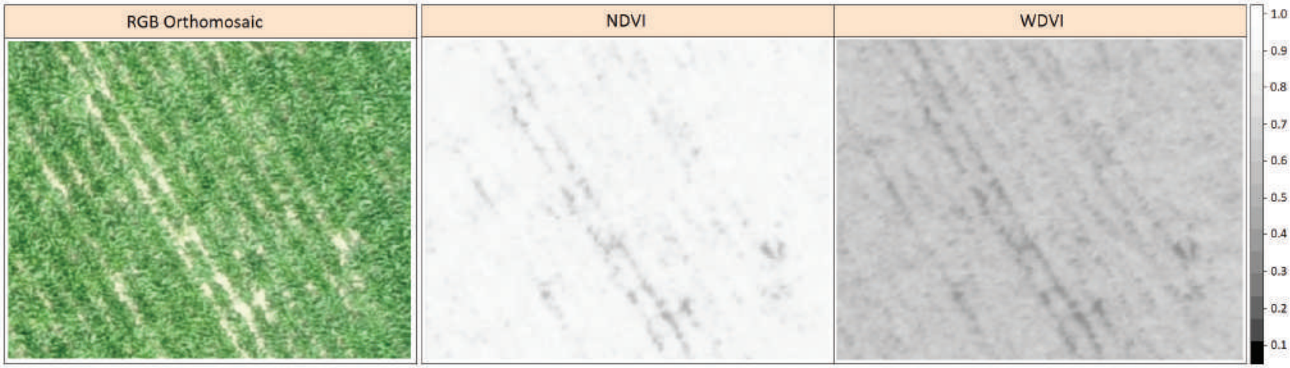

Figure 2. On the Cover: True color composite RGB orthomosaic over an area of the study field where the soil background is visible (left) along with the corresponding NDVI (middle) in which the index is highly saturated, while WDVI (right) exhibits a sharper soil background that enables proper discrimination between vegetation and soil clusters.

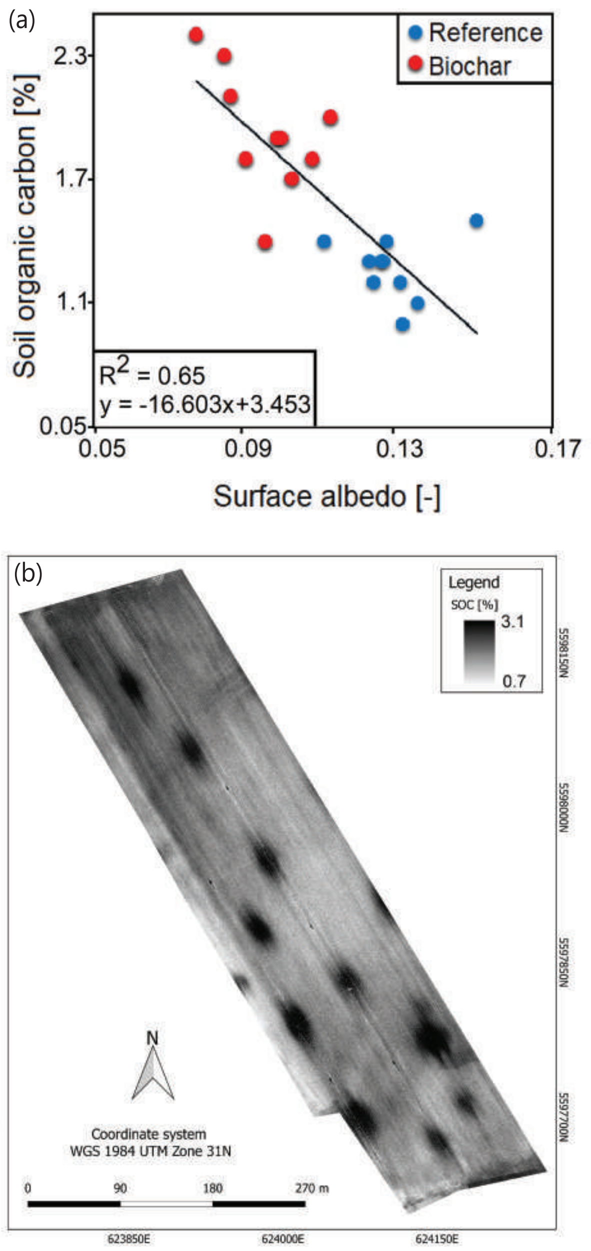

Figure 3. (a) Relationship between in-field soil organic carbon (SOC) and UAV-based surface albedo. (b) The predicted map of soil organic carbon (SOC) based on UAV-based surface albedo and in-field SOC values.

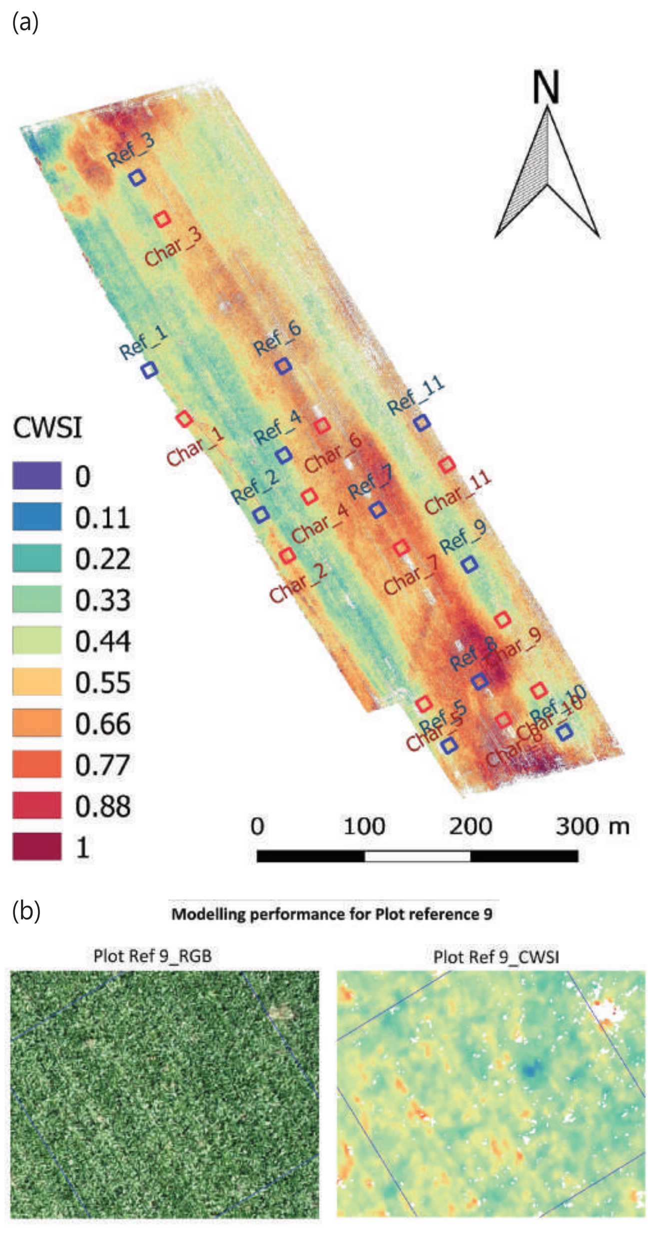

Figure 4. (a) r-CWSI maps along with the (b) image detail showing the robustness of the CWSI modelling for the reference plot 9 comparing the CWSI result with the original RGB image.

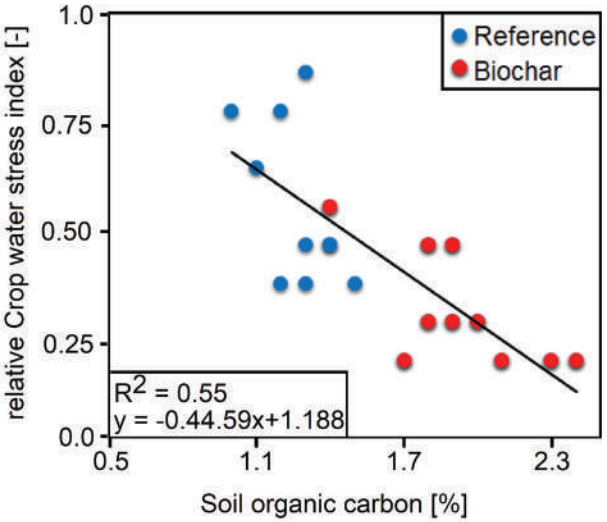

Figure 5. (Relationship between soil organic carbon (SOC) and relative crop water stress index (r-CWSI).

4. Conclusions

The present study demonstrated the utility of combining UAV thermal, multispectral, and RGB images to address precision agricultural needs. We illustrated the potential of multispectral images to map SOC in the agricultural fields. The modelled r-CWSI indicated a negative relationship with SOC across the biochar patches. The approach we present can be readily applied to assess crop water stress as a function of any other precision agricultural treatments. Future research may repeat our approach combining satellite and airborne images across a larger extent.

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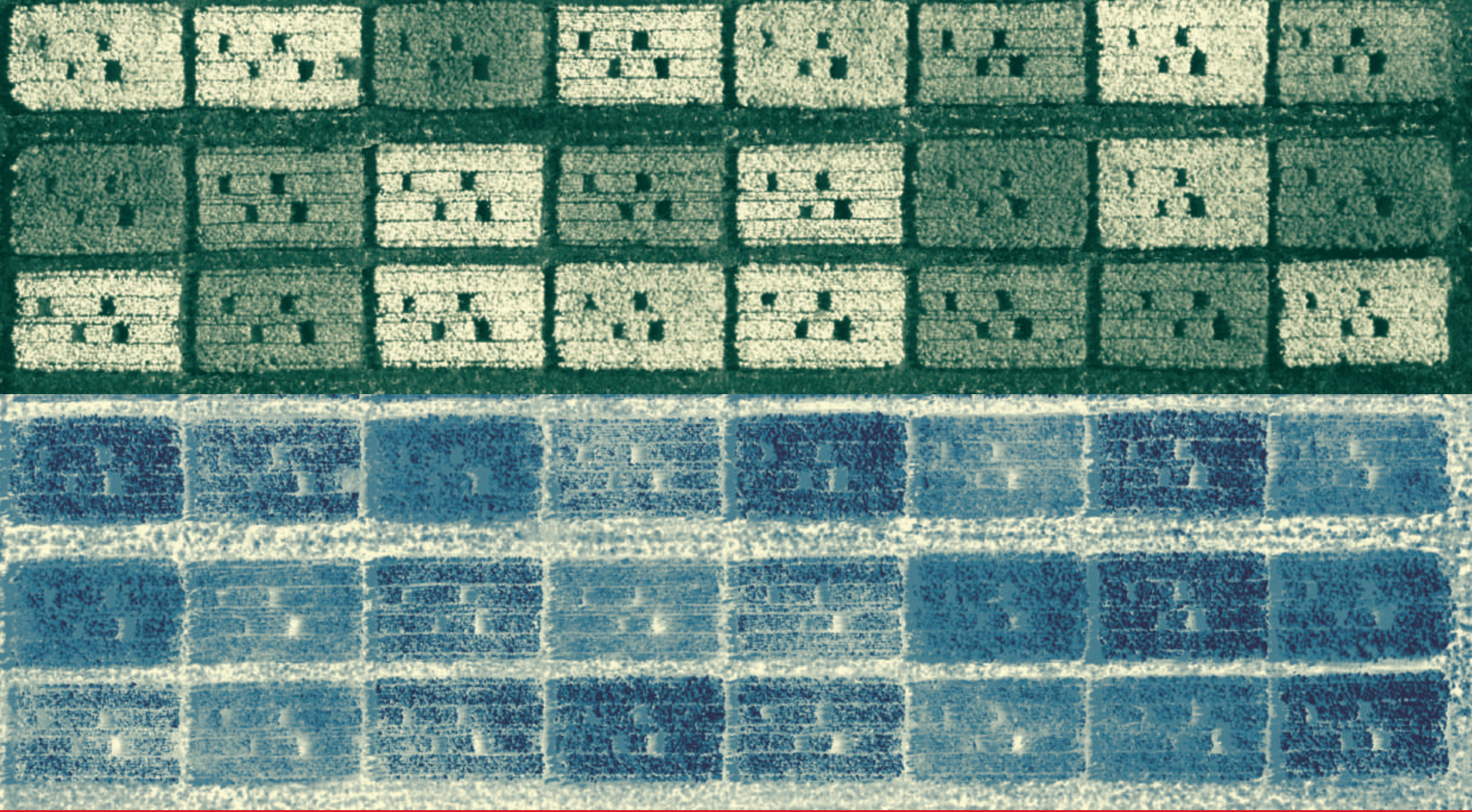

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Keywords:
UAV, PROSAIL, GAM.

UAV-based remote sensing to evaluate nitrogen and irrigation effects on LAI and LCC dynamics combining PROSAIL model and GAM

1. Introduction

Leaf area index (LAI) and leaf chlorophyll content (LCC) are among the most important crop traits retrieved in remote sensing applications (Xie, Yang 2020). Spatial and temporal information on LAI and LCC are usually regarded as relevant traits to monitor the status of crop growth (Duan et al. 2019). Recently, several studies have demonstrated that the coupling of unmanned aerial vehicle (UAV) remote sensing and the PROSAIL model enables reliable retrieval of crop traits, such as LAI and LCC (Wan et al. 2021; Zhu et al. 2019). However, these studies only evaluated the ability of the PROSAIL model to retrieve crop traits, without characterizing the dynamic of crop traits evolution along the growing season using the values estimated by the PROSAIL model.

2. Objectives

The objectives of this study were: i) to retrieve the hemp and tomato traits, leaf area index (LAI) and leaf chlorophyll content (LCC) by UAV-based remote sensing using the inversion of the PROSAIL model and ii) to characterize the dynamics of crop traits (LAI and LCC) under different nitrogen fertilization (hemp) and irrigation (tomato) levels via generalized additive model (GAM).

3. Materials and methods

Hemp and tomato crops were investigated during the year 2020. The field experiments were conducted in the province of Piacenza (N Italy) (Figure 1). The hemp experimental layout was a complete randomised block design with two cultivars differing in their phenotype (a green and a yellow one) and four nitrogen levels: 0, 25, 50 and 100 kg ha-1 for a total of n = 32 plots (Figure 1). The tomato experimental layout was a strip block design with 3 irrigation levels: 25%, 50%, 100% of plant available water (PAW) for a total of n = 36 plots (Figure 1).

Georeferenced field measurements were carried out for each plot to measure leaf area index (LAI), leaf chlorophyll content (LCC), leaf dry content per unit leaf area (Cm), and leaf water per unit leaf area (Cw) (Figure 2a). The field measurements area was fixed at the start of the growing season and georeferenced using targets visible on UAV images. LAI measurements were collected within the area and other destructive measurements outside of it.

Unmanned aerial vehicle (UAV) flights were carried out at the same time as field measurements, and supplementary flight missions were also carried out to improve the crop traits dynamics characterization (Figure 2a). The UAV used in the experiments was the DJI Matrice 210 RTK (Real Time Kinematic) which was equipped with MicaSense RedEdge-Mx multispectral camera. RedEdge-Mx camera acquired the images in five spectral bands: blue (475 nm centre, 32 nm FWHM), green (560 nm centre, 27 nm FWHM), red (668 nm centre, 14 nm FWHM), red edge (717 nm centre, 12 nm FWHM) and near-infrared (840 nm centre, 57 nm FWHM). All flights were performed in clear sky conditions between 11 a.m. and 3 p.m. The flight altitude above ground level (AGL) was 50 m and the forward overlap was set at 80% and lateral overlap was set at 75% of the images. The ground sampling distance (GSD) was 2.78 cm, and the flight speed was set at 3 m s-1.

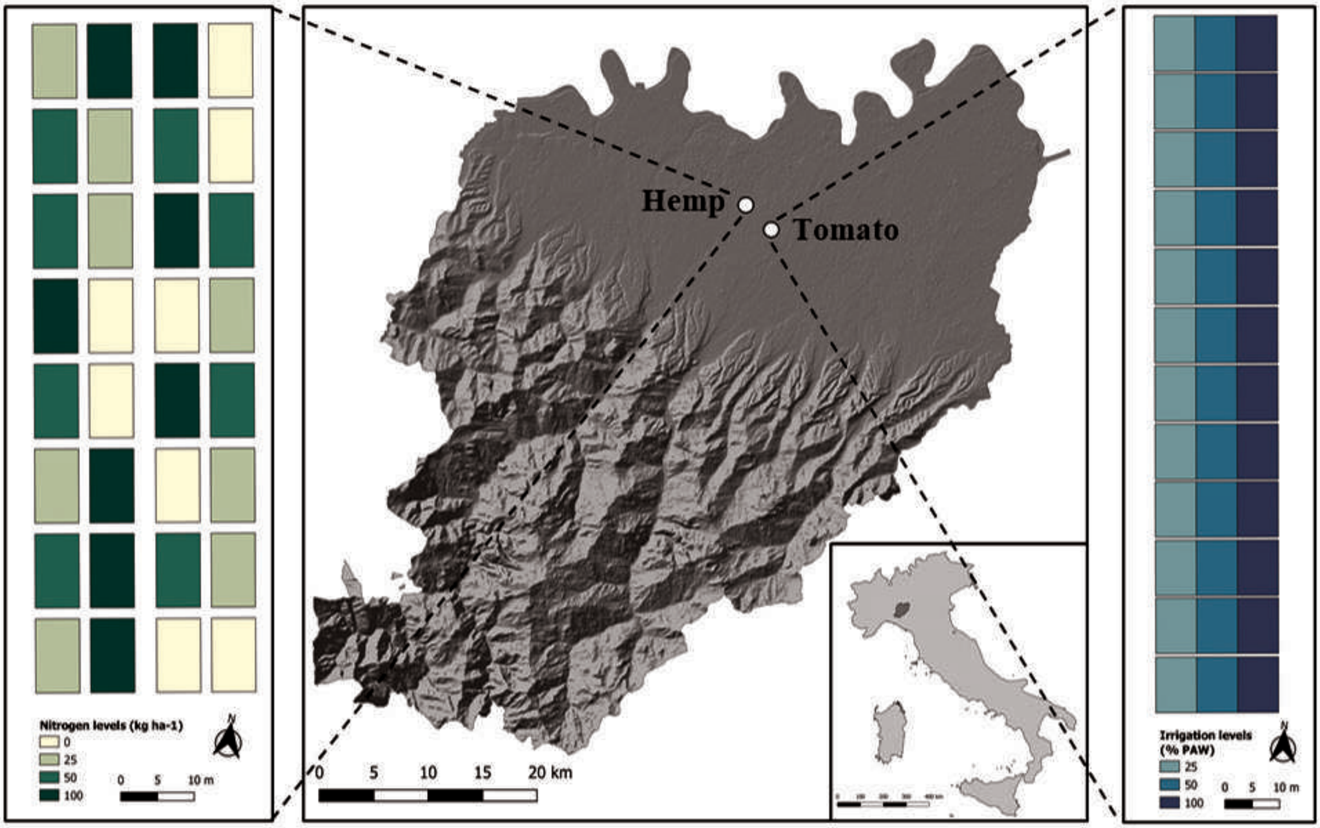
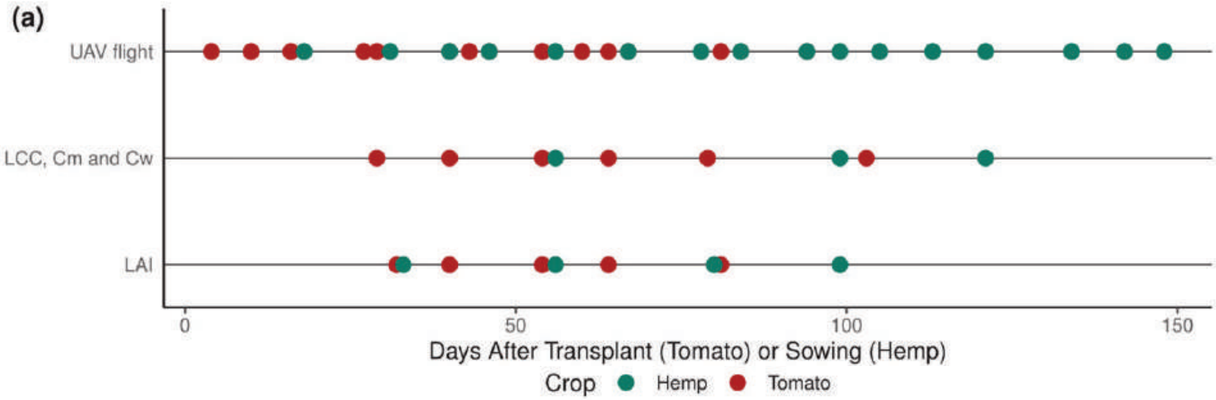


Figure 1. Locations and experimental field design of hemp and tomato.

For the radiometric calibration of the images, the reflectance of a spectral panel with reflectance values provided by MicaSense, was captured before each flight. In addition, a light sensor that automatically adjusts the readings to ambient light was mounted at the top of the UAV to minimize error during image capture. The radiometric calibration, image mosaicking and orthomosaic generation were done using the Pix4D mapper. The field measurements acquired during the growing season were used to select the ranges of the canopy and leaf parameters of the PROSAIL model and to validate the retrieval of LAI and LCC by the PROSAIL model inversion. Two databases were generated by the PROSAIL model, one for each crop, following the ranges of parameters reported in Figure 2b, and the spectral reflectance simulated were resampled based on multispectral camera characteristics. The retrieval of LAI and LCC by the inversion of the PROSAIL model was done using the gaussian process regression (GPR) algorithm. GPR was trained with the 5 spectral reflectance simulated by PROSAIL model.

The LAI and LCC retrieved from multiple UAV flights using the inversion of the PROSAIL model were used to characterize the dynamics of LAI and LCC and identify differences among nitrogen fertilization and irrigation levels. The statistical analysis of the LAI and LCC time series was carried out via a generalized additive model (GAM).



(b)

	Parameter	Abbreviation	Unit	Values	
				Hemp	Tomato
Leaf	Structure parameter	N	Unitless	1.5	1.25
	Chlorophyll content	LCC	$\mu g\ cm^{-2}$	5 – 60 (step =5)	30 – 72 (step = 3)
	Equivalent water thickness	C_w	$g\ cm^{-2}$	0.006 – 0.03 (step = 0.004)	0.022 – 0.028 (step = 0.003)
	Dry matter content	C_m	$g\ cm^{-2}$	0.004 – 0.007 (step = 0.001)	0.003 – 0.004 (step = 0.0005)
Canopy	Leaf area index	LAI	$m^2\ m^{-2}$	0.1 – 6 (step = 0.3)	0.1 – 6 (step = 0.3)
	Average leaf inclination angle	ALIA	deg	10 – 30 (step = 10)	50 – 70 (step = 10)
	Hotspot parameter	hot	$m\ m^{-1}$	0.1	0.1
	Solar zenith angle	tts	deg	20 – 30 (step = 5)	20 – 30 (step = 5)
	Observer zenith angle	tto	deg	10	10
	Relative azimuth angle	psi	deg	190 – 195 (step = 5)	190 – 195

Figure 2. (a) UAV flight and field measurements (LAI, LCC, Cm and Cw) seasonal calendar and (b) ranges of input parameters of the PROSAIL model for the database generation.

4. Results and discussion

4.1. PROSAIL model validation

The accuracy of LAI and LCC retrieved from the inversion of the PROSAIL model was evaluated using in-situ field measurements. The RMSE values for LAI retrieves were 0.53 m2 m-2 for tomato and 0.73 m2 m-2 for hemp (Figure 3a). The RMSE values for LCC retrieves were 6.72 µg cm-2 for tomato and 10.39 µg cm-2 for hemp (Figure 3b). LAI retrieval was more accurate than that of LCC due to the poor signal propagation from leaf to canopy scale, as found in previous studies (Darvishzadeh et al. 2008; Sehgal et al. 2016). Maps of LAI and LCC retrieves of hemp are reported in Figure 4.

4.2. GAM to characterize LAI and LCC dynamics

GAM was applied to time series of LAI and LCC values of hemp retrieved by the inversion of the PROSAIL model, with the lowest fertilization dose (0 kg ha-1) as reference to estimate significant differences among the nitrogen fertilization levels.

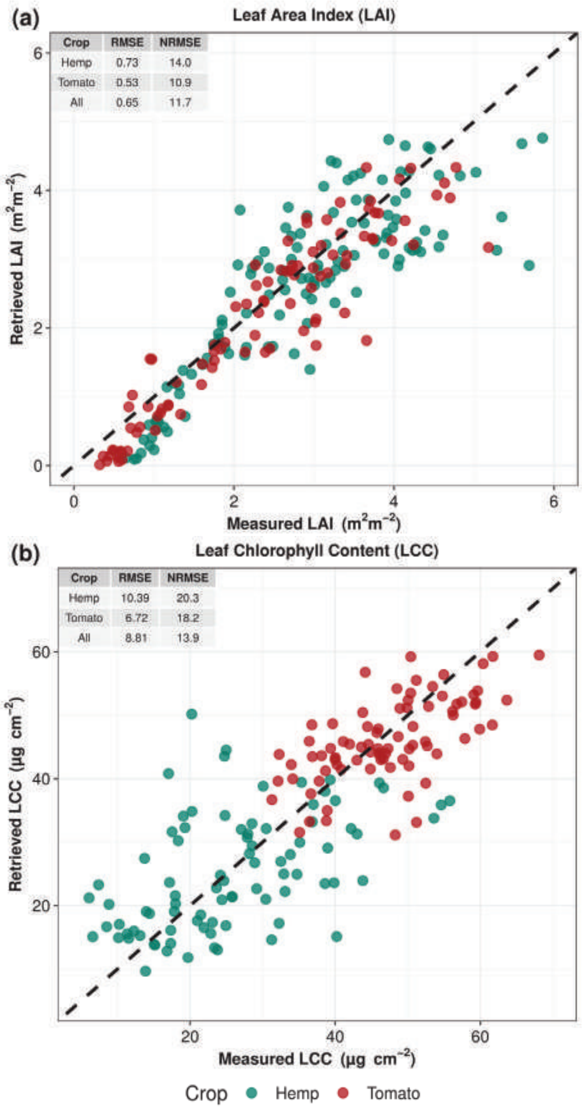


Figure 3. Retrieved vs measured LAI (a) and LCC (b) of hemp and tomato.

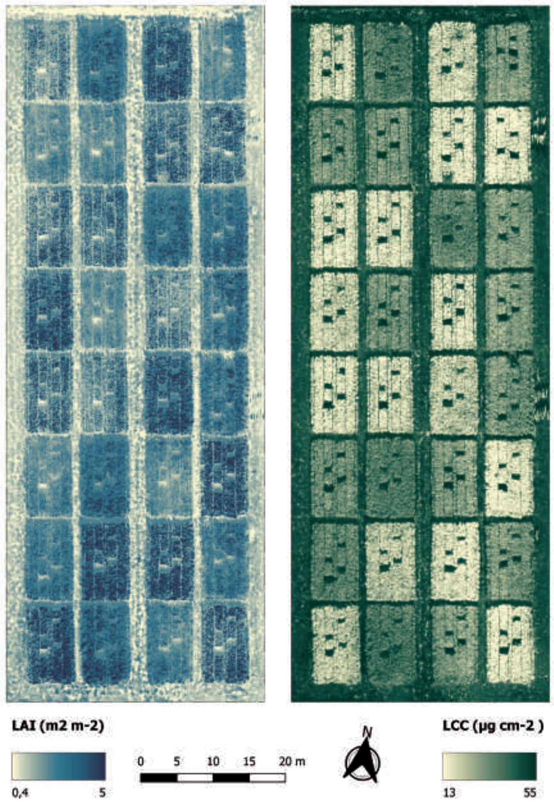


Figure 4. Maps of LAI and LCC retrieves of hemp on 105 DAS by UAV multispectral images using the inversion of the PROSAIL model.

The analysis showed that the effect of nitrogen dose was significant for LAI and LCC (Figure 5a). The largest estimated differences were observed with the highest nitrogen level and decreased proportionally to the nitrogen dose. LAI and LCC showed the highest estimated difference at the end of the vegetative growth from 60 days after sowing (DAS) to 90 DAS approximately (Figure 5a). The increase of nitrogen fertilization led to increases in nitrogen uptake and accumulation by the crop, with a subsequent significant increase of LAI (Seleiman et al. 2013) and of LCC (Yang et al. 2021). The intense nitrogen uptake during the early phases of the growing season (Ivonyi et al. 1997) could explain the general increase of differences of LAI and LCC until 60-90 DAS (Figure 5a).

Regarding tomato, GAM analysis enabled the efficient discrimination across the season of the irrigation treatments. Concerning LAI, the comparison between irrigation levels highlighted a statistically significant

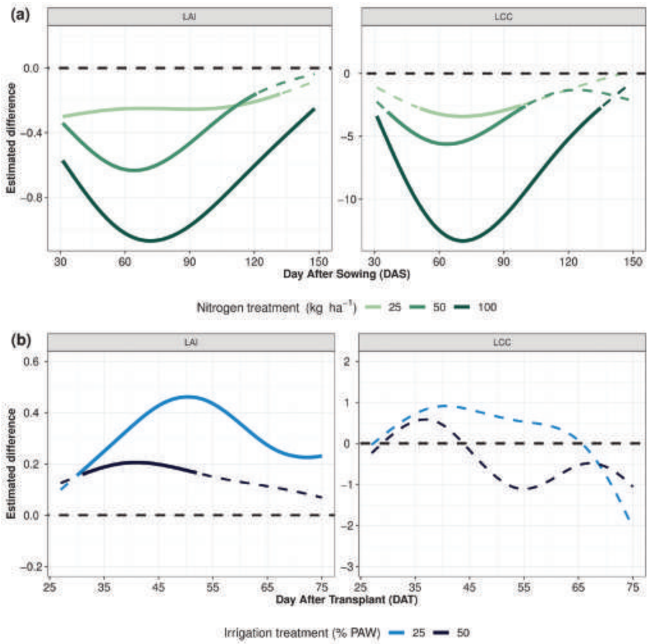


Figure 5. Differences between nitrogen and irrigation treatments for the LAI and LCC analysed via GAM. Solid and dashed coloured line denotes respectively significant (P<0.05) and not significant differences of the corresponding treatment levels compared to reference level. The reference level was (a) 0 kg ha-1 for nitrogen treatment and (b) 100% PAW for irrigation treatment.

difference between the 100% versus 50% and the 100% versus 25% PAW (Figure 5b). LCC comparison between irrigation levels highlighted no statistically significant difference among treatments (Figure 5b).

5. Conclusions

This study demonstrated that LAI and LCC of tomato and hemp can be retrieved with good accuracy by the inversion of the PROSAIL model using multispectral images acquired by UAV. The LAI can be retrieved better than the LCC, probably because of the poor signal propagation from leaf to canopy scale. The GAM analysis showed differences in the LAI and LCC dynamics of both crops between the agronomic treatments (nitrogen fertilization and irrigation levels) that significantly affected the dynamics of LAI and LCC. UAV-based remote sensing proved a powerful tool to retrieve crop traits and improve our understanding of the traits' dynamics under different agronomic management during the entire growing season.

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Keywords:
Video game engine, Precision agriculture, Aerial swarm robotics.

Photorealistic simulations of crop fields for remote sensing with UAV swarms

1. Introduction

Swarms robotics represents a promising technology for precision agriculture (Dorigo et al., 2020), and UAV swarms have been proposed to increase efficiency and accuracy of monitoring activities in extensive fields (Albani et al., 2017). However, real world applications are very scarce and most of the research studies are limited to simulated environments with highly ideal conditions. Realism in visual perception is often overlooked, but is essential to develop deployable solutions including on-board data analysis and decision making. The latter allow to move beyond the classic paradigm that sees UAVs employed as passive sensors. To improve efficiency and accuracy, UAVs need to decide in real time where to observe and at what resolution, collaborating to increase accuracy in feature detection. Designing similar abilities in real world conditions can be very cumbersome. Hence, photo-realistic simulations that can support advanced visual perception are invaluable tools.

We propose a simulation environment that exploits the photo-realistic rendering capabilities of the video game engine Unity to provide a simulator for plant perception with UAVs. Specifically, we focus on the problem of classifying crops and weeds to create a precise field map for automatic weed control. State of the art methods make use of convolutional neural networks (CNNs), where pixel segmentation classification and object detection are the most promising approaches (Lottes et al., 2018; Ruigrok et al., 2020). However, a high volume of plant imagery is necessary for CNN training, which is costly in terms of imagery gathering and labelling. Hence, synthetic photo-realistic rendering engines (e.g., Blender) have been proposed to provide high amount of training data with automatic-generated labels (Barth et al., 2018). This can be useful for off-line feature detection, but fall short when real-time image processing must be tested, as is the case for UAV swarm simulators. Video game engines, instead, proved reliable for CNN training in multiple research fields (e.g., Babiker et al., 2019), owing to the powerful flexibility of the rendering engines to generate photo-realistic imagery in real time while allowing the users to implement any type of desired environment and interaction conditions.

We developed a photo-realistic environment based on the Flightmare UAV simulator (Song et al., 2020) to generate synthetic imagery that could provide detection results comparable with real world data. We exploit Unity as the video game engine, which was previously used for field monitoring from ground robots (Carbone et al., 2021), and we adapt it to the photo-realistic simulation from UAVs of a sugar beet field where weeds (i.e., volunteers potatoes) must be identified. The Unity-generated imagery serves to build reliable data sets for CNN training, validation and testing of UAV monitoring. In this context, a reliable result means that CNN performance trained with synthetic generated data remains similar or better than the performance achieved by training with real data.

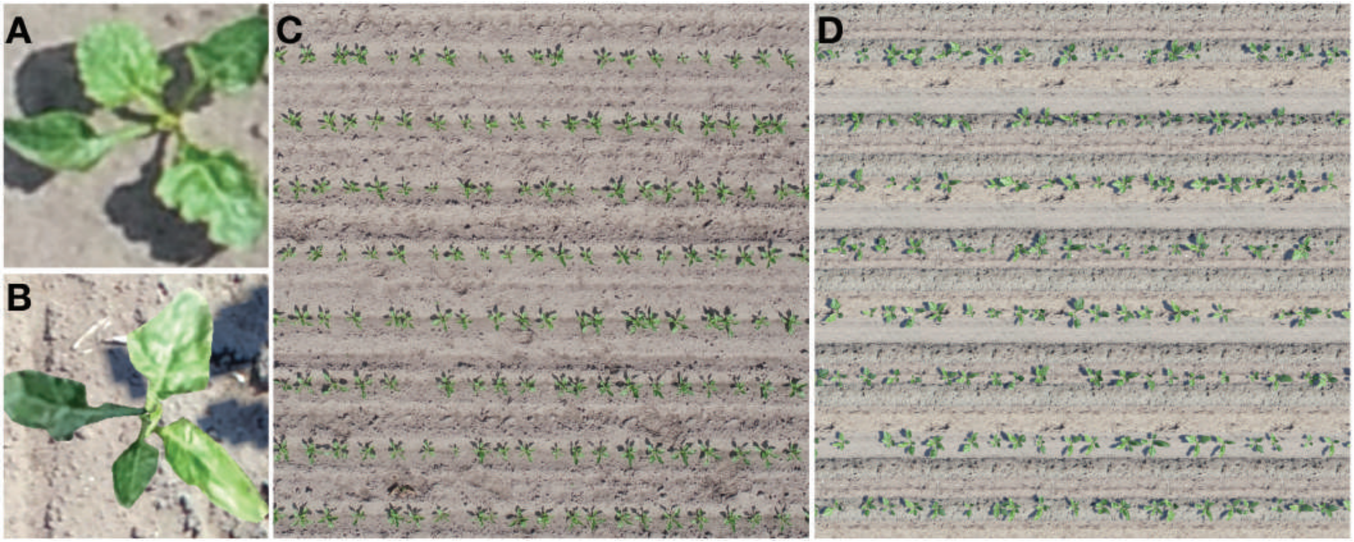

Figure 1. Photo-realistic simulation of sugar beet plants with Unity. (A-B) Closeup of real and simulated plants. (C-D) Field appearance in real and simulated imagery.

2. Experimental setup and Results

A real data set with potato and sugar beet plants is used as reference for the experiments in this paper. The data set includes images taken with a UAV in a sugar beet field and a potato field in Wageningen, the Netherlands. We extracted leaf textures for both plants and the field ground, and included them within 3D models in Unity. Then, we generated procedural scripts to spawn the plants and the simulated field achieving an accurate plant structure with a photo-realistic aspect. Figure 1 and 2 show samples of both real and simulated plants, as well as the full field appearance. Multiple training sets have been generated taking into account the variability that can be injected in the imagery when UAVs are exploited. Indeed, to obtain a robust feature detection, the conditions encountered in the real world need to be accurately simulated. We identified as relevant sources of variability the following aspects: (i) motion blur; (ii) camera rotation; (iii) camera points of view (POV); (iv) UAV altitude; (v) light intensity; and (vi) light rotation.

Three different levels of magnitude for the said variations have been considered in the generation of simulated imagery: no variations (0R), variations calibrated to be similar to the ones observed in the real data (-R), and high levels of variation (+R). Based on the type of images included, the data sets used for experiments are summarized as follows:

- Real: data set containing only real data to train the CNN to use as a baseline performance.
- Unity: data sets containing only synthetic data from Unity, with the three types of variation discussed above.
- Unity-R small: data set including the -R imagery, but only considering the same amount of images as available in the real data set.
- Augmented: data set combining the real data and the Unity +R data.

We have trained a CNN with each of these data sets, and used the validation data set to identify the best network obtained during training. We also record the parameters of the last obtained neural network (hence sensitive to over-fitting).

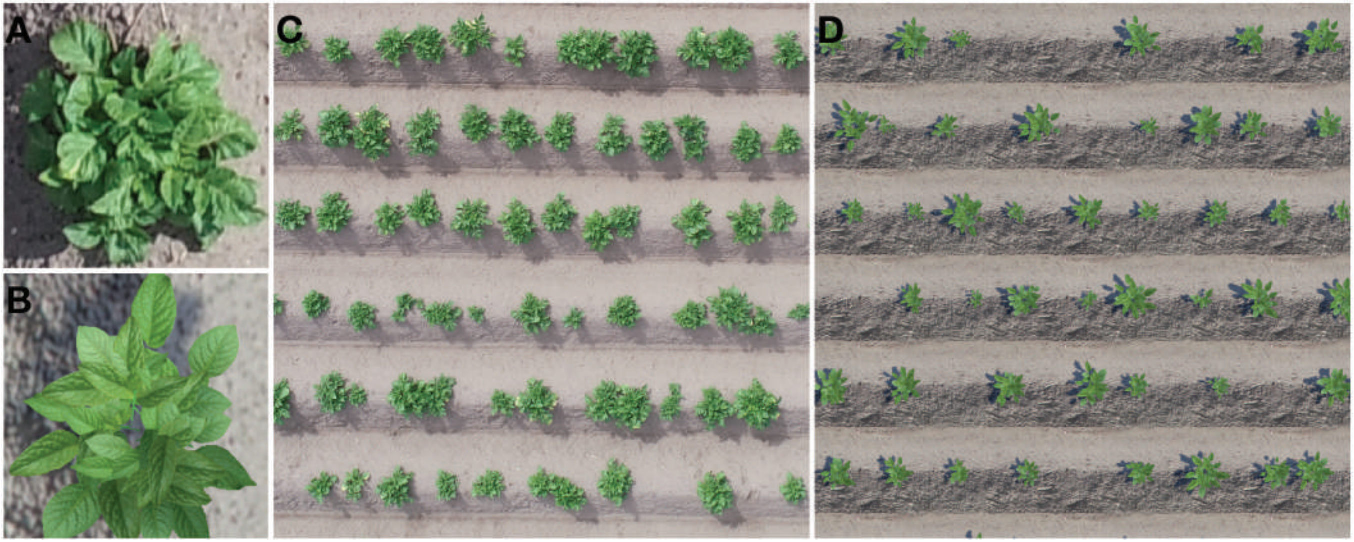

Figure 2. On the Cover: Photo-realistic simulation of potato plants with Unity. (A-B) Closeup of real and simulated plants. (C-D) Field appearance in real and simulated imagery.

We consider the intersection over union (IoU) as the metric to evaluate the classification on real images (see Figure 3). Best performance is obtained with the augmented data set for both sugar beets and potatoes. If we consider data sets containing only simulated imagery, best performance is given by the data set with large amounts of variation, which ensures good performance although with a significant loss in accuracy in the identification of sugar beets.
Lower amount of noise lead to poor performance, especially for the sugar beets case. Overall, the obtained photo-realism is sufficient and can be exploited for design of UAV monitoring strategies.

3. Conclusions

We have presented a tool for photo-realistic simulation of crop fields to be monitored by UAV swarms. The results for visual perception demonstrate that video game engine can serve to reliably simulate photo-realistic imagery, and can be used in real time in support to the design of UAV monitoring strategies for precision agriculture. Furthermore, the experiments demonstrate how Unity can be used to generate plant imagery with controlled variation on several parameters of interest. This is highly useful as such sources of variation in real world are unpredictable and difficult to replicate.

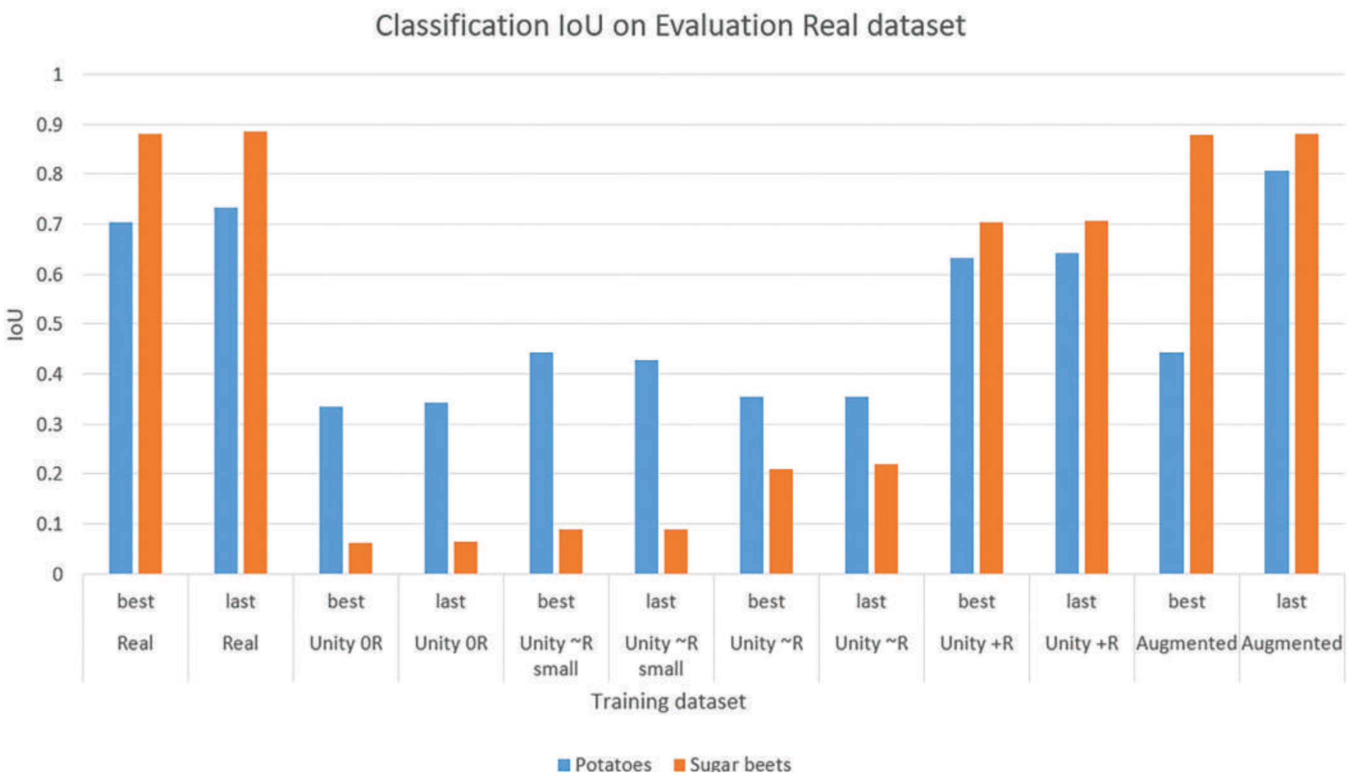

Figure 3. Results after evaluating real images available with CNNs (best and last) trained according to different data sets (X axis).

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Precision irrigation, Remote sensing, Agricultural management zone,
Principal component analysis.

Use of vegetation indices from Sentinel2 and UAV in precision viticulture applications

1. Introduction

Precision viticulture is based on information related to the within-field variability of the crop-soil system; this information is used to optimize input supply and management practices, to improve grape quality and yield. Technological tools are available to accurately investigate this variability, through remotely or proximal sensed data. Geophysical surveys are usually employed to investigate soil variability, while canopy variability is monitored through multispectral imagery. In the latter case, vegetation indices are computed from measurements acquired with sensors mounted on different platforms, from satellite to unmanned aerial vehicle (UAV) and quad. Sentinel-2 data are free and readily available, while UAV data have a cost for both acquisition and processing. Conversely, spatial resolution increases from Sentinel-2 (10 m) to UAV (few centimetres) data. The accuracy in crop row monitoring provided by UAV is required for a site-specific and variable-rate management of agronomic inputs, or to assess whether a certain intervention has reached the goal.

However, a variable rate irrigation management is often operated not looking at the crop variability in a certain date, but mainly considering the soil variability, since soil is the reservoir from which the roots get their water supply. Even though geophysical methods are the reference tools to delineate the agronomic management zones (MZs) from soil maps, also multispectral images time-series can be used. As multispectral images describe crop variability both in space and time, multi-temporal images can be used to extract time-stationary components, mainly related to soil variability rather than to time-variable factors as plant diseases or agro-meteorological conditions.

This research focuses primarily on comparing Sentinel-2 and UAV data acquired in drip irrigated vineyards, to assess their ability to describe the vine vigour along the rows. Secondly, after demonstrating how Sentinel-2 data are more correlated with the grass inter-row vigour (strongly affected by soil properties, as grass is not irrigated) than with the vine condition, the use of Sentinel-2 multi-temporal images to delineate MZs is explored. Both objectives were pursued on datasets acquired in the Colli Morenici region (south of Lake Garda, Italy).

2. Materials and Methods

The study considers irrigated vineyards with grass inter-rows located in the Colli Morenici region, south of the Garda lake in northern Italy (Figure 1). The distance between rows is 2.5 m on average, and the vineyards include different vine varieties (Merlot, Cabernet Sauvignon, Chardonnay and Traminer).

Multispectral images acquired from UAV surveys at the end of July, in years 2020 and 2021 for the Cavriana site, and 2019 and 2021 for the Monzambano site, as well as non-cloudy Sentinel-2 images for dates as close as possible to the UAV flights, were analysed. From all data, NDVI maps were obtained. Additionally, the complete 2020 time-series of Sentinel-2 NDVI maps for the Cavriana's vineyards (82 images) was elaborated,

Figure 1. On the cover: Study vineyards located in: (a) Cavriana: field 1 (4 ha) and field 2 (6 ha); (b) Monzambano: field 3 (1 ha).

obtaining average NDVI maps for each month, to assess their suitability to produce a MZ map.

Sentinel-2 and UAV NDVI maps were compared through linear regression analysis. Correlation coefficient was calculated between the satellite NDVI values and the UAV ones, the latter resampled from the UAV pixel to the Sentinel-2 one: in turns, all the UAV-based values, only the vine ones, and only the inter-rows ones were considered. Hence, for each couple of UAV and Sentinel-2 images, three correlation coefficients were obtained, named UAV, vine UAV and inter-row UAV, respectively.

The 2020 time-series of Sentinel-2 NDVI maps was analysed through Principal Component Analysis (PCA) to investigate the time-stationary components whose spatial variability was likely related to the effects of soil properties on vegetation vigour. Finally, a cluster analysis was applied on these components through the MZA software (Fridgen et al., 2004), to delineate MZs. Finally, this MZ map was compared to the one obtained from the electrical conductivity (EC) map produced by a geophysical survey. The Pearson's coefficient and the bivariate Moran Index between the EC map and the maps of the time-stationary components were calculated. The difference between Pearson's coefficient and Moran Index was quantified, to assess the correlation between maps not affected by distances (Chen, 2015).

3. Results and Discussion

The inter-row UAV correlation coefficient with the Sentinel-2 NDVI, calculated for each vineyard, variety and year, is quite similar (or even higher) to the UAV value, and always higher than that found for the vine UAV (Figure 2). This behaviour highlights how Sentinel-2 images describe mainly the inter-row grass vigour variability rather than that of the vine, in accordance with the results obtained by Khaliq et al. (2019).

As inter-row grass is not irrigated (study vineyards are drip irrigated), its condition is strongly affected by soil variability. This fact leads to hypothesize that Sentinel-2 images acquired at least during summertime (when absence of irrigation for inter-row vegetation prevents its optimal development even accentuating its vigour variability due to soil properties) can be used to investigate the vegetation heterogeneity mainly related to soil variability.

PCA was applied to the multi-temporal Sentinel-2 NDVI

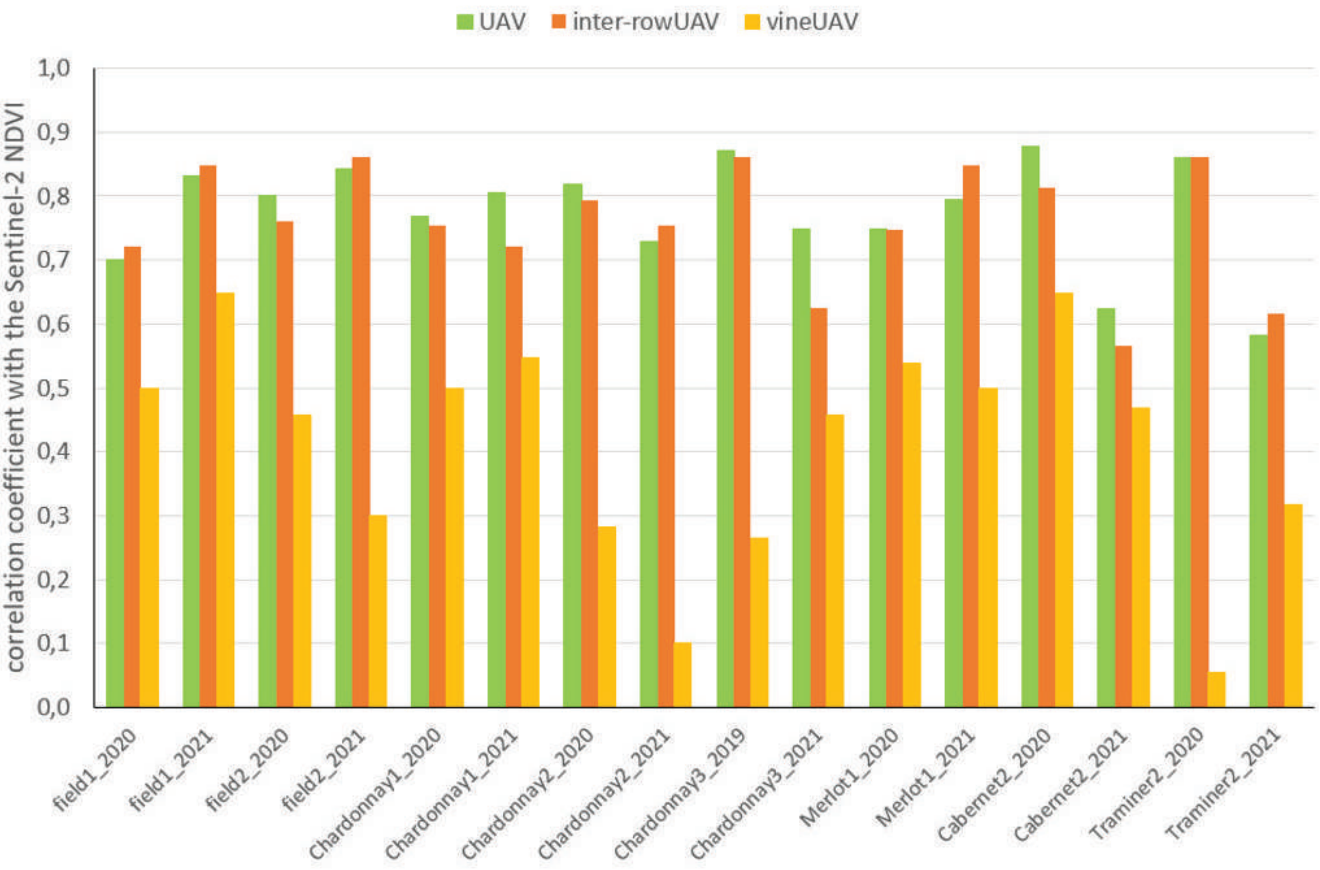

Figure 2. Correlation coefficients between satellite-based NDVI values and UAV-based ones for the period 2019-2021. UAV, inter-row UAV and vine UAV correlation coefficients refer to considering respectively all the UAV-based values, only those in the inter-rows, and only those in the rows. The bars in the first 4 blocks illustrate correlations for the fields in the Cavriana site independently from the varieties in field1 and field2. The bars in the other blocks illustrate correlation for each combination of variety (Chardonnay, Merlot, Cabernet and Traminer) and field (field 1, 2 and 3). UAV values were resampled from the UAV pixel (about 0.05 m) to the Sentinel-2 one (10 m).

dataset for the year 2020 at the Cavriana site, to extract the components more related to the vegetation spatial variability due to soil properties. The results show the different behaviour of NDVI maps for autumn and winter months, compared with those for summer months (Figure 3a). Then, a further PCA analysed only the NDVI maps for months from May to August (Figure 3b). Finally, only the maps from May to July were considered, since the map for August was found weakly correlated to the others (Figure 3b) due to its spatial pattern largely different from the others. The first and second principal components (PC1 and PC2), explaining the 88% of the total variability in the dataset, describe the crop spatial variability mainly related to soil properties and were then used to delineate MZs by cluster analysis.

The proposed method looks promising, in fact the MZ

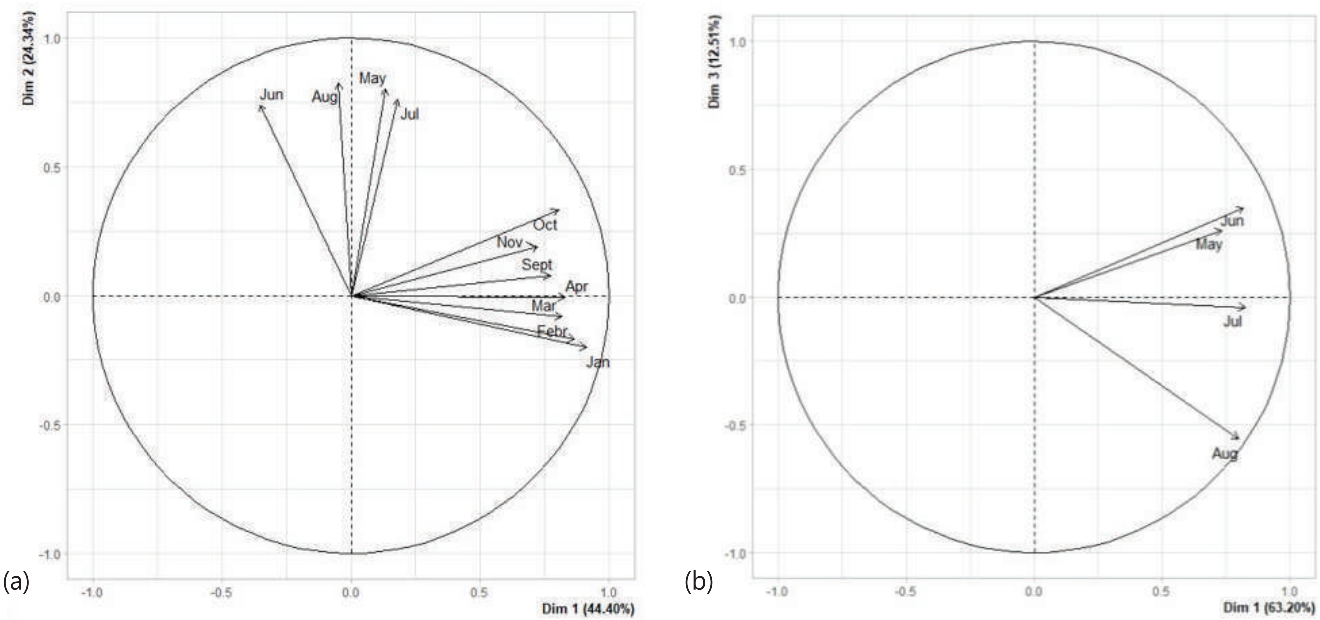

Figure 3. PCA results, obtained from: (a) all the NDVI maps from January to November 2020; (b) the NDVI maps for the summer months, from May to August 2020. Dim1, Dim2 and Dim3 refer to the components PC1, PC2 and PC3, respectively; the percentage of the total variability explained by each component is shown in brackets.

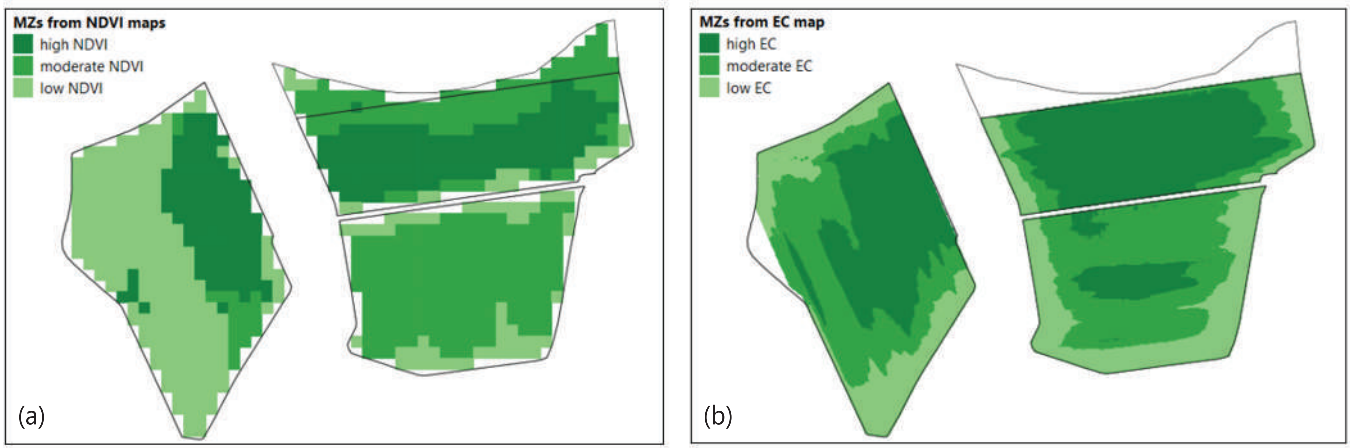

Figure 4. MZs maps determined from: (a) PC1 and PC2 maps obtained by analysing the average Sentinel-2 NDVI maps for months from May to July 2020; (b) EC map obtained through a survey with a geophysical sensor (1 m pixel).

map obtained from Sentinel-2 NDVI images (Figure 4a) showed to be well in line with the one elaborated from the EC map (Figure 4b). The values of correlation coefficient and bivariate Moran Index, each one calculated comparing PC1 and PC2 maps with EC map, are 0.52 and 0.35, and 0.49 and 0.33. The differences between correlation coefficient and Moran Index are less than 3% in both cases, demonstrating that most of the correlation is due to the spatial pattern of maps.

4. Conclusions

Sentinel-2 and UAV images for drip irrigated vineyards were compared. The results, obtained for different vine varieties and years, showed that correlation between satellite data and inter-row UAV data is higher than that between satellite and vine UAV data. This means that Sentinel-2 images: 1) do not allow to monitor the vigour of row crops such as vines with sufficient accuracy; 2) can be used to investigate the spatial variability of the inter-row vegetation due to soil properties, and thus to delineate MZs, if multi-temporal images are acquired in a low-precipitation and high water demand periods (summer months). A procedure based on PCA was developed and applied to a single Sentinel-2 multi-temporal dataset, providing promising results.

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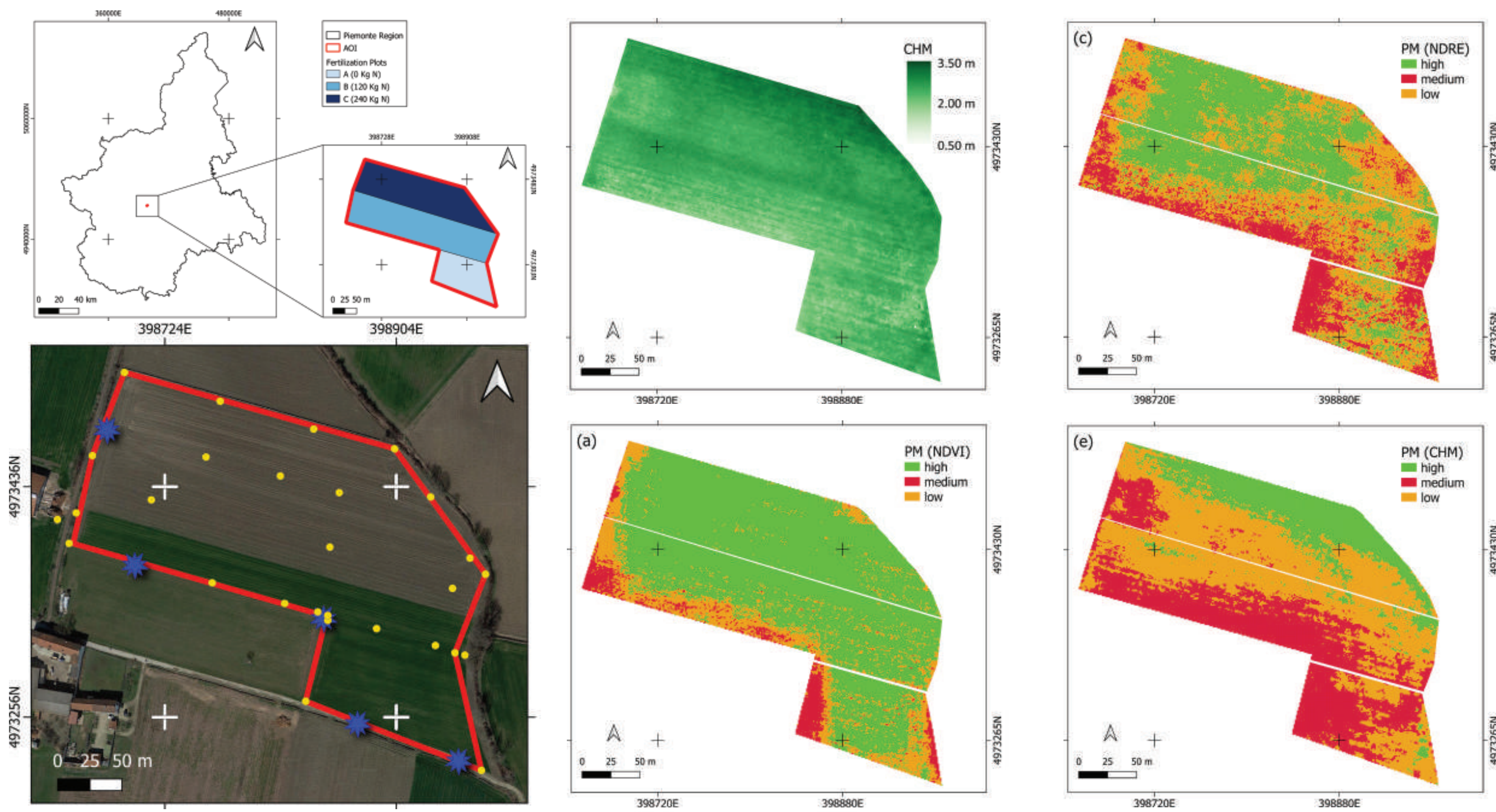

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Keywords:
Canopy height model, Precision farming, UAV, RPAS, Spectral index.

Geometric vs Spectral content of RPAS images in the precision agriculture context

1. Introduction

Precision agriculture (PA) has been defined as a new type of agriculture that looks for climate, environmental, economic, productive, and social sustainability. This is said to be possible supporting traditional agriculture with new technologies like Geographic Information System, Global Navigation Satellites Systems (GNSS), digital photogrammetry and remote sensing. PA can therefore support farmers to maximize the cost-benefit ratio in yield production (Lambert, Lowenberg-De Boer 2000).

Prescription maps (PMs) are widely used in PA to map crop intra-field anomalies to better address fertilisation, irrigation, and phytosanitary treatments. The aim is minimizing negative externalities (i.e., water, air, and soil pollution) and maximising yield. As far as remote sensing is concerned, multispectral information from aerial or space platforms can effectively support PMs generation, depending on a proper choice of the adopted sensor in terms of spatial, spectral, radiometric and temporal resolution (Boccardo et al. 2003; Mondino et al. 2012).

Costs associated to aerial and RPAS (remotely piloted aerial systems)-based acquisitions are known to be difficult to be estimated since strongly dependent on the required data processing level and size of the imaged area (Borgogno Mondino, Gajetti 2017; Perz, Wronowski, 2019). Nevertheless, they can provide a very high spatial resolution typically ranging from 0.5 m to 1 cm and make possible 3D measures thanks to their stereoscopic capabilities. This peculiarity can be proficiently exploited to integrate spectral information. This can be generally achieved assuming digital surface models (or directly point clouds) as additional discriminants effective for deriving information about canopy and biomass of surveyed crops. As far as multispectral features from RPAS sensors are concerned they certainly represent a potential breakthrough in PA. Several spectral indices (SI) can be, in fact, generated for providing valuable vegetation-related information. Two of the mostly used SIs in PA are the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Red Edge Index (NDRE).

They are known to be effective for monitoring of vegetation physiology (Seo et al. 2019), estimation of crop production (van Klompenburg et al. 2020), monitoring of crop nitrogen (N) content (Boiarskii, Hasegawa 2019; Song et al. 2020). An extensive list of multispectral imaging sensors can be easily found on market the most of them acquiring bands in the VNIR (400-1000 nm) spectral range.

MAIA S2 (MS2) is one of the most performing ones in terms of spectral resolution. MS2 acquires 9 bands in the range 390-950 nm using 9 separated optical systems equipped with filters (Marinello 2017) that are aligned to the ones of the Sentinel 2 MSI sensor. To explore the potentiality of MS2 from drones to generate useful information in agriculture, a pilot experience was achieved focusing on a corn field managed with three different N fertilisation doses. Both geometric and spectral properties of MS2 were investigated testing their capabilities in detecting the effect of different N doses on maize.

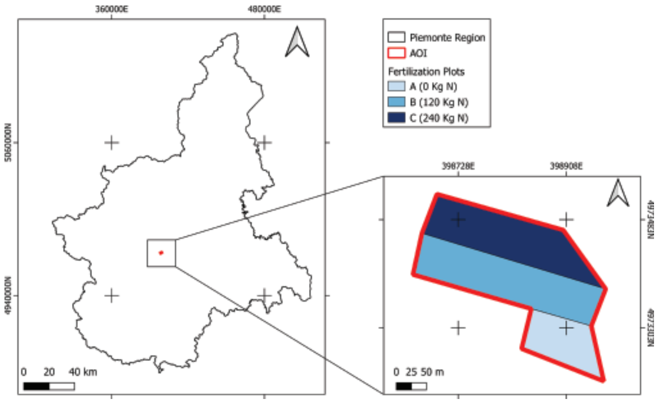

Figure 1. On the cover: Area of Interest (AOI) within Piemonte Region (N-W Italy) is represented by a red polygon. AOI was subdivided into three plots (A, B and C) which were treated with three levels of fertilization at the stem elongation stage (0, 120, 240 Kg N respectively). (Reference system WGS84 / UTM 32N, EPSG: 32632).

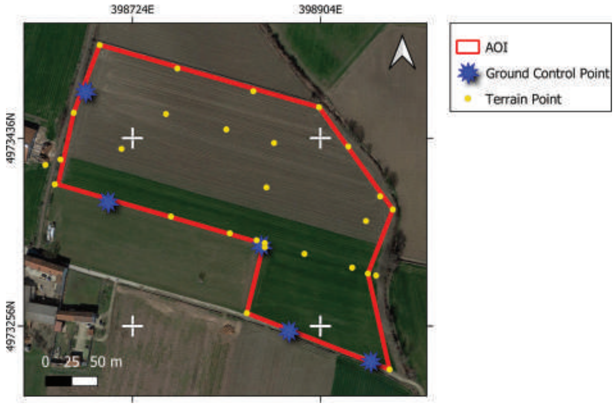

Figure 2. On the cover: Terrain Points and Ground Control Points acquired within the AOI (Reference System WGS84/UTM 32N, EPSG: 32632).

2. Materials and Methods

2.1. Study area

The study area (AOI) is in Carignano (Piemonte region - Italy) and sizes about 5 ha. AOI corresponds to a corn field. It has been divided into three plots (hereafter called A, B and C) that were fertilized with different doses of N-based mineral fertilizers: 0 kg•ha^{-1} N, 120 kg•ha^{-1} N and 240 kg•ha^{-1} N, respectively (Figure 1). AOI was selected as representative of local agricultural corn management, being corn the most important crop in the area.

2.2. Aerial and Ground Surveys

An aerial survey was performed on 14th June 2021 using a quadcopter (DJI Matrice 300 RTK) equipped with MS2 sensor. MS2 technical features are the following: focal length = 7.5 mm, physical pixel size = 3.75 µm, sensor size = 1280 × 960 mm. Forward and side overlap were set equal to 95% and 90% respectively and the aerial survey was performed @ 80 m AGL (above the ground level). The free software *Mission Planner v1.3.58* was used to plan the flight and set up the autopilot for the flight. Flight time resulted to be 15 min. Imaged area was about 10.30 ha corresponding to 1600 frames (raw format). Five Ground Control Points (GCPs) were surveyed during the flight by GNSS (Figure 2) operated in VRS-NRTK (Virtual Reference Station – Network Real Time Kinematic) mode supported by the Interregional Piemonte-Lombardia SPIN-GNSS service (https://www.spingnss.it/spiderweb/frmIndex.aspx). A GNSS receiver *Leica GX1200 system* was used for this task. The average 3D-positional accuracy was 35 mm. To locally model with adequate accuracy the local ground level, 28 additional points, namely Terrain Points (TP), were surveyed and used to compute a digital terrain model needed for CHM generation. This was achieved spatially interpolating TPs by Delaunay triangulation in SAGA GIS 7.9 (Olaya and Conrad, 2009) obtaining a gridded digital terrain model (DTM) having a grid size of 0.1 m.

3. Data Processing

MS2 raw images were pre-processed by MultiCam Stitcher Pro v 1.4-Beta 2 (MCS). Images were geometrically corrected to remove/minimize distortions related to sensor lens system and design using the available automatic procedure in MCS. Nominal calibration parameters, different for each band, are recorded within MCS and automatically applied during processing (Nocerino et al., 2017). A co-registration step aiming at aligning bands was successively achieved and a multi-layer image, stacking 9 co-registered and undistorted bands was generated. During the process, radiance to reflectance conversion was operated using data from the MS2-coupled incident light sensor (ILS). Image block bundle adjustment was operated by *Agisoft Metashape v 1.7.4* (APS) using the above mentioned 5 GCPs. Camera auto-calibration was activated, fixing the focal length at its nominal value and estimating cx, cy, k1, k2, k3, k4 ("Agisoft PhotoScan User Manual - Professional Edition, Version 1.4). A Leave One Out approach (Brovelli et al., 2008) was used to test 3D accuracy of image block orientation and vertical and horizontal RMSE computed. A photogrammetric point cloud (PPC) sizing 17013157 points was generated and filtered to remove outliers. A raster Digital Surface Model (DSM) was then computed by regularization setting a GSD of 0.1 m. Finally, the correspondent MO was generated with a GSD of 0.05 m. The default images blending mode was used, admitting that native radiometry of images would have been distorted. Nevertheless, since the main task was zoning, authors preferred to guarantee a better spatial continuity of images that only a blending mode can guarantee. MO was projected into the WGS84 UTM 32N reference frame. CHM, mapping the local crop height above the ground level, was computed by grid differencing between local DSM (from RPAS) and DTM (from GNSS survey). NDVI and NDRE (Bannari et al., 1995) maps were computed from the calibrated bands of MO by raster calculation. Given the high geometric resolution of MO and CHM, plants inter-row (equal to 0.75m) was also detected thus introducing noise in a wall-to-wall mapping of crop properties. To reduce this limiting factor while zoning, a vector graticule sizing 1m x 1m was generated and zonal statistics computed with reference to the above mentioned NDVI, NDRE and CHM raster maps. Specifically, the local mean value was computed for NDVI and NDRE, while the local 95th percentile was computed from CHM. This was intended to transfer to the 1m x 1m graticule cell the information about the top of the canopy, thus excluding plants inter-rows related heights. Downsampled NDVI, NDRE and CHM were used to derive a zonation of the field possibly

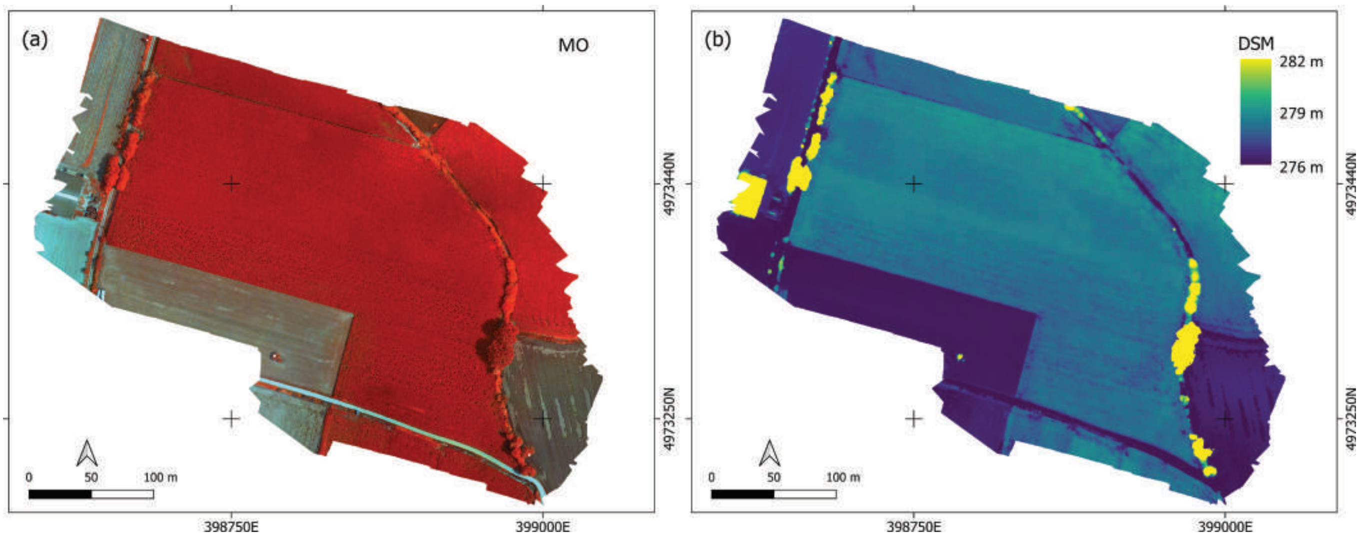

Figure 3. (a) False colour composite from MO (R: NIR band, G: Red band, B: Green band). (b) Digital surface model (Reference System WGS84/UTM 32N, EPSG: 32632).

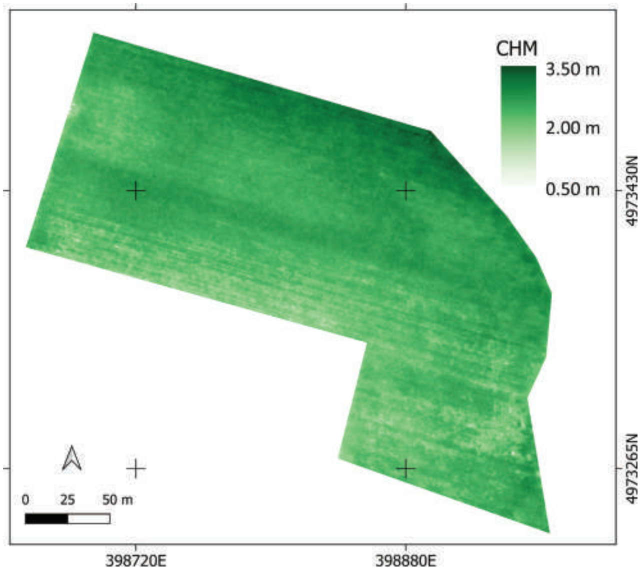

Figure 4. Canopy Height Model of the imaged corn field (Reference System WGS84/UTM 32N, EPSG: 32632).

corresponding to the three doses of N. Resulting maps can be somehow intended as the basis for deriving prescription maps - PMs (Bates et al. 2018) useful for a variable rate-based field management. Zonation was achieved by unsupervised classification of NDVI, NDRE and CHM (singularly considered). The K-means clustering was applied looking for 3 clusters (expected to reflect crop high, medium and low vigour conditions). Since in a cluster analysis class meaning is not a-priori known, to recover it, the mean and standard deviation values (NDVI, NDRE and CHM) were *a-posteriori* computed for each cluster and interpreted with the following interpretation keys: (i) high vigour class is the one showing the highest mean NDVI, NDRE and CHM values; (ii) low vigour class is the one showing the lowest NDVI, NDRE and CHM values; (iii) medium vigour class is the intermediate one. Differences affecting corn field development can be reasonably ascribed to the N fertilization since environmental conditions can be assumed similar over AOI sub-plots. For this reason: field A (N = 0 kg•ha^{-1}), field B (N = 120 kg•ha^{-1}) and field C (N = 240 kg•ha^{-1}) were expected to correspond to the low, medium and high vigour class, respectively. It is worth to remind that a corn field is an open and unlimited context where nutrient exchange at soil level and among-plants competition during the growth phase can occur (Cahill Jr 1999). To test truthfulness of their hypothesis, authors proceeded by polygon intersection locally comparing PMs classes with A, B and C plots and looking for the highest occurrences.

4. Results and Discussions

Data processing – Accuracy of bundle adjustment was found to be 0.02 m (horizontal) and 0.03 m (vertical). These accuracy values well fits PA requirements (Rokhmana, 2015) especially when the geometric 3D content of images is expected to be exploited to derive useful information about crops. The obtained dense cloud (PPC) sizing 17013157 points. It was then regularized with a GSD = 0.1 m to generate the correspondent DSM (Figure 3b). Finally, DSM was used to generate MO having a GSD = 0.1 m, as well. This was used to generate the NDVI and NDRE maps. With reference to the DTM from ground surveyed TPs it was used to derive crop CHM (Figure 4). The mean CHM value in AOI was found to be 2.5 m in agreement with the expected corn height reached in the heading phenological phase (June). Zonal statistics were applied with reference to the above mentioned 1m x 1m cell graticule to downsample NDVI, NDRE and CHM maps, thus minimizing local effects (on both radiometry and geometry) from plants inter-row. K-means clustering (3 clusters) was singularly applied for the obtained downsampled NDVI, NDRE and CHM maps (Figure 4). To recover cluster meaning, an intersection was achieved between clusters and management zones (A,B,C). Meaning correspondence was obtained looking at occurrences of combinations. Corn development and relative biomass were expected to be high, medium and low for the respective A, B and C areas. Occurrences (%), mean and standard deviation values of class combinations are reported in Table 1. PM from NDVI shows that A, B and C were characterised by a mean NDVI value of 0.88, 0.94 and 0.97, respectively (Table 1). PM from NDRE, differently, shows that A, B and C were characterised by having an average NDRE value of 0.22, 0.25 and 0.27 respectively. PM from CHM shows that A, B and C were characterised by an average canopy height value of 2.21 m, 2.58 m and 2.96 m respectively. Based on these results, PM vigour levels (managed plots) can be associated to the corresponding clusters. Specifically, vigour levels appear to be high, medium and low respectively for C, B and A in all PMs for clusters. Finally, the effects of fertilisation detected by PM were evaluated and the relative statistical distribution reported in Figure 5. According to Figure 5a, PM from NDVI appears to be mainly dominated by the high vigour class. Specifically, plot A, B and C are characterized by having predominance of high vigour class (53%, 70% and 92% respectively). Concerning PM form NDRE, plot A, B and C are, respectively, characterized by mid-low, medium and high vigour classes (46-40%, 46% and 60%). Finally, PM from CHM shows that plot A, B and C are, respectively, characterized by low, medium and medium-high vigour classes (61%, 51% and 50-41%). Based on this results, one can deduce that PM from NDVI appears to poorly detect N-related differences rising some doubts about NDVI applications in PM generation during corn late phenological phases. Conversely, NDRE- and CHM-derived PMs reasonably reflect the different N fertilizations rates. It is worth to remind that whatever cluster map would never perfectly fit the N-fertilization plots, since transition zones between treatments (Chekli et al. 2017; Kim et al. 2019) are always present as a natural consequence of treatments dynamics in the environment. Findings from this work are supported by recent literature (Feng et al. 2016) where (i) NDRE is shown to be correlated with different leaf N concentration; (ii) N content of vegetation is better detected by NDRE rather than NDVI (Boiarskii, Hasegawa 2019). What actually is relevant is that the geometric information related to crop CHM can be proficiently used as further, or alternative, detecting tool suggesting that, for this type of applications, low-cost RGB sensors (Grenzdörffer 2014), properly managed within a digital photogrammetric workflow, can provide similar, or complementary, information about crops in the PA framework.

Index	Number of Pixels	Pixels (%)	Mean	Standard deviation	Field treatment
NDVI	35184	75.54%	0.97	0.01	C
	8632	18.53%	0.94	0.01	B
	2763	5.93%	0.88	0.03	A
NDRE	18128	38.92%	0.27	0.01	C
	19694	42.28%	0.25	0.01	B
	8757	18.80%	0.22	0.01	A
CHM	8218	17.68%	2.96	0.16	C
	22650	48.72%	2.58	0.10	B
	15625	33.61%	2.21	0.14	A

Table 1. Number of pixels and relative %, mean and standard deviation values of clusters from NDVI, NDRE and CHM maps.

5. Conclusions

To explore the potentiality of MS2 from drones for generating useful information in agriculture, a pilot experience was achieved focusing on a corn field managed with three different N fertilisation doses. MS2 were geometrically and spectrally pre-processed and the related multispectral orthomosaic and digital surface model, derived. The former was used to compute the correspondent NDVI and NDRE maps. The latter was differently used to derive a corn canopy height model. An unsupervised classification approach @3 clusters was then applied to NDVI, NDRE and CHM maps to zone the field. Zones from clustering were therefore compared with field sections at different N doses to test capacity of the above mentioned spectral and geometric discriminants to map differences. Results suggest that PM from NDVI appears to poorly detect N-related differences. Contrarily, PMs from NDRE and CHM reasonably reflect the different N fertilization doses. Specifically, CHM proved to be able to detect crop height and, consequently, biomass differences that are known to be induced by different rates of fertilization. What actually is relevant is that the geometric information related to crop CHM can be proficiently used as further, or alternative, detecting tool suggesting that, for this type of applications, low-cost RGB sensors can provide similar, or complementary, information about crops in the PA framework.

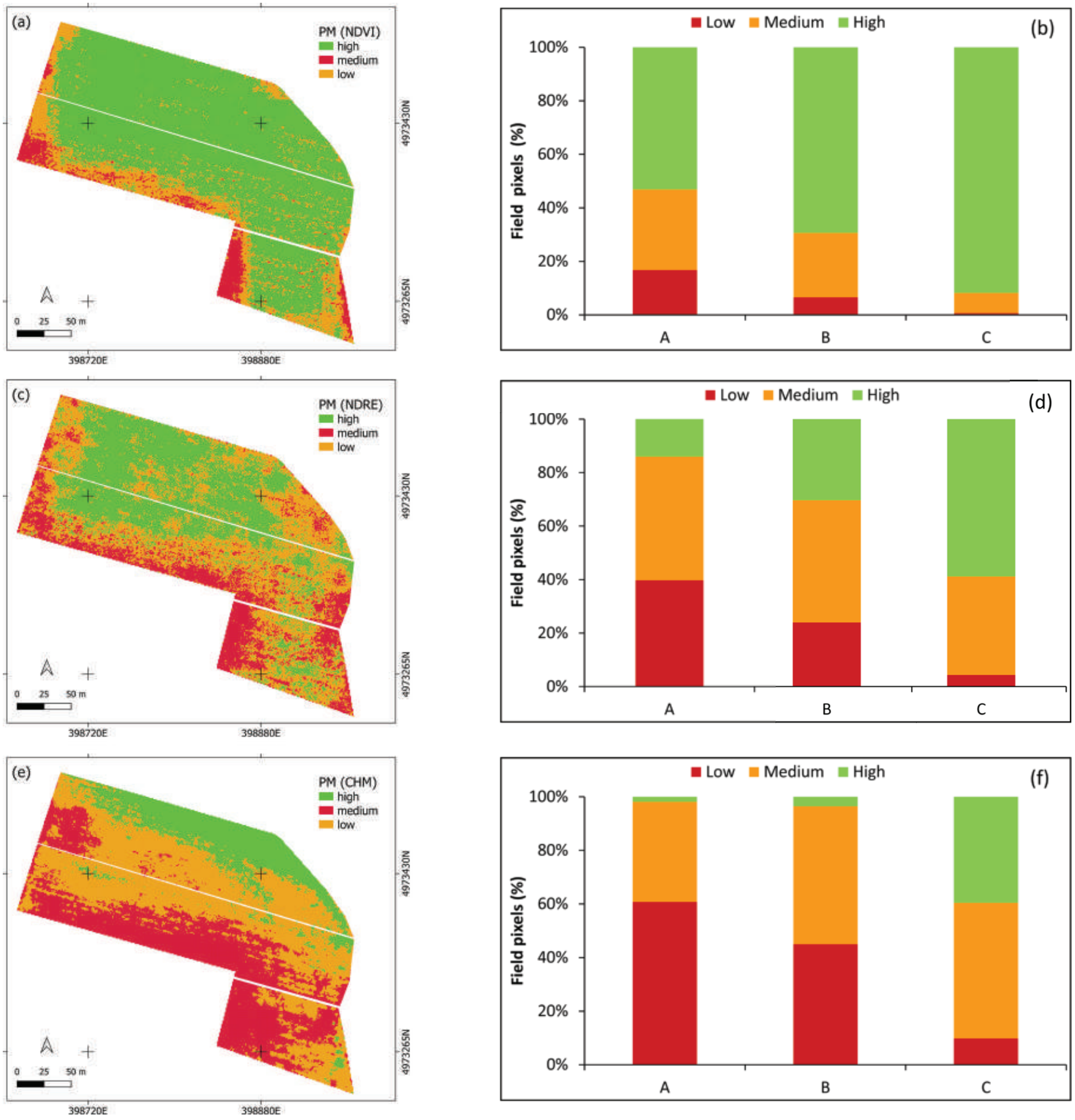

Figure 5. On the cover: (a) Prescription map generated from the NDVI map. (b) Statistical distribution of vigour classes derived by PM (NDVI) for the different fertilisation test applied in the corn field. (c) Prescription map generated starting from the NDRE map. (d) Statistical distribution of vigour classes derived by PM (NDRE) for the different fertilisation test applied in the corn field. (f) Statistical distribution of vigour classes derived by PM (CHM) for the different fertilisation test applied in the corn field (Reference System WGS84/UTM 32N, EPSG: 32632).

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Drone-as-a-Service, Smart Farming, weed detection.

T-DROMES®, Drone-as-a-Service solutions for Smart Farming

1. Introduction

Smart-farming services based on remote-sensing data can benefit from the use of drones, due to the higher resolution and the great variety of available sensors. High resolution images subjected to specific processing allow, for example, the detection of pathogens that couldn't be caught with satellite or aerial data and, in addition, they can improve the performances of these traditional means.

This kind of information can be significantly important for single farmers, for cooperatives as well as for Institutions, Agencies and Regional/National administrations.

The all-phases management of a smart-farming service with drones, from the definition to the execution of flights and the delivery of the final products, is a critical aspect. This is definitely true for those services applicable to large areas of interest, needed to involve several drone operators.

The two solutions presented below, realized by Telespazio in 2021 with T-DROMES® service platform, implement all these constraints using a drone-as-a-service paradigm with an industrialized end-to-end chain and standard final products.

2. GeoAdventice: Datura in a mobileApp

Datura stramonium is a widespread annual plant, containing atropine, hyoscyamine, and scopolamine, which can produce poisoning with a severe anticholinergic syndrome. In Europe Datura can be found in several agricultural crops, making possible to contaminate the harvests.

Commission Regulation (EU) 2021/1408 established maximum levels of tropane alkaloids in certain foodstuffs. These lead farmers to enhance methods to locate Datura plants in their crops, in order to eradicate them, before the harvest.

GeoAdventice is the service realized by Telespazio France with the collaboration of Telespazio Italy, aimed to locate Datura in summer crops like sweet corn or green bean crops, thanks to the processing of images acquired by drones. It is addressed to farmers and scale up through agricultural cooperatives and agribusiness players.

The solution uses the drone-as-a-service paradigm: the Cooperatives provide T-DROMES® with the parcels to be acquired and the suitable time intervals, receiving back notifications about the day and time of the flight and, within 3 days from the flight, the digital detection mapping of *Datura*.

The Datura Detection Maps provide the position of the weeds surely or probably recognized as Datura. Farmers can therefore go on their parcels directly to extirpate the mapped weeds, through the mobile application FarmingApp of T-DROMES® available both for iOS and Android smartphones. The Farming app allows the farmer to visualize on field the weeds position and then to communicate if the extirpation was completed or in case of doubts request a double-check by an agronomist. The on-going activities in the field allow the Farmers an effective and efficient way to ensure the dynamic monitoring of the crop status providing benefits in terms of food security and promoting sustainable agriculture.

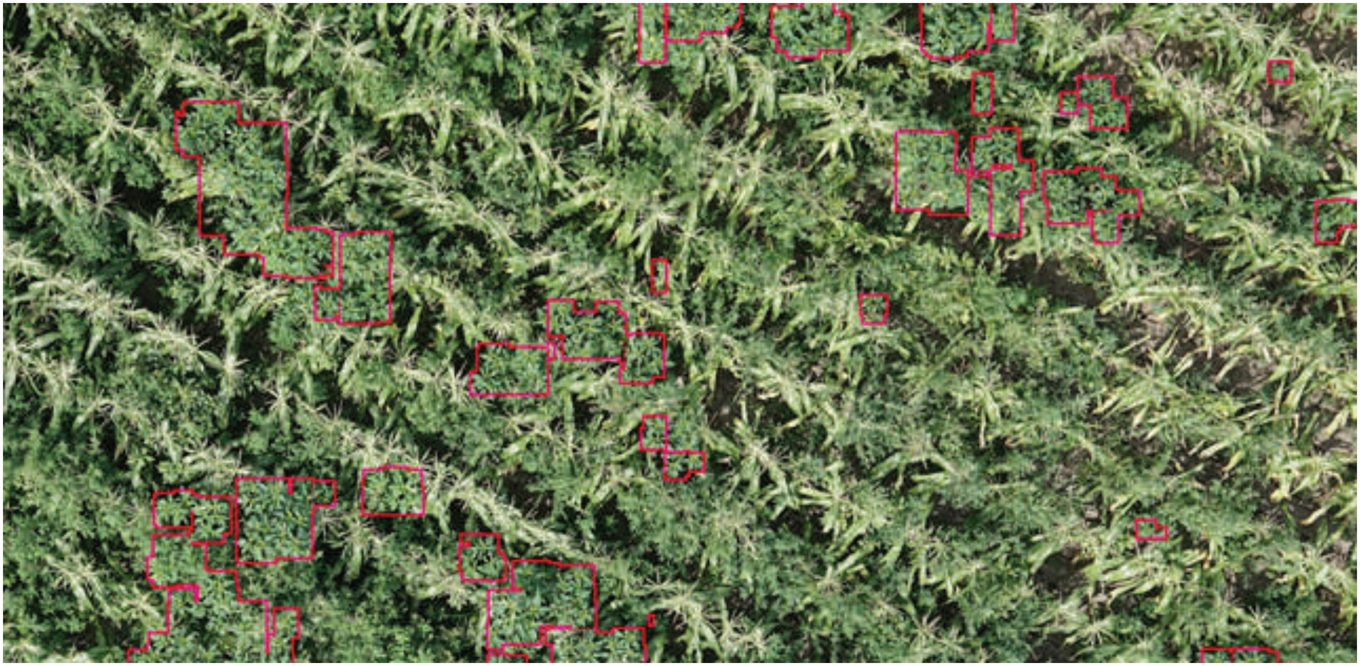

Figure 1. Datura in a corn plant by drone flight.

The weed detection is provided with the direct georeferencing method therefore each weed point is associated to a point 2D coordinate. On the field, the T-DROMES Farming App allows the Farmer to choose the GPS natively provided by the mobile phone or to use any external third party GNSS in cases where high accuracy of the weed geolocation is required. This approach offers an alternative and more efficient method than visual inspection of weeds. The farmer does not need to have agronomic knowledge for the identification of the weed, moreover he has to pay attention on specific weed points rather than indiscriminately verify the weed over a large area of cultures. An operative backend manages all the workflow of this service: reception of user requests, planning of the flights with the drone operator, processing of images and quality check. Planning of flights is a crucial phase since it merges Cooperative needs (that can always change) with the UAV regulatory constraints and drone operator availability. Datura detection is performed through artificial intelligence algorithms on single images (no mosaicking), with a final quality double-check by experts.

In 2021, GeoAdventice campaign lasted 5 months between May and September with more than 900 users registered to FarmingApp. 20.000 ha of plantations have been managed, on almost 2.400 different parcels.

The UAV operations have been conducted through a custom multirotor from Air Marine, the AM704, equipped with a RGB sensor at 48MP, flying between 25-38 meters height with 10% overlap.

3. Xylella information layer for decision makers

Xylella fastidiosa is a plant pathogen transmitted by xylem fluid-feeding sap insects. Symptomatic infections of Xylella fastidiosa can cause many plant diseases. In olive trees it is causing olive quick decline syndrome, entailing withering and desiccation of terminal shoots,

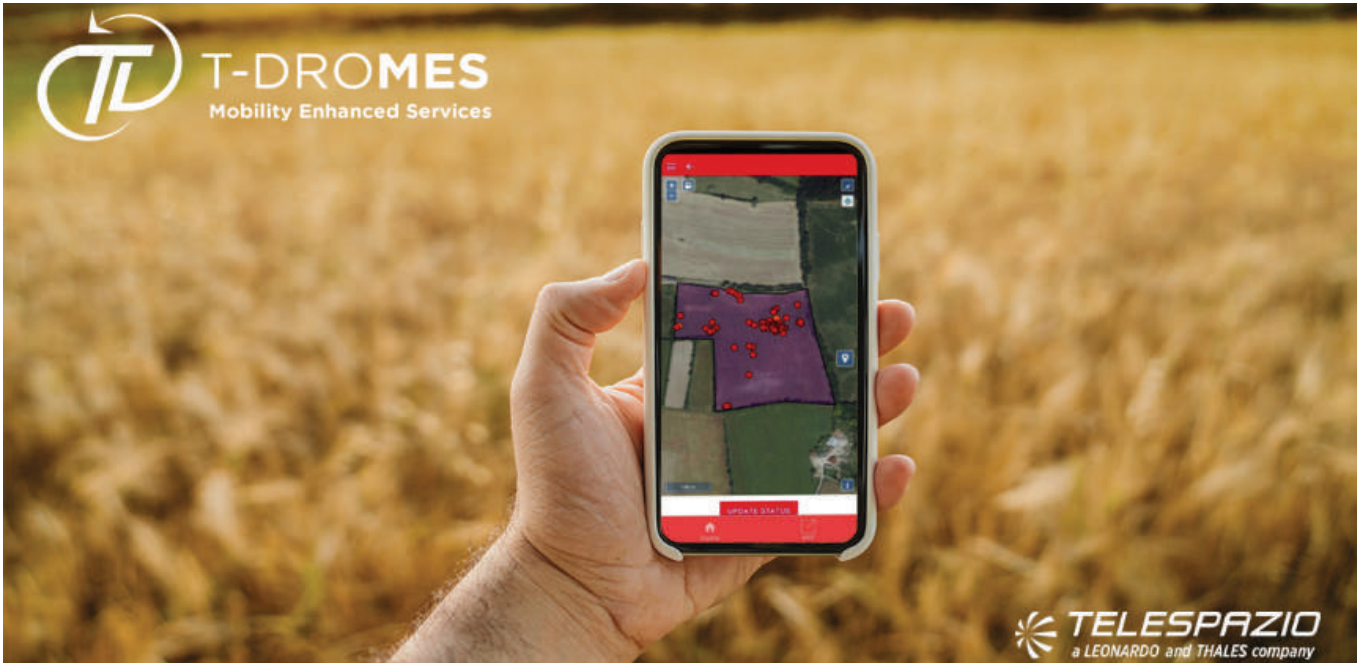

Figure 2. On the cover: Datura detection map.

distributed randomly at the beginning, but then expanding to the rest of the canopy resulting in the collapse and death of trees.
Since no cure has been found yet, the contrast to this pathogen and its diffusion starts from the sudden capability to recognize and monitor the presence of the infection.
The scope of the service was to contribute to the monitoring of olive trees in Puglia Region for AGEA Agency, through drone analysis to identify the typical initial symptoms attributable to Xylella f.
The service is composed by three phases: strategical planning of missions, flight execution and processing of images with delivery of final products.
The end-to-end service has been managed through T-DROMES® platform by Telespazio SpA, powered by COTS for mosaicking of orthoimages and CLEOS Platform, by e-Geos, for the image processing and generation of info-product. The plan of flights has included the time schedule and the characteristics definition of each flight, taking into account aeronautical constraints.
Flights took place between May and July 2021, on 13 sample areas, belonging to different control and buffer zones.
Two drones have been used: a fixed wing SenseFly eBee X RTK and a DJI Matrice 300 RTK, equipped with several sensor (thermal, RGB, multispectral), flying at different heights with 80% overlap. The most suitable combination for the purpose resulted the multispectral tool (red, green, blue, red edge and NIR) with 8,5 cm of GSD.
Through automatic procedures based on artificial intelligence algorithms opportunely trained, canopies were separated from soil and olive trees distinguished from other species.
More than 164,000 olive crowns have been automatically extracted and recognized in 1,296 ha.
Within canopies only, a supervised classification based

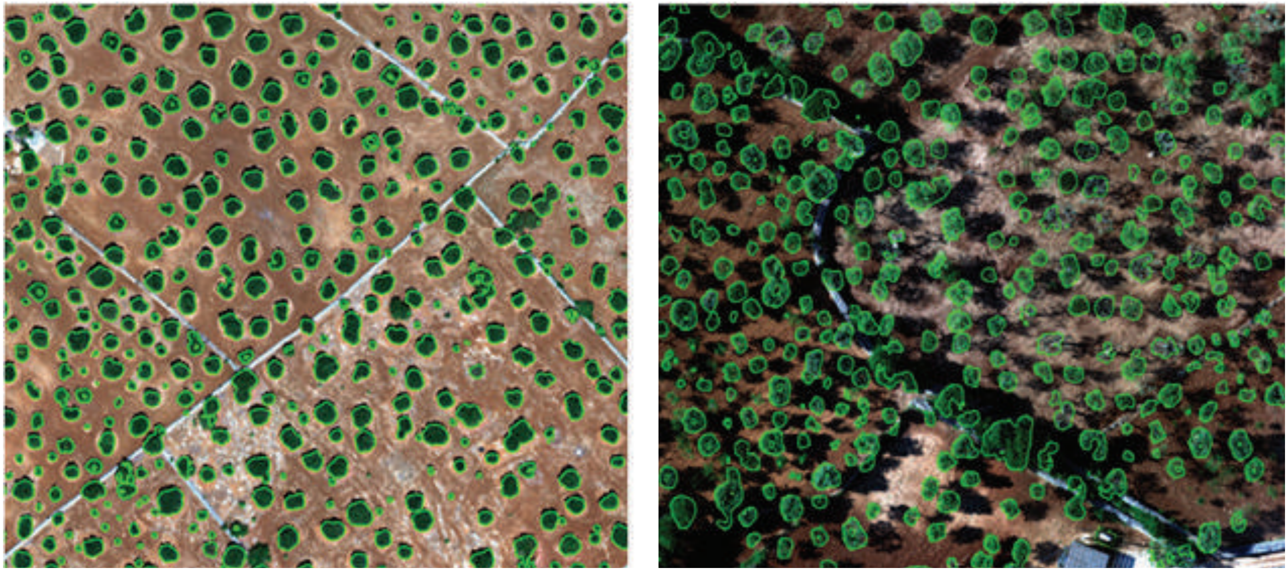

Figure 3. Crown canopies of olive trees extracted through AI algorithms.

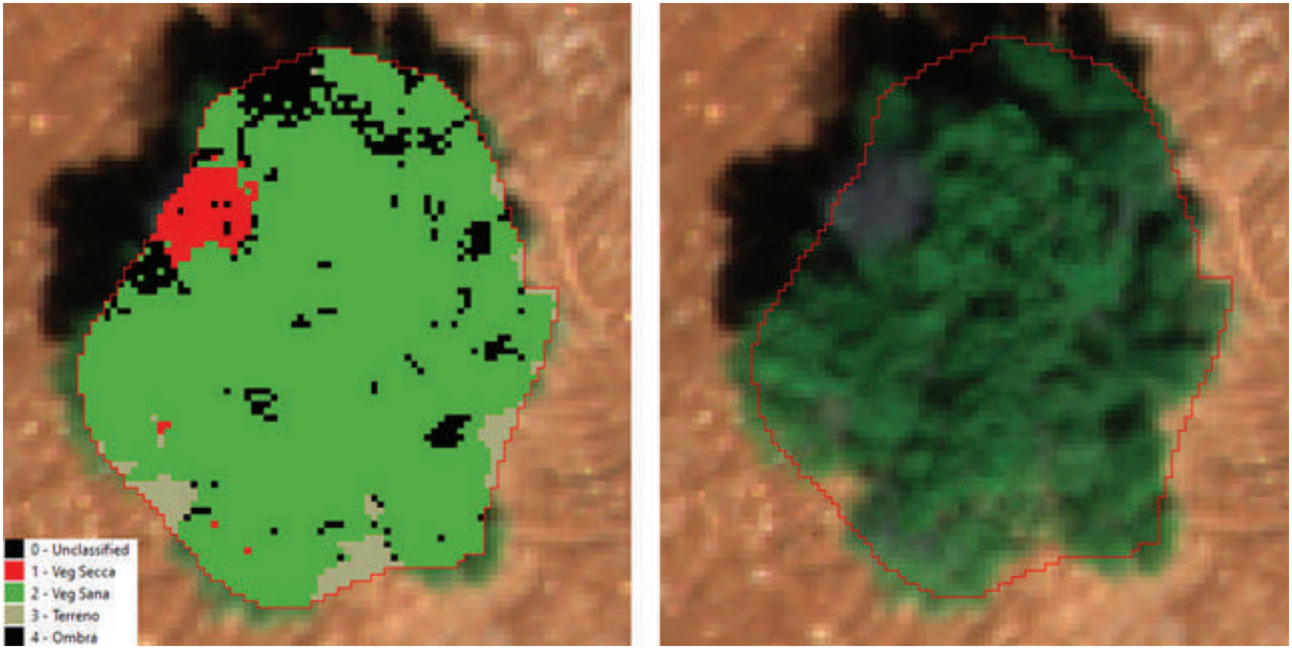

Figure 4. Supervised classification of canopies example.

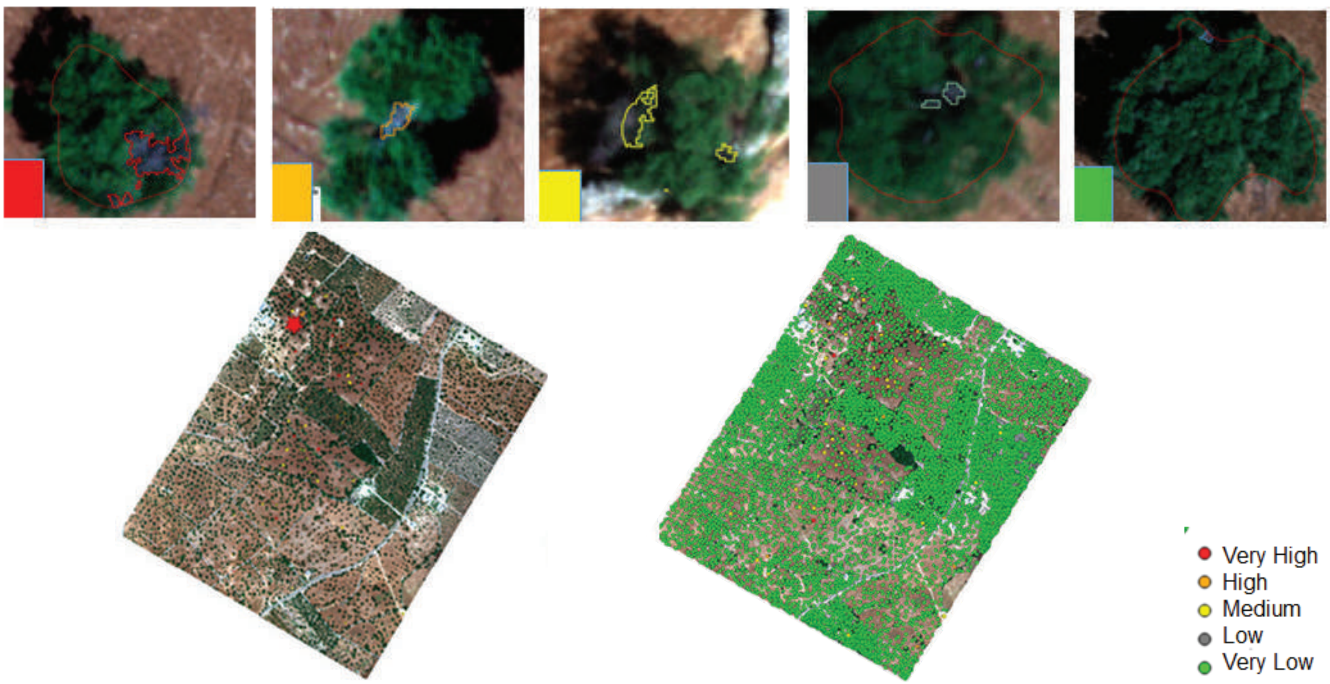

Figure 5. Probability classes of infection by Xylella and health status map of olive trees.

on spectral analysis identified 4 classes: dry vegetation, health vegetation, soil and shadows. The combined analysis of the shape of the dry portions inside the canopy and the NDVI value of the entire canopy, produced a classification of the probability to be affected by Xylella f. for each olive tree.

The probability varies from 1-Very High to 5-Very Low. The final product was a raster layer with the 5 bands used for the analysis and a vector layer in which every point indicates an olive tree with the attribute of probability to be affected by Xyella f. (from very high in red to very low/healthy in green).

This information is supporting the monitoring activity of the agriculture agency AGEA, indicating where the disease seems to be more present, addressing and focusing the field inspections with a reduction of time and costs.

4. Conclusions

The two cases represent a demonstration of services with drones that gather innovation and reliability, available for both farmers and public entities. The scalability of such services allows engaging several drone operators for the production of a common, standard and comparable final product.

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Precision forestry, UAV, Drone, Forest structure, Biodiversity.

UAV FOREST APPLICATION SUPPORTING SUSTAINABLE FOREST MANAGEMENT

1. Introduction

Forests play an important role in mitigating the effect of climate change and making recreation and economic contributions to our society. However, nowadays both knowledge of the capacity of forests to provide ecosystems services and the pressure on them are increasing. In this context, forest scientists and researchers, aim to enhance and improve their ability to monitor forests (Torresan et al. 2017). Addressing these demands, remote sensing is widely used for forest monitoring, inventory, and mapping applications designed to assess the extent of forest cover and its changes. Furthermore, new methods and tools to integrate spatially and temporally accurate information for monitoring forest ecosystems are needed to support sustainable forest management (Santopuoli et al. 2019; Shang et al. 2019; Winter et al. 2018). The targets of the research studies, together with the spatial and temporal scales of the analysis, condition the choice of the remote sensing technology to be used, and consequently of the sensors.

Aerial and satellite data have been widely used, while in recent years unmanned aerial vehicles (UAVs), are increasingly being used to collect data for forestry purposes. Particularly, three-dimensional (3D) remotely sensed (RS) data have become a key source of information for spatial prediction of forest properties (Maltamo et al. 2014; Næsset et al. 2004). In addition to the well-known airborne laser scanner data, modern digital photogrammetry based on UAV data has received increasing attention for the acquisition of 3D RS data (White et al. 2013; Giannetti et al. 2018). UAVs have many advantages such as low material and operational costs, and high-intensity data collection, which make them suitable for forestry use (Tang, Shao 2015). UAVs can be equipped with different types of sensors according to the parameter under consideration and can be used at the desired time (Figure 1). In the context of precision forestry (Taylor et al. 2002), to plan and conduct site-specific forest management, the demands for small-scale forest information have increased (Giannetti et al. 2020). Maps representing the forest environment under different points of view are considered crucial to support forest management activities (Corona et al. 2017; Fardusi et al. 2017). Data acquisition with a high spatial resolution typical of UAVs allows the development of objective and robust methods, which are a critical aspect of sustainable forestry. In this study, we presented the main Italian UAV applications in support of sustainable forest management.

2. Applications of UAVs in Forestry

2.1 Precision Forestry and Sustainable Forest Planning Management

Parameters such as canopy cover, number of trees, estimated volume, viability, or stand composition are essential parameters in forest planning and sustainable forest management. Rapid and accurate determination of canopy cover can be achieved using UAVs facilitating decisions and improving forest quality and productivity.

Figure 1. Mainly used UAV: octocopter with a light detection and ranging (LiDAR) sensor (left) and fixed-wing eBee drone (right).

Chianucci et al. (2016) used a commercially available fixed-wing eBee (senseFly Ltd., Switzerland) equipped with a commercial 16 MP Canon Power Shot/ELPH 110 RGB camera, to collect images in a Tuscany study area, to prove the effectiveness of the data for obtaining rapid economic and timely estimates of forest canopy attributes at medium to large scales. Field reference data are used to calculate a set of structural complexity indices based on tree Diameter at Breast Height (DBH) and height (i.e., basal area; quadratic mean diameter; the standard deviation of DBH; DBH Gini coefficient; the standard deviation of tree heights; dominant tree height; Lorey's height; and growing stock volume) to combine 3D variables derived from UAV imagery (using a SenseFly eBee Ag fixed-wing UAV equipped with a SONY WX 18 MP RGB) in two Tuscany study sites (Giannetti et al., 2020). Specifically, based on the derived photogrammetric data, DTM-independent predictors were calculated for each field plot as reported by Giannetti et al. (2018). Multiple linear regression models were used fitting each forest structure indices, derived by field data, demonstrating that 3D UAV photogrammetric data alone are suitable for modeling, mapping, and estimating forest structure indices in temperate mixed forests. Floris et al. (2012) estimated the forest stand volume of approximately 8 ha, composed mainly of conifers, in northeastern Italy through a regression model that used a metric extracted from the CHM derived from high-resolution UAV (hexacopter equipped with a VIS-RGB 550D camera (Canon Inc., Japan) orthophotos as an explanatory variable.

2.2 Forest canopy cover monitoring

To perform detailed analyses of canopy cover, its changes, and health status, UAV data are particularly suitable. The influence of image pixel resolution (ground sampling GSD) on canopy cover estimation in poplar plantation located in northern Italy, obtained from the field (cover photography; GSD < 1 cm), was compared with UAV (multirotor STC_X8_U5; GSD < 10 cm) and satellite imagery (Sentinel-2- S2; GSD = 10 m) (Chianucci et al., 2021). The results show that S2 can be used for large-scale monitoring and routine assessment of canopy cover in poplar plantations. The higher resolution of the UAV allows for a finer assessment of canopy structure and health monitoring, limiting the need for ground-based measurements (Chianucci et al., 2016).

Forest disturbances, especially those caused by wind and snow, directly affect stand regeneration, biodiversity,

Figure 2. On the cover: An example of partially and totally defoliated crowns identified by visual interpretation of the eBee RGB orthomosai (from FreshLIFE project).

and productivity, and mapping forest canopy gaps can provide an accurate status of these types of disturbances. So far, small gaps in forest canopy cannot be accurately measured using satellite data, which are characterized by too large spatial resolutions but can now be achieved using remote sensing with drones. In the study carried out in central Italy by Bararam et al. (2018) using aerial images collected by a fixed-wing eBee UAV (SenseFly, Switzerland), equipped with a commercial SONY WX 18. MP RGB camera, results revealed that small gaps in the canopy cover (75% smaller than 7 m2) can be accurately extracted from RGB band UAV images using red band segmentation and contrast division. Relating gaps data to biodiversity data, the research highlights that UAV data can potentially provide covariate surfaces of variables of interest for forest biodiversity monitoring, conventionally collected in forest inventory plots. Furthermore, by integrating UAV data and field surveys, these variables can be accurately mapped over small forest areas and at high spatial resolution.

2.3. Forest species detection

Gini et al. (2018), investigated the use of UAV imagery in tree species classification, through a supervised classification of very high-resolution images (0.01 m) in a park in the northwest of Italy, to assist the forest park authority to manage selective cuttings. In addition to multispectral data, the addition of texture features, defined as the measures of smoothness, coarseness, and regularity of an image region generated from a spatial relationship of pixels, improved the overall classification accuracy values, as well as user and producer accuracy.

2.4 Post-fire recovery

Aicardi et al. (2016), used a temporal sequence (2008-2015) of DSMs obtained from ALS data and UAV digital imagery (2015) to detect changes in a Scots pine forest in northwestern Italy that was affected by a crown fire in 2005. In summer 2015, an eBee UAV (senseFly Ltd., Switzerland) was used to acquire images over approximately 50 ha. The UAV-DSM was compared with the ALS-DSM captured in 2008 within the burned areas. Analysis of the DSMs showed that the increase in forest stand height was mainly caused by post-disturbance regeneration of vegetation, mainly broadleaf trees.

5. Conclusions

Some common conclusions are drawn by the different applications presented: Drones are unmanned aircraft of small size, very low energy consumption, and low cost to operate, with no risk to the operator. The current use of drones in forestry applications has shown great potential. The increasing accessibility in terms of cost and size of LiDAR and infrared sensors along with data combining methodologies has encouraged the use of UAVs in forestry. Despite the many pros, some limitations in UAV applications are found for large area acquisition due to their limited flight duration (Matese et al. 2015). The size and payload capacity limits the ability to carry onboard sensors with technologies that are not yet sufficiently miniaturized. However, future generations of UAV will continually evolve and offer increased flight time and improved sensors, allowing to further expand the possible forest applications.

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Geology and UAV: research, experiences and future perspectives

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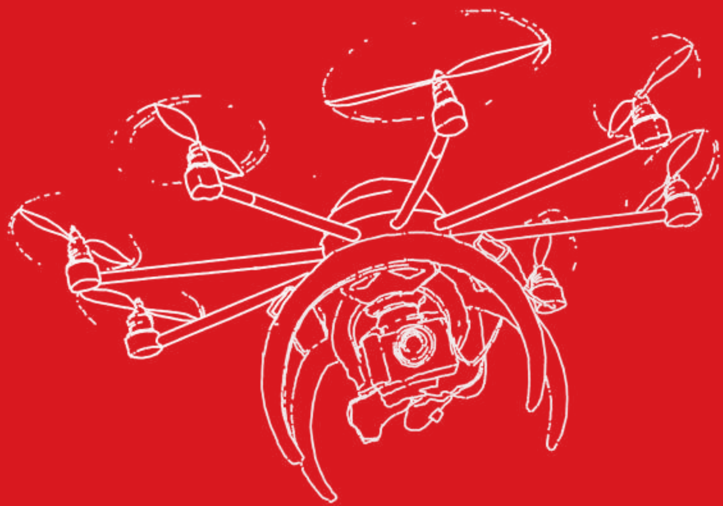
The use of UAV (s.l.) has grown exponentially in recent years, thanks to the simultaneous development of increasingly performing platforms and a heterogeneous range of sensors. The ability to use the potential of this mixing has made it possible to increase acquisition productivity and significantly reduce operating costs and hazards, as well as opening the door to a plethora of new applications. Geology is benefiting more than others from this favorable trend. This session is proposed to improve the level of knowledge of this context, for all disciplines concerning Geosciences (Geomorphology, Geomechanics, Geophysics, Geochemistry, Pedology, etc...) sharing state of the art experiences and research, without forgetting the future.



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Keywords:
Geomorphology, Drones, Watercolour boards, Torquato Taramelli.

Art and Drones: retracting the paths of Torquato Taramelli 100 years later

Torquato Taramelli (Bergamo 1845 - Pavia 1920) was one of the fathers of the modern geology and his academic career was studded by numerous prestigious awards. Taramelli conducted large part of his research in the Northern Apennines studying the single rocks as well as the relation of the Apennine nappes of the area. Nowadays we know that during his field campaigns, the geologist used to realize sketches and watercolours of landscapes of particular interest. The watercolours inherited and preserved by the Department of Earth and Environmental Sciences of the University of Pavia show amazing landscapes on which are clearly reported the geological formations and the relationship between them. Currently it is possible retracing the path of Taramelli discovering the areas reported in the watercolour, and through new technologies i.e., Google Earth images and drone acquisition, to observe the landscape evolution, the land use change, the anthropization of those places, as well as reinterpret in a modern geological point of view the studies of Taramelli. Especially drones can significantly contribute to observe and study the landscape due their possibility to move easily and quickly and find the optimal point-of-view. To capture the most similar Taramelli's landscapes we used a light-weight quadcopter (< 600 grams), type DJI Mavic Air 2, equipped with a 48 Megapixel camera (1/2" CMOS sensor) with an 35mm equivalent focal length of 28mm. Its high resolution and wide-angle lens (FOV = 84°) make it very useful in reproducing the Taramelli's watercolours.

The Figure 1 show the comparison between the original watercolour realized in 1896 by Taramelli, (Figure 1a) with the actual landscape observed through a drone survey (Figure 1b).

The title of the watercolour (Figure 1a) highlights the presence of serpentinites as well as conglomerates rich of ophiolites and granite. Nowadays it is well known that these bodies belong to the External Ligurian Unit. This tectonic unit is mainly composed of Late Cretaceous sedimentary successions some of which retain slide blocks of oceanic and continental crustal rocks as well as subcontinental mantle rocks. The rocks that stand out at Pregola and Monte Groppo are hectometre-sized ultramafic rocks characterized by mantle peridotites extensively or partially serpentinized. As insight by Taramelli, these formations were surrounded by erodible fine sedimentary Formations named nowadays e.g., *'Complesso di Monte Ragola'*, and *'Arenarie di Scabiazza'*, and shaped by differential erosion. The drone observation was fundamental to detect the morphological evidence of the outcrop and to identify the correct perspective. In fact, comparing the watercolour with the acquired image it is evident that the peak of ultramafic rocks it is currently more rounded respect the watercolour. Moreover, it is possible to observe a deep land use change in the valley. The agricultural field and vineyards reported by Taramelli were replaced by mowing grass field and forest. The study highlights how a simple drone survey can be a valid instrument to observe and to study areas of past and present interest.

Figure 1. Original watercolour of T.Taramelli.

Figure 2. Image acquired by drone survey.

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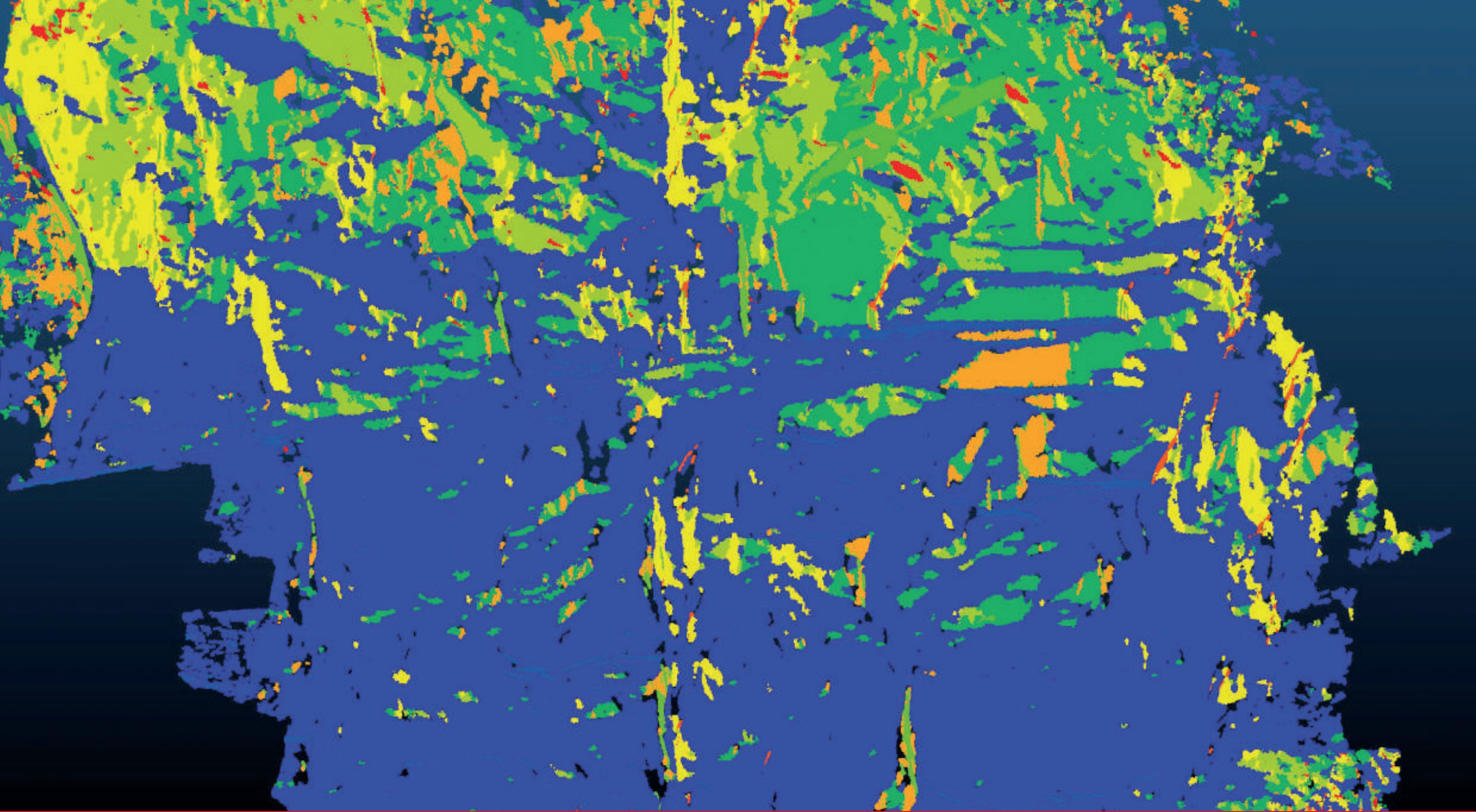

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Keywords:
Engineering geology, Stability analysis, Discontinuity.

Uncrafted Aerial Vehicle-based rock slope stability analysis of Baveno granite quarry area: the tailing and waste rock extractive site of Ciana-Tane Pilastretto (Montorfano)

1. Introduction

Here we present the preliminary results of an Uncrafted Aerial Vehicle (UAV)-based rock slope stability analysis of Ciana-Tane Pilastretto extractive site of the Montorfano (Southern Alps, Italy).

Since XVI century, the Montorfano was an important quarry area for the extraction of granite rocks and, in particular, the *Ciana-Tane Pilastretto* site was one the main extractive site for production of the Montorfano White Granite (Dino et al. 2012). During the past, the exploitation of the site using blasting technique caused the accumulation of a very large amount of rock waste on the lower side of the slope.

From the half of 90's, the mining companies start to exploit this quarry waste for the production of secondary raw materials, as F60P, SNS-sand, NGA-coarse black sand, SF-wet feldspar, SF100 and SF200 (Dino et al. 2012).

At the *Ciana-Tane Pilastrello* site, before the start of the exploitation of quarry waste, the deposit covers an area with an altitude difference of ca. 300 m and a width of ca 500 m. The thickness of this deposit was initially unknown because the real shape of the buried rock slope was never mapped, but during the exploitation process, thicknesses of 60 meters have been discovered. During the progressive removal of this thick waste cover, different and unexpectedly rock slope instability phenomena occurred. Fortunately, most of these phenomena occurred in off-work time and, therefore, no workers were injured. Whereas these instability events were considered as statistically possible, due to the effect of the cover removal and the consequent confinement stress reduction, they were not localized, due to the huge dimension of the slope and the high number of rock discontinuities. It is for this reasons that we decided to perform a UAV-photogrammetric analysis of the rock slope.

2. Method

Using UAV-photogrammetric technique and two different quadcopter types, a DJI Phantom 4Pro (P4P) and a DJI Mavic Air 2 (MA2), we were able to acquire different aerial images of the rock cliff. The main dataset was acquired using P4P, is composed by ca. 400 pictures and covers the entire *Ciana-Tane Pilastrello* site with a photo-resolution of 2.5cm. The other datasets were acquired with MA2, are composed by a total amount of ca. 600 photographs and cover three regions of interest with a higher resolution (from 2 to 7 mm/pixel). All the datasets were then processed using the Agisoft Metashape v.1.7 with the higher quality/resolution setting. This software is based onto Structure from Motion (SfM) - Multi View Stereo (MVS) algorithms and allows to develop densified point clouds, and texturized 3D meshes.

The analysis of the 3D point clouds and meshes, was performed using CloudCompare open-source software. In particular, we used the Tracing polylines tool that allows to sample points on to the 3D model that belong to rock discontinuity traces or planes (Menegoni et al. 2019). For each mapped

discontinuity, after the points sample procedure a best-fit plane representing the discontinuity plane is calculated and the orientations, dimensions and positions of the discontinuities were estimated.
Successively, an algorithm for the automatic recognition of the discontinuity surfaces, called Discontinuity Set Extractor (DSE; Riquelme et al. 2014) was applied.
For each point of the cloud the DSE algorithm calculates normal vector representing the local orientation of rock slope, classifies points with similar orientation in discontinuity sets and merges points belonging to the same discontinuity surface using coplanarity and distances tests.
The DSE results can be very useful when it is necessary to perform a qualitative and quick rock slope analysis, notwithstanding, they are affected by several issues, such as the presence of artifacts (Menegoni et al. 2019). Therefore, these results must be carefully filtrated and validated by expert users and then eventually used as a benchmark for the manual mapping analysis. The kinematic analysis of the possible failure mechanism was performed using the Markland tests.

3. Preliminary results

The preliminary manual analysis of 3D photogrammetric model of *Ciana-Tane Pilastretto* extractive site (Figure 1a) shows the presence of 4 main set of discontinuities that often can be differentiated in subsets (Figure 1b).
The automatic analysis (Figures 1c and 1d) shows discontinuity sets orientation similar to those of the manual one (Figure 1b), but clearly wrongly identifies as discontinuities the debris and human artifacts (e.g. small building in the middle of the model), and overestimates the discontinuity surfaces dipping toward SE (e.g. sets A1a and A1b).
For this reason, to perform the rock slope kinematic analysis only the manual measures were used (Figure 2). Considering the rock slope dips with an average of 48° towards 159°N, the analysis suggests that:

• planar sliding can occur on some discontinuities of set K3 (Figure 2b);
• wedge sliding can occur mostly onto the intersections between discontinuity sets K1b and K2b, and with minor criticality onto intersections K1a-K3b and K2a-K3c;
• flexural toppling can be caused by the discontinuity sets K4a, K4b and K4c.

Looking at the percentual of discontinuity planes and intersection possibly involved into failure mechanisms, the most critical mechanism appears to be the flexural toppling involving 8% of the total amount of discontinuity planes. It is followed by the planar sliding that involves 4.62% of total amount of discontinuity planes. At last, the wedge sliding appears to be the less critical mechanism involving 4% of the total amount of virtually possible discontinuity intersections.

4. Preliminary conclusion

A preliminary analysis of the discontinuity network and stability of the rock slope of *Ciana-Tane Pilastretto* excavation area was performed on a drone-based photogrammetry model. Manual and automatic mapping show similar results indicating a correct identification of the main discontinuity set. Due to the main limitations of automatic mapping the preliminary analysis of the slope stability was conducted using the manual mapping results. These indicates that the most critical instability phenomena could be the flexural toppling followed by planar sliding and wedge sliding.
Notwithstanding, it must be kept in mind that this stability analysis is a preliminary qualitative analysis because manual mapping was not completely performed onto the 3D model representing the slope. Further complete and more detailed manual mapping and analysis of the 3D drone-based photogrammetric model will allow to better define the discontinuity network that affects rock slope and, therefore, perform a more adequate stability analysis.

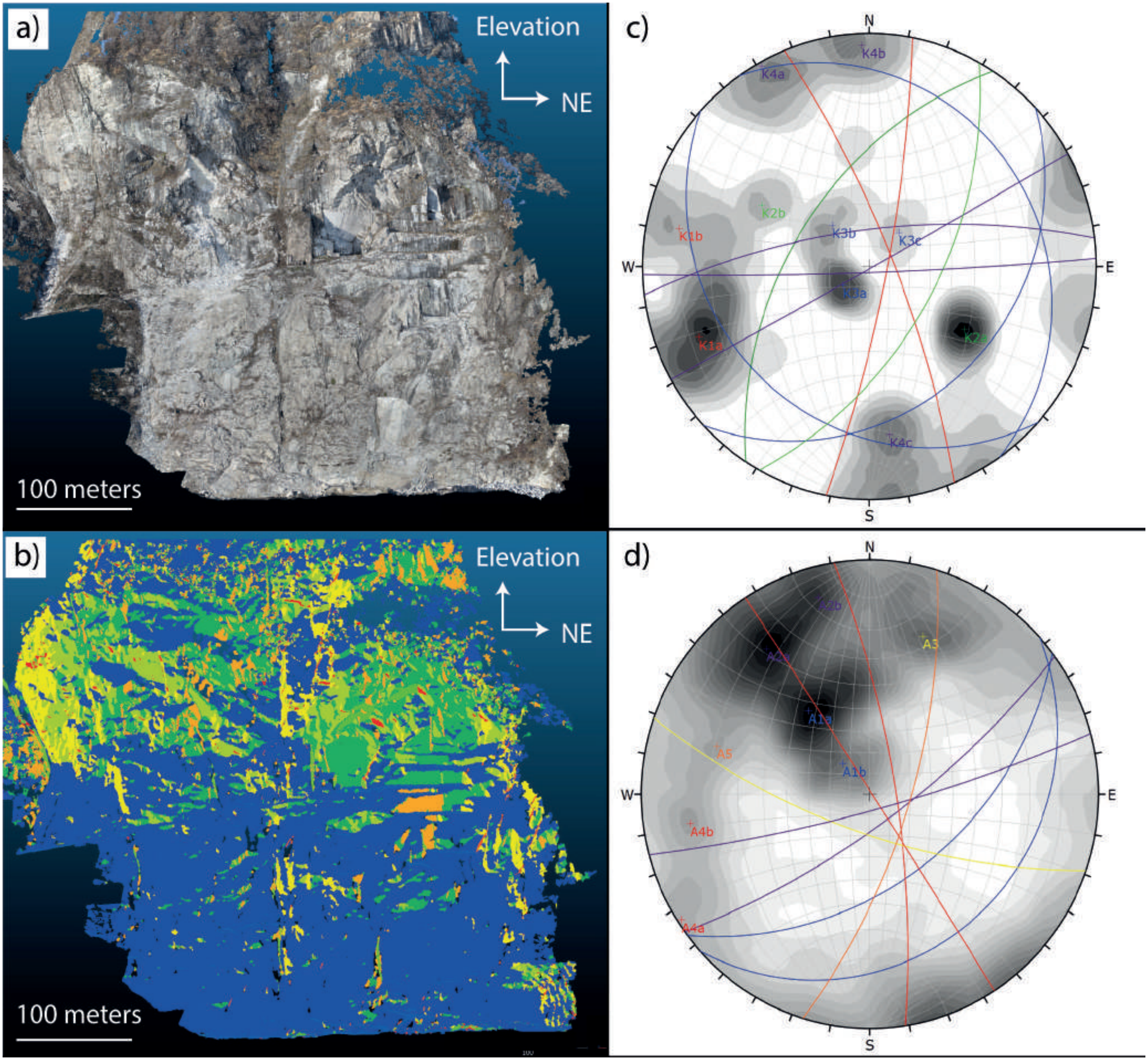

Figure 1. On the cover: (a) 3D point cloud representing the analyzed rock slope. (b) Results of the automatic discontinuity recognition performed using DSE algorithm. (c) and (d) Lower hemisphere stereographic projections and contours of the manually mapped and DSE discontinuities, respectively onto the 3D model of the rock slope. The mean pole and plane of each discontinuity set and/or subset are marked and named.

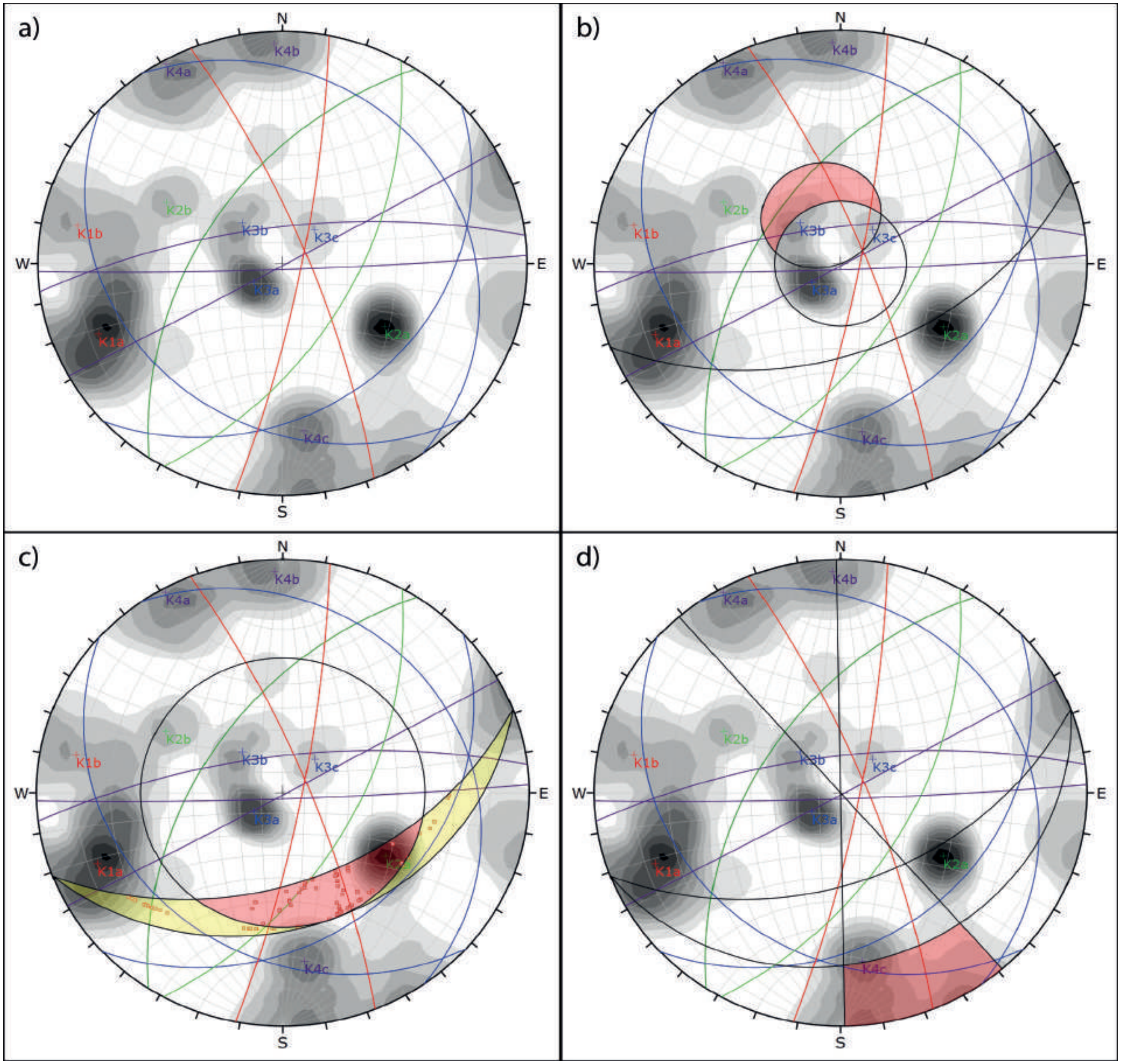

Figure 2. (a) Lower hemisphere stereographic projection and contour of the manually mapped discontinuities onto the 3D model of the rock slope where the mean pole and plane of each discontinuity set and/or subset are marked and named. (b) Planar sliding test where the poles of the critical/unstable discontinuity fall in the red area. (c) Wedge sliding test where the critical/unstable discontinuity intersections fall in red (sliding on both discontinuities forming the intersection) and yellow areas (sliding on a single discontinuity surface). (d) Flexural toppling test, where the poles od the critical/unstable discontinuity planes fall in the red area.

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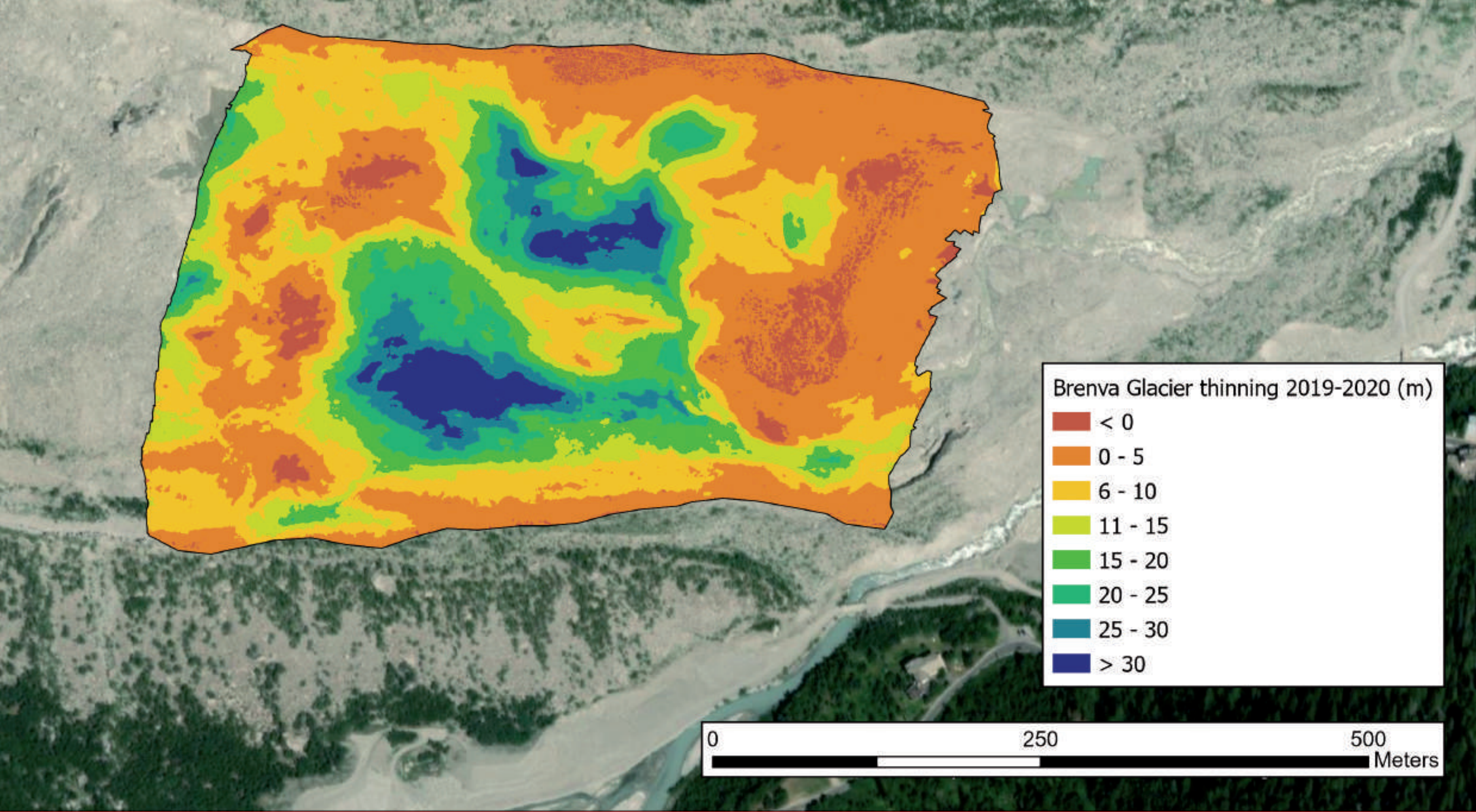

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Keywords:
Alpine glaciers, height changes, GNSS post-processing, point cloud.accuracy.

UAVs in cryospheric studies: experiences from Alpine glaciers

Alpine glaciers are showing signs of rapid downwasting and retreat, which are interpreted as a clear consequence of climate change. While conventional remote sensing techniques from satellite and aerial platforms remain useful to monitor large catchments, UAVs have recently emerged as ideal tools to investigate individual glaciers thanks to the ability to carry different payload types and the possibility to undertake on-demand surveys. In this study, we describe our experiences with UAVs to monitor the evolution of several Alpine glaciers, in Italy, Switzerland and Austria. Among them is Forni Glacier, one of the largest of the Italian Alps (area greater than 10 km2) and a tourist site in the Ortles-Cevedale group, part of Stelvio National Park, which has experienced severe thinning in recent years, including the fragmentation of the glacier tongue in separate sections. UAV surveys were conducted here in 2014, 2016, 2017, 2018, 2020 and 2021, experimenting with different platforms (fixed-wing and multi-rotor) and optical cameras.

Additionally, in 2020 and 2021 we carried out UAV surveys as part of the expedition "On the Trails of glaciers" led by Fabiano Ventura to disseminate the impacts of climate change on glaciers to the general public. The 2020 expedition was held on the Italian side of the Alps and in the Appennini range, while in 2021 we visited glaciers on the northern side. We conducted surveys on Amola Glacier (Adamello region), Brenva and Miage Glacier (Mont Blanc region), Calderone Glacier (the only ice body in the Appennini), Morteratasch Glacier in the Swiss Bernina, and Pasterze Glacier in the High Tauern of Austria.

In our work, we investigated methodological and technical aspects as well as glaciological ones: on Forni Glacier, we carried in 2016 a simultaneous survey using a multi-rotor UAV, terrestrial photogrammetry and a terrestrial laser scanner (TLS) with the goal of assessing the quality of the UAV dataset.

The resulting point clouds were intercompared using the MC2 algorithm in Cloud Compare, which showed a good agreement between the point clouds (max 38 cm RMSE between UAV and TLS). In 2020 and 2021, we used a RTK UAV on Forni Glacier and evaluated Leica Infinity software to post-process UAV GNSS tracks, which eliminates the need for GCPs and allows for greater flexibility when conducting high elevation surveys. In terms of glaciological results, our investigations showed increasingly higher thinning on the Forni glacier tongue, with an average -5.20 my-1 between 2014 and 2016 and much greater negative changes locally, up to -38.71 m between 2014 and 2016 and -31.6 m in a single year between 2016 and 2017. On Brenva Glacier, we documented the extreme thinning of the glacier tongue, with more than 40 m thinning between 2019 and 2020 (see Figure 1).

Future tests will focus on experimenting with other sensors like thermal cameras for glacier debris cover monitoring.

Figure 1. On the cover: Thinning of the Brenva glacier tongue between 2019 and 2020 from repeat UAV surveys.

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Keywords:
Unmanned Aerial Vehicle, Structure from Motion, Digital Elevation Model, Hydro-geomorphological hazard.

Application of UAV system and SfM techniques to address the hydro-geomorphological hazard in a fluvial system

Photogrammetry is one of the most reliable techniques to generate high-resolution topographic data being key to territorial mapping and change detection analysis of landforms especially in hydro-geomorphological high-risk areas.

Specifically, the Structure from Motion (SfM) is an emerging topographic survey technique that addresses the problem of determining the 3D position of image descriptors to estimate three-dimensional structures. Thanks to the potential of SfM algorithm and the development of Unmanned Aerial Vehicles (UAVs) that allow on-demand acquisition of high-resolution aerial images, it is possible to survey wide areas of the Earth surface and monitor active phenomena through multitemporal surveys. Therefore, these tools represent key elements to address geomorphological and hydrological variables in a dynamic system such as the fluvial one, in order to accurately understand the level of hazard from instability events (flooding hazard). However, the development of new UAV mapping techniques (i.e., BVLOS flight missions) related to the increasing need to detect larger areas at high-resolution for a better understanding of fluvial processes, may involve the acquisition of large datasets and limit the photogrammetric process due to the need for high-performance computing (HPC).

One of the main aspects investigated in this research concerns the implementation of a photogrammetric workflow based on Free and Open-Source Software (FOSS), which is able to return different high-resolution outputs and to manage large amount of data in reasonable time, through the distribution of the most computationally expensive steps on computing cluster hosted by the ReCaS-Bari data center for scientific research. The results are given in terms of performance evaluations based on different computing configurations of the clusters and setups of the steps of the workflow.

On the other hand, it has been investigated how the high-resolution outputs resulting from the SfM (Figure 1) process can affect the hydro-geomorphological analyses, by providing an original approach of probabilistic hazard assessment. Specifically, sensitivity analyses were performed to evaluate both the influence of the resulting high-resolution DEM on flooding hazard values in extended reach of the Basento river (Basilicata, southeastern Italy) and the influence of k_s values (roughness coefficient) resulting from UAV images photo-sieving analysis, and morphological change detection analyses over short-time ranges (2019-2021).

The key conclusion of this research is that the integrated UAV-SfM-HPC system and the resulting outputs are key for the effective management of alluvial environments and, specifically, for the detailed monitoring of hydro-geomorphological variables, which are crucial to assess future scenarios of instability (flooding hazard) and to timely plan emergency management activities in case of catastrophic events with significant time and cost savings.

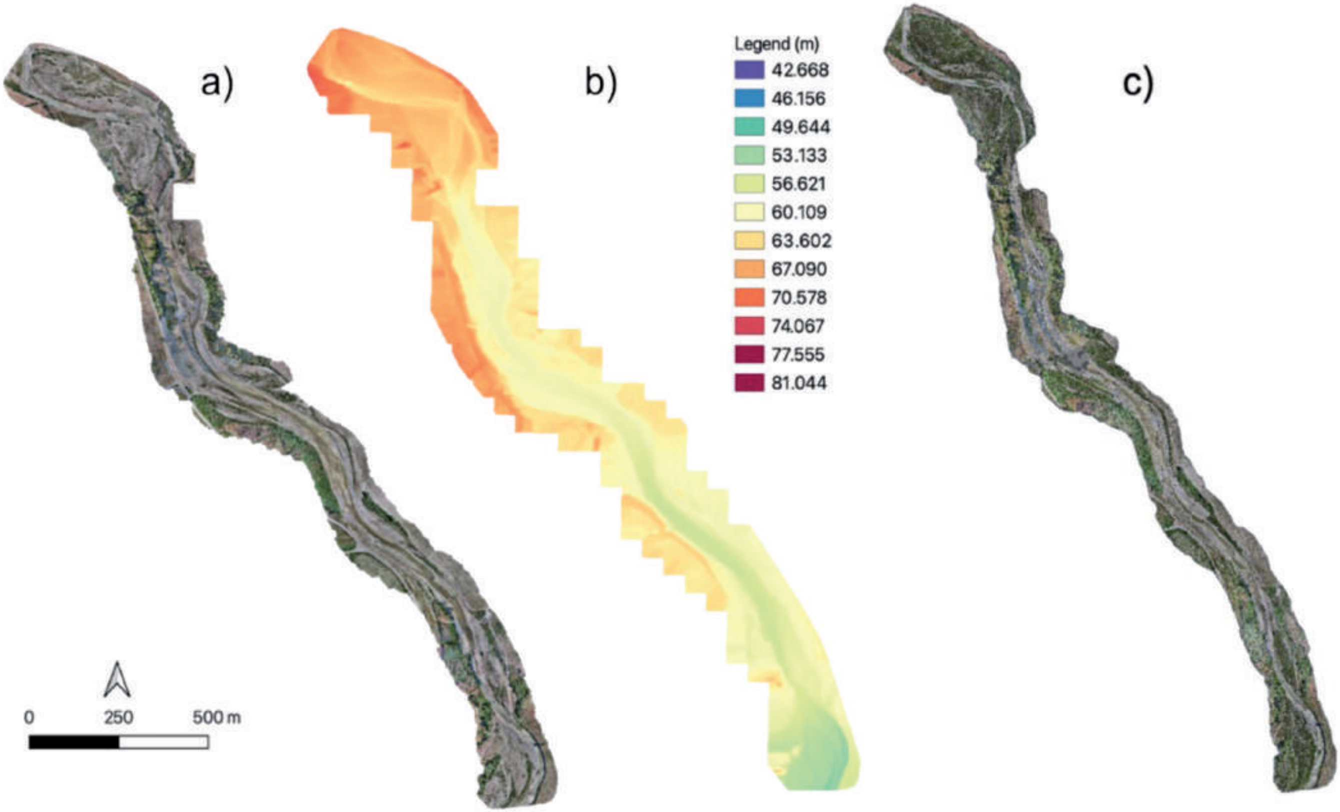

Figure 1. a) Orthophotomosaic (1.3 cm/pixel); b) Digital Elevation Model (6 cm/pixel); c) Point cloud (about 25.000.000 densified points) related to an extended reach of the Basento river.

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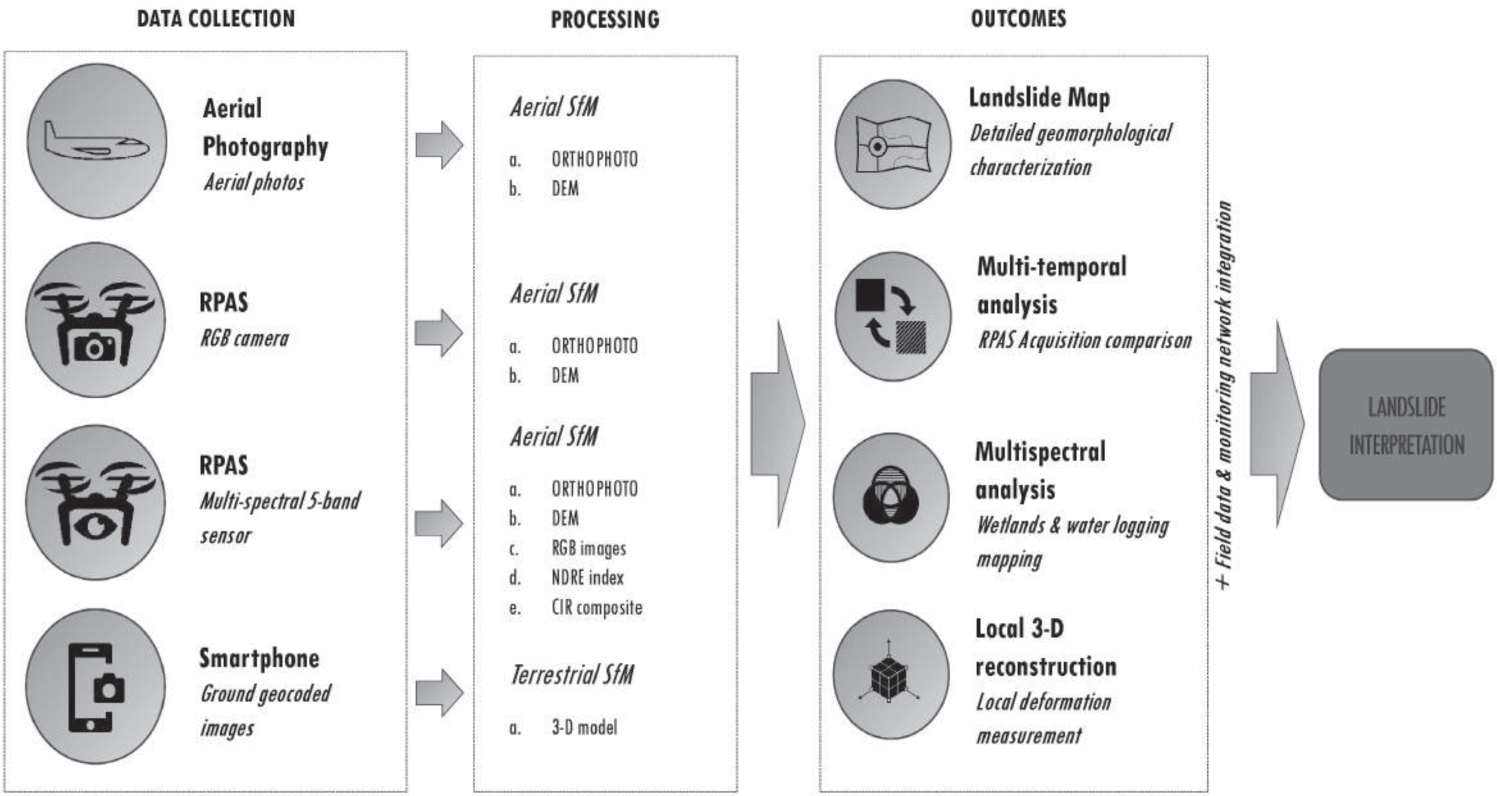

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Keywords:
Landslide-infrastructure interaction, Photogrammetry, Deep-seated gravitational slope deformation.

Structure from motion multi-source application for landslide characterization and monitoring

Unmanned aerial vehicles (UAV) can be considered a valuable solution for the acquisition of high resolution dataset functional for the identification and characterization of active landslides. Usually, UAV are equipped with RGB cameras for the acquisition of sequence of images, consequently processed by an algorithm, derived from Computer Vision field, called Structure from Motion (SfM). SfM is a powerful tool able to compute a 3D point cloud from a sequence of images taken from different points of view (Giordan et al. 2019). The use of this approach for capturing of RGB images is only a possible solution, but many other low-cost options can be adopted, i.e. smartphone. In the presented case study, we applied SfM to process three different datasets for the assessment of the evolution of the Champlas du Col landslide, a complex slide reactivated in spring 2018 in Piemonte Region (north-western Italy) (Cignetti et al. 2019). The reactivation of Champlas du Col landslide was principally due to snow melting at the end of a winter season, characterized by a remarkable amount of snow accumulation. This landslide interrupted the main national road used to reach *Sestriere*, one of the most famous ski resort of north-western Italy.

We decided to test how SfM can be used to process high-resolution dataset to carry out the study of the landslide evolution. We use this algorithm to process different datasets: i) two RPAS RGB images sequence of the landslide taken in different moments, ii) an RPAS multi-spectral image sequence iii) terrestrial sequence of most representative kinematic elements due to the evolution of the landslide.

Using these datasets, we defined the boundary of the landslide by image plotting and photointerpretation of the RGB orthoimages. By the application of band indices (Im, Jensen 2008) on the multispectral orthoimage we recognized the main water springs that have a direct influence in the activation of the landslide. Analysing the terrestrial and UAV 3-D model we assessed the displacement occurred between the two RGB acquisitions.

The proposed approach showed that it is possible to obtain reliable and useful data for landslide hazard definition, employing a cost-effective and rapid methodology based on SfM principles that is easily repeatable to characterize and investigate active landslide in other contexts.

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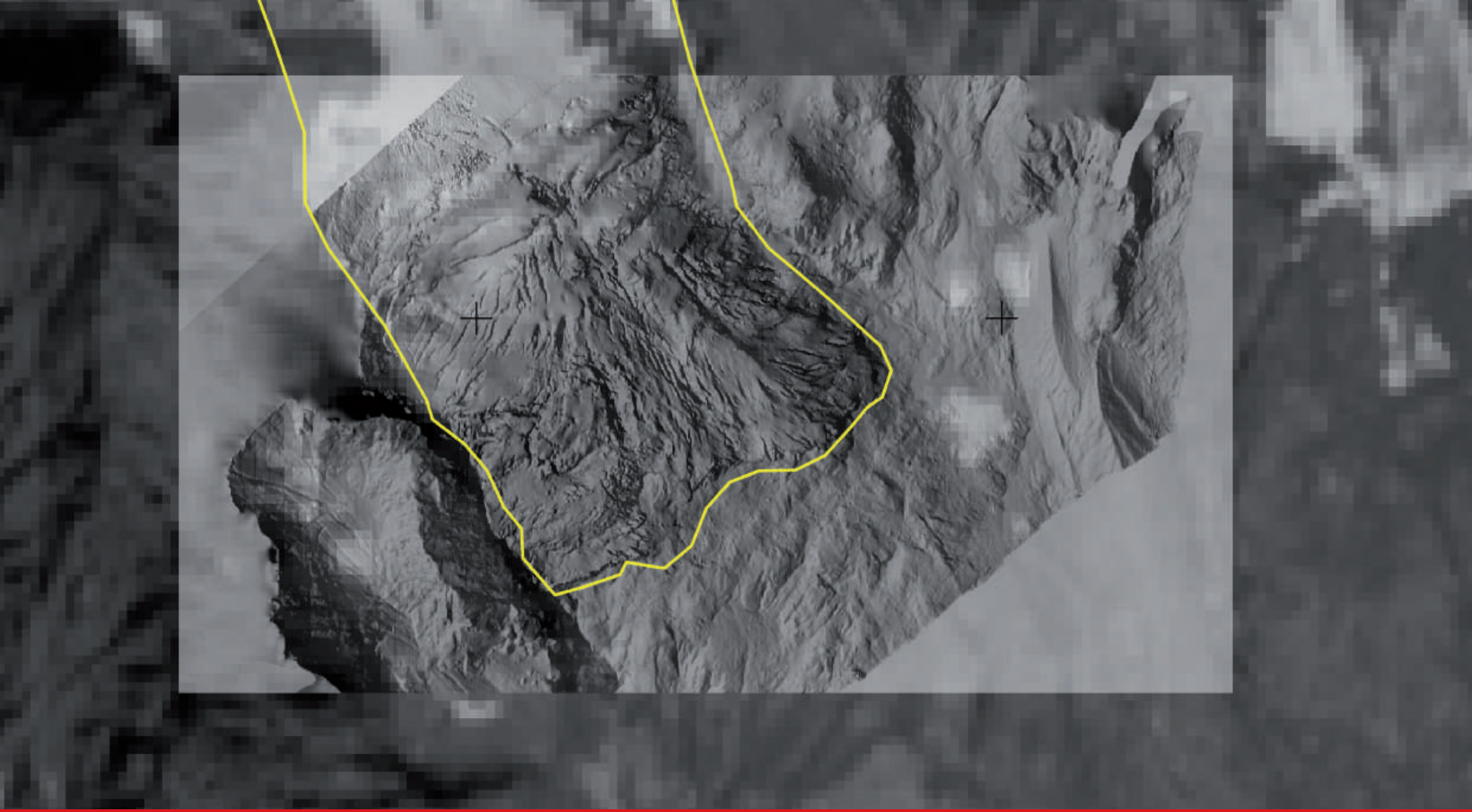
Figure 1. On the cover: Workflow of the proposed method.



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Keywords:
UAV, Photogrammetry, Glaciology, risk, Monitoring.

UAV observation of the recent evolution of the Planpincieux glacier (Mont Blanc)

Planpincieux Glacier is a glacier located on the Italian side of the Mont Blanc (Italy). This glacier is monitored using a system of permanent time-lapse cameras since 2013. In 2019, the frontal part of the glacier has been characterized by a critical acceleration that could trigger a large ice avalanche able to reach the underlying Planpincieux village. During the emergency, the working group composed of *Fondazione Montagna Sicura,* CNR IRPI and the Aosta Region Authority improved the monitoring system with a ground-based SAR to control the glacier evolution. An important data source used for a better understanding of the structure of the unstable frontal glacier sector has been the acquisition of a multitemporal sequence of digital terrain models (DTMs) acquired by unmanned aerial vehicles (UAV) and helicopters. The approach adopted for the DTM generation is the acquisition of a photo sequence and the application of the structure from motion algorithm. The investigated area of the glacier is located in high-mountain environment and it characterized by a complex topography that does not facilitates the use of UAV. But the availability of a sequence of DTMs (Figure 1) has been very useful for the improvement of the knowledge of the current state and recent evolution of the Planpincieux Glacier. In particular it is nowadays possible to update the volumetry of unstable sectors which evolves during the summer season by mean of coupling the obtained DEMs with a Bedrock DEM obtained by an Aerial GPR survey in 2020. This is crucial as larger unstable volumes need to be taken into account into safety plans and road closures and evacuations of buildings must be undertaken.

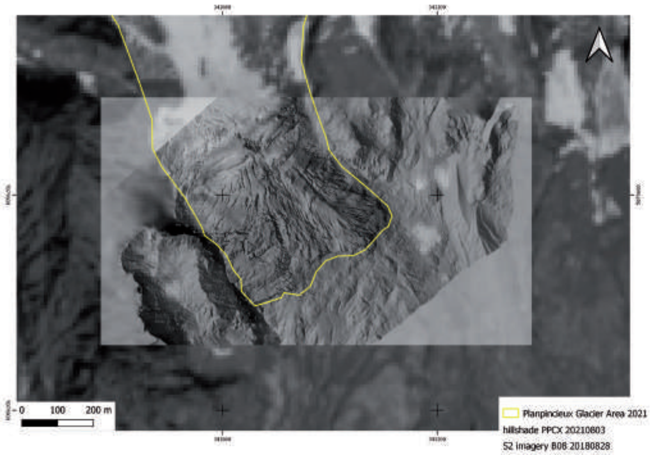

Figure 1. Hillshaded DEM acquired on Planpincieux Glacier front on 3rd August 2021.

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Keywords: UAV, Geology, Rockfalls.

Photogrammetric monitoring by drone of San Leo landslide (Rimini)

The town of San Leo, in the centre of the "*Val Marecchia*" in province of Rimini (IT), rises, together with its historic fortress, on an isolated rocky cliff surrounded by clay soils, which for centuries have made it a place affected by phenomena of hydrogeological instability and a real open-air geological laboratory. In fact, the paintings by Vasari (1560) and Mingucci (1626) show a cliff of San Leo that is different from what we see today, and much more extensive, bearing witness to the phenomena of erosion and collapse that have shaped it.

The cliff of San Leo is a strip of epi-ligurian succession in the center of the "*Val Marecchia*" blanket, which is a large Klippe of the Ligurian blanket of the northern Apennines. In 2014 there was an important landslide phenomenon that led to the detachment of about 330000 m^3 of rock mass with a front of about 160m by 90m high. That of 2014 is not the first phenomenon of collapse of the cliff: another important phenomenon occurred in 2006 and, as mentioned, also in past centuries.

In this contribution we illustrate the first results of the control and monitoring of the landslide of San Leo only performed with aerial photogrammetric technique through the use of drone. The monitoring is addressed both to the wall, front of the 2014 collapse, and to the debris accumulation at the base of the wall itself.

The monitoring of rock wall is aimed at assessing any morphological changes due to collapse. It is also important to take into account small collapses that may be indications of detension along fractures (tensile fractures) that delineate larger rock masses and may therefore be the prelude to major landslides. The photogrammetric monitoring allows to have a control on the wall and on the edge of the wall in a diffused way on the whole front of interest, integrating perfectly with the geotechnical monitoring system installed in San Leo, which even if it monitors many of the fractures present on the top and inside the rock mass, it doesn't get to control the most external fractures, nor is it able to control the most superficial collapses on the wall.

The photogrammetric monitoring also keeps under control, although not continuously, the enormous debris mass that has accumulated at the foot of the collapse front. This debris blanket currently covers the contact between the rock mass and the underlying clay substrate, protecting the shales from erosion and limiting the phenomenon of deep excavation that is at the origin of large collapses such as that of 2014. It remains clear, however, that the deterioration and reflux of clays can only be prevented through the removal of water at the clay-rock mass contact.

The regional agency for the safety of the territory and the civil protection has already realized two structural works for the containment of the debris flow and a first water regulation in the area below the landslide with the aim of maintaining the debris flow close to the rocky wall. From this point of view, the monitoring of the debris cover assumes an important role for the prevention of the general hydrogeological risk of the cliff and, at the same time, allows to evaluate the efficiency of the works carried out so far.

Aerial, Ground and Underwater Robotics for Cultural Heritage

Chair

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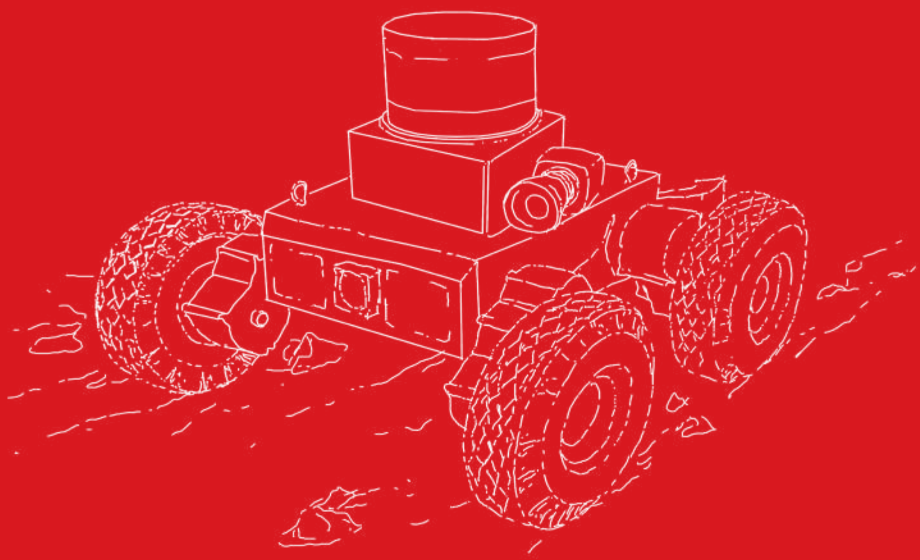
The involvement of high-technological robotic vehicles and tools modified the operational aspects of the work of many professionals. The field of Cultural Heritage is not exempt from this wide spectrum revolution. Necessities within this specific field of application drove, in the last years, part of the research and innovation. New possibilities of e.g. cost-affordable aerial imagery, 3D scanning, and underwater site exploration are fostering novel applications worldwide. The goal of this Special Session is to bring together experts of Unmanned Vehicle research development, operations and best practice with focus on technological transfer from research institutions to vehicle integrators and end-users.



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Keywords:
Robotic environmental monitoring, Legged robotics, Natural intelligence.

UAV FOR ENVIRONMENTAL MONITORING

1. Introduction

The average Earth surface and ocean temperature raised, especially in the last forty years (Levitus et al. 2017), (Von Schuckmann et al. 2020); the sea level rose about 20cm in the last century and its growing rate is increasing and climate change is expected to continue through the current century (Mackay 2008), (Stocker et al. 2013). Even these few observations are an alarm bell for the conservation of the Life on Earth. Therefore, taking on time the right measures to ensure Natural protection is of paramount importance.

This can be obtained through a continuous, repeatable, and affordable monitoring of the preservation status of the natural habitats. To this end, the European Union realized the European Green Deal, which includes deeply transformative policies[1]. One of these policies aims at the restoration and preservation of ecosystems by increasing the coverage of protected biodiversity-rich land and sea areas building on the Natura 2000 Network (N2000N)[2]. N200N is a network - established by the EU - of protected areas, selected because of their rich and diverse biodiversity, that should be continuously monitored. Monitoring operations of this network are nowadays performed exclusively by human operators for two main reasons. First, the assessment of the healthy status of a habitat requires specific skill and knowledge. Then, human beings are the only possessing the physical ability to move for hours in extremely irregular environments such as the natural ones.

The burden on the human workforce could be eased by robotics. However, the state of the art in robotic environmental monitoring is limited and their real application is virtually null. In (Dunbabin, Marques 2012), the Authors review the main results related to this topic. Yet, the main target is underwater application such as (Williams et al. 2009), (Li et al. 2006), while land monitoring is performed with unmanned aerial vehicles (Rango et al. 2006), (Watts et al. 2010), (Körner et al. 2010). However, the latter solution fails when the monitoring mission requires long-lasting operations (Dunbabin, Marques 2012).

In this work, we propose an approach to perform environmental monitoring with legged robots. The challenges to achieve such an ambitious goal are numerous and range from locomotion in unstructured environments to classification of natural habitats. The solution we propose is to empower robots with the Natural Intelligence (Bryson 2012) emerging by the interaction of environment, body and mind of the robot. In this context, Artificial Intelligence (AI) addresses autonomous classification of plants species and habitats, autonomous navigation in natural environments, and efficient and effective physical environment-robot interaction. On the other hand, articulated soft-robotic mechatronics provides resilience and adaptability to the body of the quadruped robots.

2. Environmental Monitoring

In this section, we briefly summarize the key points of monitoring of natural habitats. The three main functions of environmental monitoring are: i) compare the current environment status with a reference status; ii) to assess

the effect of actions focusing on the preservation of the natural status; iii) to assess the effects of perturbations and disturbs (Legg, Nagy 2006). The EC guidelines (Evans, Arvela 2011) specifies that the structure and functions, and typical species that characterize a natural habitat can be measured via the assessment of its vegetation.
N2000N is composed of nine biogeographical regions: Alpine, Boreal, Mediterranean, Atlantic, Continental, Pannonian, Black Sea, Macaronesian, and Steppic. The Habitat Directive (Directive 1992) requires Members States to implement surveillance of the conservation status of habitat and species of community interest. Each country has its own decision chain.
In (Gigante et al. 2016), the methodological foundations of habitats monitoring are presented. Each habitat has its own specific physiognomy, structure and characteristics, and therefore its own specific parameters indicating its conservation status.

3. Proposed Approach

In order to deploy robots in real natural environments, we propose to confer them a Natural Intelligence (Bryson 2012), which we describe as the combination of three components: environment, mind and body. The environment imposes the specification the robotic platforms should present and guides the system development thanks to the feedback obtained from field testing.
The body presents features such as compliance and *adaptivity* to grant to the robot robustness and resilience w.r.t. unexpected forceful interactions with the natural environments. This can be obtained through the adoption of soft robotic elements (Albu-Schaffer et al. 2008). For example, adaptive end-effectors such as (Catalano et al. 2021) enable safe interactions with unstructured environments. Furthermore, they can also improve locomotion, which is a challenging task in environments involving steep slopes, irregular grounds, and slippery surfaces such the natural ones. Analogously, soft bodies and compliant actuation enable features such shock absorption and resilience to the unavoidable contacts and falls occurring when moving in extremely harsh terrains.

The mind includes methodologies for planning and controlling the robot motion in natural environments. For example, autonomous navigation with legged systems is one of the most challenging task because it merges the perception of complex environments with the control problem of locomotion over highly uneven grounds. In this context, robot compliance should be considered during planning and control to maximize the system performance. Fall recovery policies should also be included to avoid mission failures. Environmental monitoring field missions are generally a time-consuming activity, which may require a full working day of an operator (Angelini et al. 2016). For this reason, energy efficiency is also a critical point to execute long-lasting robotic operations.
Finally, the mind includes AI algorithms for the interpretation of natural habitats, with specific focus on the assessment of their conservation status. This is a challenging goal, indeed, work in computational botany has not yet reached the development of methods that can work in the wild in a completely unsupervised manner (Dias, Borges 2016). Although plant science and its changes are studied by botanists using large bulk of data, for instance collected via geostationary satellites and in the field by trained personnel, most work is carried out in herbaria, a posteriori (Lõhmus et al. 2018). Computer science and AI methods can help classifying and identifying plant material (usually organs such as leaves, seeds and flowers, but also bark) and plants as a whole (for instance the canopy shape and the exterior shape of the analyzed plant) (Cope et al. 2012).
A fourth crucial element to concretely apply robotics to environmental monitoring is benchmarking. This is the process of assessing the system performance by analyzing them by means of standard mythologies or references. Benchmarks are already widely diffused in many market domains, but they are not clearly and broadly established in robotics (Torricelli et al. 2020). This lack of benchmarking methods, protocols, and test-beds is even more evident when referring to specific applications such as robotic environmental monitoring.

4. Conclusions

In this work, we described what is environmental monitoring and its influence on the future of Life on Earth. Robotics and Artificial Intelligence could improve the ecosystem monitoring, but several issues are yet unsolved. The solution we proposed is the realization of robots with Natural Intelligence, which is the combination of body, mind and environment. The field of environmental monitoring addressed within the Natural Intelligence project share common needs with the Cultural Heritage (CH) monitoring for digitalization, the authors think the use of legged robots can have a great impact on the field of CH monitoring.

5. Acknowledgment

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Figure 1. On the cover: Robotic environmental Monitoring of Natural Habitats.

Notes

1 https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1576150542719&uri=COM%3A2019%3A640%3AFIN

2 https://ec.europa.eu/environment/nature/natura2000/index_en.htm

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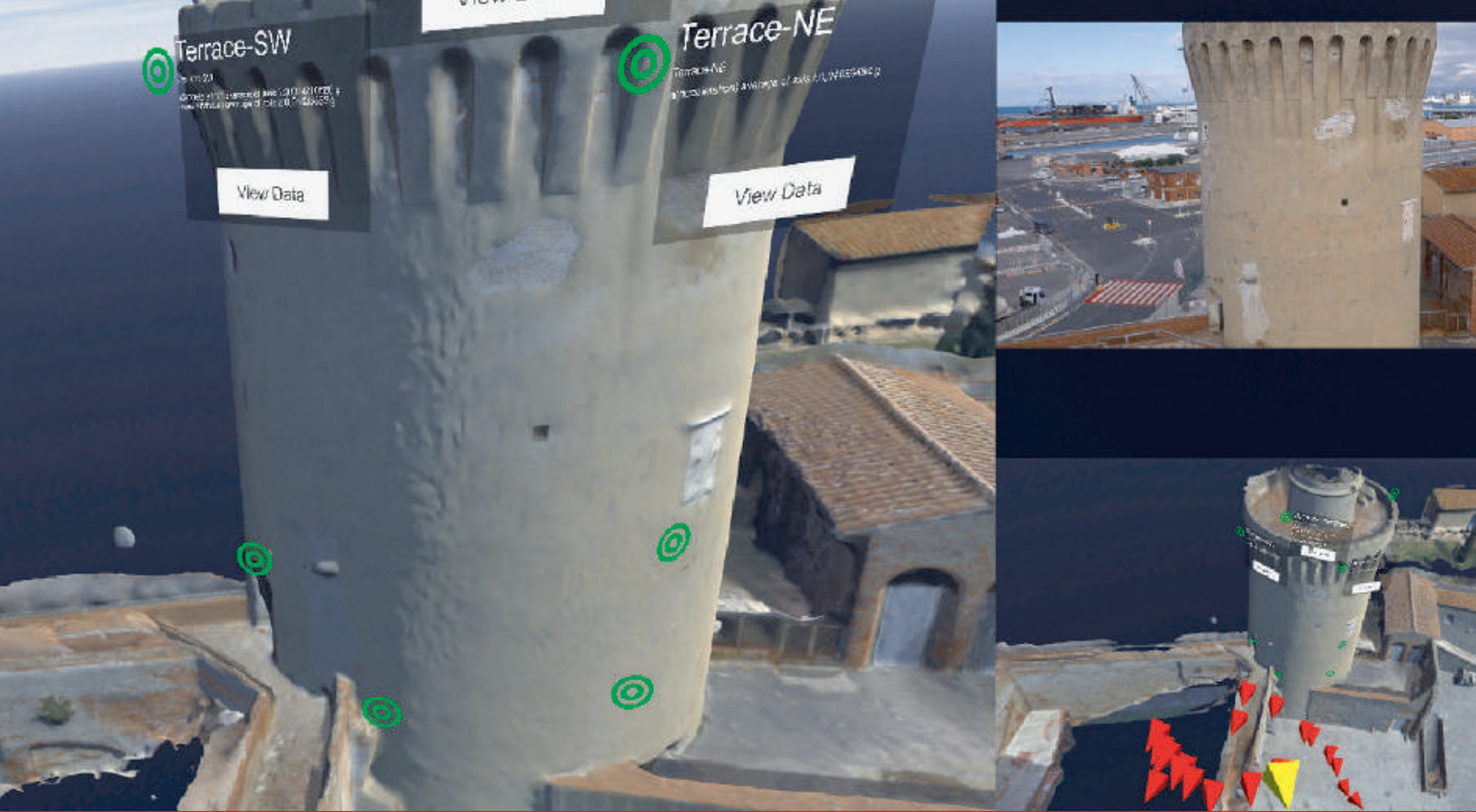

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Keywords:
UAV, Structural Health Monitoring, Crack monitoring.

Exploring UAVs for structural health monitoring

The preservation and maintenance of architectural heritage on a large scale deserve the design, development, and exploitation of innovative methodologies and tools for sustainable Structural Heritage Monitoring (SHM).
In the framework of the Moscardo Project (https://www.moscardo.it/), the role of Unmanned Aerial Vehicles (UAVs) in conjunction with a broader IoT platform for SHM has been investigated. UAVs resulted in significant aid for a safe, fast and routinely operated inspection of buildings in synergy with data collected in situ thanks to a network of pervasive wireless sensors (Bacco et al. 2020). The main idea has been to deploy an acquisition layer made of a network of low power sensors capable of collecting environmental parameters and building vibration modes. This layer has been connected to a service layer through gateways capable of performing data analysis and presenting aggregated results thanks to an integrated dashboard. In this architecture, the UAV has emerged as a particular network node for extending the acquisition layer by adding several imaging capabilities.
Applicability of the proposed architecture has been demonstrated in real case studies in Tuscany, among which the Torre Grossa in San Gimignano and the Fortezza Vecchia, an ancient fortress complex in Leghorn. Indeed, in the San Gimignano case, the UAV has been relevant for photogrammetric reconstruction and visual inspection of the towers and surrounding structures which are very difficult to be reached and inspected by other means. The second case study of the Fortezza Vecchia has an additional interesting feature: it presents several critical crack patterns. Since the sea partially surrounds such a Tuscan historical building, monitoring its ancient walls is very hard by manual methods. Besides, the sides of most of the cracks along the fortress walls are quite far from each other and don't lie on the same plane. Therefore, using standard methods (e.g., those based on planar crack gauges) may not allow for obtaining an absolute and accurate measurement of the separation of the sides. With the aim to monitor such complex crack patterns over time, an ad hoc image processing pipeline has been identified and tested in a controlled environment (Germanese et al. 2018a) and then applied for long-term monitoring on-site (Germanese et al. 2019), where measurements accuracies are reported. In brief, the proposed method is a marked-based approach for extracting quantitative information about the absolute value and displacement over time of a set of predefined targets around a crack pattern to be studied. In this way, for instance, a crack enlargement can be detected as well as shear displacements.
At first, under the suggestion and guidance of an expert such as a civil engineer or architect, a configuration of planar markers is installed around the crack pattern or damage to be monitored. Notice that this is the only step, which, at the moment, requires physical access to the damaged part, while the actual monitoring can be executed remotely, thanks to the use of the UAV.
At each inspection time, either following a predefined mission or in manual flight mode, the UAV can reach waypoints nearby a crack and capture a set of pictures using a standard camera (in our case, an RGB camera). Collected images are then transmitted to the service layer and there processed for extraction of a matrix of

Figure 1. Panoramic view of San Gimignano and Torre Grossa, a case study of Moscardo project.

distances among the various planar markers as well as their orientation. Tests have allowed demonstrating that the results are reproducible. A UAV can obtain that acceptable images under normal operating conditions (no further requirements on wind speed and weather have been required) during daylight. It has been possible to perform routine analysis of cracks and to understand possible seasonal changes in a way that is safe for operators since it is not required to reach damaged and critical areas. Further capabilities of the UAVs might be considered in the future, such as adding infrared vision to analyse defects and other onboard intelligent systems to detect faults (Jalil et al. 2019).

The first flights executed in the case studies also allowed to acquire image surveys for performing a 3D photogrammetric reconstruction of the monitored structures, which has been used to provide a Virtual Reality (VR) system (Germanese et al. 2018b). Such a VR system aims at enriching the historical building monitoring and providing support to the UAV operator during inspections. For each monitored zone, a detailed photogrammetric reconstruction has been realised and placed inside a 3D scene. The scene also contains all the sensors in the acquisition layer of the IoT platform for SHM. The VR system can retrieve and display the raw data

Figure 2. The operator pilots the AUV around Mastio di Matilde, a tower in the *Fortezza Vecchia* complex in Leghorn, which has been considered as a case study in the framework of Moscardo project.

measured by each sensor as well as the output of data processing. The VR system can be experienced in several ways: (i) freely exploring it and interacting with displayed sensors; (ii) accessing past UAV inspections and retracing UAV flights performed during a selected inspection; (iii) live during a UAV inspection by following live movements. During the UAV flight, the user has no control of camera movement and orientation; indeed, camera movements reproduce actual UAV movements estimated using SLAM algorithm ORB-SLAM (Mur-Artal et al. 2015). Thanks to this solution and the high fidelity of the 3D model, UAV operators can rely on this tool to plan the drone's route and have a quick look at the sensor position relative to the

Figure 3. *Bastione della Capitana*. This area of the *Fortezza Vecchia* complex has been considered for long time monitoring of cracks and damages in building by AUV inspection. A configuration of markers has been placed around a crack to perform quantitive 3D measurements.

Figure 4. On the cover: The VR interface is composed of three elements: (i) the central part shows reconstructed virtual scene with installed sensors and their gathered values; (ii) in the upper right side of the screen, the video recorded by the AUV during the inspection operations is shown; (iii) in the lower right side, a panoramic view of the virtual scene is displayed reporting also AUV actual position (yellow pyramid) and followed path (represented as a set of smaller red pyramids).Please, see http://moscardo.isti.cnr.it/ for an interactive demo.

UAV and possible obstacles surrounding the vehicle. In this modality, the interface is composed of three parts:

- The central and main one is devoted to showing the subjective 3D scene from the vehicle. From here, it is possible to view near sensors and acquired measurements;
- The upper right side displays the direct view of the UAV acquired by the onboard camera;
- The lower right portion shows a perspective view of the entire scene with the actual position of the UAV.

The Moscardo solution has proved to be feasible, minimally invasive and customisable depending on the peculiarity of the architectural asset. From a technical point of view, the use of such a system, based on the use of a net of sensors and UAVs, can be quite effective in acquiring a rich set of data for long-term monitoring of ancient structures. Indeed, the local authorities demonstrated a strong interest in collecting data beyond the end of the project, and research scientists, including the authors, are still collaborating on planning future actions to exploit and further improve the Moscardo system.

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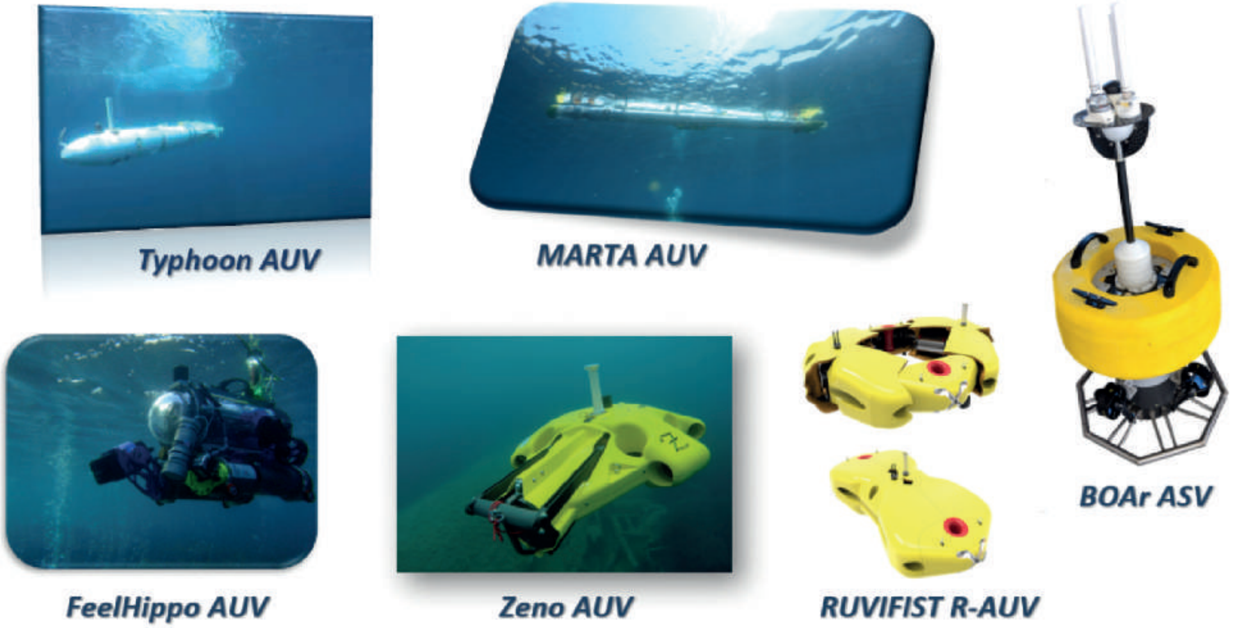

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Keywords:
Marine robotics, Autonomous Underwater Vehicles, Underwater Cultural Heritage.

Autonomous Underwater Vehicles for Underwater Cultural Heritage: some experiences from the University of Florence

Hereinafter the experience and expertise acquired by the Department of Industrial Engineering (DIEF) of the University of Florence (UNIFI) in the framework of research projects during the last ten years are described. Some Autonomous Underwater Vehicles (AUV) and their operation will be reported. UNIFI is also part of ISME (Integrated Systems Interuniversity Center for the Marine Environment - www.isme.unige.it), the national interuniversity center on marine robotic technologies. AUVs are increasingly used for data collecting (e.g., optical images, sonograms, measurements about water properties and quality, etc.) in "rich" fields, such as defense, security, and Oil&Gas. Nowadays AUVs show potential to be used also in "non rich" fields such as biology, geology, archaeology, as well as monitoring of fresh-water and marine infrastructures. The integration with sensors, such as CTD probes or magnetometers, makes the AUVs suitable for application in environmental monitoring or sea lines and cable ducts identification / inspection. In the coming future AUVs may be used in the monitoring of alpine lakes, whose characteristics are quickly modifying due to rapid climate changes. An integrated system based on the cooperation among AUVs, aimed at collecting and georeferencing bottom (and water column) sensory data, is an effective tool for many of the tasks described above.

The THESAURUS project (http://thesaurus.isti.cnr.it) was funded by the Tuscany Region in the framework of the program PAR FAS, Action Line 1.1.a.3, devoted to "Sciences and Technologies for the Safeguard and the Promotion of Cultural Assets." THESAURUS stands for "*TecnicHe per l'Esplorazione Sottomarina Archeologica mediante l'Utilizzo di Robot aUtonomi in Sciami*". In the framework of the project, a novel class of AUVs named "Typhoon" was designed and a dyad of Typhoon vehicles with rated depth 300m is operative since 2013. The main requirements for the Typhoon-class AUVs were: moderate cost, multi-role (different payloads), 8h autonomy, high maneuverability (hovering capabilities), acoustic communication capabilities for cooperative underwater exploration. Several different missions have been performed with the Typhoon class AUVs (e.g., in Italy, Israel, and Croatia), either in single vehicle fashion or in dyad configuration.

The FP7 European project ARROWS (*http://www.arrowsproject.eu)* coordinated by the University of Florence proposes to adapt and develop low cost AUV technologies to significantly reduce the cost of archaeological operations. A modular hovering vehicle named MARTA (MArine Robotic Tool for Archaeology) with rated depth of 120 m was developed by the University of Florence in the framework of ARROWS and is still in operation.

From 2017 to 2019 the research group collaborated with MDM Team SRL, an official spinoff of UNIFI, to develop Zeno AUV in the framework of the EASME European project ARCHEOSUb (http://www.archeosub.eu). Zeno is a highly maneuverable AUV, exploited with success, e.g., in Tuscany and Israel.

A picture of the prototypes developed by UNIFI DIEF during the last ten years is here below.

Other vehicles developed during the years are:

- FeelHippo is a low-cost and compact AUV (Allotta

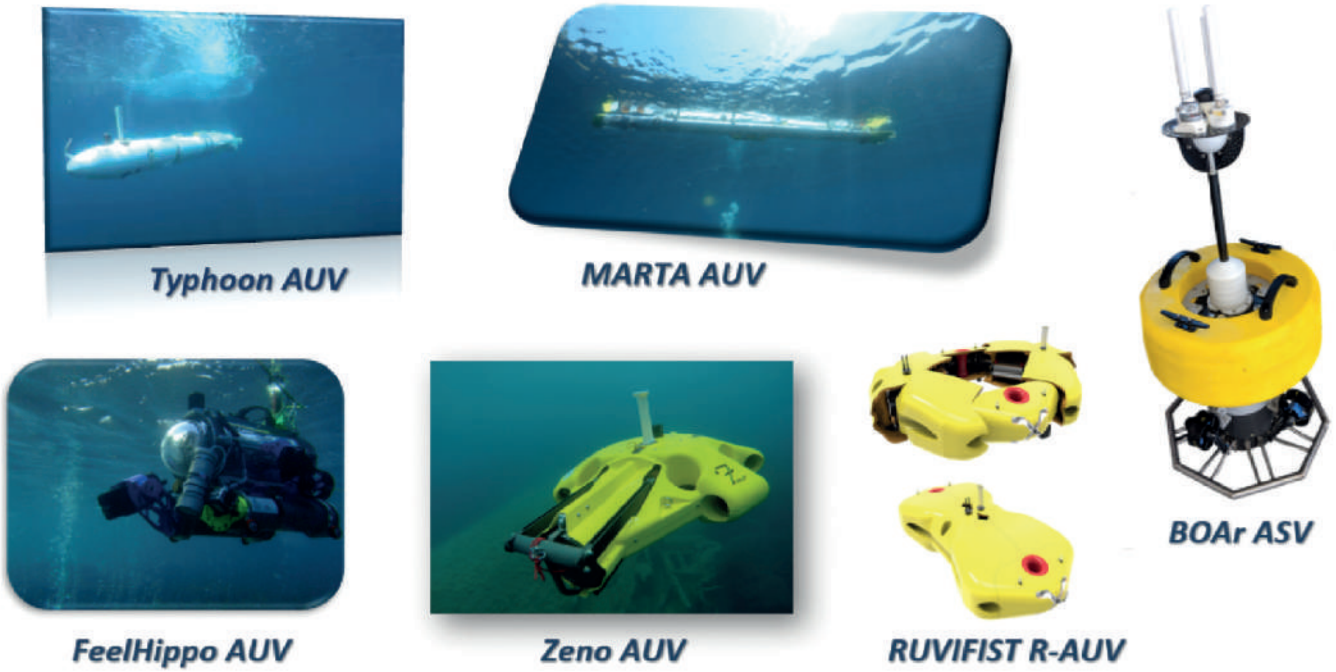

Figure 1. On the cover: The various AUV and ASV protypes developed by the Department of Industrial Engineering of the University of Florence.

2017). It can perform monitoring and patrolling tasks and may result useful in various scientific applications. It is currently used in the framework of the H2020 European project PASSport (https://h2020-passport.eu);

- RUVIFIST R-AUV is an innovative Reconfigurable AUV (R-AUV), covered by an Italian and a PCT patent (Pagliai 2018);
- BOAr ASV is an Autonomous Surface Vehicle able to locate underwater vehicles in order to increase their navigation performance (Meschini 2019).

Some examples of applications of these mobile robots are: safeguarding and protection of biodiversity, environmental monitoring, underwater archaeology, early monitoring systems, geology, biology, etc. Robotic systems for the inspection, maintenance and repair of plants (inspection, repair and maintenance) represent an essential technology for a sustainable future, for example systems for the generation of energy from renewable sources at sea (waves, tides, wind). The same robotic systems can be used to monitor the ecosystem (water column, seabed, coastal environment) with a view to protecting and increasing the situational awareness for environmental risks. Multidomain robotic systems can also be used as early warning systems in high natural risk areas.

In summary, the UNIFI research group deals with the hardware and software development of innovative technologies in the marine robotic sector: prototypes of customizable vehicles are created, both wire-guided (Remotely Operated Vehicle - ROV) and autonomous (AUV) and in the last years their level of autonomy has been increased, thanks to machine learning techniques implemented on board (such as Automatic

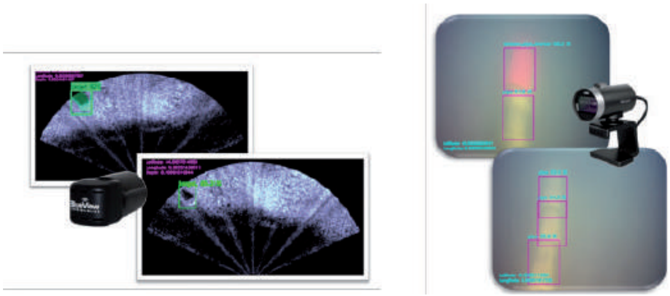

Figure 2. Real-time Automatic Target Recognition performed by FeelHippo AUV starting from acoustic images (on the left) and optical images (on the right).

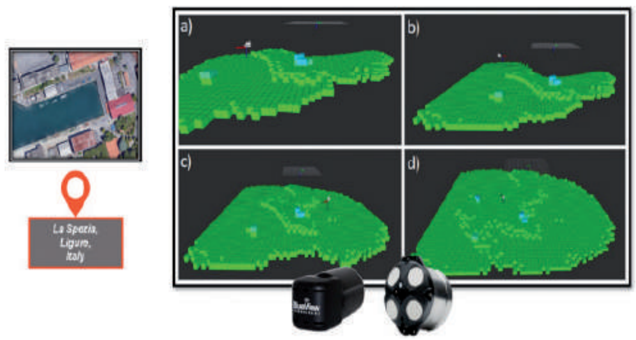

Figure 3. Probabilistic 3D occupancy maps achieved by fusing the measurements from onboard acoustic devices.

Target Recognition - ATR - and autonomous mission replanning). At a software level, the entire navigation system of the vehicles themselves and the mission management interface are developed. Finally, it should be noted that the group has carried out intense offline work in the last five years and in-real-time processing of the data acquired from the optical and acoustic payloads installed on the vehicles, to provide the end users with 2D mosaics, bathymetric analyzes or 3D reconstructions of the marine environment.
Some results, achieved by means of FeelHippo AUV, are depicted in the following figures: in the first two pictures some ATR results are given (acoustic images on the left side, optical ones on the right side). In the last picture, instead, some probabilistic 3D occupancy maps are achieved by fusing the measurements of onboard acoustic devices. In 'green' the seafloor morphology is

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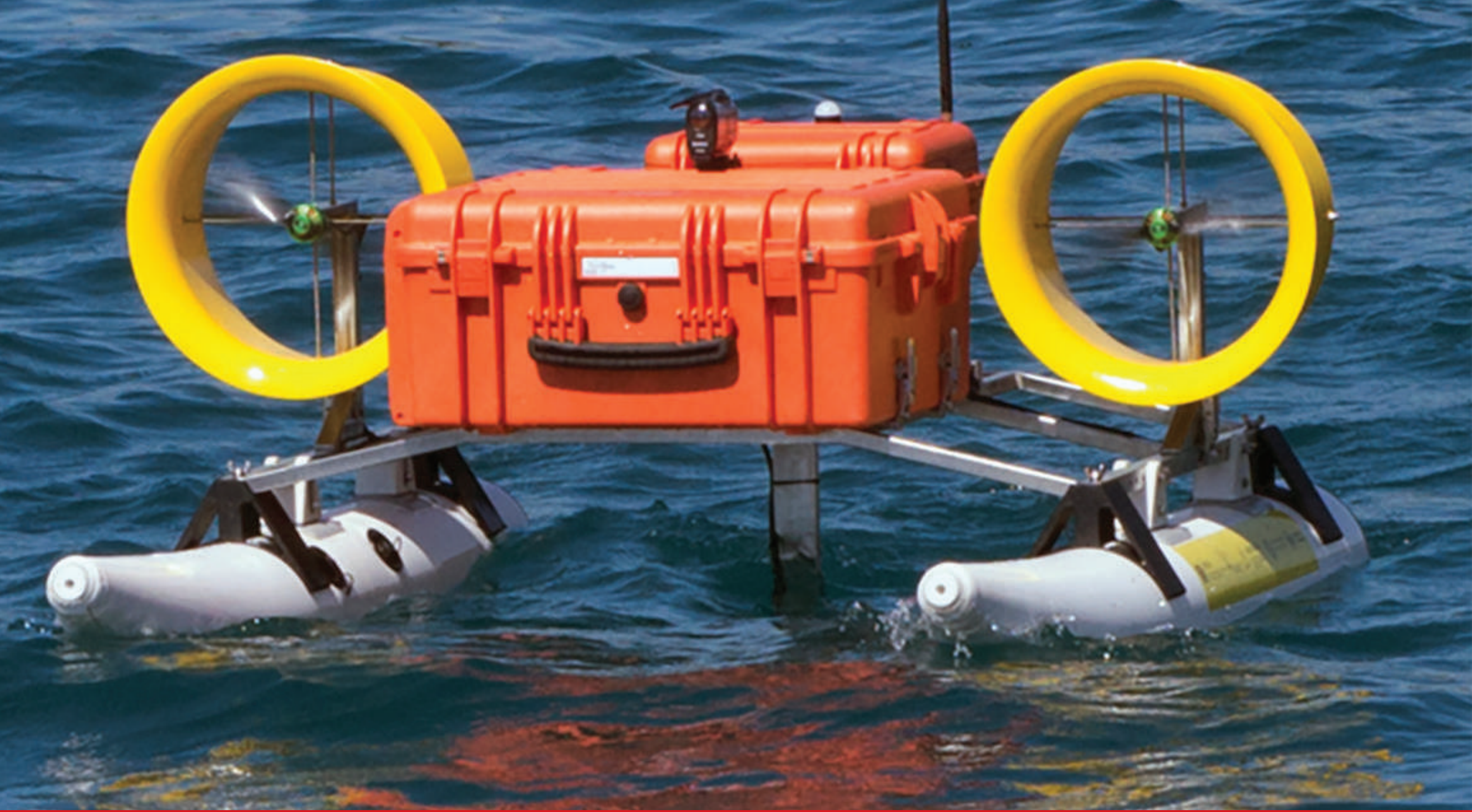

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Underwater Archeology, Autonomous Surface Vehicle, Marine Robotics.

Autonomous Surface Vehicles to support underwater archaeologists in survey and documentation

1. Introduction

In recent years, marine robotics is emerging as a promising field offering a wide range of possibilities by providing a number of new solutions and opportunities for reducing cost, improving methods, and increasing efficiency in underwater archaeology. Activities such as survey and documentation of underwater archaeological sites have benefited from the advent of unmanned marine vehicles, both for the surface (ASV, Autonomous Surface Vehicle) and the submerged (UUV, Unmanned Underwater Vehicle) environment (Japitana et al. 2018, Vasilijević et al. 2017). A large variety of ASVs has been currently developed and put on the market (Jorge et al. 2019, Caccia 2006). Their widespread use is due to their versatility and variety of sizes and prices that make them be adopted in many operating contexts, such as oceans, lakes, and rivers, and for a large number of different missions (Bayat et al. 2017, Bruno et al. 2019). In shallow water, ASVs are capable of executing automatic photogrammetric acquisitions with their ability to take thousands of instant measurements and photos along precisely georeferenced survey line, or they can be used to support divers in the gathering of data related to the archaeological remains and to the marine environment in which they are located. In this paper, the focus is to describe one of the main results obtained in the framework of the MOLUX project (Bruno et al. 2019) which aims to design and develop a system capable of supporting the underwater operators by means of innovative technologies for the diagnosis, recovery, management, conservation, and valorization of the archaeological and naturalistic assets in the marine environment.

2. Results

The proposed system is depicted in Figure 1. It is composed of 1) a supervision and control unit (SCU), placed on a support vessel that allows the operators to plan and monitor the mission; 2) an underwater tablet that performs an acoustic geolocalization of the diver's within a preloaded map of the site and it is equipped with different sensors to provides diverse functionalities that support and facilitate the scientific activities carried out in the submerged environment; 3) an ASV that allows to perform bathymetric surveys and follow the diver during his/her movements in order to optimize the reliability and accuracy of the geolocation. The communication between the SCU and the underwater tablet occurs thanks to the ASV that serves as a bridge between the two devices and performs the data exchange through acoustic signals. Instead, outside of the marine environment, the SCU communicates with the ASV through dedicated wireless communication channels consisting of long-range telemetry radio and Wi-Fi transmissions (Figure 2). Furthermore, for saving, downloading, and synchronizing information (such as bathymetries, planned missions, mission logs, etc.) among the different devices, the SCU operates on the database by means of a Web service implemented on a local network or internet.

During a typical archaeological survey campaign, ASV could be used to collect data for building a preliminary map of the site, extremely useful to plan the subsequent underwater tasks, while the tablet for performing a detailed photographic and photogrammetric documentation,

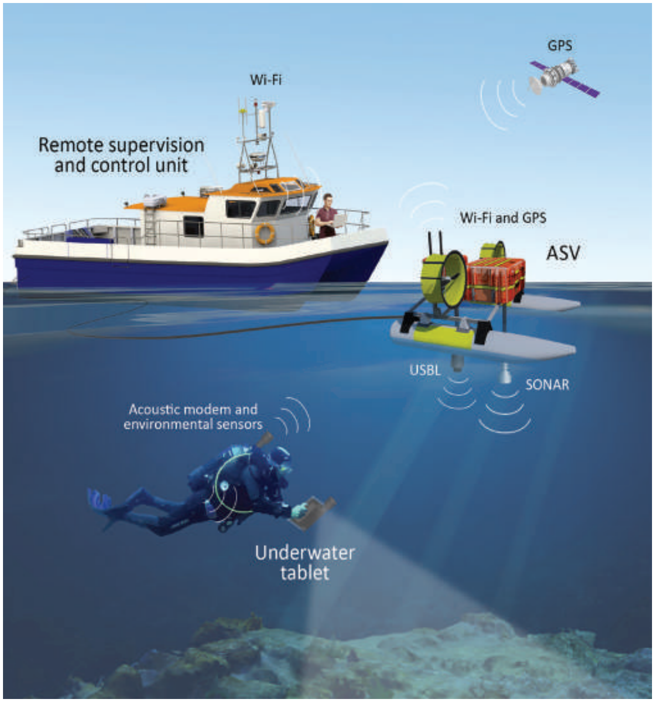

Figure 1. Main components of the MOLUX system.

optimizing the operational performances of underwater operators and improving their safety at the same time.
Figure 3 illustrates the two complementary configurations of the ASV DEVSS (DEvelopment Vehicles for Scientific Survey). They are both featured with a catamaran-type structure and equipped with an autopilot system for autonomous navigation. Each vehicle is composed of two main modules, a Navigation Unit, and a Sensor Unit. The Navigation Unit consists of a PixHawk 4 navigation board equipped with GPS, IMU, digital compass, and barometer, while the Sensor Unit is a watertight case designed for extending the vehicle's functionalities by housing a wide range of sensors (optical camera, multibeam, side-scan sonar, multi-parametric probes, USBL). It is equipped with a communication box that provides a Wi-Fi link with the SCU for real-time control of the sensing equipment. The main difference between the two vehicles is in the propulsion, which affects the operating conditions. DEVSS AIR has a dimension of approximately 1.44 m × 1.50 m, and is equipped with two aerial thrusters; while DEVSS JET has the dimension of 1.15 m × 1.50 m, and is actuated by two 3.3 KW hydro jet engines that provide an overall thrust of about 25 N and a cruising speed up to 5 kn. Without submerged thrusters and rudders, DEVSS AIR has been designed to perform surveyor activities in shallow waters such as lakes, swamps, or river basins. It represents a light solution with inflatable and detachable neoprene hulls that grant a maximum payload of 15 kg. The trim has 5 setups, changing the relative position between frame and hulls.
Conversely, DEVSS JET has a more powerful propulsion system that extends its operational scenarios. It is able to perform missions in more critical conditions such as in strong sea currents or for a longer time and with a heavier payload. The hulls are made in carbon fiber reinforced with Kevlar that ensures smooth and precise navigation (Bruno et al. 2019). The engine compartments and the battery are housed in the hulls. As for the AIR version, a hinge system allows to vary the trim of the vehicle changing the distance between the parts.

3. Conclusions

Current technology is providing tools and methods for developing innovative robotic platforms that can simplify and make safety the activities carried out in underwater sites through the cooperation between man and technology. It can therefore represent an efficient solution to overcome the difficulties in working in a difficult and unpredictable context like the marine environment.

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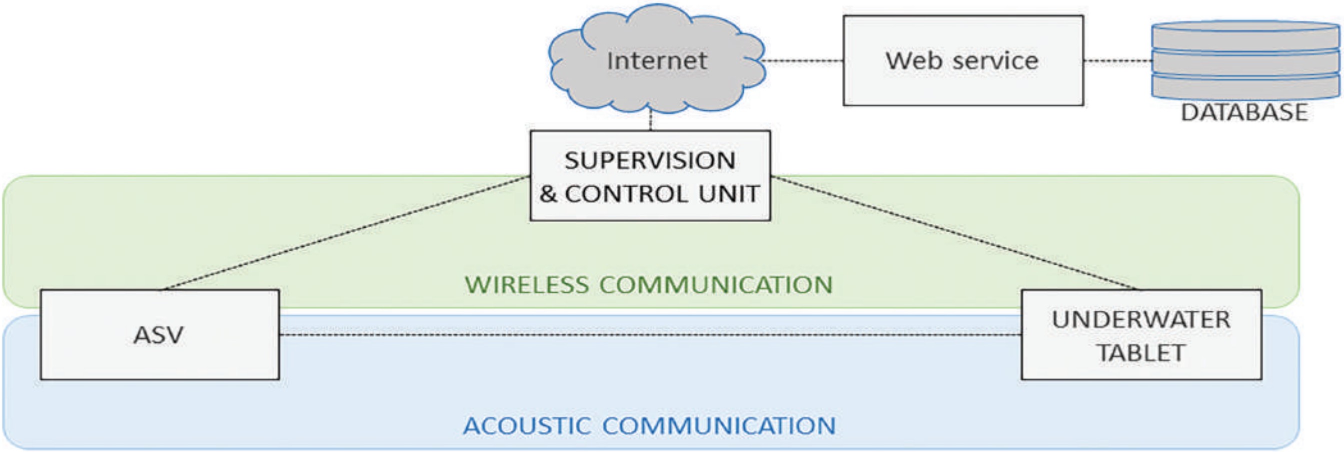

Figure 2. Network infrastructure of the MOLUX system.

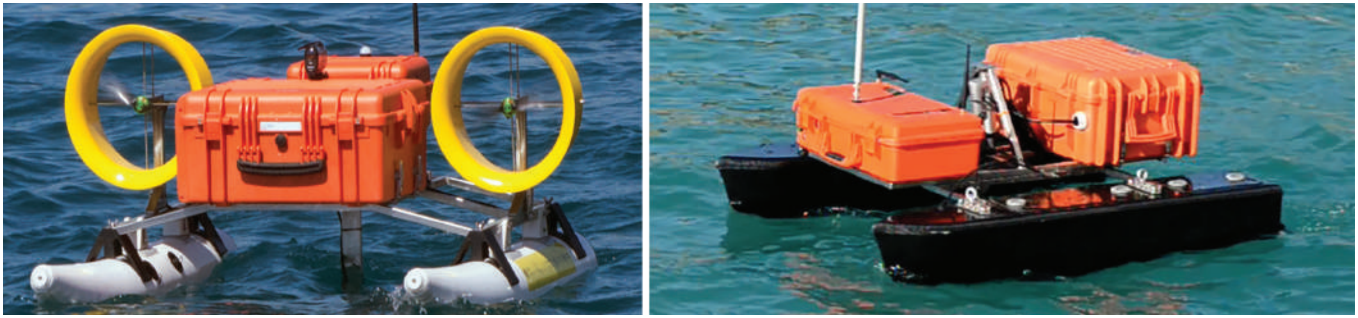

Figure 3. The two configurations of the ASV DEVSS: DEVSS AIR (left) and DEVSS JET (right).

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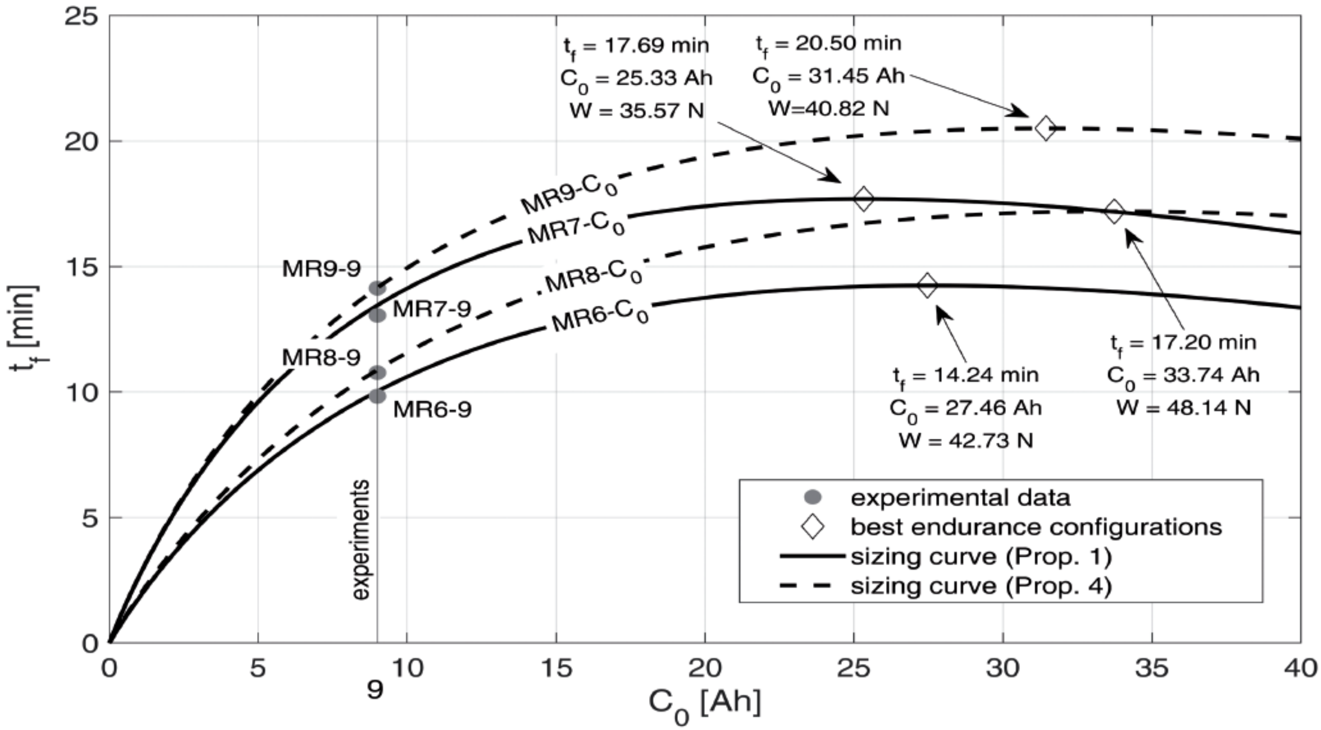

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Keywords: Unmanned systems, Remote sensing, Smart mobility.

High-range/high endurance rotary wing aircraft for environmental protection and Cultural Heritage valorisation

Remotely–Piloted Aerial Systems (RPAS), particularly small battery– powered fixed and rotary–wing platforms, gained a large interest in the scientific community. Reduced size, weight, and operational costs, in fact, make such systems one of the most suitable solutions for a wide range of applica- tions, including load transportation, search and rescue, risk management, surveillance, aero–photogrammetry, and, in general, remote sensing activities, (Harwey S., Lucieer A. 2012; Cai G. et al. 2014).
Among the available rotary–wing configurations, multi-rotor platforms proved to be particularly attractive (de Angelis et al. 2018). On the one hand, low structural complexity and simplicity of use allow for operative cost reduction. On the other hand, the hovering and vertical take–off and landing capabilities empower effective operations in restricted and obstructed areas (Valavanis, Vachtsevanos 2015). Also, with respect to a conventional helicopter with the same take–off weight, a multirotor is typically characterized by a more compact size, with satisfactory robustness to external disturbances and improved maneuvering capabilities (de Angelis, 2019; de Angelis 2018). Such features are achieved by spreading the total disc area into multiple propulsion units, where the use of smaller propellers rotating at a higher speed comes at the cost of a loss in efficiency with respect to the conventional, single rotor configuration. This, in addition to the limited endurance–to–weight ratio typical of electrically–driven systems, makes the performance of the hovering condition a critical, but challenging, issue. In this respect, the larger demand for high endurance RPAS operations, has increased the interest on research programs which aim at deriving numerical and analytical tools for range/endurance prediction and optimal preliminary sizing, (Hwang Cha 2018).
Currently, to obtain an accurate estimation of rotorcraft performance, the actual power system needs to be available since the early stages of the design process. The scope of this research contribution is to illustrate an analytical framework allowing for an accurate and physically consistent estimate of multirotor hovering endurance, based on a limited number of design features, propeller characteristics, and battery parameters, [9]. In this respect, the obtained closed–form expressions represent a valuable resource for performance analysis as well as a useful tool for rotorcraft and/or payload preliminary sizing, especially when the platform design process is at an early conceptual stage.
Within this approach, the total power required for the hovering condition is calculated according to the procedure presented in Ref. (Fuller 2014). Then, in order to characterize the aerodynamic behavior of the propeller, an analytical model is proposed to describe the rotor figure of merit as a function of few relevant blade parameters. To this aim, results of the classical Blade Element (Momentum) Theory (BET), (Avanzini et al. 2016), are enhanced by introducing an empirical correction function allowing for a more accurate prediction of the required blade tip speed, for a given thrust condition. Following a similar approach, a semi–empirical expression of the figure of merit as a function of blade Reynolds number (Cerny, Breitsamter 2020) and propeller pitch/diameter ratio is finally derived. These results are obtained thanks to a dedicated experimental campaign performed on a selection of commercial–of–

the–shelf propellers, optimized for small–scale multirotor applications. At the cost of few simplifying assumptions, flight endurance is analytically evaluated according to the battery model presented in Ref. (Wang et al. 2020), adapted for the first time to the analysis of multirotor platforms. Finally, such model is applied to prove the existence of an optimal battery configuration (namely the configuration determining the maximum hovering endurance). In fact, unlike conventional fuel–powered vehicles, where an increased fuel fraction always provides increased endurance and range, the weight of electrically–powered vehicles remains constant. Hence, the beneficial effect of weight loss during flight is not experienced (Wang et al. 2016). In this case, increasing battery weight may not necessarily provide an increased endurance and/or range, if the energy cost of lifting more weight overcomes the benefit of the increased battery–pack capacity. In this respect, a solution to the optimal sizing problem is provided and the corresponding battery capacity is expressed as an analytical function of rotorcraft parameters and battery coefficients. The entire analytical framework is depicted in Figure 1, and predictions from this model are validated with a few test cases in relevant scenarios. Figure 2 shows the results of the proposed approach.

In particular, the curves representing predicted endurance are plotted as a function of nominal capacity for all the considered configurations.

The presence of a maximum in all the curves clearly points out that, if endurance is pursued as the most relevant goal in the design process, it is useless to increase the size of the battery pack beyond a certain limit, provided that the corresponding growth in rotorcraft weight affects required power. Beyond the maximum, this growth is not compensated by the increase in available energy (thus decreasing multirotor endurance).

Best endurance configurations are indicated by diamond markers.

Note that, for all the considered configurations, the maximum is 'flat', meaning that very large variations of battery weight are necessary for marginal gains in terms of expected flight time. From the practical standpoint, this growth in battery capacity is clearly not justified, when one considers that a bigger battery is more expensive and the corresponding additional weight typically requires more powerful motors and robust structures.

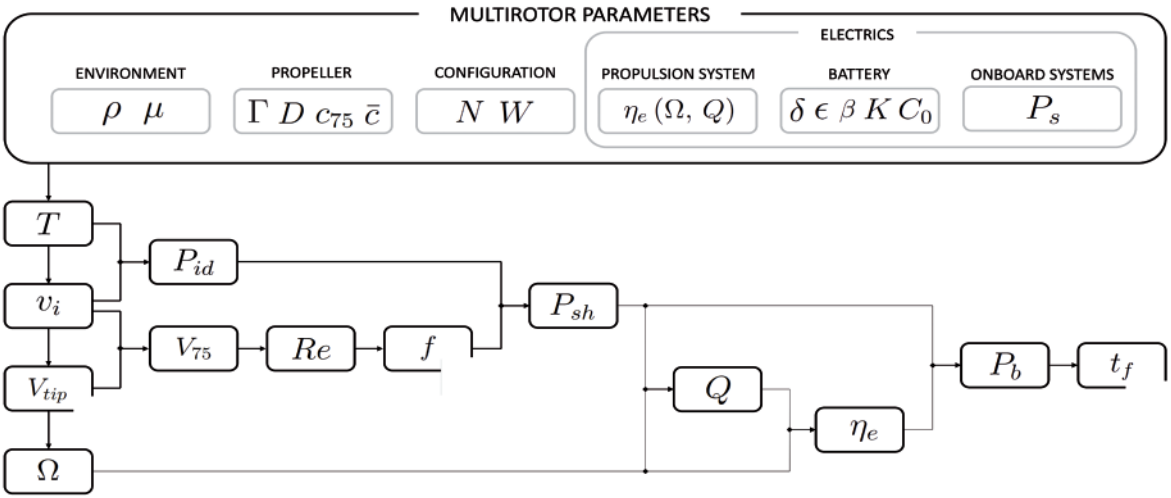

Figure 1. Block diagram for the performance analysis procedure.

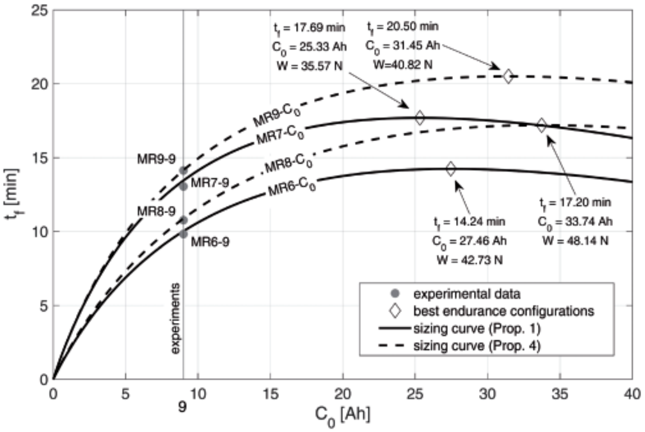

Figure 2. Estimate and predicted rotorcraft endurance.

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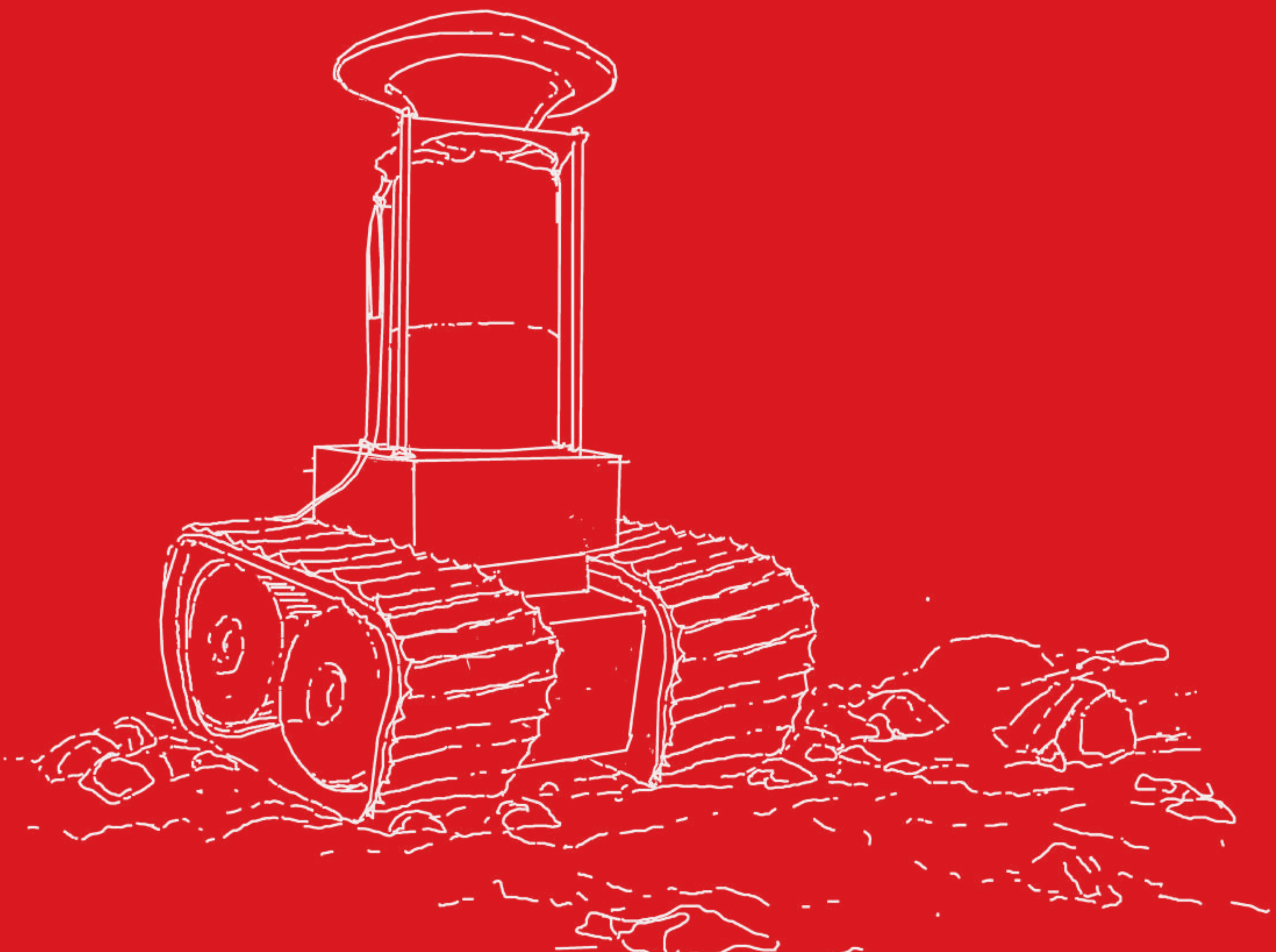

Afterword

Checking UAV navigation systems for a photogrammetric survey campaign in Pompeii.

Afterword

Salvatore Barba, Andrea di Filippo
University of Salerno, DICIV - Department of Civil Engeenering

We have finally reached the second edition of the International Conference *D-SITE - Drones, Systems of Information on culTural hEritage* -, a clear sign of how topical the issues related to the application of Unmanned Aircraft Systems (UASs) for surveying and documentation are and can represent a profitable opportunity for the research sector. Reinforcing this idea are the numerous contributions received again this year, from both Italian and foreign universities, which have found their way into this volume. The latter aims to bring together the latest applications of drones in the civil domain, including monitoring, remote sensing, infrastructure inspection, precision agriculture, geology and more.

This collection allows us to draw an overall picture of the current situation. On the one hand, we can follow the continuous technological evolution of these instruments which, thanks to their increasing flight autonomy, speed and flexibility in the choice of sensors (active or passive) to be combined with them, have rightfully carved out a prominent place for themselves among the tools aimed at detection, also contributing to lower costs and higher data quality than classical aerial applications.

On the other hand, we can indirectly compare ourselves with the different research groups in order to share approaches, workflows and results, thus contributing substantially to the definition of a best practice and a stable network for knowledge dissemination.

Precisely in relation to the latter, the contributions show that UAS applications hardly constitute isolated experiences but follow the current trend of integrating data and sensors of various natures to maximize the effectiveness and efficiency of surveying operations, opening new lines of investigation directed especially at low-level integrations, involving paradigms ranging from Terrestrial Laser Scanning (TLS) to the latest Mobile Mapping Systems (MMSs).

In this vein is the work of the CNR group from Rome, which focused on the analysis of algorithms for integrating data from passive (UAV photogrammetry) and active (TLS) sensors to verify their performance by taking advantage of a topographic backing survey. The reality-based modelling products for the nuragic complex in Arzachena are compared to describe the distributions of discrepancies with respect to the TLS point cloud, deriving accuracy indicators. In the same vein is the work by Florio et al., which benchmark is the *Piscina Mirabilis*, the final reservoir of the *Serino* aqueduct in the city of Naples. Photogrammetric and TLS surveys, in this case, are complemented by infrared thermography investigations to reveal anomalies present in the masonry apparatus of the structure.

A similar approach is followed in the contribution by Zerlenga et al., where photogrammetry and infrared thermography, both from UAS, are used to monitor the bell tower of the Cathedral of *San Michele Arcangelo* in *Caserta*. In this case, the entire data flow is managed using open-source solutions.
Quattrini et al. propose the integration of UAS, TLS and GNSS to document 12 cultural sites located along the *Porto-Vigo* railway line, selecting the most appropriate technique in relation to scale, in order to generate effective reality-based models to support travellers in discovering the railways landscape thanks to a mobile geo-localised app. The obtained results demonstrated the flexibility of digital reproduction, able to offer not only an accurate documentation of the state of conservation of cultural sites, but also to enable proper ways for their promotion.
Very often, the integrated information is used to build a database for subsequent source-based modelling using BIM methodology. The goal of these applications is not to propose alternative forms of representation for survey data but to contribute to the systematization of knowledge and production of questionable and updatable virtual content, support for asset management throughout the entire life cycle. An example is the contribution of Losè et al. which, starting from the fusion of photogrammetric and mobile system data, proposes a Scan-to-BIM approach for the bell tower of *Santa Marta*, in the municipality of *Montanaro*. Particular attention is paid to the traceability and accuracy of the geometric attributes of the BIM model.
In addition to parametric virtualization, surveying with UAS also becomes a valuable tool for archaeological or historical architecture studies, providing reliable data for a better understanding of the growth and stratification dynamics in the urban fabric. The work of Arrighetti et al., for example, applies this paradigm to structures in the historic centre of *L'Aquila*, focusing in particular on the Church of *San Silvestro*. The aim of the integrated survey is to highlight morphological and material variations in the architectural elements, in order to trace the construction techniques and distinguish the stratigraphic units. The work of Fiorillo et al. exploits the output of the photogrammetric survey for the training of machine learning algorithms aimed at degrade analysis. The objective is to perform a supervised classification of the roof covering of the *Palazzo Littorio* in *Caronno Pertusella* in order to effectively identify phenomena of degradation or damage.
The in-depth examination of methodological aspects always plays a dominant role. Lin et al. are concerned with differentiating the possible applications of UAS

in Cultural Heritage preservation in relation to the distinct stages of protection, from purely cognitive and investigative to promotion and dissemination. The case study is the *He Xinwu*, a typical example of a *Hakka* enclosure in the city of *Heyuan*, China.
A similar approach is followed by Bernal et al., using the outputs of the photogrammetric survey for both the investigation and dissemination through AR and VR applications of the knowledge gained about the Roman house in the *Alcazaba* in *Mérida* (Spain).
Another noteworthy field of application for drones is the expeditious documentation of assets in high-risk scenarios, both for operators and for the artefacts themselves. Conte and Bixio present their experiences on the Abbey of *San Michele* in *Montescaglioso*, province of Matera, interrupted by an ongoing failure on the central drum of the dome, and on the Pomarico landslide, also in the province of Matera, responsible for collapses and damage to the historical fabric.
The use of drones is obviously not limited to aerial acquisitions. Cera et al. propose the installation of low-cost photographic sensors on underwater vehicles for the photogrammetric reconstruction of submerged sites, in combination with UAS photogrammetry for the emerged parts. The case study is the Roman harbour of *Minturno*, in the province of *Latina*.
Pirinu et al. present a UAS application aimed at cataloguing military architecture dating back to World War II, investigating its distribution over the Sardinian territory. The artefacts analysed fall within the territories of *Quartu Sant'Elena*. The examples show different levels of accessibility, a limit that can be exceeded with the use of drones. This choice also allows extending the survey area to the landscape to investigate the territorial system, reaching a good level of documentation. The main goal becomes the production of an interactive map to which different types of bunker information are linked and can be viewed and consulted by users.
The synthesis of the published research activities, however, reveals the opportunity to promote a broader discussion on the need to standardize methods of investigation and data processing, capable of accompanying the regulatory alignment on the use of drones that we are witnessing in Europe and worldwide.
The multiplicity of topics and the presence of numerous researchers from different fields allowed us - thanks to the work of the committee and the scientific secretariat - to outline a global vision of the state of the art, as well as of the future prospects related to the digital representation supported by UAS.

UAV image of the Capo Colonna National Archaeological Park.

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Attiva Spa is the main distributor of DJI Enterprise products in Italy thanks to the consolidated synergy between the excellent logistics structure and the vast ecosystem of System Integrators.

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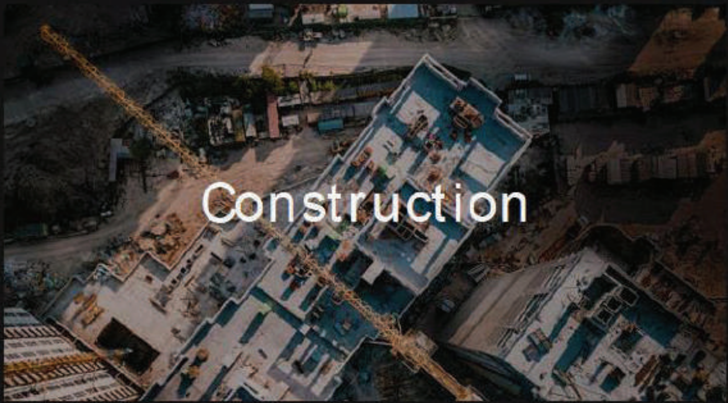

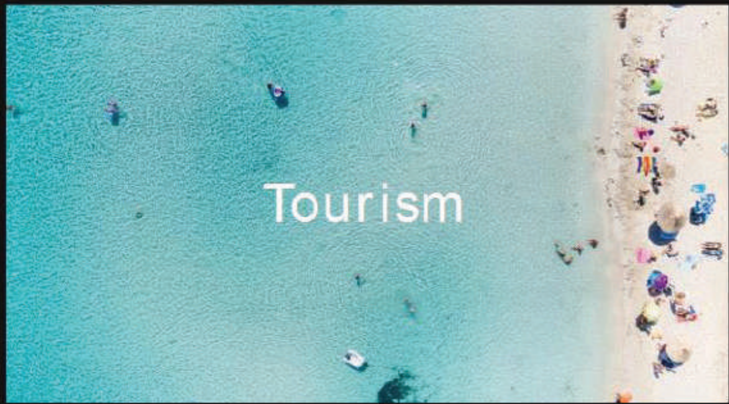

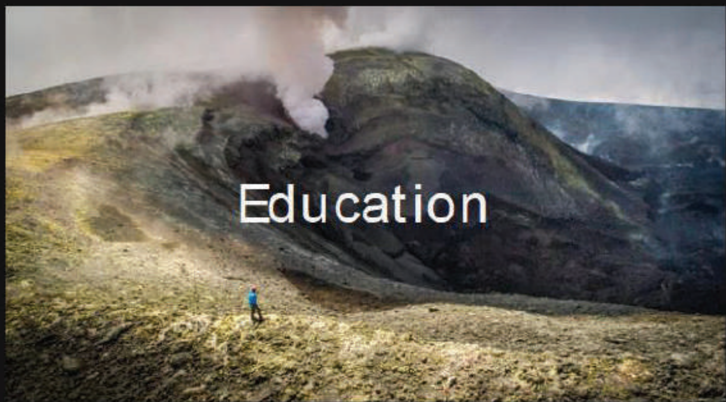


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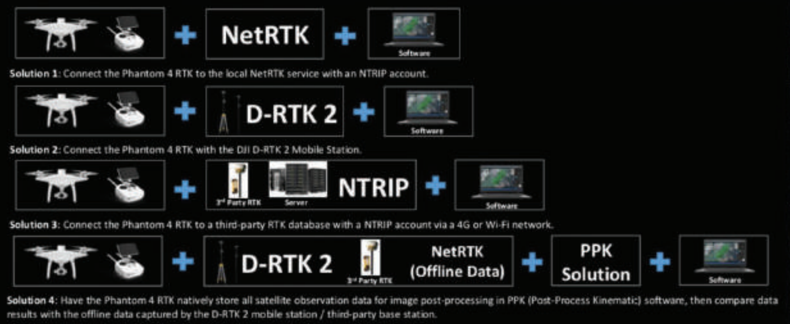
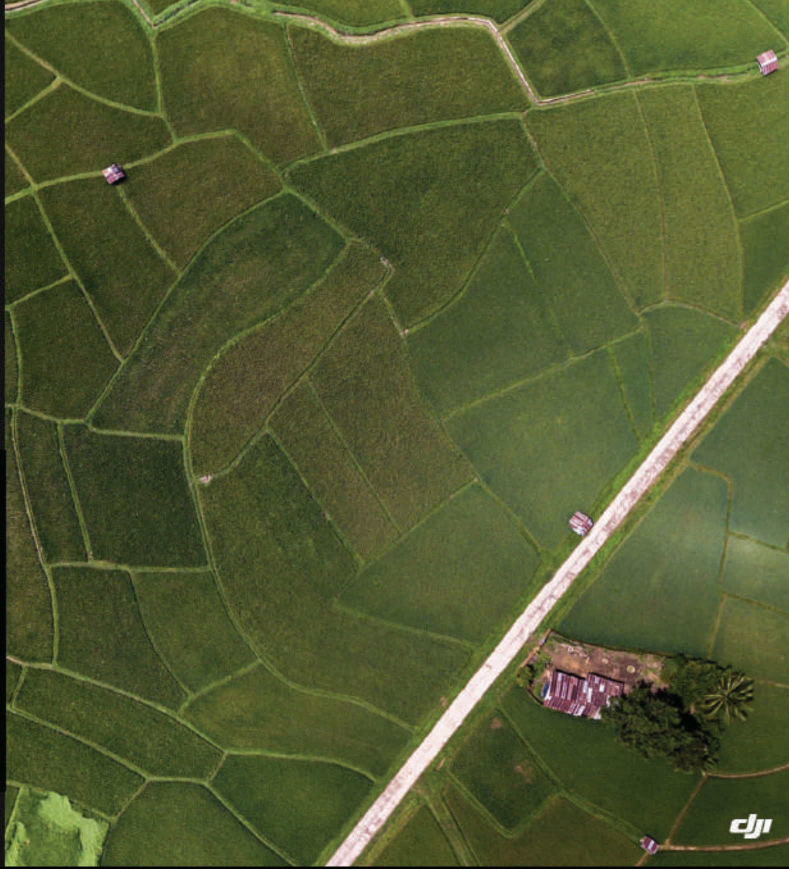
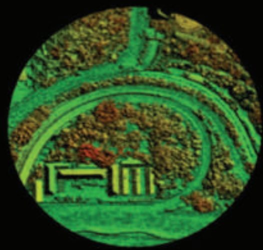





Ancient building


Tel Tower


City Planning


Surveying


Small scene modeling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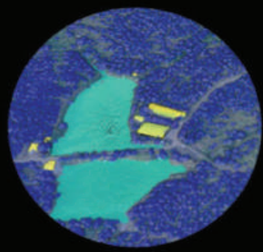

Digital agriculture

Milano droni S.r.l.
Milano mongolfiere S.r.l.

MILANO MONGOLFIERE was born from the desire to turn the dream of flying in a balloon into reality. At the base of everything there is therefore the passion for flight of our operations director, former airplane pilot, who joins the organizational skills of the accountable manager: from here our business originates, which allows us to know and make many happy people, offering a unique and unforgettable experience like that of a hot air balloon flight.

But passion alone is not enough to carry out an activity like ours on a professional level: Milano Mongolfiere, which is a Srl, is in fact an operator that complies with the European standards governing commercial flights with hot air balloons (EU REG. 395/2018).

This means that, like any other aircraft operator, we are controlled by ENAC (National Civil Aviation Authority) both for the preparation of our crews and for the maintenance of our aircraft. Flying in a balloon with us is a safe and fascinating experience, with minimal impact on the environment: in fact, we use propane gas and operate in such a way as to cause minimal damage to the area. Milano Mongolfiere Balloon Flights is one of the most important Italian companies for commercial passenger flights with balloons in Italy ; we are not a club but a real airline; we are certified by the Italian National Civil Aviation Authority (CAA)for Aerial Work, Commercial passenger Transport and Pilot School.

We place the centre of our attention :

The safety of the operations

For this reasons all the aircrafts are new, we make periodical checks on our crew and we also have a pilot school to raise new pilots.

Respect the rules

All our our employees have a contract due to national law and are insured for the specific risks of the aeronautical sector.

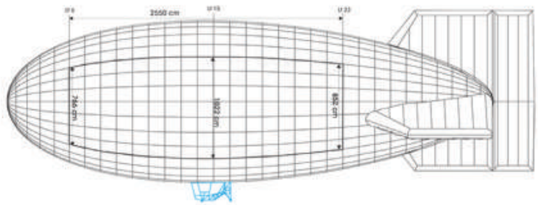
Protecting the environement

We are careful to cause minimal harm during our operations during preparation of the balloon and the landing.In fact we are the only ones that are allowed to fly

in the territory of the Parco del Ticino, a natural park 30 km from Milan.

Trasparency towards our clients

Milano Mongolfiere, unlike other operators, publishes the rates, certifications, terms and conditions on the website.



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ETRURIA VOLO S.R.L.

Etruria Volo S.r.l. is a company founded in 2015 and provides technological and professional services based on the use of Unmanned Aerial Vehicles. It was not born from nothing to exploit the "drone boom", but from a long and consolidated experience of the founders in the aeronautical world, ranging from teaching to design and construction, aeronautical research and development since the '80s, and in remote piloting since '91. As it is natural that, over time, collaborations with numerous and important private and public bodies have developed, including UNIFI, UNIFG, UNICH, CNR di Firenze, ANMIL, Versalis S.p.a., Eurallumina S.p.a., Raffinerie di Roma, Icaro S.r.l, Publiacqua S.p.a., ThyssenKrupp Italia, Timiopolis (BS), Polizia Municipale di Scandicci, Polizia Municipale di Prato, AREU Lombardia, etc. Our company is located in Castiglion Fiorentino, in the province of Arezzo, at the Aviosuperficie Serristori, former home of the VDS school and a particular love for flying, which in '94 realized the desire to modify its airplanes in order to be able, finally, to pilot people with motor disabilities in Italy, from which the association "Baroni rotti" was born. Etruria Volo is a company certified by ENAC for aeronautical education.For general aviation we have therefore set up an ATO (with identification IT.ATO.0084); based at the Aviosuperficie Serristori, where we use our 2 Cessna, a 180 (L-IUMM) and a 150 (I-CMAO). For remote pilot training, we have the UAV Training Centre (ENAC.CA.APR.030), also based at the Aviosuperficie Serristori and, in addition, secondary offices in Massarosa (Lucca), Montemelino (Perugia), Foggia and Tortolì (near Dorgali, Sardinia). In the Training Center we do training for both multiplane and fixed wing pilots, in basic, critical day and night operations, and we train Flight Instructors. We do both traditional training (for those who need to obtain flying qualifications), that training focused on operations, generating specific courses to be able to train in the pilot the knowledge and experience necessary to carry out specific types of operational missions, both for acquisition and inspection activities.

This type of teaching is possible through the classic courses of photogrammetry (RGB, IR and multispectral), and special courses in which we focus particularly on the specific activity that pilots will perform. Particular were the courses for AERU Lombardia, where we trained the Alpine and Speleological Rescue of Lombardy Region to operate efficiently with drones in the impervious alpine areas; or for Publiacqua S.p.a. (Florence). In addition to be instructors, we are also operators, and in order to be able to perform acquisition operations different from what is ordinary, it is spontaneous to use our decades of experience to create aircraft, sensors and procedures that adapt efficiently to the need of the activities that are required. Typical example is the use for years of IR sensors to carry out scans for structural verification, or to verify the geomorphology of the soil, or energy efficiency; or the combined use of typical and atypical sensors to verify the state of water, soil and air. Doing both Instructors and Operators and Builders, helps us to see what we do in a broad way and without losing sight of the objectives, imagining the "drones" as a convenient aerial stand that we can place where we need, it comes spontaneously to imagine and create an efficient "stand" that we can stop where we like, equipped with sensors suitable for the needs and duly modified, with the aim of acquiring multiple reliable data that can be used concretely. If one adds knowledge, love, passion and tenacity, the results are the natural consequence.

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Microgeo s.r.l.

MicroGeo has been guaranteeing solutions and expertise in the fields of surveying, measurement and non-destructive testing PnD for twenty years, with the aim of improving and organizing technical and commercial skills in some important fields of precision "contact less" measurement.
MicroGeo is partner of the main global brands operating in the field of instrumentation for UAVs systems and LiDAR sensors. As DJI Enterprise partner, MicroGeo guarantees an accurate and careful analysis of DJI drones and onboard sensors for professional use in the Photogrammetry and LiDAR sectors.
One of MicroGeo's solutions for the LiDAR UAVs survey is the combination of the new DJI 300 RTK Matrice with the DJI Lidar Zenmuse L1 sensor.
The Matrice 300 RTK is the new industrial drone of DJI House that gets its inspiration directly from modern aeronautical systems. With over 55 minutes of battery life, integration of advanced IA, six-directions sensing and positioning and many other features, the M300 RTK sets a new standard for intelligence and reliability combined with performance that has never been seen before.
The Matrice 300 RTK has a payload capacity of 2.70 kg and up to 3 instrument loads simultaneously. The new ZENUMUSE series (L1, P1, H20T,...) sensors also brings a completely different meaning to work efficiency. The unique intelligence and integrated design offer unprecedented aerial imaging capabilities for a wide range of applications in the UAV world. Because of its considerable load capacity, MicroGeo believes that the 300 RTK Matrice is perfect as a drone LiDAR survey solution. A survey solution therefore that makes the DJI Matrice 300 RTK the most competitive of the moment in the world of industrial drones. Another equally valid solution the combination of the DJI Matrice 300 RTK with the LiDAR MiniVux2 from Riegl. Riegl company has always been distinguished by the use of the highest quality instruments in the field of terrestrial laser scanners and LiDAR sensors.

The MiniVux-2 is compact and lightweight (1.55 kg) with a measurement speed of 200,000 points per second, achieving up to 100 scans per second with a field of view of 360°. The sensor can include in addition to the laser head, an IMU/GNSS System and up to two RGB cameras.
There are many fields of application among which the following are listed:
Agricultural and forestry;
Glacier and snowfield mapping;
Archaeology and Cultural Heritage;
Construction site monitoring;
Landslide monitoring.
For photogrammetric and laser scanner data processing MicroGeo offers 3DF ZEPHYR Aerial software from the Italian software house 3D Flow.
With Zephyr it is possible to reconstruct 3D models starting from photographs. The reconstruction procedure is completely automatic and does not require any particular instrument. The software has multiple surveying tools such as orthophotos, contour lines, georeferencing of the point cloud using GCP. Moreover, the possibility to integrate point clouds from Photogrammetry (terrestrial and drone) and point clouds from Laser Scanner allows Zephyr to be one of the most complete software in the field of Geomatics.
Terrasolid is the industry standard software for point clouds and images processing, developed specifically for the demanding requirements of geospatial, engineering, operations and environmental experts.
Terrasolid suite provides versatile and capable tools to create 3D vector models, feature extractions, orthophotos, terrain representations, advanced point cloud visualizations, etc., no matter the data source, no matter the sensor. The finest tools for calibration and matching of point clouds for LiDAR data are included



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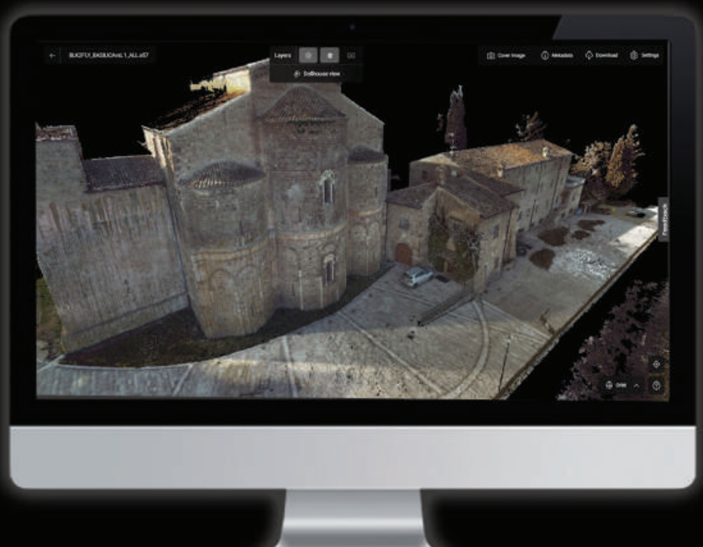
LEICA GEOSYSTEMS S.P.A



SCAN ME

Hexagon is a global leader in digital reality solutions, combining sensor, software and autonomous technologies. Our technologies are shaping production and people-related ecosystems to become increasingly connected and autonomous – ensuring a scalable, sustainable future. Each of our divisions pools collective industry knowledge and experience from teams around the world. Hexagon's Geosystems division provides a comprehensive portfolio of digital solutions that capture, measure, and visualise the physical world and enable data-driven transformation across industry ecosystems. Our reality-capture technologies create digital worlds from different views, whether a single dimension between two walls in a house, cadastral boundaries of properties or 3D shapes of cities, infrastructures, utilities, entire countries or even crime scenes. Revolutionising the world of measurement and survey for 200 years, Leica Geosystems, part of Hexagon, creates complete solutions for professionals across the planet.

The Leica BLK2GO introduced never-before-seen mobility for scanning complex indoor environments. The handheld-imaging laser scanner combines visualisation, LiDAR, and edge-computing technologies to scan in 3D while in motion, allowing users to be much more agile and efficient in capturing objects and spaces. The BLK2GO has a wide range of applications from adaptive reuse projects in the architecture and design industries to location scouting, pre-visualisation, and VFX workflows for media and entertainment.

Leica Geosystems is making reality capture fully autonomous by expanding capabilities from handheld operation to scanning with autonomous robots and from the sky. With real-time autonomous reality capture, the ability to create 3D digital twins and direct-to-cloud storage, these GrandSLAM-powered autonomous BLK laser scanners are changing the way smart digital reality is captured.

The Leica BLK ARC, an autonomous laser scanning module for autonomous mobile robots, brings its innovative 3D reality capture technology to robotic carriers and platforms. The first BLK ARC robotic integration is with the Boston Dynamics SPOT robot, with future integration plans for other robotic carriers. This innovative technology expands opportunities to capture 3D data without human intervention, continuously scanning and storing real-time data while augmenting and improving the robot's autonomous navigation system. The latest in Leica Geosystems' solutions is especially useful in dangerous or hazardous environments, with automated and repeatable scan paths to command the robot carrier while keeping employees safe. BLK ARC completes both static and mobile scans during the same mission for greater scanning agility, which boosts productivity and eliminates extra work. BLK ARC can be used in a variety of use cases, such as documenting ongoing site conditions, exploring underground mines and for public safety applications such as fire or crime scene investigations and search and rescue missions.

The Leica BLK2FLY takes reality capture innovation to a new level as the world's first autonomous flying laser scanner. BLK2FLY offers advanced obstacle avoidance while allowing users to plan entirely autonomous missions, from autonomous flight paths and scanning to intelligent return to home for battery changes to continue its mission.

Featuring simple operation and the fastest in-field setup time in the industry, Leica Geosystems' latest UAV technology can scan buildings, inaccessible areas like rooftops and facades, and other complex structures with no scan shadows and safe, stress-free user operation. Additionally, the easy-to-use BLK2FLY Live App offers real-time video view, simple touch controls for automated scanning and virtual joysticks for manual flight. BLK2FLY is the perfect drone for documenting construction progress, rapid laser scanning for BIM processes and creating digital twins for retrofits and redesigns.

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FLYTED

Flyted is an innovative start-up which collects strategic data on structures and territory.
The Company employs UAS (Unmanned Aerial Systems) and topographic-grade aerial and ground laser scanners to carry out surveys in the field of design, construction and maintenance of assets. The main application sectors are Transport Infrastructure, Telecommunications Infrastructure, Energy Infrastructure and Real Estate.
The services provided include geo-referenced survey, inspection and monitoring, with production of Point Clouds, 3D Digital Twins, CAD drawings, BIM models, photogrammetric mesh and orthophotos, high resolution RGB images and 360 ° photographs. The integration of those services allows to perform in-depth analysis, both visual and structural, about the "As-Built" or the design and construction phases of an asset.
Flyted delivers millimeter-accurate results in a tenth of the time compared to traditional methods, while eliminating workplace hazards.
The Company is part of United S.p.A., a group of companies which operate internationally in the field of “Safety & Security” and specializes in the planning, construction and management of strategic infrastructures and national interest sites. Furthermore, Flyted is supported by leading public and private equity firms such as CDP Venture Capital SGR and AVM Gestioni SGR.

OUR PRODUCTS

Digital Twin - LIDAR

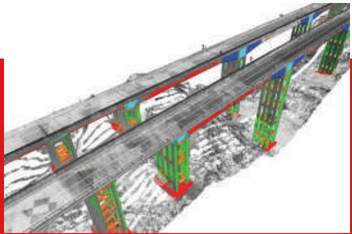
Flyted, following the detection of data with LiDAR technique by laser scanner, produces 3D geo-referenced Digital Twins of the target asset with an accuracy up to 5 mm.
The method of acquiring data from laser scanners, terrestrial and airborne (transported by UAS), is the most precise from a geometric standpoint, being able to detect the actual state (“As-built”) of the asset. The survey campaign output is a Point Cloud which represents the geometry with millimeter precision. The following phase of processing the point cloud, with a CAD or BIM modeling, is aimed to reconstruct the asset and its components.
Through our surveys, we can also create a three-dimensional reconstruction of the territory, returning a georeferenced 3D model where to calculate volumes, measurements and altimetric profiles.
Our aerial laser scanners, transported by UAS, are excellent in penetrating vegetation and generating accurate DTM (Digital Terrain Model) and DEM (Digital Elevation Model).

Digital Twin - Photogrammetry

The Digital Twin produced using aerial photogrammetric techniques is aimed to obtain hyper-realistic models and represent the original texture of the detected object. The output is a polygon mesh, able to show the smallest structure’s details, which is ideal to perform visual inspections and monitor the conditions.

Photographic inspections

We perform accurate infrastructure inspections, operating the most efficient sensors to return specific data. The visible spectrum (RGB) images are collected with full-frame (61mp) or medium format (100mp) cameras with calibrated lenses and 360-degree imaging sensors. We can then integrate LWIR (radiometric IR), SWIR and hyperspectral bands, with resolution up to 1000 bands.



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