Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 60 (2022) 600–607

Transportation Research Procedia

www.elsevier.com/locate/procedia

XXV International Conference Living and Walking in Cities - New scenarios for safe mobility in urban areas (LWC 2021), 9-10 September 2021, Brescia, Italy

Investigating objective and perceived safety in road mobility

Marco Boffi[a]*, Barbara E. A. Piga[b], Lorenzo Mussone[c], Giandomenico Caruso[d]

[a]*University of Milan, Dept. of Cultural Heritage and Environment, Via Festa del Perdono 7, Milan 20122, Italy*
[b]*Politecnico di Milano, Dept. of Architecture and Urban Studies, Via Bonardi 3, Milan 20133, Italy*
[c]*Politecnico di Milano, Dept. of Architecture, Built environment and Construction engineering, P.zza Leonardo da Vinci 32, Milan 20133, Italy*
[d]*Politecnico di Milano, Dept. of Mechanical Engineering, Via La Masa 1, Milan 20156, Italy*

Abstract

The paper presents the human-centered interdisciplinary methodology "SafeMob - Safe Mobility Experiential and Environmental Assessment" developed by the authors. The method combines Objective Safety (OS) with Perceived Safety (PS) to evaluate the performance of mobility solutions. The interrelation of data from the person (physio/psycho) and the environment (road, vehicle, and the surrounding or interacting context - including flows, buildings, and weather) makes the methodology holistic and interdisciplinary. The final goal is to provide a 'Decision Support System' for stakeholders in the mobility field, the automotive sector, and the urban planning area. The paper describes the overall theoretical approach and a specific case study application using a car simulator. Emotional reactions of users, driving through the same virtual scenario with different Level of Details, are assessed to gather information about the perceived safety of the environment.

Keywords: drive simulator; emotions; virtual reality; Level of Detail; physiological measures.

1. Introduction

The studies on wellbeing and quality of life have a well-established practice of combining environmental objective measures and individual subjective experiences. The Scandinavian approach, rooted in sociological studies, is traditionally focused on objective resources that can improve wellbeing (Erikson, 1993). The Anglo-Saxon perspective of psychological studies emphasizes the importance of how wellbeing is perceived by individuals themselves (Campbell, 1976). Many contributions attempted a synthesis, agreeing on the need of considering both dimensions to properly tackle the issue (Noll, 2004). Such an integrated perspective was initially developed to design effective social indicators informing decision-makers responsible for welfare policies. Despite this, it can be fruitfully applied also for effective urban governance, designing initiatives for the transformation of the territory which include professional, scientific, and local population knowledge (Raymond et al., 2010). This approach emphasizes the need for analysing not only people and their environment but also the relationship established among them (Rainisio et al., 2015). Our

* Corresponding author. Tel.: T +39.02503 12954.
E-mail address: marco.boffi@unimi.it

10.1016/j.trpro.2021.12.077

aim is to apply such an integrated approach to studying urban mobility, through a method that allows supporting various stakeholders in designing high-quality mobility environments and practices. In this contribution, we are going to address the specific topic of safe mobility.

Road safety and then safe mobility is often analysed by investigating crash characteristics (with data limited to crashes with injured or dead people). It is an ex-post analysis that aims at identifying measures to reduce crash risk (Hughes et al., 2015) but it can lack effectiveness due to the statistical nature of a crash event, which is random and rare. Since the 1990s (Crafer, 1995) road safety audits have been established to study a priori the impact on safety of an infrastructure or specific traffic policy. But, in this form, it cannot consider the real effects and consequent reactions of drivers to a certain road project or regulation policy.

To this purpose, the integration of traditional data with subjective ones is a fruitful approach for assessing safe mobility more comprehensively. In particular, the usage of scientific constructs for assessing the subjective experience in a certain environment is particularly useful, as they enable not only the description of a phenomenon but also the production of hypotheses and interpretations (Devine-Wright, 2005; Boffi & Rainisio, 2017). In particular, emotions are among the most investigated aspects to describe the sense of safety experienced by people in space in many research fields (Panek et al., 2017). A study in a virtual construction site showed that emotions, even if they do not influence the recognition of hazards, are the primary driver affecting the resulting risk assessment and safety decision (Bhandari et al. 2020). In the mobility field, real-time monitoring of drivers' emotions can increase safety by detecting near-miss accidents, which inform the design of safer environments (De Nadai et al., 2016). An index of safety can rely also on the presence of road infrastructural calming elements, which can be identified with an eye-tracker in a real-life urban environment and whose presence is demonstrated to affect drivers' behaviour (Vetturi et al., 2020). Emotions assessment is also explored for prospective affect-aware vehicles, which can help in tracking aggressive driving behaviours (Requardt et al., 2020). Despite the heterogeneous approaches to the notion of emotion in the literature, an established model by Russell (1980) describes them in terms of pleasure (a continuum ranging from happiness to unhappiness) and arousal (a continuum ranging from excitement to relaxation), conceived as orthogonal axes defining an emotional plane; the combination of the two dimensions provides a circumplex model, where different emotions can be described as low, intermediate or high in pleasure and arousal. A third dimension about Dominance (a continuum ranging from submissiveness to autonomy) is included in some studies (Mehrabian & Russell, 1974).
In this article, we aim to frame our interdisciplinary method for assessing the physio-psychological and behavioural effects of the mobility environment on traveling people. The method supports technical and political stakeholders in making decisions on current conditions or future design projects. Focusing on a part of the method, the goal of this article is to appraise the emotional reaction of drivers to a simulated environment with different levels of detail. This informs an efficient development of virtual scenarios for the pre-assessment of the mobility solution performance.

2. The framework of the interdisciplinary methodology

The interdisciplinary approach of our research team enables studying the in-motion experience from different perspectives by combining environmental, physiological, and psychological data (Ruscio et al., 2017; Shi et al., 2020). This enables a comprehensive and interscalar phenomena understanding, from the larger scale of 'the context' (e.g. urban morphology, visibility, weather conditions) to smaller scales, i.e. 'the infrastructure' (e.g. road, intersection, pedestrian area), 'the vehicle' (e.g. car, e-scooter, bicycle), 'the person' (e.g. physiological and physiological data), walking or using different means of transportation. Our 'Safe Mobility Experiential and Environmental Assessment' (SafeMob) method enables assessing mobility safety in an integrated perspective. It combines Objective Safety (OS) with Perceived Safety (PS) to evaluate the performance of mobility solutions. The approach is grounded on an interdisciplinary literature as well as experimental activities carried out over the years by the authors. SafeMob is able to measure and assess the in-motion experience for providing a reliable 'Decision Support System' tool. Indeed, the outcomes of the analysis can support decision-making for several stakeholders, e.g. within the automotive sector and the urban planning area. The method combines different tools: experiential simulation and mobility simulators, psychometric scales, physiological sensors, traffic monitoring systems, and mobility and urban assessment tools.

Experiential simulation is particularly useful when it is not possible to run the experiment in real settings for several reasons, e.g. non-safe environment or assessment of future design solutions, or to reduce or vary specifically the experiment variables, e.g. weather conditions, vehicle characteristics, or road features. Since it enables collecting reliable users' responses, i.e. comparable subjective reactions between the simulated and the real environment, its use is pivotal for running in-vitro experiments (see for instance: Piga & Morello, 2015). The simulation scenario is essential in creating an appropriate virtual environment. According to the specific need, the model can have different Levels of Detail (LOD), as defined by the Open Geospatial Consortium (OGC) (Kolbe 2009; Piga et al., 2020). The LODs define what is represented in the simulation, and then its details according to the scale: 1) LOD 0 regional, landscape; 2) LOD 1 city, region; 3) LOD 2 city districts, projects; 4) LOD 3 architectural models (outside), landmarks; 5) LOD 4 architectural models - interior. Choosing the needed LOD for each case study is crucial since it enables minimizing the overall effort, e.g. human resources and time and tools required for computation.

Psychometric scales (PS) allow collecting deliberate answers from individuals. Indeed, a list of questions concerning the investigated issue demands an intentional mental elaboration from the participants. They are among the most used tools in psychology to quantify theoretical constructs. They offer more valid and reliable results compared with more simple quantitative tools, e.g. single questions. The quantitative results obtained with psychometric scales can be integrated with qualitative data referring to the same or other constructs (see Fumagalli et al., 2020) or with psychophysiological measures (see Chamberlain and Broderick, 2007).

Psychophysiological measures (PS) are increasingly adopted to infer the affective condition of people, as they provide real-time, continuous, and not voluntarily controlled assessment of the personal experience (Ravaja, 2004). Yet, there is no one-to-one correspondence between physiological reactions and psychological experience, hence it is hard to effectively describe the emotional experience solely relying on this data. The combination of physiological measures and self-report scales offers a more complete representation of the personal emotional conditions, allowing the description of both subconscious and conscious emotions (Chamberlain and Broderick, 2007). Physiological data includes, for instance: EKG measures, galvanic skin response, eye and head movements; psychological data recorded during and after the mobility experience includes issues such as the emotional and cognitive variables.

Traffic monitoring systems (OS) allow collecting traffic data at a network level and investigating macroscopic travel choices. Mobility tools of traffic engineering are used for assessing circulation characteristics and then studying the interaction between demand and supply.

Urban assessment tools (OS) enable the study of urban/landscape environment characteristics. Urban features are complex and diversified, and tools should be defined according to the context and investigation scope. The study of the environment conditions may for instance include morphological analysis (e.g. urban tissue patterns and land use), visibility studies (e.g. isovist or skyview factor), light assessment (e.g. glare related to urban materials), and so on (see for instance: Morello & Ratti, 2009, Gobster et al., 2019).

In a nutshell, the overall interdisciplinary methodology aims at making the in-motion experience measurable and comparable for a proper and targeted assessment of the current or designed mobility solution. The single parts of this comprehensive method are presented in previous contributions referred to the same case study application (e.g. Ruscio et al., 2017; Caruso et al., 2020; Piga et al., 2020; Shi et al., 2020a; Shi et al., 2020b). Indeed, the practical application of the method has been analysed first from each disciplinary perspective, and then as a new whole system, i.e. by combining the different approaches and thus validating the SafeMob methodology as a single assessment tool. For the purpose of this contribution, the analysis is focused on the subjective experience, namely on the emotions lived while driving in simulation scenarios with different LODs. The same method is conceived to be applied with other means of transportation or walking.

3. Case study and procedure

The case study is an area located in the North-West of Milan, Italy (45°30'06"N 9°09'21"E). The modeled area (Fig. 1) is about 350m x 350m wide, and the path of the driving simulation is about 1.12 km long. This is the public one-way ring road that runs along and in between the Campus Bovisa La Masa of Politecnico di Milano. The area is mainly composed of isolated buildings, surrounded by open spaces and fences.

The survey involved 29 students, 66% males and 34% females; their age varies from 21 to 26 years (M=23.31, SD=1.17). All participants have from 2 to 5 years of driving experience, with family-owned cars. Only 10 of them drive every day, 17 drive 2-3 times a week, whereas 2 never drove during the last three months before the experiment. Only 4 of them previously experienced a crash and 8 were fined in the past for breaking highway rules, but not the same involved in car crashes. The sample characteristics are consistent with the Italian student population.

The experiment is organized as follows (Fig. 2). First, the subjects were invited to sign the informed consent, then, they started to fill in the first part of the questionnaire concerning socio-demographic information. After these preliminary activities, the subjects were invited to sit on the simulator seat and to set height, inclination, and distance from the steering wheel to reach a comfortable posture. Then sensors were connected with the drivers' fingers and eyes to collect the physiological response during the testing. Emotional assessment and physiological baseline were performed. All subjects started the experiment by driving for 3 minutes through an adaptation scenario, to become more familiar with the simulator; they were asked to check visibility, gas pedal, brake pedal, and steering wheel reactions. Subsequently, the subjects carried out the actual experimental task: driving through four testing scenarios, each one with different LODs. The four scenarios included elements consistent with the given definitions of LOD 0, 1, 2, and 3 (Fig. 3). The duration of the one-driving path was approximately 95 seconds, but it can be slightly different according to the subject's driving style. Subjects run the path of the testing scenario twice for each LOD. At the end of the second loop, they were invited to answer the questions related to the driving experience, which included emotions. A physiological baseline was recorded between the LODs to calibrate the assessment. The emotion assessment is carried out with one of the most established self-report tools, the Self-Assessment Manikin (SAM) (Bradley and Lang, 1994) adopted in a broad range of theoretical and applied fields. It is a pictorial tool designed to measure pleasure, arousal, and dominance on a 5-points Likert scale. For all three dimensions a stylized character represents the subjective reaction to affective stimuli, offering a non-verbal description to the respondent.

To assess the difference in the emotional experiences between the four LODs, the values of pleasure, arousal, and dominance are compared. Descriptive statistics are used to represent the emotional state in the emotional space. Inferential statistics are applied to identify significant differences, with a one-way ANOVA using LODs as independent variables and the three emotional dimensions as dependent variables.

Fig. 1. The planimetry of Campus Bovisa La Masa.

Fig. 2. Experimental protocol: participants are randomly assigned to one of four LODs sequences (0123), (1230), (2301), (3012).

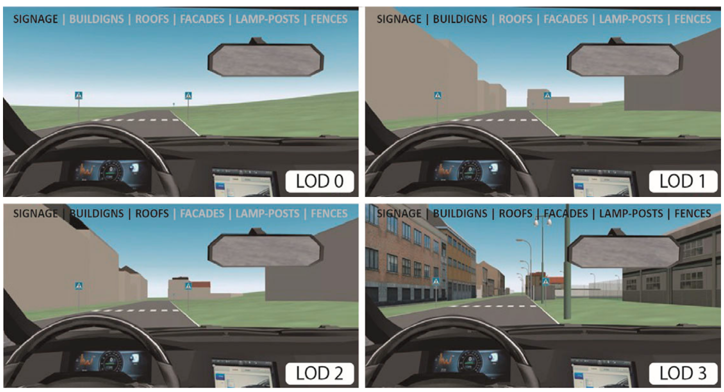

Fig. 3. The image shows the four scenarios with different LODs used for the driving experiment

4. Result and Discussion

For the purpose of representing the interaction among the emotional dimensions and their position in the affective space, we rely solely on pleasure and arousal. It is possible to define the "core affect" using these two bipolar dimensions, which are sufficient for placing the experience of each individual in the emotional space (Russell and Barrett, 1999). The resulting cartesian plane shows high-pleasure emotions on the right, and low-pleasure emotions on the left, high-arousal on the top, and low-arousal on the bottom. The plane is divided into sections, each corresponding to basic emotions. The closer the experience is to the perimeter of the figure, the more intense the emotion. The position of the dots in Fig. 4 (a)-(d) represents the frequency distribution of the experiences of single participants between the four LODs. In all LODs the majority of participants experience a moderately positive and intensely deactivating emotion, as they are included in the bottom-right quadrant of the plane (96,6% LOD0, Fig. 4 (a); 100% LOD1 and 2, Fig. 4 (b) and (c); 93,2% LOD 3, Fig. 4 (d)). LOD0 is the only case where a completely negative emotion is recorded, whereas LOD3 shows the sole case of emotion with an arousal value above the intermediate value (upper-right quadrant of the plane). Fig. 5 shows the average values of participants of each LOD, which are all included in the 'calm' section.

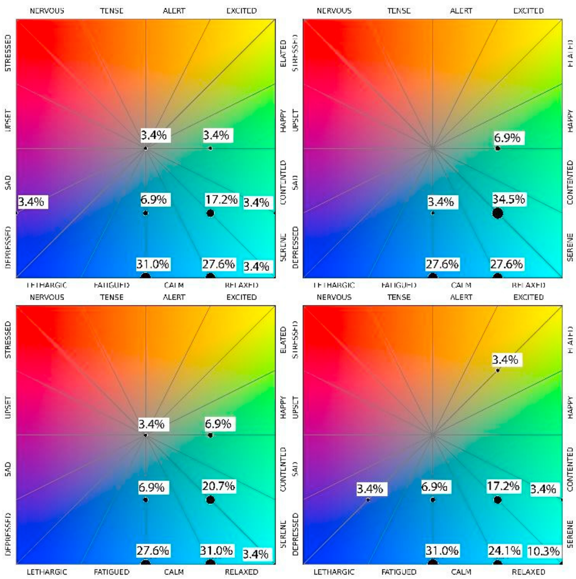

Fig. 4. Participants in the emotional space for LOD 0 (a, top left); LOD 1 (b, top right); LOD 2 (c, bottom left); LOD 3 (d, bottom right).

The ANOVA shows no significant difference ($p > .05$) between the LODs for all the three emotional dimensions (Table 1). No effect of LODs on pleasure, arousal nor dominance is observed.

The results show that conscious emotions do not significantly vary between the LODs, hence the driving experience is consistently lived as 'calm' by participants. This outcome offers a new and counterintuitive perspective on the role of LODs in affecting the environmental experience. In fact, previous studies analysing psychophysiological measures on the same case study (Piga et al., 2020) showed that LOD 0 is perceived as fatiguing due to the lack of environmental clues aiding the driving and the identification of the carriageway. The poorer scenarios, in particular LOD 0, appear to be distracting as drivers direct their attention to the missing environmental details (e.g., fences, facades). This is confirmed by the significant effect of LODs both on skin conductance, a psychophysiological measure serving as an index of cognitive effort, and the usage of gas pedal, a behavioural reaction to the simulated environment (Caruso et al. 2020). Consistent results are obtained with eye tracking data that shows a significant increase of pupil diameter, an index of attention, with higher LODs. It is associated with non-significant changes in the number of fixations between the LODs (stable workload) and a decrease of fixation duration in LOD 3 (reduced workload) (Shi et al., 2020a).

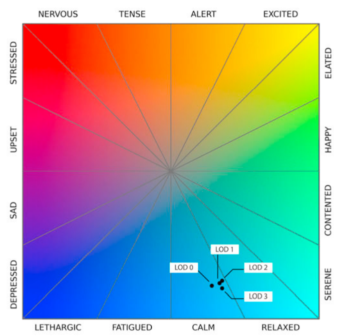

Fig. 5. Average values in the emotional space for LOD 0, 1, 2, 3.

Table 1. SAM values (pleasure, arousal, and dominance) between the four LODs.

	LOD 0	LOD 1	LOD 2	LOD 3	F (df), p
Pleasure	M = 3.58 SD = 0.57	M = 3.79 SD = 0.62	M = 3.72 SD = 0.59	M = 3.59 SD = 0.63	0.86(115), 0.4664
Arousal	M = 1.52 SD = 0.63	M = 1.48 SD = 0.69	M = 1.41 SD = 0.68	M = 1.45 SD = 0.63	0.13(115), 0.9407
Dominance	M = 4.03 SD = 0.68	M = 4.14 SD = 0.74	M = 4.14 SD = 0.63	M = 4.10 SD = 0.72	0.142(115), 0.9349

Despite not all behavioural and psychophysiological measures vary between LODs, the overall results suggest the importance of an adequate level of realism of the scenario. Nevertheless, this effect is not observed for the emotions assessed through SAM as they do not differ significantly between LODs. It is worth noting that they differ from previous data for two reasons. In the first place, they are conscious emotions, investigated through explicit questions to participants. This conscious aspect is often integrated with subconscious emotions described by psychophysiological measures, which can provide a better understanding also in case of discrepancies between different sources of data (Chamberlain & Broderick, 2007). In the second place, they are collected at the end of the simulation, whereas previous data is gathered in real-time during the driving experience. Hence, they represent a retrospective evaluation of the experience relying on what is retained in memory, which can vary significantly even in comparison to conscious real-time assessments (Fredrickson & Kahneman, 1993). Overall, these results do not underplay the importance of the level of realism in preparing a simulation but highlight the need of including diverse types of assessment for the subjective experience to integrate the objective perspective. Moreover, they suggest considering the simulation design, the experimental procedure, and the assessment phase as a whole. In fact, the choice of the right level of detail depends not only on the goals of the simulation but also on the available assessment tools. If no psychophysiological or behavioural data collection is possible, some of the differences observed between the LODs may disappear. In such a perspective the choice of the most suitable LOD can vary according to the potential variations detected by the selected tools or constructs. In our study emotions assessed through SAM do not differ between the LODs, hence collecting data using LOD 0 allows obtaining the same results with a minor simulation effort. Further development of the method regards the exploration of the discriminating power of other psychometric tools for conscious emotional assessment and of other psychological constructs. This allows us to identify the best combination of simulation and assessment methods. The ultimate goal is to obtain a reliable description of the emotional reaction contributing to the perceived safety, making the minimum effort in creating the scenario.

5. Conclusions

This paper presents an integrated approach to safe mobility, which aims at combining objective and subjective data. The resulting 'Safe Mobility Experiential and Environmental Assessment' methodology includes simulation techniques and measurement tools, which can be, applied both to physical and simulated environments. The current study is focused on the emotions assessment as a way for appraising the safety of a subjective experience in a simulated environment with different LODs. No significant differences are recorded between the LODs for the emotional dimensions of pleasure, arousal, and dominance; hence all the scenarios are in the same section of the emotional plane.

The results suggest that conscious emotions are not sensitive to the simulated scenarios, unlike psychophysiological and behavioural reactions measured in the same virtual environments. This contributes to informing about the adequate LOD to use according to the specific goal of the investigation and related tool\s. This is crucial for speeding up the process since model making is very time-consuming. As presented above, the psychological assessment is one part of the method; depending on the type of assessment (e.g. psychological, psycho-physiological, and/or behavioural) researchers should choose the adequate LOD. Such reflections are conceived as support for facilitating the inclusions of subjective feedback of users in the designing and evaluation phases. Indeed, the paper illustrates an example of subjective data that can be integrated in the SafeMob matrix, which combines Objective Safety (OS) with Perceived Safety (PS) for assessing the performance of existing or designed mobility solutions. The combination of the resulting information allows to describe four types of environment: high OS and PS (safe environment and behaviours; mobility for all users), high OS and low PS (safe environment; worried behaviours; sensitive users inhibited, e.g., less active mobility, limitations for elders), low OS and high PS (dangerous environment; illusory safe behaviours; sensitive users exposed to high risk), low OS and PS (dangerous environment; worried behaviours; severe limitations to mobility especially for sensitive users). The results of this study bear some limitations. In particular, we used a convenience sample that well represents the class of students. A more varied sample, including different ages and driving experience, is desirable. Moreover, the scenario is located in a medium density urban context with a mixed, and mainly open, urban tissue, which is only one of many urban patterns to investigate, including extra-urban ones. The experiment was carried out in-vitro, in-vivo testing would consolidate the results. Further investigations, currently under development by the research team, vary the means of transportation, the type of scenario, and include in-vivo data collection. A multimodal data collection would also be useful to tackle issues related to real-life mobility conditions.

Acknowledgments

The interdisciplinary method presented in this paper is developed by the Politecnico di Milano 'i.Drive - Interaction between Driver, Road Infrastructure, Vehicle, and Environment' Laboratory (https://www.idrive.polimi.it/), an interdepartmental research facility investigating behavioural aspects in relation to the vehicle and the environment, and the Research Unit of Social and Environmental Psychology of the University of Milan, focusing on the psychological reaction to different environmental conditions and mobility means.

References

Bhandari, S., Hallowell, M. R., Boven, L. V., Welker, K. M., Golparvar-Fard, M., & Gruber, J., 2020. Using Augmented Virtuality to Examine How Emotions Influence Construction-Hazard Identification, Risk Assessment, and Safety Decisions. *Journal of Construction Engineering and Management*, *146*(2), 04019102. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001755

Boffi, M., & Rainisio, N., 2017. To Be There, Or Not To Be. Designing Subjective Urban Experiences. In B. E. A. Piga & R. Salerno (A c. Di), *Urban Design and Representation: A Multidisciplinary and Multisensory Approach* (pagg. 37–53). Springer International Publishing. https://doi.org/10.1007/978-3-319-51804-6_4

Bradley, M. M., & Lang, P. J., 1994. Measuring emotion: The self-assessment manikin and the semantic differential. *Journal of Behavior Therapy and Experimental Psychiatry*, *25*(1), 49–59. https://doi.org/10.1016/0005-7916(94)90063-9

Campbell, A., Converse, P. E., & Rodgers, W. L., 1976. *The Quality of American Life: Perceptions, Evaluations, and Satisfactions*. Russell Sage Foundation.

Caruso, G., Shi, Y., Sayed, A. I., Ferraioli, A., Piga, B. E. A., & Mussone, L., 2020. Driver's behaviour changes with different LODs of Road scenarios. *European Transport Conference*. https://aetransport.org/past-etc-papers/search-all-etc-conference-papers?state=b&abstractId=6804

Chamberlain, L., & Broderick, A. J., 2007. The application of physiological observation methods to emotion research. *Qualitative market research : an international journal.*, *10*(2), 199–216. https://doi.org/10.1108/13522750710740853

Crafer, A., 1995 Review of road safety audit procedures. Occasional Paper. London: Institution of Highways and Transportation.

De Nadai, S., D'Incà, M., Parodi, F., Benza, M., Trotta, A., Zero, E., Zero, L., & Sacile, R., 2016. Enhancing safety of transport by road by on-line monitoring of driver emotions. *2016 11th System of Systems Engineering Conference (SoSE)*, 1–4. https://doi.org/10.1109/SYSOSE.2016.7542941

Erikson, R., 1993. Descriptions of Inequality: The Swedish Approach to Welfare Research. In M. Nussbaum & A. Sen (A c. Di), *The quality of life* (pagg. 67–87). Clarendon Press.

Fredrickson, B. L., & Kahneman, D., 1993. Duration neglect in retrospective evaluations of affective episodes. *Journal of Personality and Social Psychology*, *65*(1), 45–55. https://doi.org/10.1037/0022-3514.65.1.45

Fumagalli, N., Fermani, E., Senes, G., Boffi, M., Pola, L., & Inghilleri, P., 2020. Sustainable Co-Design with Older People: The Case of a Public Restorative Garden in Milan (Italy). *Sustainability*, *12*(8), 3166. https://doi.org/10.3390/su12083166

Gobster, P. H., Ribe, R. G., & Palmer, J. F., 2019. Themes and trends in visual assessment research: Introduction to the Landscape and Urban Planning special collection on the visual assessment of landscapes. *Landscape and Urban Planning*. Scopus. https://doi.org/10.1016/j.landurbplan.2019.103635

Hughes B.P., S. Newstead, A. Anund, C.C. Shu, T. Falkmer, 2015. A review of models relevant to road safety, Accident Analysis & Prevention, Volume 74, Pages 250-270, https://doi.org/10.1016/j.aap.2014.06.003.

Kolbe, T. H., 2009. Representing and Exchanging 3D City Models with CityGML. In J. Lee & S. Zlatanova (Eds.), 3D Geoinformation (pagg. 15–31). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-87395-2_2

Mehrabian, A., & Russell, J. A., 1974. *An approach to environmental psychology.* the MIT Press.

Morello, E., & Ratti, C., 2009. Sunscapes: 'Solar envelopes' and the analysis of urban DEMs. Computers, Environment and Urban Systems, 33(1), 26–34. https://doi.org/10.1016/j.compenvurbsys.2008.09.005

Noll, H.-H., 2004. Social Indicators and Quality of Life Research: Background, Achievements and Current Trends. In N. Genov (A c. Di), *Advances in Sociological Knowledge* (pagg. 151–181). VS Verlag für Sozialwissenschaften. https://doi.org/10.1007/978-3-663-09215-5_7

Pánek, J., Pászto, V., & Marek, L., 2017. Mapping Emotions: Spatial Distribution of Safety Perception in the City of Olomouc. In I. Ivan, A. Singleton, J. Horák, & T. Inspektor (Eds.), *The Rise of Big Spatial Data* (pagg. 211–224). Springer International Publishing. https://doi.org/10.1007/978-3-319-45123-7_16

Piga, B. E. A., Caruso, G., Ferraioli, A., & Mussone, L., 2020. Modeling Virtual Road Scenarios for Driving Simulators: A Comparison of 3D Models with Different Level of Details. *CONNECTING Drawing for weaving relationships*. 42° International Congress UID 2020., 792–802. http://ojs.francoangeli.it/_omp/index.php/oa/catalog/download/548/373/3107-1

Piga, Barbara E. A., e Valentina Petri., 2017. Augmented Maquette for Urban Design. Pagg. 104–13 In T. Maver, P. Chapman, C. Platt, V. Portela, e D. Eaton (Eds.). *Envisioning Architecture: Space / Time / Meaning*. Glasgow (GB): Mackintosh School of Architecture and the School of Simulation and Visualization at the Glasgow School of Art.

Piga, B., & Morello, E., 2015. *Environmental Design Studies on Perception and Simulation: An Urban Design Approach*. International Journal of Sensory Environment, Architecture and Urban Space. http://ambiances.revues.org/647

Rainisio, N., Boffi, M., & Riva, E., 2015. Positive Change in Environment: Aesthetics, Environmental Flowability and Well-Being. In *Enabling Positive Change* (pagg. 91–104). De Gruyter Open Poland. https://www.degruyter.com/document/doi/10.2478/9783110410242.6/html

Raymond, C. M., & Brown, G., 2011. Assessing spatial associations between perceptions of landscape value and climate change risk for use in climate change planning. *Climatic Change*, *104*(3–4), 653–678. https://doi.org/10.1007/s10584-010-9806-9

Raymond, C. M., Fazey, I., Reed, M. S., Stringer, L. C., Robinson, G. M., & Evely, A. C., 2010. Integrating local and scientific knowledge for environmental management. *Journal of Environmental Management*, *91*(8), 1766–1777. https://doi.org/10.1016/j.jenvman.2010.03.023

Ravaja, N., 2004. Contributions of Psychophysiology to Media Research: Review and Recommendations. *Media Psychology*, *6*(2), 193–235. https://doi.org/10.1207/s1532785xmep0602_4

Requardt, A. F., Ihme, K., Wilbrink, M., & Wendemuth, A., 2020. Towards affect-aware vehicles for increasing safety and comfort: Recognising driver emotions from audio recordings in a realistic driving study. *IET Intelligent Transport Systems*, *14*(10), 1265–1277. https://doi.org/10.1049/iet-its.2019.0732

Ruscio, D., Bascetta, L., Gabrielli, A., Matteucci, M., Ariansyah, D., Bordegoni, M., Caruso, G., & Mussone, L., 2017. Collection and comparison of driver/passenger physiologic and behavioural data in simulation and on-road driving. *5th IEEE International Conference on Models and Technologies for Intelligent Transportation Systems (MT-ITS)*. https://doi.org/10.1109/MTITS.2017.8005705

Russell, J. A., 1980. A circumplex model of affect. *Journal of Personality and Social Psychology*, *39*(6), 1161–1178. https://doi.org/10.1037/h0077714

Russell, J. A., & Barrett, L. F., 1999. Core affect, prototypical emotional episodes, and other things called emotion: Dissecting the elephant. *Journal of Personality and Social Psychology*, *76*(5), 805–819. https://doi.org/10.1037/0022-3514.76.5.805

Shi, Y., Xu, Y., Ferraioli, A., Piga, B. E. A., Mussone, L., & Caruso, G., 2020a. A method of processing eye-tracking data to study driver's visual perception in simulated driving scenarios. *European Transport Conference*, 1–18. https://aetransport.org/past-etc-papers/search-all-etc-conference-papers?abstractId=6844&state=b

Shi, Y., Bordegoni, M., & Caruso, G., 2020b. *User studies by driving simulators in the era of automated vehicle*. Computer-Aided Design and Applications, 18. https://doi.org/10.14733/cadaps.2021.211-226

Vetturi, D., Tiboni, M., Maternini, G., & Bonera, M., 2020. Use of eye tracking device to evaluate the driver's behaviour and the infrastructures quality in relation to road safety. *Transportation research procedia, 45*, 587-595.