A Simultaneous Multiuser Collaborative Immersive Design Environment: Extended Reality and Digital Photogrammetry for the Valorisation of Heritage Sites

Alessandro Camiz, Özge Özkuvancı, Kartal Turhan and Bora Sezer

Keywords XR · Digital survey · Architectural composition · Heritage valorisation · Immersive design

1 Introduction

Immersive design, an innovative notion deriving from the gaming industry [1], has recently invaded the architectural design practice, generating at times innovative architectural solutions and perhaps a new style which is not widely accepted. This new style has generated a strenuous opposition to innovative tools within the rather conservative architectural composition research field. In fact, our interest is not in the possibility of generating complex forms using these technologies, but rather in their deployment for a proper representation of heritage buildings or contexts, within a design environment where to define conformal and contextually placed design solutions. The notion of immersive design is ambiguous as it points both to designing an immersive interface or environment and to using an

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immersive interface or environment for design purposes [2]. The easy interpretation of this notion (immersive design) intended as using an immersive environment for design purposes [3], derives from the objectable equation that immersive technology is one of the following: Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR), and Extended Reality (XR) [4]. In fact, we believe that there is much more to it, as we can interpret the notion of immersion for all the five senses and not only for the sight [1, 5]. Anyhow, according to the aforementioned reductive interpretation, immersive design means designing something using one of those environments (VR, AR, MR, XR) as a human machine interface [6]. Following this interpretation, a number of VR centred digital design tools are already available on the software market [7]. The paper will illustrate the digital photogrammetric survey of a traditional wooden house located in San Sebastian, Madeira (Portugal), the transformation of the point cloud into a lightweight textured mesh, which was imported into the SketchUp design platform. With the use of a specific plugin (VR-Sketch), it was possible to generate a digital twin of the house within a simultaneous multiuser design environment, allowing different users to interoperate on the primitive database using VR glasses and joysticks, as well as a PC and a digital tablet with a digital pen. This design environment allows not only an effective teamwork in the design workflow, but also and most of all, the placement of the designed object within a 3D immersive digital twin of the surveyed heritage context. This research will further develop such an experimental design environment in order to deploy it for the interactive architectural composition within archaeological areas. We developed this research as Özyeğin research unit within the ‘ID4Ex-Immersive Design for Excellence. New Digital Competences for the Rehabilitation and Valorisation of the Built Heritage’, 2021–2023 Funded Programme Erasmus+, Action Type: KA220-HED Cooperation partnerships in higher education, Call 2021, Round 1, Higher Education, 2021-1-PL01-KA220-HED-000032239.

2 Immersive Design for Excellence

The ID4Excellence project intends to meet Europe 2030 growth strategy priorities on employment and education. The project also considers the EU Roadmap Opening up Education (04/2013), enhancing education and skills development through new technologies and underlining the insufficient supply of quality digital contents across languages, subjects and needs. The construction sector is facing great challenges, not least the current health emergency that forces to rethink the places and spaces of both supply chain and value-chain, from the training to the design phase, from construction sites to the use and maintenance. In this context, the digitization of the sector represents an important driver to face not only the challenges of effectiveness and efficiency to foster project innovation, but also the excellence and specialization of the skills, which is of main importance for the industrialization of the sector itself. Moreover, an immersive design approach

to the project innovation could lead to inclusive products and services in order to engage all the actors and stakeholders involved in the process. Supporting the updating of skills and competences through an inclusive approach to the built heritage intervention, experimenting new technologies and the combination of Key Enabling Technologies, (KETs), Virtual Reality (VR), Immersive Interactive Experience (IIE) and advanced 3D modelling are the general aims of the project. Immersive Design (ID) describes design work, which ranges in levels of interaction and leads users to be fully absorbed in an experience. This form of design involves the use of VR (Virtual Reality), AR (Augmented reality), and MR (Mixed Reality) that creates the illusion that the user is physically interacting with a realistic digital environment.

3 Defining Immersive Technologies

It is possible to find in the existing literature innumerous definitions of immersive technologies [2, 8, 9], but in order to be original, we decided to go to the origins. After recalling the use of immersion for mnemonic purposes, a very old tradition rooted into classical culture (Fig. 1) [10, 11], we thought of researching the origins of the word. It comes from the Latin composite verb in+mergere = immergere, which means to put underwater. The equivalent Greek word, βαπτίζω, baptizō, with

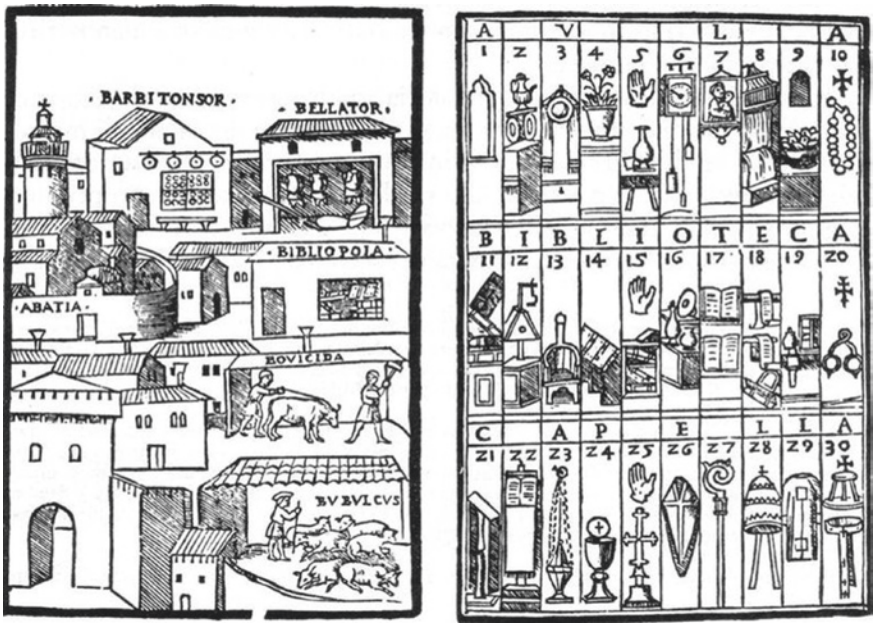

Fig. 1 Places, spaces and figures as mnemotechnic devices. *Source* Romberch [11]

the same meaning, is at the base of the baptism found within most flavours of the Christian religion. This idea seems to derive from the Hebrew ritual of the טְבִילָה, tevilah, a full body ritual immersion usually done in a מקווה, mikveh. In addition, the الوضوء al-wuḍū', is the Islamic procedure for cleansing parts of the body before the prayer, a type of ritual purification, or ablution. We also have something similar in the Hindu practice of submerging in the river Ganges. It is important to underline how this idea of 'putting underwater' is at the core of most of the monotheistic religions. There must be something very much important in this idea of putting underwater. Nevertheless, even though we mostly do use the word Immersive technologies today to include a number of different activities Virtual Reality (VR), Augmented Reality (AR), Extended Reality (XR) and Mixed Reality (MR), we should recall that the definition of immersive is indeed much broader. We can talk about immersion whenever anyone of the human senses makes you feel to be within a given environment. To a certain extent, we can say that literature and painting, as well as many other social practices, are immersive technologies (Figs. 1, 2, 3).

We should also recall here that immersive technologies are very effective for teaching and learning purposes [1, 4, 5, 12–17], and as Makransky points out "the immersion principle in multimedia learning is that immersive virtual environments promote better learning when they incorporate multimedia design principles. In short, immersive media do not necessarily improve learning but effective instructional methods within immersive virtual environments do improve learning" [18] (Fig. 4).

4 A Collaborative Immersive Design Environment

Nevertheless, for the sake of the understanding of how it is possible to deploy immersive technologies within the design workflow, we made an experimental application based on a very small traditional house, in Madeira, a small island belonging to Portugal, in a town called San Sebastian of which we did a digital photogrammetric survey (Fig. 5).

Nothing advanced; we shot the photos using a Samsung phone during our ID4Ex transnational meeting in Madeira. However, we wanted to test the use of a digital survey for design purposes [19]. So, of course, we transformed the photogrammetric survey into a point cloud and a textured mesh using Agisoft Metashape (Fig. 6). After this phase, we optimized the mesh so to obtain a very lightweight file. Using Blender, we reduced the size of the mesh from 178 to 18 Megabytes (Fig. 7). We wanted to import this mesh into a design environment and make it suitable in terms of speed and effectiveness for design purposes. We then imported this lightweight mesh in two different applications: an Augmented Reality app using the phone, and a design platform SketchUp, which today has a plugin (VR Sketch) allowing the use of virtual reality interfaces. So, for the Augmented Reality we exported an FBX file for Android phones and for the IOS application the Apple proprietary USDZ file format. We tested this procedure during the workshop we organised within the Erasmus + project ID4Ex.

Authors	A property of the system	A perceptual response	A response to narratives	A response to challenges
Slater (2003)	***System immersion***: A property of the technology mediating the experience. The higher the fidelity of displays and tracking, the greater the level of immersion.			
Witmer and Singer (1998)		**Immersion:** A feeling of being enveloped by, included in, & interacting with the virtual environment.		
Arsenault (2005)		**Sensory immersion:** A sensation of being enveloped by the multisensory representation of the virtual world delivered via high-fidelity displays.	**Fictional immersion:** The sensation of being mentally absorbed by fictional stories, worlds or characters.	**Systemic immersion:** The mental absorption experienced when facing challenges that match one's capabilities, including the challenges involved when exposed to nonparticipatory media.
McMahan (2003)		**Perceptual immersion:** The sensation of being surrounded by the virtual environment that increases proportionally with the number of modalities provided with artificial stimuli.	**Psychological immersion (immersion on a diegetic level):** The mental absorption experienced during exposure to the world of a game's story.	**Engagement (immersion on a nondiegetic level):** The state of focused attention on the game brought about by the desire for gaining points and/or devising a winning or spectacular strategy.
Adams and Rollings (2006)			**Narrative immersion:** A state of intense and focused attention on the story world & the unfolding events and acceptance of these as real.	**Strategic and tactical immersion:** A state of intense preoccupation with observation, calculation, & planning or with swift responses to obstacles.
Ermi and Mäyrä (2005)		**Sensory immersion:** The feeling of being surrounded by the multisensory representation of virtual worlds delivered through large screens and powerful sounds.	**Imaginative immersion:** The sensation of being mentally absorbed by a game's story, its world, or its characters.	**Challenge-based immersion:** The mental absorption experienced when facing challenges requiring mental or motor skills.
Ryan (2003; 2008)			**Narrative immersion:** A state of intense focus on a narrative; can be divided into 3 subcategories: *immersion* (elicited by a strong sense of place and the joy of exploration), *temporal immersion* (caused by a desire to know what will happen next), and *emotional immersion* (brought about by emotional attachment to characters).	**Ludic immersion:** A state of intense absorption in the task currently being performed.

Fig. 2 Summary of the presented definitions of immersion. *Source* Nilsson et al. [8]

During the training called 'An online crash course on immersive design for building rehabilitation and valorisation', held from the 3rd to 7th of July 2023, students learned how to import a textured mesh 3D model on their phone. Using both on iOS and Android platforms, students were able produce a screenshot of

Terms	Form	Content	User response
System immersion (e.g., Slater, 2003)	A property of media form describing the degree to which a system is able to faithfully reproduce natural perception and action through multisensory displays and tracking.	System immersion is separate from content because it is used to describe the technology used to present the content rather than the content itself.	Although system immersion may influence the user response, the reverse is not true.
Immersion (Witmer & Singer, 1998), *perceptual immersion* (McMahan, 2003) and *sensory immersion* (Ermi & Mäyrä, 2005).	Form factors, such as isolation from the physical environment and interfaces allowing for natural interaction, are believed to influence the experience of immersion.	Content is generally not viewed as a factor influencing the subjective sensation of immersion.	Immersion is view as a sensation of being enveloped by, included in, and interacting with an environment

Fig. 3 Immersion as technology and immersion as a reaction to technological envelopment in terms of form, content, and user response. *Source* Nilsson et al. [8]

Fig. 4 Word cloud generated by the students answering the question: immersive technologies are… during the id4ex training an online crash course on immersive design for building rehabilitation and valorisation, 3–7 July 2023 (Editing: Authors in 2023)

the placement of that model within their home, studio, office, or wherever they were. The results of the AR workshop are visible in Fig. 11 (left).

On the other hand for the application of the same lightweight 3D textured mesh for design purposes we were looking into the different platforms that today allow you to do design within an immersive VR environment. Even though the definition of immersive technology is quite recent, this idea is much older as we have seen. However, today a number of dedicated design environments are available, and these are being used especially within the automotive industry for the design of vehicles. We were able to notice that Kia, McLaren and Ford are currently promoting their latest products as designed using a dedicated VR environment. However, the question we should ask ourselves should be in our opinion even though it is indeed possible today to design objects such as cars or small

Fig. 5 On the left the traditional house in San Sebastian (Madeira, Portugal) (Photo: Authors in 2022). On the right the ID4Ex logo (Editing: Authors in 2021)

Fig. 6 A lightweight textured mesh generated from the digital photogrammetric survey of the traditional San Sebastian House (Madeira, Portugal) (Editing: Authors in 2022)

gadgets using a VR interface, is it possible, moreover convenient to do the same for buildings in the field of architectural and interior design? I do believe we still have some issues to be solve, one of them being the scale. With VR, the design

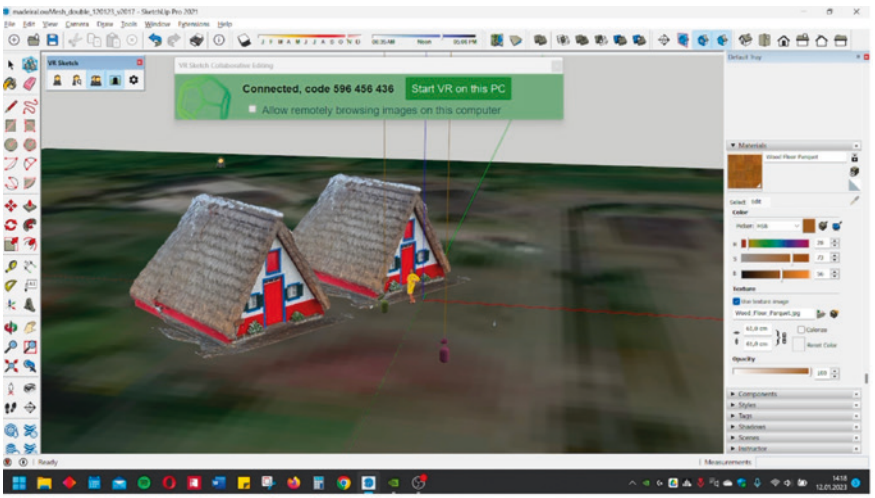

Fig. 7 Deploying digital twins of the traditional San Sebastian House (Madeira, Portugal) in the simultaneous multiuser collaborative immersive design environment (Editing: Authors in 2023)

interface is the human body with joysticks and the headset, but we should compare the measure of the human body interface to the measure of the object that we want to design. Using a VR interface makes perfectly sense if the object is smaller or close to the dimension of the human body, but if you are designing a bridge and your body is 200 times smaller, does it still make sense? Yes, it is possible to zoom in and out. However, what is the purpose of using a VR interface in this case if you are not able to manage it at the appropriate scale.

Nevertheless, we tested the application of this VR design procedure by importing the same mesh produced for the house in San Sebastian with a different file format called Collada (DAE extension) which is compatible and can be imported into SketchUp. The SketchUp platform has recently announced a third party plugin (VR Sketch) that allows the use of the headset within the design environment. Therein it is also possible to place the model within the integration of Google Earth. So you can basically import the lightweight texture mesh within the SketchUp environment and place it within the Google Earth integration, geolocating and tagging it within a 3D terrain generated by Google Maps. Not very accurate, but good enough for general design purposes. Once the textured mesh is imported it is obviously possible to do some editing on it, and most importantly, it is possible to design objects using the SketchUp interface. The application runs on Mac, PC and IOS, so it works on the iPad as well, and together with the Apple pencil, it is a very interesting interface for the practice of architectural design. In Fig. 7, you can see two of those houses imported into the SketchUp environment.

Most interestingly though, it is possible to design buildings, and therefore you can see the design of a small totem as a demonstration of the possibility of doing so within that environment (Fig. 8). Within the VR Sketch plugin, it is possible

to connect a headset by introducing a numeric code generated by the plugin, and then join the design session using your headset (Fig. 9). What is surprising of this feature is that with the headset it is possible to edit the primitives, and even more than one user can do this simultaneously on the same file: we tested this application with one user on the computer and two users with the headset, and it worked very well (Fig. 10). It is indeed not very common to find on commercial software a multiuser interface capable of editing the same file simultaneously. There are numerous other plugins and applications available today, which allow the integration of design software and headset, but most of them only consent to display for the client the 3D environment that was already designed elsewhere. None of them, at least the ones we have been testing, allows you to do the primitive editing. The reason why we were interested in SketchUp and the VR Sketch plug in is the possibility of doing the editing through the headset, which is not that common.

In Fig. 8, you can see our experiment generating some very simple objects within an immersive design environment by using both the computer and the headset. I forgot to mention that this application runs also on the iPad. When you use the iPad with an Apple Pencil, you end up designing with a very advanced digital interface in a way that is very similar to what we used to do when some time ago when the design process was accomplished on paper with pens and pencils. Therefore, it is clear that the application of immersive technologies within the design field in a heritage context has been improving in recent times and to this day, it is possible to do what we have shown. In the future, we do believe that the integration between the headset provided by the gaming industry and the design sector will increase meaningfully.

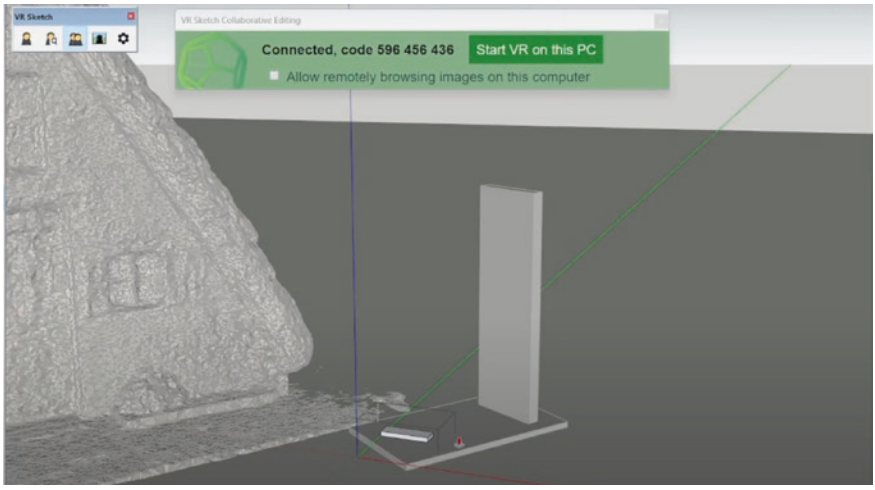

Fig. 8 Designing a small totem next to the San Sebastian house in the simultaneous multiuser collaborative immersive design environment (SMCIDE) deployed during the research (Editing: Authors in 2023)

Fig. 9 Three users (two using the headsets and 1 using a PC) are simultaneously editing the primitive database of the same file using SketchUp and the VR sketch plugin. (Editing: Authors in 2023)

Fig. 10 Özge Özkuvancı is testing the headset interface of the simultaneous multiuser collaborative immersive design environment (SMCIDE) deployed during the research (Photo: Authors in 2023)

In Fig. 11 you can see the application of the SketchUp and VR sketch during a workshop organized within the ID4Ex Erasmus+, 'An online crash course on immersive design for building rehabilitation and valorisation', 3–7 July 2023. During the training, architecture, interior design and engineering students experimented how deploy an immersive design environment in a heritage context. We tested again the same application with similar results within the ID4Ex Intellectual Output 4—IO4, 'Report on pilot actions for immersive design experts, Türkiye local training, Hybrid Course on Immersive Design for Building Rehabilitation and Valorization' held at Özyeğin University, Faculty of Architecture and Design.

Istanbul, Turkey, From November 21st to December 5th, 2023 (Figs. 12 and 13).

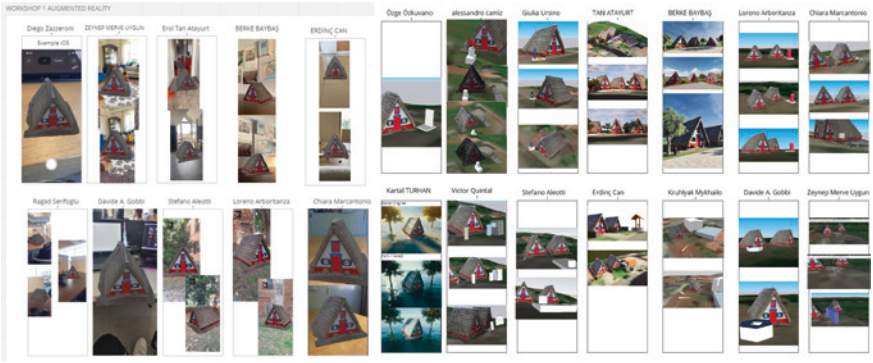

Fig. 11 The results of the workshop on augmented reality directed by Enrico Santori and Diego Zazzeroni (MORE srl) (left). The results of the workshop on Sketchup and VR for design in heritage contexts, directed by Özge Özkuvancı and Kartal Turhan (Özyeğin University) during the ID4Ex training an online crash course on immersive design for building rehabilitation and valorisation, 3–7 July 2023 (right) (Editing: Authors in 2023)

Fig. 12 Students practicing with the VR headset in the OZU VR LAB during the 'ID4Ex Turkey hybrid course on immersive design for building rehabilitation and valorization', held at Özyeğin University, from November 21st to December 5th, 2023 (Photo: Authors)

Fig. 13 Group photo from the 'ID4Ex Turkey hybrid course on immersive design for building rehabilitation and valorization', held at Özyeğin University, from November 21st to December 5th, 2023. (Photo: Authors in 2023)

Therefore, we can predict that the gaming industry will be pushing the integration between VR and design platforms in the future. Besides the one we tested, other proprietary interfaces allow designing using VR and a headset. One of them is Gravity Sketch, which appears to be very much industrial design oriented.

5 Conclusions

We based the theoretical framework guiding the research on the integration between digital technologies and architectural composition in heritage contexts. Therein an immersive environment based on a lightweight digital twin of the heritage building, can provide guidance on the design process in an unprecedented way, allowing a stronger integration between the context and its modifications. It is possible to deploy this same procedure successfully not only in archaeological areas and heritage buildings, but also in any other design context. Furthermore, this procedure allows a deeper integration between the design process and the surrounding environment. However, indeed its strongest application is in heritage building/archaeological areas, where the existing buildings or ruins constitute greater part of the overall figure, and in a way should be enhanced by the design

proposal rather than be overwhelmed by contrast, as often happens in contemporary architecture. We are suggesting one *caveat* here for the future development and application of this research: please do not intend the deployment of a digital twin as a substitute of the original building, but rather as means to better understand and analyse the original building. In other words, the digital twin should not replace the original, but rather serve in parallel as an integration of the original, in order to be able to better study, enhance, modify and preserve it for the future generations. This specific segment of digital technology is developing very quickly, as the gaming industry is pushing the software market towards the integration of VR and the design platforms. Most of the existing plugins and applications, allow displaying in a VR environment the design products. Now only a few plugins and applications allow the user to design within the VR environment. In the near future, we foresee more of this VR-Design Platform integration. Now the use of a VR interface for design is most suitable for the industrial design field. We underlined some critical scale issues related to the productive use of a VR interface for architectural design. Nevertheless, we believe that the integration between VR and other traditional interfaces, such as mouse/screen, tablet/digital pen, can become very interesting in the future. Furthermore, immersive technologies (in a broader sense) can provide strong integration with the design workflow within heritage sites for educational purposes.

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Project website: https://id4ex.il.pw.edu.pl/

Facebook group: https://www.facebook.com/groups/ID4Excellence

Youtube channel: https://www.youtube.com/@id4ex816/

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AI&XR and Heritage Routes

Digital Innovations in Architecture, Engineering and Construction

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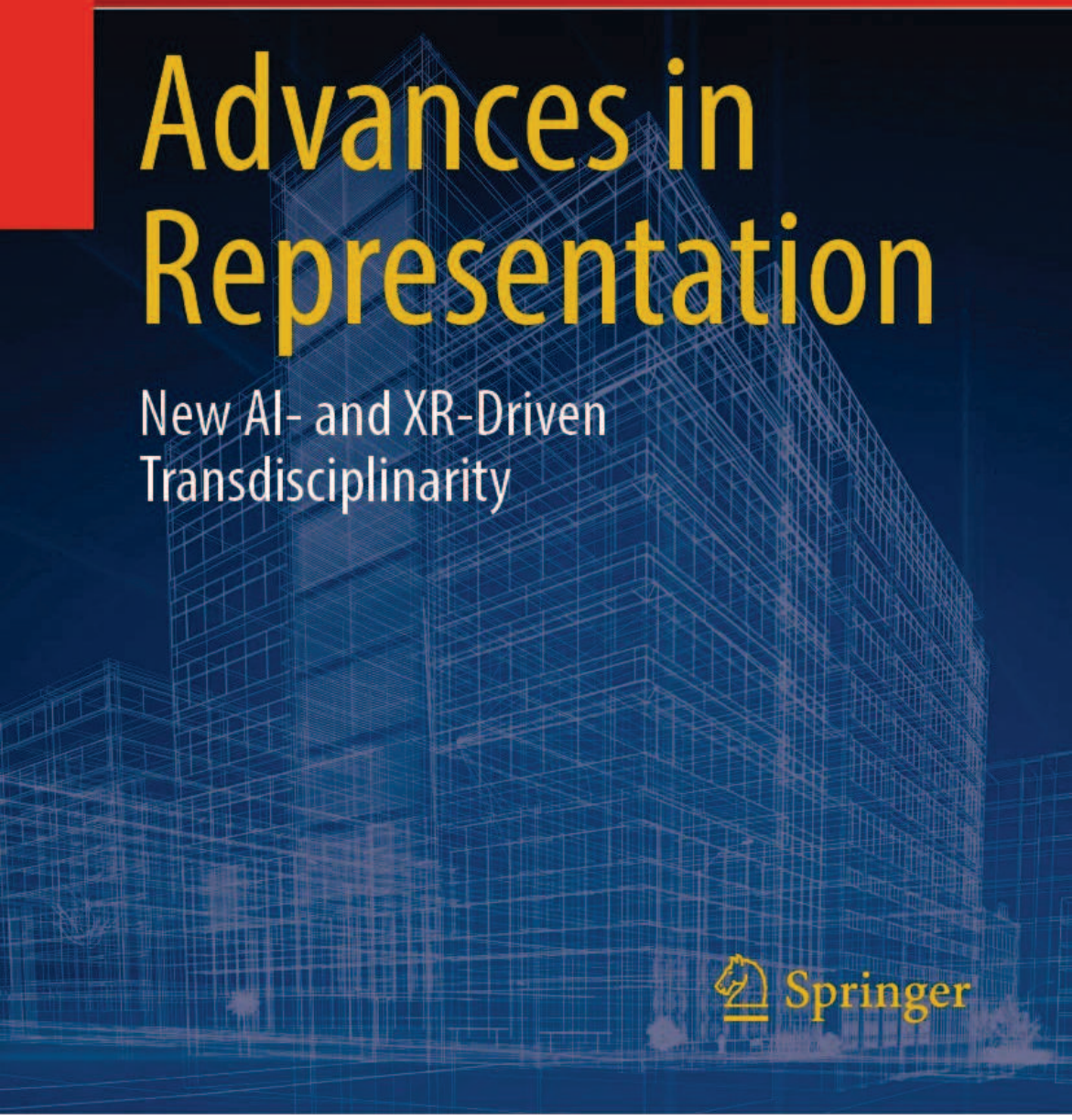
Advances in Representation

New AI- and XR-Driven Transdisciplinarity



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- Interoperability: building/city information modeling.
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Foreword

The volume that Andrea Giordano, Michele Russo, and Roberta Spallone are publishing today collects the results of research conducted, as the editors testify, by some 180 scholars from five continents, who collectively or individually present 57 papers, plus two invited papers.

The collection of books dedicated to the advances and challenges of representation disciplines, now in its fourth volume, demonstrates the consolidation of the REAACH association's role as antennae for the extent to which digital methodologies and technologies affecting the discipline in its relations with the design, the built environment, and the heritage appear, disappear, evolve, and transform.

Connected to these developments, different fields of knowledge converge and intertwine from time to time, seamlessly between humanities and hard sciences. It is precisely the dual humanistic and scientific nature of the drawing discipline that acts as a catalyst in this new phase of knowledge reconfiguration around the artificial intelligence revolution. The latter, central to the interests featured in the research presented in this volume, takes the form of an opportunity to see, to borrow Pierluigi Contucci's words, the most fascinating humanistic questions dialoguing amiably with scientific ones (P. Contucci, Rivoluzione Intelligenza Artificiale, 2023, Edizioni Dedalo, Bari, p. 7).

In this sense, the REAACH association's objective of fostering the mutual exchange of knowledge and multidisciplinary research, increasing the network of research interconnections, is continually being updated and attracting new partnerships.

The book offers this varied panorama of knowledge, viewpoints, and internationally relevant case studies, looking ahead to new developments in which the future is already present.

April 2024

Francesca Fatta
UID President

Preface

The volume *Advances in Representation. New AI- and XR-Driven Transdisciplinarity* collects the outcomes of experimental transdisciplinary research carried out by international teams. The discipline of representation emerges as an explorer, inventor, and creator of new methodologies, technologies, and fields of application, catalyzing and promoting unprecedented connections with other knowledge.

The volume we are about to release results from a year-long work. It was a matter of selecting international research that would show the most up-to-date panorama of innovative and experimental research in the field of artificial intelligence (AI) and extended reality (XR) and guiding them through the different stages of double-blind review to the achievement of scientifically validated results.

The contributions have been collected according to eight topics, in which the AI&XR binomial, through the mediation of representation, is experimented in the different fields of heritage, design, and education, articulated in the focus on Historical Sources, Archaeological/Museum Heritage, Heritage Routes, Classification/3D Analysis, Building Information Modeling, Building/City Monitoring, Education, Shape Representation.

Our thanks go to Francesca Fatta, president of the Unione Italiana Disegno (UID), for her advice and constant support during all phases of our work, to Alessandro Luigini, president of the IMG Network, for sharing ideas and insights, to the scientific and review committee, consisting of Marco Giorgio Bevilacqua (University of Pisa), Stefano Brusaporci (University of L'Aquila), Valeria Cera (University of Naples Federico II), Francesca Fatta (Mediterranea University of Reggio Calabria), Alessandro Luigini (Free University of Bozen-Bolzano), Federica Maietti (University of Ferrara), Barbara Ester Adele Piga (Politecnico di Milano), Cettina Santagati (University of Catania), for their proactive proposals, hard work, and continuous support. Special thanks go to Giulia Flenghi and Enrico Pupi for carefully editing this volume.

Finally, our heartfelt thanks go to the scholars who responded to the call rigorously and skillfully, with high-quality contributions that exceeded our expectations.

We hope that their papers will stimulate interest and inspiration for innovative research in readers.

Padua, Italy — Andrea Giordano
Rome, Italy — Michele Russo
Turin, Italy — Roberta Spallone
April 2024

Preface: Introducing the Relationships Between Digital Representation and AR/AI Advanced Experiences

Keywords Digital Representation · AI · XR · Cultural Heritage · Building Design

Introduction

The breadth of interests that emerges around the discipline of Digital Representation linked with Artificial Intelligence (AI) and extended reality (XR) experiences, offering new ways of interacting with the real, coupled with the very rapid development of technologies, tools, and devices, as well as careful monitoring of the disciplines that can be involved, are in the center of the interests for this book. In this sense, the fields of application open to the worlds of tangible and intangible cultural heritage, architectural, environmental, infrastructural, and product design, and education as a place for advanced training and as a tool for educational enhancement.

This collective volume intends to explore, through the lens of the Representation discipline, the research areas that gravitate around AI-XR, opening up new transdisciplinary thinking.

Digital Representation, AI, and XR in Cultural Heritage Domain

In recent years, the intertwining of digital representation with artificial intelligence (AI) and extended reality (XR) advanced experiences is finding a fertile field of application in Cultural Heritage (CH).

The broad concept of Cultural Heritage encompasses those declinations of heritage, tangible and intangible, that comprise the objects of the applications of interest for this volume:

The historical building and artistic goods—mainly referring to the statuary, paintings, artifacts, and tools that populate the anthropized spaces—in their different states of conservation;

The sources documenting the design of the built heritage and artworks, their realization, and transformations;

The routes, connecting the different assets through relationships of meaning that include material and immaterial aspects of heritage.

It is on these thematic bases that the contributions in the three sections mentioned above are articulated, sometimes interweaving AI and XR, some others employing only one or the other, bringing novel and original results to the attention of the international scientific community. The research displayed dialogues with the built environment, whether existing or disappeared; it confronts the historical and archival documentation of the design process and the transformations of artifacts and the urban fabric; it seeks answers to the complex relationships between the remains of settlements and individual monuments of the past and the works and products of man preserved in the collections; and it creates new spatial connections between places, buildings, objects, and documents.

In the field of digital representation for heritage, methodologies of graphic analysis, reconstructive, regressive, interpretative modeling and techniques of geometric, parametric, informative, and algorithmic modeling are relatively well established in terms of theoretical statutes, operating methods, and available hardware and software tools. Conversely, as is well known, the discipline of artificial intelligence is developing rapidly and continuously in application to all fields of knowledge and everyday life. In particular, AI has seen new opportunities offered in the field of cultural heritage aimed at documentation and protection [1], accessibility [2], semantic enrichment of CH images [3], artifact recognition [4], up to the most recent developments of generative AI [5, 6] to feed the field of reconstructive hypotheses in a creative sense.

AI's challenges in analyzing and classifying archaeological heritage [1] can be usefully extended to the broader field of the historical built environment. Indeed, the uses of artificial intelligence in archaeology, i.e., machine learning (ML) and deep learning (DL) algorithms, convolutional neural networks (CNN), and deep learning (DL) models, aimed at distinguishing archaeological remains and detecting changes in them over time to make decisions on appropriate strategies for conservation and protection, are matched by various strategy for monitoring the built environment.

Concerning the issues of cognitive accessibility to heritage, technologies to create and deliver in situ, i.e., in museums and cultural sites, and online experiences can use AI to broaden the scope of enjoyment. One of the most exciting perspectives is the idea expressed in [2] of employing eXplainable AI (or XAI) and Human-Computer Interaction (HCI) as enabling technologies with richer interfaces that adapt to the target audience dynamically. Such developments can be made possible by an interdisciplinary approach involving other disciplines, such as interaction design and pedagogical and participatory design, in the creation of a cultural offer suitable for all.

The semantic enrichment of CH images [3], through the concrete and abstract values, often left unexploited that they include in the cultural, social, economic,

and political spheres can profitably make use of AI technologies, such as Computer Vision (CV) and semantic web technologies. With the emergence of new technologies and the availability of cultural heritage images in digital format, methodologies to semantically enrich and utilize these resources provide a new information apparatus, feed knowledge, and generate new connections between artworks and assets that are far apart in space and time.

The use of convolutional neural networks (CNNs) to recognize architectural textures and monuments [4] represents one of the most recent developments in AI that can also be used on mobile devices thanks to the spread of machine learning technologies on them. The use of personal tablets and smartphones for the enjoyment of cultural content, undoubtedly fuelled by the restrictions of the pandemic period, can change the experience of visiting cultural sites by making vast digital collections of text, models, images, and other data accessible in situ.

Similarly, the extended reality (XR) domain—i.e., virtual (VR), augmented (AR), and mixed reality (MR)—in the spatial sciences [7] and, more specifically cultural heritage [8] is rapidly changing the interactions between the real and the virtual, allowing for increasingly articulate and engaging interactions for the public.

As noted, in recent years, the term extended reality (XR) has been used as an umbrella term to encapsulate the entire spectrum of VR, AR, and MR [7], and in some sense, is similar to the well-known reality–virtuality continuum proposed in the seminal work by Milgram e Kishino (1994) [9].

AI and XR are not simply engaged as the last step, that of communication, in the process of analysis, interpretation, modeling, and presentation that constitutes the established workflow of the disciplines of representation with respect to heritage, but shape and transform its methodologies and outcomes at every stage.

Digital Representation, AI, and XR in Shape Analysis and Representation, and Education

AI&XR and Classification/3D Analysis

The subject of AI/XR for data classification and analysis mainly involves digital information obtained from an active or passive 3D survey process. On the acquisition side, research focuses on NeRF-based algorithms that can extract geometric information from images under complex environment conditions and optically uncooperative materials. Besides, applying ML and DL algorithms for semantic classification and segmentation of massive 3D data in terms of logical and hierarchical systematization is aimed at improving data understanding, management, and utilization [10].

Supervised ML machine learning involves increasingly complex datasets, and it will evaluate not only the compositional and textural aspects of the architecture but also the level of uncertainty of the process in both training and results. On the

other hand, image datasets allow experimenting with DL algorithms for semantic segmentation [11], providing increasingly articulated answers that can be organized according to knowledge graphs. A final relevant aspect relates to constructing 3D models and communicating surveyed data, mainly based on XR applications. It is fascinating to highlight how such advanced visualization and communication tools are functional in making 3D content interactive and explorable, starting from point clouds at the spatial scale to textured polygonal models at the architectural scale. These digital twins become not only the result of a critical interpretation process but also ground for simulation through virtual sensors for training and monitoring urban areas, extracting predictive data valuable for their management.

AI&XR and Shape Representation

The use of AI and XR for shape representation is not just a tool but a gateway to innovation. Given the breadth of the topic, it leads to general and specific reflections in different application areas. The aspect that disruptively connotes this area is the construction of new content. At the methodological level, great attention is focused on text-to-image generative processes [14]. The emergence and development of increasingly high-performance programs in creating images from text descriptions makes it cogent to understand generative models in depth in order to critically evaluate their use in the different stages of creating and representing a form. Neural networks show great potential, introducing new paradigms in architecture design. The reversal between description and representation opens up scenarios that affect both creative aspects and interpretation, opening up new connections between the existing and the digital imaginary. The application of predictive algorithms to represent architectural shapes that no longer exist stands as a tool to support the iterative process of understanding and interpreting vanished architecture traces. In addition, the same tools can be applied to generating new 3D spaces, unlocking unpredictable spatial relationships, and stimulating design creativity [15]. The connection between the physical and digital realms is found in AI-generated images, which are a valuable opportunity for constructing exhibitions and evolving spaces, fueling the construction of scenarios to support the performing arts. Alongside AI, applying XR techniques for visualization and interaction remains an established practice that is increasingly leaning toward interaction and immersion. In this sense, VR and AR have become fundamental tools for realistic shape prefiguration, feedback collection, and content fruition at industrial, cultural, and museum scales.

AI&XR and Education

The use of AI and XR for educational purposes is not just a trend, but a transformative force finding more and more space within experiments. It highlights the

marked propensity for both users and content creators to use new technologies but leaves many questions open [12]. The construction of multimedia itineraries based on augmented and interactive content to unveil the complexity of cultural heritage remains entrenched, offering increasingly engaging and adaptable visit routes to an increasingly heterogeneous audience regarding digital skills. The construction of such content requires combining knowledge in terms of optimized content creation and visual and multimedia communication processes. The rapid development of XR tools to support such pathways also critically reflects their role in heritage communication, considering that teaching applied and serious games are increasingly essential for enhancing Cultural Heritage [13]. From the point of view of architect and engineer curriculum training, AI may increasingly enter disruptively within the flow of parametric modeling and representation, imposing some critical reflections on the conscious use of these tools within a rapidly transforming learning process. In its declinations and ramifications versus AI and XR, this process is inescapable to address the new challenges imposed by intelligent architecture that directs us toward sustainable and on-demand production of building systems, using cutting-edge technologies supported by algorithms with energy-efficient criteria.

Digital Representation, AI, and XR in Innovative Design and Monitoring

The core prominence of the contributions of this section intends to testify how AI/XR linked to new interoperable technologies have the capacity to transform research and communication by implementing collaborative theory and practice in the creation of new assets with the production of dynamic Digital Twin for buildings [16], heritage, and infrastructures, also related to urban/landscape contests [17]. The initiative also demonstrates the current need to interpret, represent, and promote the information of assets as dynamic in space and time through digital methods and tools, focusing on the innovative and effective BIM and Scan-to-BIM processes [18]. The notion of the digital and the material is of current relevance in the field, especially as related to 3D models as repositories of data. Consequently—referring to the various examples of contribution—the proposed methodologies have interesting articulations involving four distinct phases for this type of investigation:

- Data acquisition: archival research, laser scans, and photogrammetric surveys processed and organized through 3D modeling implemented between interoperable platforms;
- Data communication: the information collected with the proposed methods conveyed through the design of apps and interactive systems for multimedia devices and web platforms. This process involves the design and testing of Augmented Reality and 3D models for multimedia devices and the implementation of Immersive Reality;

- Integration of AI/XR-based image management systems aimed at versatile simultaneous data acquisition and communication in the same workspace;
- Enabling XR visualizations for task assistance and providing contextual information linked to the inertial sensors;
- Integration of models as means of analysis in multiple processes, such as architectural/engineering design, conservation of architectural heritage with the virtual reconstruction of architectural features, management/communication of buildings and infrastructures, and urban/landscape studies for multiple opportunities.

Then the submissions are in a range of multidisciplinary skills fundamental for this project: History of art, History of architecture and of the city, Representation (in particular architectural survey, Building Information Modeling—BIM, Geographic Information System—GIS, Perspective and Photographic restitutions, Structural Engineering, Design, Conservation and Management of buildings, Information and Communications Technology—ICT to link AR/XR to BIM. Then this section of the book testifies how new technologies have the ability to "revolutionize" research and teaching by implementing collaborative theory and practice in the field of Digital, to interpret, represent, teach, and promote the knowledge, management, design, interpretation of buildings, infrastructures, cities also related to space and time connections. More of these are processed for an appropriate and fluid imagining/visualization on mobile devices and, in parallel, serve as the reference for the creation of the BIM model incorporated with all data acquired during the proposed processes. The implemented AR app, supported by the GIS geo-localization, allows the user to easily reach the hotspot on buildings—if realized—as a reference point and identifies new paths and exploration opportunities within the urban space.

The "fruitage" then is perseverance that ensures flexible workflows, which can be adapted to various case studies. Exploiting the resources developed thanks to these new technologies encourages scientific and cultural dissemination and enables new stimulus and motivations for research, exploration, and assessment for:

- Visual Studies, highlighting the reasons why we turn to the Visual to investigate subjects inherent in new architecture/engineering design, history of constructive transformations, degradation monitoring;
- Digital Visualization, concerning the theoretical/instrumental/digital contribution of Representation/Visualization, specifying the importance of the measure to understand spatial/formal data to generate interoperable 3D models (BIM) that allow experimental interpretations and punctual analysis of architecture/engineering in relation to the urban sites and landscape.

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