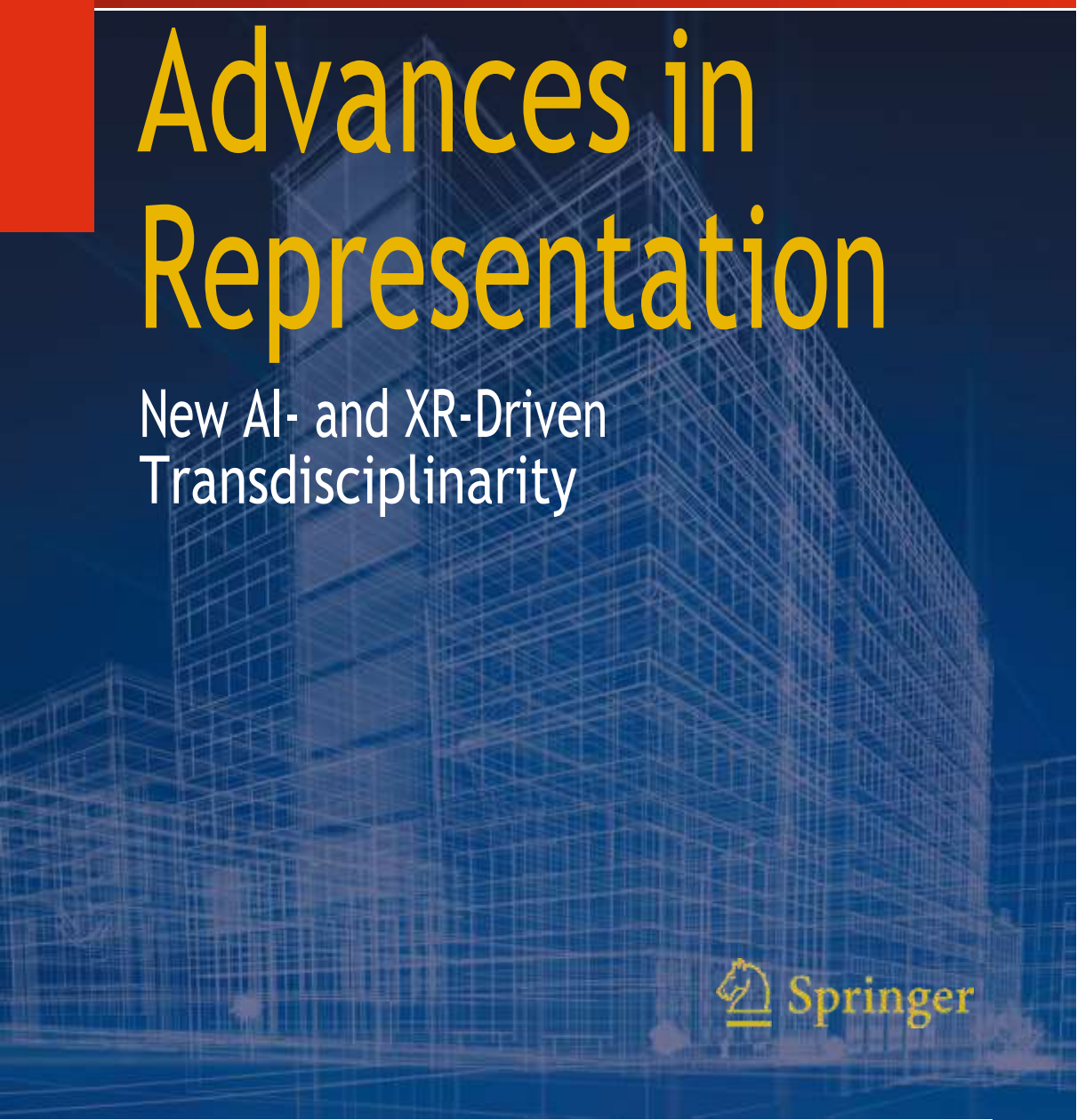
Preface: Introducing the Relationships Between Digital Representation and AR/AI Advanced Experiences

Digital Innovations in Architecture, Engineering and Construction

Andrea Giordano
Michele Russo
Roberta Spallone *Editors*

Advances in Representation

New AI- and XR-Driven Transdisciplinarity



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Digital Innovations in Architecture, Engineering and Construction

The Architecture, Engineering and Construction (AEC) industry is experiencing an unprecedented transformation from conventional labor-intensive activities to automation using innovative digital technologies and processes. This new paradigm also requires systemic changes focused on social, economic and sustainability aspects. Within the scope of Industry 4.0, digital technologies are a key factor in interconnecting information between the physical built environment and the digital virtual ecosystem. The most advanced virtual ecosystems allow to simulate the built to enable a real-time data-driven decision-making. This Book Series promotes and expedites the dissemination of recent research, advances, and applications in the field of digital innovations in the AEC industry. Topics of interest include but are not limited to:

- Industrialization: digital fabrication, modularization, cobotics, lean.
- Material innovations: bio-inspired, nano and recycled materials.
- Reality capture: computer vision, photogrammetry, laser scanning, drones.
- Extended reality: augmented, virtual and mixed reality.
- Sustainability and circular building economy.
- Interoperability: building/city information modeling.
- Interactive and adaptive architecture.
- Computational design: data-driven, generative and performance-based design.
- Simulation and analysis: digital twins, virtual cities.
- Data analytics: artificial intelligence, machine/deep learning.
- Health and safety: mobile and wearable devices, QR codes, RFID.
- Big data: GIS, IoT, sensors, cloud computing.
- Smart transactions, cybersecurity, gamification, blockchain.
- Quality and project management, business models, legal prospective.
- Risk and disaster management.

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Editors
Andrea Giordano
Department of Civil, Environmental and Architectural Engineering
Università di Padova
Padua, Italy

Michele Russo
Department of History, Drawing and Architectural Restoration
Sapienza Università di Roma
Rome, Italy

Roberta Spallone
Department of Architecture and Design
Politecnico di Torino
Turin, Italy

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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.

Padua, Italy
Andrea Giordano
andrea.giordano@unipd.it

Rome, Italy
Michele Russo
m.russo@uniroma1.it

Turin, Italy
Roberta Spallone
roberta.spallone@polito.it

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References

1. Argyrou, A., Agapiou, A.: A review of artificial intelligence and remote sensing for archaeological research. Remote Sens. **14**(23), 6000, 1–23 (2022)
2. Pisoni, G., Díaz-Rodríguez, N., Gijlers, H., Tonolli, L.: Human-centered artificial intelligence for designing accessible cultural heritage. Appl. Sci. **11**(2), 870, 1–30 (2021)
3. Abgaz, Y., Rocha Souza, R., Methuku, J., Koch, G., Dorn, A.: A Methodology for semantic enrichment of cultural heritage images using artificial intelligence technologies. J. Imag. **7**(8), 121, 1–22 (2021)
4. Andrianaivo, L.N., D'Autilia, R., Palma, V.: Architecture recognition by means of convolutional neural networks. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci. **XLII-2/W15**, 77–84 (2019)
5. Ooi, K.B., Tan, G.W.H., Al-Emran, M., Al-Sharafi, M.A., Capatina, A., Chakraborty, A., Wong, L.W.: The potential of generative artificial intelligence across disciplines: perspectives and future directions. J. Comput. Inf. Syst., 1–32 (2023)
6. Spennemann, D.: Generative artificial intelligence. Human Agency Fut. Cult. Herit. **25**, 1–16 (2023)
7. Çöltekin, A., Lochhead, I., Madden, M., Christophe, S., Devaux, A., Pettit, C., Lock, O., Shukla, S., Herman, L., Stacho, Z., Kubí, P., Snopková, D., Bernardes, S., Hedley, N.: Extended reality in spatial sciences: a review of research challenges and future directions. ISPRS Int. J. Geo-Inf. **9**(439), 1–29 (2020)
8. Okanovic, V., Ivkovic-Kihic, I., Boskovic, D., Mijatovic, B., Prazina, I., Skaljo, E., Rizvic, S.: Interaction in eXtended reality applications for cultural heritage. Appl. Sci. **12**, 1241, 1–16 (2022)
9. Milgram, P., Kishino, F. (1994). A taxonomy of mixed reality visual displays. IEICE Trans. Inf. Syst. **E-77-D**, 1321–1329
10. Yang, S., Miaole, H., Songnian, L.: Three-dimensional point cloud semantic segmentation for cultural heritage: a comprehensive review. Remote Sens. **15**(3): 548 (2023)
11. Yu, Y., Chunping, W., Qiang, F., Renke, K., Fuyu, H., Boxiong, Y., Tingting, Y., Mingliang, G.: Techniques and challenges of image segmentation: a review. Electronics **12**(5): 1199 (2023)
12. Holmes, W., Porayska-Pomsta, K.: The Ethics of Artificial Intelligence in Education: Practices, Challenges, and Debates. Taylor & Francis Ltd, Milton Park (2022)
13. Di Paolo, A., Beatini, V., Di Tore, S., Todino, M.: How serious can promote inclusion, history and cultural heritage through the virtual reality. J. Inclusive Methodol. Technol. Learn. Teach. **3**(1) (2023)
14. Albaghajati, Z.M., Bettaieb, D.M., Malek, R.B.: Exploring text-to-image application in architectural design: insights and implications. Archit. Struct. Constr. **3**, 475–497 (2023)

15. Ploennigs, J., Berger, M.: AI art in architecture. AI Civ. Eng. **2**(8) (2023)
16. Kritzinger, W., Karner, M., Traar, G., Henjes, J., Sihn, W.: Digital Twin in manufacturing. A categorical literature review and classification. IFAC PapersOnLine **51–11**, 1016–1022 (2018)
17. Ahmed, S.: A review on using opportunities of augmented reality and virtual reality in construction. Organ. Technol. Manage. Constr. Int. J. **11**(1), 1839–1852 (2019)
18. Sacks, R., Eastman, C., Lee, G., Teicholz, P.: BIM Handbook: A Guide to Building Information Modeling for Owners, Designers, Engineers, Contractors, and Facility Managers. Wiley, Hoboken, New Jersey (2018)

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