

AI+AR: Cultural Heritage, Museum Institutions, Plastic Models and Prototyping. A State of Art

*Original*

AI+AR: Cultural Heritage, Museum Institutions, Plastic Models and Prototyping. A State of Art / Vitali, Marco; Bertola, Giulia; Natta, Fabrizio; Ronco, Francesca - In: Representation Challenges. Augmented Reality and Artificial Intelligence in Cultural Heritage and Innovative Design Domain / Giordano A., Russo M., Spallone R.. - STAMPA. - Milano : FrancoAngeli, 2021. - ISBN 9788835116875. - pp. 59-63 [10.3280/oa-686.9]

*Availability:*

This version is available at: 11583/2926352 since: 2021-09-22T15:44:20Z

*Publisher:*

FrancoAngeli

*Published*

DOI:10.3280/oa-686.9

*Terms of use:*

This article is made available under terms and conditions as specified in the corresponding bibliographic description in the repository

*Publisher copyright*

(Article begins on next page)

# REPRESENTATION CHALLENGES

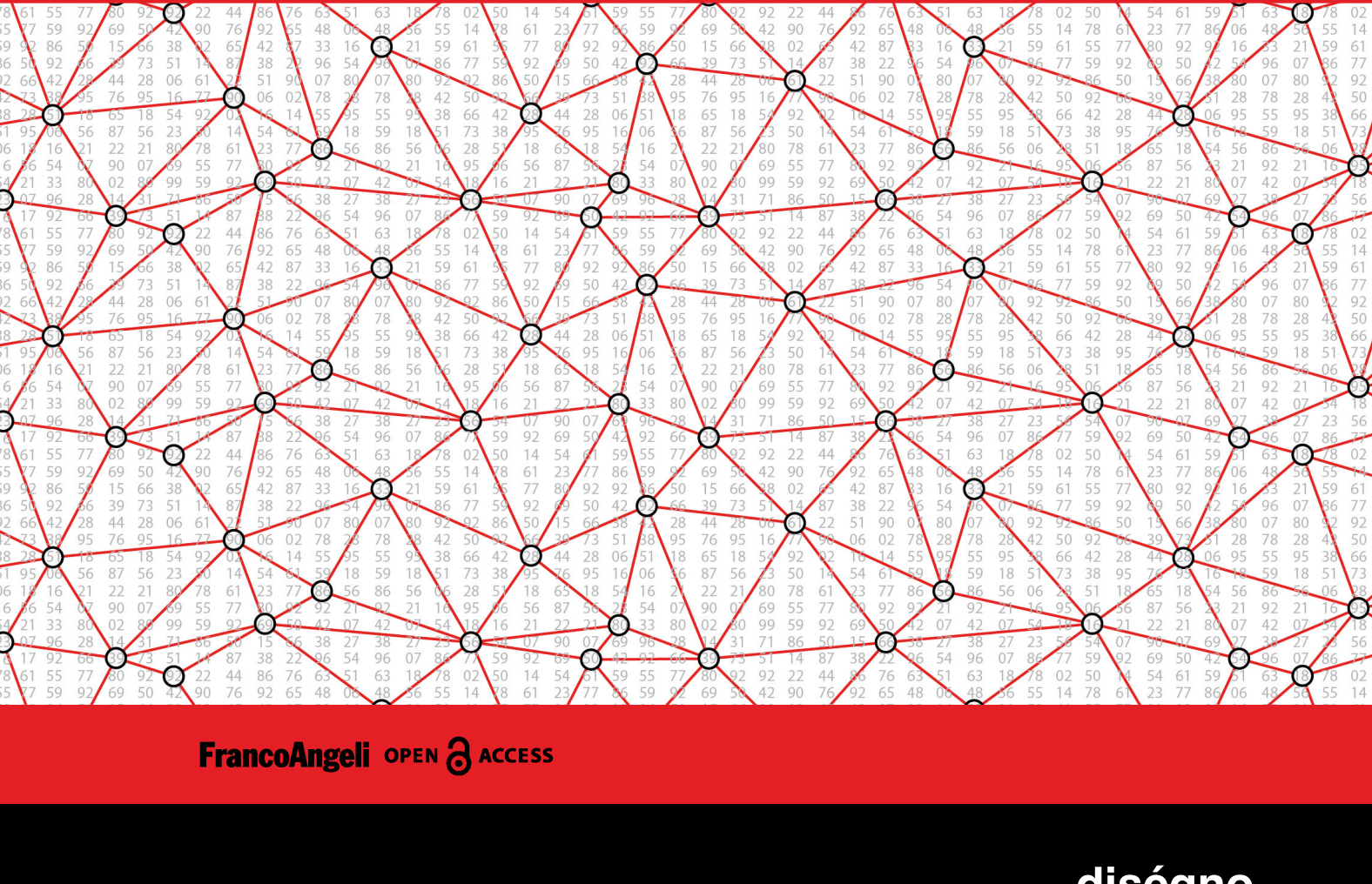
## Augmented Reality and Artificial Intelligence in Cultural Heritage and Innovative Design Domain

edited by

Andrea Giordano

Michele Russo

Roberta Spallone



director Francesca Fatta

The Series contains volumes of the proceedings of the annual conferences of the Scientific Society UID – Unione Italiana per il Disegno and the results of international meetings, research and symposia organised as part of the activities promoted or patronised by UID. The topics concern the Scientific Disciplinary Sector ICAR/17 Drawing with interdisciplinary research areas. The texts are in Italian or in the author's mother tongue (French, English, Portuguese, Spanish, German) and/or in English. The international Scientific Committee includes members of the UID Scientific Technical Committee and numerous other foreign scholars who are experts in the field of Representation.

The volumes of the series can be published either in print or in open access and all the authors' contributions are subject to double blind peer review according to the currently standard scientific evaluation criteria.

## Scientific Committee

Giuseppe Amoruso *Politecnico di Milano*  
Paolo Belardi *Università degli Studi di Perugia*  
Stefano Bertocci *Università degli Studi di Firenze*  
Mario Centofanti *Università degli Studi dell'Aquila*  
Enrico Cicalò *Università degli Studi di Sassari*  
Antonio Conte *Università degli Studi della Basilicata*  
Mario Docci *Sapienza Università di Roma*  
Edoardo Dotto *Università degli Studi di Catania*  
Maria Linda Falcidieno *Università degli Studi di Genova*  
Francesca Fatta *Università degli Studi Mediterranea di Reggio Calabria*  
Fabrizio Gay *Università IUAV di Venezia*  
Andrea Giordano *Università degli Studi di Padova*  
Elena Ippoliti *Sapienza Università di Roma*  
Francesco Maggio *Università degli Studi di Palermo*  
Anna Osello *Politecnico di Torino*  
Caterina Palestini *Università degli Studi "G. d'Annunzio" di Chieti-Pescara*  
Lia Maria Papa *Università degli Studi di Napoli "Federico II"*  
Rossella Salerno *Politecnico di Milano*  
Alberto Sdegno *Università degli Studi di Udine*  
Chiara Vernizzi *Università degli Studi di Parma*  
Ornella Zerlenga *Università degli Studi della Campania "Luigi Vanvitelli"*

## Members of foreign structures

Caroline Astrid Bruzelius *Duke University - USA*  
Pilar Chfás *Universidad de Alcalá - Spagna*  
Frank Ching *University of Washington - USA*  
Livio De Luca *UMR CNRS/MCC MAP Marseille - Francia*  
Roberto Ferraris *Universidad Nacional de Córdoba - Argentina*  
Glauca Augusto Fonseca *Universidade Federal do Rio de Janeiro - Brasile*  
Pedro Antonio Janeiro *Universidade de Lisboa - Portogallo*  
Jacques Laubscher *Tshwane University of Technology - Sudafrica*  
Cornelie Leopold *Technische Universität Kaiserslautern - Germania*  
Juan José Fernández Martín *Universidad de Valladolid - Spagna*  
Carlos Montes Serrano *Universidad de Valladolid - Spagna*  
César Otero *Universidad de Cantabria - Spagna*  
Guillermo Peris Fajarnes *Universitat Politècnica de València - Spagna*  
José Antonio Franco Taboada *Universidade da Coruña - Spagna*  
Michael John Kirk Walsh *Nanyang Technological University - Singapore*



This volume is published in open access format, i.e. the file of the entire work can be freely downloaded from the FrancoAngeli Open Access platform (<http://bit.ly/francoangeli-oa>). On the FrancoAngeli Open Access platform, it is possible to publish articles and monographs, according to ethical and quality standards while ensuring open access to the content itself. It guarantees the preservation in the major international OA archives and repositories. Through the integration with its entire catalog of publications and series, FrancoAngeli also maximizes visibility, user accessibility and impact for the author.

Read more:

[http://www.francoangeli.it/come\\_pubblicare/pubblicare\\_19.asp](http://www.francoangeli.it/come_pubblicare/pubblicare_19.asp)

Readers who wish to find out about the books and periodicals published by us can visit our website [www.francoangeli.it](http://www.francoangeli.it) and subscribe to our "Informatemi" (notify me) service to receive e-mail notifications.

# **REPRESENTATION CHALLENGES**

Augmented Reality and Artificial Intelligence in  
Cultural Heritage and Innovative Design Domain

edited by

Andrea Giordano

Michele Russo

Roberta Spallone



#### Scientific Committee

Salvatore Barba  
*Università di Salerno*

Marco Giorgio Bevilacqua  
*Università di Pisa*

Stefano Brusaporci  
*Università dell'Aquila*

Francesca Fatta  
*Università Mediterranea di Reggio Calabria*

Andrea Giordano  
*Università di Padova*

Alessandro Luigini  
*Libera Università di Bolzano*

Michele Russo  
*Sapienza Università di Roma*

Cettina Santagati  
*Università di Catania*

Alberto Sdegno  
*Università di Udine*

Roberta Spallone  
*Politecnico di Torino*

#### Scientific Coordination

Andrea Giordano  
*Università di Padova*

Michele Russo  
*Sapienza Università di Roma*

Roberta Spallone  
*Politecnico di Torino*

#### Editorial Committee

Isabella Friso  
*Università IUAV di Venezia*

Fabrizio Natta  
*Politecnico di Torino*

Michele Russo  
*Sapienza Università di Roma*

*The texts as well as all published images have been provided by the authors for publication with copyright and scientific responsibility towards third parties. The revision and editing is by the editors of the book.*

ISBN printed edition: 9788835116875  
ISBN digital edition: 9788835125280

#### Peer Reviewers

Marinella Arena  
*Università Mediterranea di Reggio Calabria*

Salvatore Barba  
*Università di Salerno*

Marco Giorgio Bevilacqua  
*Università di Pisa*

Cecilia Bolognesi  
*Politecnico di Milano*

Stefano Brusaporci  
*Università dell'Aquila*

Francesca Fatta  
*Università Mediterranea di Reggio Calabria*

Andrea Giordano  
*Università di Padova*

Massimo Leserri  
*Università di Napoli "Federico II"*

Stefania Landi  
*Università di Pisa*

Massimiliano Lo Turco  
*Politecnico di Torino*

Alessandro Luigini  
*Libera Università di Bolzano*

Pamela Maiezza  
*Università dell'Aquila*

Domenico Mediatì  
*Università Mediterranea di Reggio Calabria*

Cosimo Monteleone  
*Università di Padova*

Michele Russo  
*Sapienza Università di Roma*

Cettina Santagati  
*Università di Catania*

Alberto Sdegno  
*Università di Udine*

Roberta Spallone  
*Politecnico di Torino*

Marco Vitali  
*Politecnico di Torino*

#### Patronage



Cover image: Michele Russo

Copyright © 2021 by FrancoAngeli s.r.l., Milano, Italy.

This work, and each part thereof, is protected by copyright law and is published in this digital version under the license *Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International* (CC BY-NC-ND 4.0)

By downloading this work, the User accepts all the conditions of the license agreement for the work as stated and set out on the website  
<https://creativecommons.org/licenses/by-nc-nd/4.0>

7

*Francesca Fatta*  
**Preface**

9

*Andrea Giordano, Michele Russo, Roberta Spallone*  
**Representation Challenges: The Reasons of the Research**

## AR&AI theoretical concepts

23

*Francesco Bergamo*  
**The Role of Drawing in Data Analysis and Data Representation**

29

*Giorgio Buratti, Sara Conte, Michela Rossi*  
**Artificial Intelligency, Big Data and Cultural Heritage**

35

*Marco Ferrari, Lodovica Valetti*  
**Virtual Tours and Representations of Cultural Heritage: Ethical Issues**

41

*Claudio Marchese, Antonino Nastasi*  
**The Magnificent AI & AR Combinations: Limits? Gorgeous Imperfections!**

47

*Valerio Palma*  
**Data, Models and Computer Vision: Three Hands—on Projects**

53

*Alberto Sdegno*  
**Drawing Automata**

59

*Marco Vitali, Giulia Bertola, Fabrizio Natta, Francesca Ronco*  
**AI+AR: Cultural Heritage, Museum Institutions, Plastic Models and Prototyping. A State of Art**

## AR&AI virtual reconstruction

67

*Alessio Bortot*  
**Physical and Digital Pop-Ups. An AR Application in the Treatises on Stereotomy**

73

*Maurizio Marco Bocconcino, Mariapaola Vozzola*  
**The Value of a Dynamic Memory: from Heritage Conservation in Turin**

79

*Antonio Calandriello*  
**Augmented Reality and the Enhancement of Cultural Heritage: the Case of Palazzo Mocenigo in Padua**

85

*Cristina Cãndita, Andrea Quartara, Alessandro Meloni*  
**The Appearance of Keplerian Polyhedra in an Illusory Architecture**

91

*Maria Grazia Cianci, Daniele Calisi, Sara Colaceci, Francesca Paola Mondelli*  
**Digital Tools at the Service of Public Administrations**

97

*Riccardo Florio, Raffaele Catuogno, Teresa Della Corte, Veronica Marino*  
**Studies for the Virtual Reconstruction of the Terme del Foro of Cumae**

103

*Maurizio Peticarini, Chiara Callegaro*  
**Making the Invisible Visible: Virtual/Interactive Itineraries in Roman Padua**

## AR&AI heritage routes

111

*Marinella Arena, Gianluca Lax*  
**Saint Nicholas of Myra. Cataloguing, Identification, and Recognition Through AI**

117

*Stefano Brusaporci, Pamela Maiezza, Alessandra Tata, Fabio Graziosi, Fabio Franchi*  
**Prosthetic Visualizations for a Smart Heritage**

123

*Gerardo Maria Cennamo*  
**Advanced Practices of Augmented Reality: the Open Air Museum Systems for the Valorisation and Dissemination of Cultural Heritage**

129

*Serena Fumero, Benedetta Frezzotti*  
**The Use of AR Illustration in the Promotion of Heritage Sites**

135

*Alessandro Luigini, Stefano Brusaporci, Alessandro Basso, Pamela Maiezza*  
**The Sanctuary BVMA in Pescara: AR Fruition of the Pre-Conciliar Layout**

141

*Alessandra Pagliano, Greta Attadema, Anna Lisa Pecora*  
**Phyigitalarcheology for the Phlegraean Fields**

147

*Andrea Rolando, Domenico D'Uva, Alessandro Scandiffio*  
**A Technique to Measure the Spatial Quality of Slow Routes in Fragile Territories Using Image Segmentation**

153

*Giorgio Verdiani, Ylenia Ricci, Andrea Pasquali, Stéphane Giraudeau*  
**When the Real Really Means: VR and AR Experiences in Real Environments**

159

*Ornella Zerlenga, Vincenzo Cirillo, Massimiliano Masullo, Aniello Pascale, Luigi Maffei*  
**Drawing, Visualization and Augmented Reality of the 1791 Celebration in Naples**

## AR&AI classification and 3D analysis

167

*Marco Giorgio Bevilacqua, Anthony Fedeli, Federico Caprioli, Antonella Gioli, Cosimo Monteleone, Andrea Piemonte*  
**Immersive Technologies for the Museum of the Charterhouse of Calci**

173

*Massimiliano Campi, Valeria Cera, Francesco Cutugno, Antonella di Luggo, Domenico Iovane, Antonio Origlia*  
**CHROME Project: Representation and Survey for AI Development**

179

*Paolo Cini, Roberto Pierdicca, Ramona Quattrini, Emanuele Frontoni, Romina Nespeca*  
**Deep Learning for Point Clouds Classification in the Ducal Palace at Urbino**

185

*Pierpaolo D'Agostino, Federico Minelli*  
**Automated Modelling of Masonry Walls: a ML and AR Approach**

191

*Elisabetta Caterina Giovannini*  
**Data Modelling in Architecture: Digital Architectural Representations**

197  
Marco Limongiello, Lucas Matias Gujski  
Image-Based Modelling Restitution: Pipeline for Accuracy Optimisation

203  
Federica Maietti, Marco Medici, Ernesto Iadanza  
From AI to H-BIM: New Interpretative Scenarios in Data Processing

209  
Michele Russo, Eleonora Grilli, Fabio Remondino, Simone Teruggi, Francesco Fassi  
Machine Learning for Cultural Heritage Classification

215  
Andrea Tomalini, Edoardo Pristeri, Letizia Bergamasco  
Photogrammetric Survey for a Fast Construction of Synthetic Dataset

## AR&AI urban enhancement

223  
Giuseppe Amoruso, Polina Mironenko, Valentina Demarchi  
Rebuilding Amatrice. Representation, Experience and Digital Artifice

229  
Paolo Belardi, Valeria Menchetelli, Giovanna Ramaccini, Margherita Maria Ristori, Camilla Sorignani  
AR+AI = Augmented (Retail + Identity) for Historical Retail Heritage

235  
Fabio Bianconi, Marco Filippucci, Marco Seccaroni  
New Interpretative Models for the Study of Urban Space

241  
Marco Canciani, Giovanna Spadafora, Mauro Saccone, Antonio Camassa  
Augmented Reality as a Research Tool, for the Knowledge and Enhancement of Cultural Heritage

247  
Alessandra Pagliano  
Augmenting Anghi: Murals in AR for Urban Regeneration and Historical Memory

253  
Caterina Palestini, Alessandra Basso  
Evolutionary Time Lines, Hypothesis of an AI+AR-Based Virtual Museum

259  
Daniele Rossi, Federico O. Oppedisano  
Marche in Tavola. Augmented Board Game for Enogastronomic Promotion

## AR&AI museum heritage

267  
Massimo Barilla, Daniele Colistra  
An Immersive Room Between Scylla and Charybdis

273  
Francesco Borella, Isabella Friso, Ludovica Galeazza, Cosimo Monteleone, Elena Svaldruz  
New Cultural Interfaces on the Gallerie dell'Accademia in Venice

279  
Laura Carlevaris, Marco Fasolo, Flavia Camagni  
Wood Inlays and AR: Considerations Regarding Perspective

285  
Giuseppe D'Acunto  
Augmented Reality and Museum Exhibition. The Case of the Tribuna of Palazzo Grimani in Venice

291  
Giuseppe Di Gregorio  
The Rock Church of San Micidario of the Pantalica Site and 3DLAB VR/AR-Project

297  
Elena Ippoliti  
Understanding to Enhance. Between the Technical and Humanist Approaches

303  
Gabiella Liva, Massimiliano Ciammaichella  
Illusory Scene and Immersive Space in Tintoretto's Theatre

309  
Franco Prampolini, Dina Porpiglia, Antonio Gambino  
Medma Touch, Feel, Think: Survey, Catalog and Sensory Limitations

315  
Paola Puma, Giuseppe Nicastro  
The Emotion Detection Tools in the Museum Education EmoDeM Project

321  
Leopoldo Repola, Nicola Scotta di Carlo, Andrea Maioli, Matteo Martignoni  
MareXperience. AI/AR for the Recognition and Enhancement of Reality

## AR&AI building information modeling and monitoring

329  
Vincenzo Bagnolo, Raffaele Argiolas, Nicola Paba  
Communicating Architecture. An AR Application in Scan-to-BIM Processes

335  
Marcello Balzani, Fabiana Raco, Manlio Montuori  
Integrated Technologies for Smart Buildings and PREdictive Maintenance

341  
Fabrizio Banfi  
Extended Reality (XR) and Cloud-Based BIM Platform Development

347  
Carlo Biagini, Ylenia Ricci, Irene Villoresi  
H-Bim to Virtual Reality: a New Tool for Historical Heritage

353  
Fabio Bianconi, Marco Filippucci, Giulia Pelliccia  
Experimental Value of Representative Models in Wooden Constructions

359  
David Campagnolo, Paolo Borin  
Automatic Recognition Through Deep Learning of Standard Forms in Executive Projects

365  
Matteo Del Giudice, Daniela De Luca, Anna Osello  
Interactive Information Models and Augmented Reality in the Digital Age

371  
Marco Filippucci, Fabio Bianconi, Michela Meschini  
Survey and BIM for Energy Upgrading. Two Case Study

377  
Raissa Garozzo  
A Proposal for Masonry Bridge Health Assessment Using AI and Semantics

383  
Federico Mario La Russa  
AI for AEC: Open Data and VPL Approach for Urban Seismic Vulnerability

389  
Assunta Pelliccio, Marco Saccucci  
V.A.I. Reality. A Holistic Approach for Industrial Heritage Enhancement

## AR&AI education and shape representation

397  
Maria Linda Falcidieno, Maria Elisabetta Ruggiero, Ruggero Torti  
Visual Languages: On-Board Communication as a Perception of Customer-caring

403  
Emanuela Lanzara, Mara Capone  
Genetic Algorithms for Polycentric Curves Interpretation

409  
Anna Lisa Pecora  
The Drawn Space for Inclusion and Communicating Space

415  
Marta Salvatore, Leonardo Baglioni, Graziano Mario Valenti, Alessandro Martinelli  
Forms in Space. AR Experiences for Geometries of Architectural Form

421  
Roberta Spallone, Valerio Palma  
AR&AI in the Didactics of the Representation Disciplines

427  
Alberto Tono, Meher Shashwat Nigam, Stasya Fedorova, Amirhossein Ahmadian, Cecilia Bolognesi  
Limitations and Review of Geometric Deep Learning Algorithms for Monocular 3D Reconstruction in Architecture

# AI+AR: Cultural Heritage, Museum Institutions, Plastic Models and Prototyping. A State of Art

Marco Vitali  
Giulia Bertola  
Fabrizio Natta  
Francesca Ronco

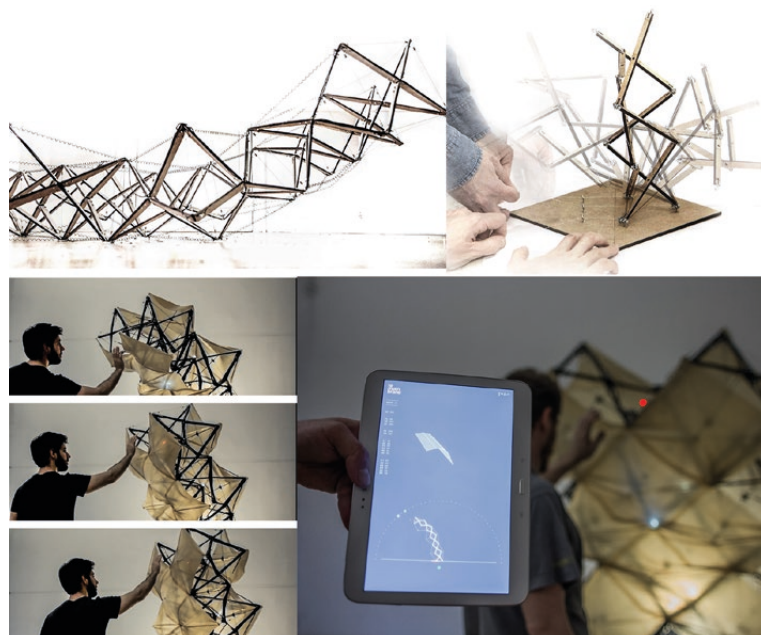
## *Abstract*

The links between representation and artificial intelligence (AI) invade many fields of architectural research, recording continuous and significant advances: they require, on the one hand, a constant update of the state of the art and, on the other hand, careful consideration of the role of Representation in interdisciplinary research in this field.

The present contribution intends to investigate these intertwining in some of the most frequented research fields in recent years: the valorization and communication of Cultural Heritage and cultural tourism, the experiences in the museum field, the research on the role of the prototype within the processes of artificial intelligence applied to architecture.

## *Keywords*

cultural heritage, museum, digital fabrication, artificial intelligence, augmented reality.



## Introduction (MV)

The intertwining of representation – in particular in its manifestations in the field of augmented reality (AR) – with artificial intelligence (AI) spans many fields of architectural research and registers in the contemporary world continuous and significant advances that require, on the one hand, a constant updating of the state of the art and, on the other hand, careful considerations on the role of Representation in interdisciplinary research in this field. The present contribution intends to investigate these connections in some of the most frequented fields in architectural research in recent years: research on the enhancement and communication of Cultural Heritage and cultural tourism, research on the most recent and innovative experiences in the museum field, research on the role of the prototype within the processes of artificial intelligence applied to architecture.

According to the most recent experiences conducted on the valorization and communication of Cultural Heritage, the most used tools to ensure its success range from the creation of cognitive maps to the development of AI technologies for the automatic digitization of cultural heritage, or the use of Deep Learning for the recognition of monuments and the construction of mobile apps.

In the museum field, artificial intelligence is increasingly used to develop different tools such as robots, chatbots, and websites, which allow analyzing data related to visitors and collections, where the contribution of representation disciplines is nowadays mainly connected to the possible outputs of Object recognition operations and the applications of this technology. The link between plastic model, AI, and AR is articulated in several aspects based on the 'human-model' interaction and is articulated in some prevalent research strands, such as studies on computational design methods developed for 3D printing and component evaluation, or the work on Responsive Architecture, in which the physical model is the medium through which to experiment and communicate the design of dynamic and adaptive buildings.

## AI (and AR) in Cultural Heritage (FN)

According to the most recent experiences with the valorization and communication of Cultural Heritage (CH), they should be the result of a balanced synergy between interaction, experience, and representation.

The current scenario offers research methodologies investigating Cultural Heritage through Artificial Intelligence (AI) tools to increasingly democratize the access of CH, the development of AI technologies for automatic digitization, or the use of Deep Learning (DL) for monument recognition and the development of mobile apps. As an example, the study by Pisoni et al. (2021) proposes the use of AI to support the accessible design of CH. One of the points of greatest research interest is now on eXplainable AI (XAI) techniques, "a suite of machine learning techniques that produces more explainable models while maintaining a high level of learning performance (e.g., prediction accuracy), and enable humans to understand" [Barredo et al. 2020, p. 2]. The tools offered by these developments in technology can enable museums and CH sites to modify their knowledge transmission. By opening up informal learning opportunities to the general public, based on experience and personal interaction with CH, gaps in Natural Language Processing (NLP) and Computer Vision (CV) can be assessed.

Another research approach is that by Traviglia and Del Bue (whose study focuses on the development of AI technologies for the automatic digitization of CH: the different nature of the CH assets does not facilitate the creation of common standards and protocols going in this direction. The main idea of the approach is to incrementally build a 3D reconstruction that is not metric (i.e. where positions are measurable with a metric reference) but rather in the space of projective geometry. In this way, the digitization is made user-independent making total automation of the scanning process possible [Traviglia, Del Bue 2019].

A line of research to be highlighted is that developed by Valerio Palma. He introduces a project aimed at studying the techniques of convolutional neural networks (CNN) in the field of architectural heritage, which workflow has still to be developed. The first steps and results in the development of mobile applications for monument recognition are discussed:

while AI is just beginning to interact with the built environment through mobile devices, heritage technologies have long produced and explored digital models and spatial archives. The interaction between DL algorithms and state-of-art information modeling is addressed as an opportunity both to exploit heritage collections and to optimize new object recognition techniques [Palma 2019, pp. 551-556].

The developments that these research can bring are almost all aimed at enriching the databases, which are still quantitatively limited and refer much towards two-dimensional objects that are “easier” to read in ML algorithms. Another challenge related to AI relates to the use of personal data. The implementations that augmented CH experiences can provide necessarily involve reading and constantly updating regulations and ethical guides for the responsible use of this powerful tool.

### The Digital Transformation in Museums: AI and AR as Tools to Engage Visitors (FR)

Within museum institutions, artificial intelligence is increasingly used to develop different tools such as robots, chatbots, and websites, which allow analyzing data related to visitors and collections [Styx, 2020]. The network “Museums + Artificial Intelligence” (n.d), founded in 2019 by Oonagh Murphy and Elena Villaespesa is proof of this growing interest in AI tools applied in this field.

At the same time, VR and AR have become a popular trend worldwide for the dissemination, communication, and enhancement of cultural heritage [Bekele et al. 2018].

The contribution of representation disciplines in the AR field is quite evident: just think of the use of 3D virtual models, holograms, graphics for specific apps, and gaming, up to True AR technology [Sandor 2015]. The group coordinated by Geronikolakis (2020) proposes an interesting application in the field of cultural heritage conservation to improve the experience of visitors, involved in the construction and restoration of archaeological sites.

In the field of AI, the representation disciplines could mainly be involved in the outputs of Object Recognition operations. The applications of this technology involve the user also outside the museum, as in the project ‘Recognition’, winner in 2016 of the IK award [Styx, 2020] or the application ‘Art Selfie’. Several museums base the exploration of their collections on Object Recognition: on color similarities, [Cooper Hewitt Smithsonian Design Museum, n.d; Dallas Art Museum, n.d.], formal, line direction, or space and light [Barnes Foundation, n.d].

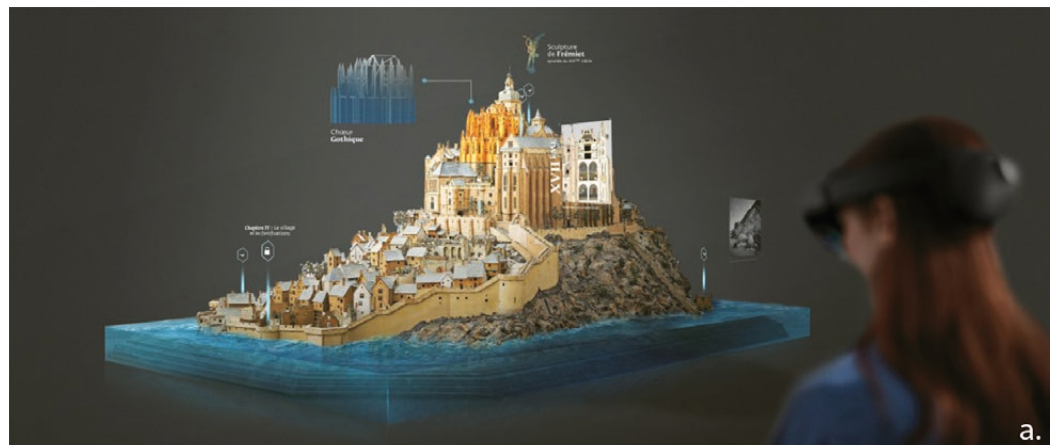


Fig. 1a. Exhibition Mont Saint-Michel. Digital Perspectives on the Model (photo by Microsoft, source: <https://iciseattle.com/en/mont-saint-michel-in-mohai/>); Fig. 1b. The system of ICAR-CNR group experienced in art and tech exhibitions [Caggianese et al., 2020].

In recent years, technologies have made considerable progress in the creation of content tailored to the needs and interests of different types of users, with a democratic and human-centered approach. However, there are still few examples where AI has been used to foster accessibility and inclusion in the field of museums and cultural heritage [Pisoni et al., 2021]. The AI context is certainly characterized by a high level of multidisciplinaryity. The mixed-use of AI/AR/VR technologies represents an important field of investigation to meet the needs of an increasingly wide audience, from an inclusive perspective.

The exhibition "Mont Saint-Michel – Digital Perspectives on the Model" (fig. 1a), held in late 2019 at MOHAI (Museum of History and Industry) in Seattle, represents an example of the application of mixed techniques [Ici Seattle, 2019]. Visitors were immersed in the history of Mont-Saint-Michel by framing a real scale historical model of the site with a mixed reality device (Microsoft HoloLens 2).

Another example in this frame is the work conducted by ICAR-CNR [Caggianese et al., 2020] related to the display of Leonardo da Vinci's machines (fig. 1b). This presents the combined use of cutting-edge technologies, such as holograms, with artificial intelligence (AI) to offer the visitor an augmented space involving new forms of interaction (visualization, manipulation, and conversation).

### AI in Digital Fabrication Experiences on Architecture (GB)

The link between real model, virtual reality and augmented reality is articulated on two main lines of research. The first one is based on the construction of informative real models, the second one on the interaction 'human-material' through the practices of 'augmented craftsmanship' and 'design by making'. Regarding the first, many studies are now focused on the creation of prototypes aimed at the transmission of knowledge and information of architectural heritage. In the last years, this has happened both through the realization of static models on which to apply immersive technologies, and with more complex dynamic systems in which physical and digital models have come to overlap to the point of almost confusing.

With regard to the application of immersive technologies, reference can be made to the experience carried out for the Basilica of Loreto [Rossi et al. 2017, pp. 239-255]. A project that involved the setting up of a space consisting of a multimedia table with a 3D printed physical model, conceived as a 'wunderkammer' equipped with a series of technological devices referable to different applications characterized by different levels of interactivity and immersiveness. In recent years, however, rapid advances in technology have begun to challenge even those aspects that go beyond the mere static and physical representation of architecture. An example is the interactive model of InFORM [Follmer et al. 2013, pp. 417-426] a dynamic shape display proposed by the Massachusetts Institute of Technology (MIT), that suggests different ways of physical interaction in real time between users, physical model and digital data. Regarding the 'human-material' interaction, the main fields of investigation concern the application of biological principles on architectural construction and the study of innovative structural morphologies through digital fabrication methods. In particular, the ICD/ITKE Research Pavilions are a series of full-scale prototypes realized through the integration of computational engineering, advanced analytical techniques and digital fabrication aimed at investigating the architectural potential of fiber composites [Doerstelmann et al. 2015]. Regarding the same themes, in London there are also the Protohouse project and the Flow-

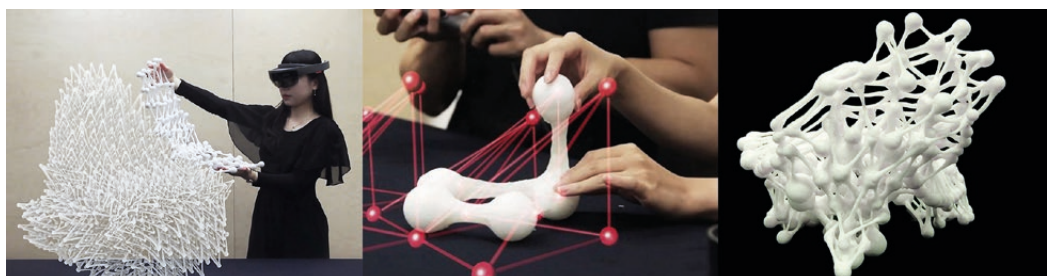


Fig. 2. Project FLOWMORPH [Hahm et al. 2019].

Morph project [Hahm et al. 2019, pp. 553-562] (fig. 2), that proposes an unconventional method of fabrication using *Mixed Reality* to materialize highly complex geometries that could not be realized manually or by robotic fabrication alone.

The practices of *digitally augmented craftsmanship* open to a series of reflections on the theme of interactive digital simulations and their link with traditional craft practices. Mario Carpo, within his book *The Second Digital Turn* [Carpo, 2017], emphasizes the value of such simulations as they allow today's artisans to learn intuitively, through mistakes, trial and attempts, by making and unmaking as many test samples as possible.

## References

- Barnes Foundation. Barnes Collection Online. <https://collection.barnesfoundation.org/> (1 March 2021).
- Barredo Arrieta Alejandro et al. (2020). Explainable Artificial Intelligence (XAI): Concepts, Taxonomies, Opportunities and Challenges toward Responsible AI. In *Information Fusion*, 58, pp. 82-115.
- Bekele Mafereseb Kassahun, Pierdicca Roberto, Frontoni Emanuele, Malinverni Eva, Gain James (2018). A Survey of Augmented, Virtual, and Mixed Reality for Cultural Heritage. In *Journal on Computing and Cultural Heritage*, 11 (2), art. 7.
- Caggianese Giuseppe, De Pietro Giuseppe, Esposito Massimo, Gallo Luigi, Minutolo Aniello, Neroni Pietro (2020). Discovering Leonardo with artificial intelligence and holograms: A user study. In *Pattern Recognition Letters*, 131, pp. 361-367.
- Carpo Mario (2017). *The Second Digital Turn. Design Beyond Intelligence*. Cambridge (MA): MIT Press.
- Cooper-Hewitt Smithsonian Design Museum. The Collection. <https://collection.cooperhewitt.org/> (1 March 2021).
- Doerstelmann Moritz, Knippers Jan, Koslowski Valentin, Menges Achim, Prado Marshall, Schieber Gundula, Vasey Lauren (2015). ICD/ITKE Research Pavilion 2014-15: Fibre Placement on a Pneumatic Body Based on a Water Spider Web. In *Architectural Design*, 85, pp. 60-65.
- Follmer Sean Weston, Leithinger Daniel, Olwal Alex, Hogge Akimitsu, Ishii Hiroshi (2013). inFORM: Dynamic Physical Affordances and Constraints through Shape and Object Actuation. In *Proceedings of the 26th annual ACM symposium on User interface software and technology (UIST '13)*. New York: ACM Digital Library, pp. 417-426.
- Geronikolakis Efstratios, Zikas Paul, Kateros Steve, Lydatakis Nick, Georgiou Stelios, Kentros Mike, Papagiannakis George. (2020). A True AR Authoring Tool for Interactive Virtual Museums. In Liarokapis Fotis, Voulodimos Athanasios, Doulamis Nikolaos, Doulamis Anastasios (eds.). *Visual Computing for Cultural Heritage*. Cham: Springer, pp. 225-242.
- Hahm Soomeen, Maciel Abel, Sumitomo Eri, Rodriguez Alvaro Lopez (2019). FLOWMORPH. Exploring the human-material interaction in digitally augmented craftsmanship. In *Proceedings of the 24th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA)*, Vol. 1, Hong Kong, CAADRIA, pp. 553-562.
- High Level Expert Group on Artificial Intelligence (2019). *Ethics Guidelines for Trustworthy AI: Technical Report*. European Commission.
- Ici Seattle (2019). The Mont-Saint-Michel in the MOHAI. <https://iciseattle.com/en/mont-saint-michel-in-mohai/> (1 March 2021).
- Jun Ji Won, Ilubia Josep Alcover, Silverio Matteo (2015). Remembrance. Responsive Kinetic Structure. <http://www.iaacblog.com/programs/remembrance/> (15 March 2021).
- Palma Valerio (2019). Towards Deep Learning for Architecture: A Monument Recognition Mobile App. In *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Volume XLII-2/WV9, pp. 551-556.
- Pisoni Galena, Diaz-Rodríguez Natalia, Gijlers Hannie, Tonolli Linda (2021). Human-Centred Artificial Intelligence for Designing Accessible Cultural Heritage. In *Applied Sciences*, 11 (2), p. 870.
- Rossi Daniele, Meschini Alessandra, Feriozzi Ramona, Olivieri Alessandro (2017). Cose dell'altro mondo. La realtà virtuale immersiva per il patrimonio culturale. In Luigini Alessandro, Pancioli Chiara (eds.), *Ambienti digitali per l'educazione all'arte e al patrimonio*. Milano, FrancoAngeli Open Access, pp. 239-255.
- Sandor Christian, Fuchs Martin, Cassinelli Alvaro, Li Hao, Newcombe Richard, Yamamoto Goshiro, Feiner Steven (2015). In *Breaking the barriers to true augmented reality*. arXiv preprint arXiv:1512.05471 (1 march 2021).
- Styx Lauren (2020). How are museums using artificial intelligence, and is AI the future of museums? Museum Next. <https://www.museumnext.com/article/artificial-intelligence-and-the-future-of-museums/> (1 march 2021).
- Traviglia Arianna, Del Bue Alessio (2019). Intelligenza Artificiale per la Digitalizzazione 3D del Patrimonio Culturale. In *Italia-IA Italia Intelligenza Artificiale*. <https://www.google.com/search?client=firefox-b-d&q=Traviglia+Arianna%2C+Del+Bue+Alessio+%282019%29.+Intelligenza+Artificiale+per+la+Digitalizzazione+3D+del+Patrimonio+Culturale%2C+In+Italia+Intelligenza+Artificiale> (1 march 2021).

## Authors

Marco Vitali, Dept. of Architecture and Design, Politecnico di Torino, marco.vitali@polito.it  
Giulia Bertola, Dept. of Architecture and Design, Politecnico di Torino, giulia.bertola@polito.it  
Fabrizio Natta, Dept. of Architecture and Design, Politecnico di Torino, fabrizio.natta@polito.it  
Francesca Ronco, Dept. of Architecture and Design, Politecnico di Torino, francesca.ronco@polito.it