

Data Modelling in Architecture: Digital Architectural Representations

*Original*

Data Modelling in Architecture: Digital Architectural Representations / Giovannini, Elisabetta Caterina - In: REPRESENTATION CHALLENGES - Augmented Reality and Artificial Intelligence in Cultural Heritage and Innovative Design Domain / Giordano A., Russo M., Spallone R.. - ELETTRONICO. - Milano : FrancoAngeli, 2021. - ISBN 9788835116875. - pp. 191-195

*Availability:*

This version is available at: 11583/2922212 since: 2021-09-08T17:44:54Z

*Publisher:*

FrancoAngeli

*Published*

DOI:

*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

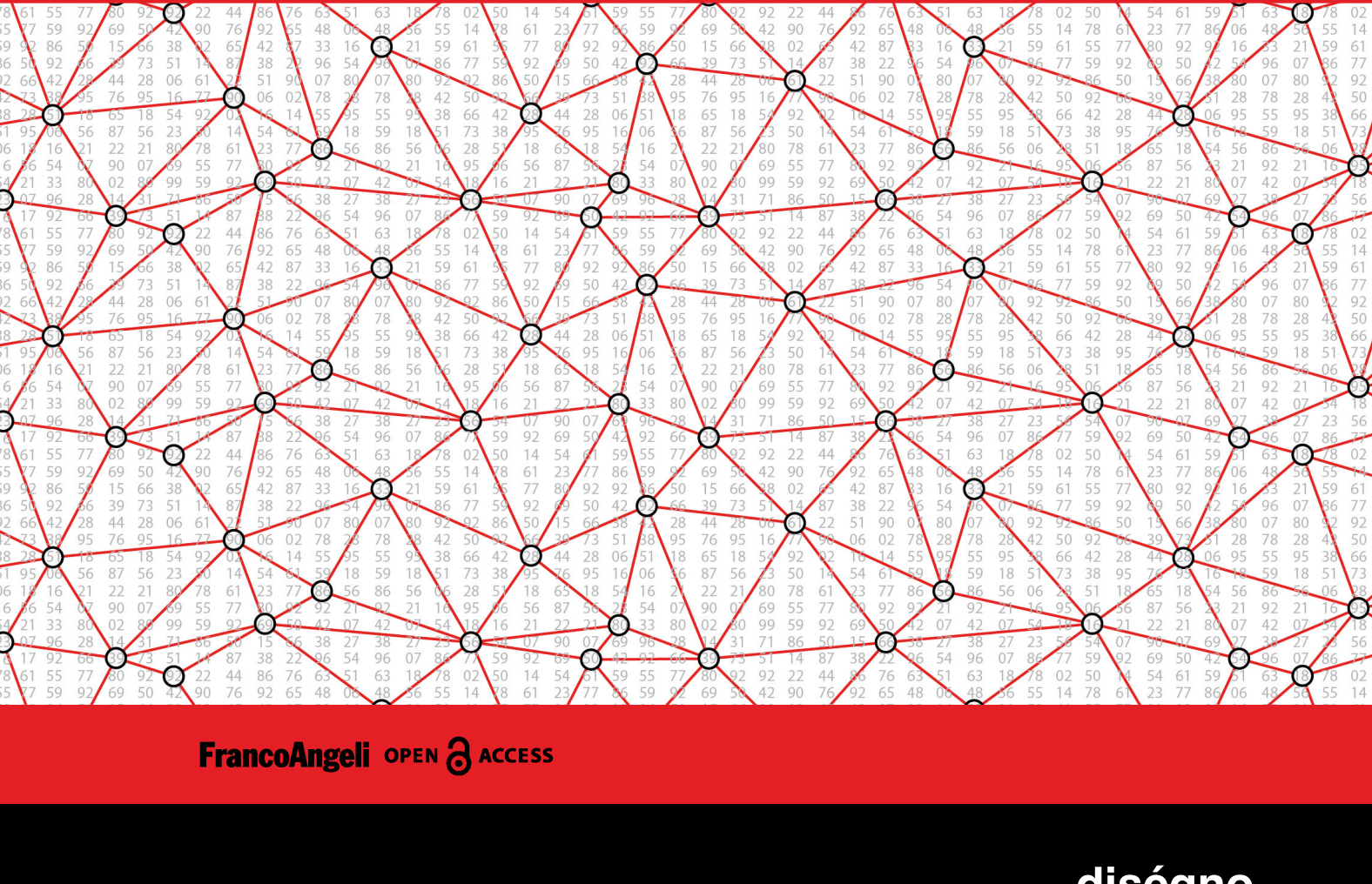
## Augmented Reality and Artificial Intelligence in Cultural Heritage and Innovative Design Domain

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*  
Glaucia 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 Villaresi  
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

# Data Modelling in Architecture: Digital Architectural Representations

Elisabetta Caterina Giovannini

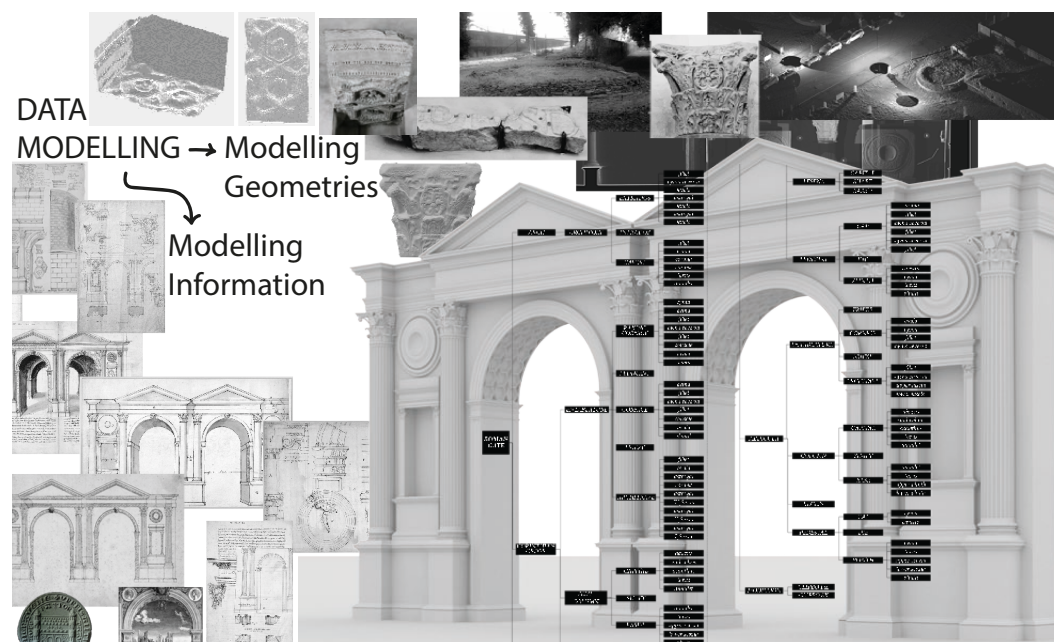
## Abstract

Digital Architectural Representations represent the most fruitful field of research of the last decade. Digital technologies and the use of internet in architectural representation shows how 3D visualization combined with storytelling can help to spread scientific knowledge over the web. These new technologies also affect the way of thinking 3D models, how to design them and how to build their related knowledge with the purpose of future reuse of information and data.

The paper is focused on the analysis of current methodologies and workflows for data modelling in Architecture to better understand the potential of using standards in the 3D modelling sector with a focus on cultural and architectural heritage.

## Keywords

3D models, semantics, data models, standards, ontologies.



## The Complexity of Digital Architectural Representations

Since the '90s of the last century, with the advent of computers, information technologies and computer-aided design (CAD) systems have seen the beginning of the use of digital models in archaeology and architecture [Boccon-Gibod, Golvin 1990; Frischer 2006; Reilly 1991]. The use of these three-dimensional models, which I like to define as digital representations of architecture, poses nowadays, unlike in the past, some questions about the meaning and the scientific value [Borra 2004; Borghini, Cariani 2011; Dell'Unto et al. 2013] that they assume for diverse target audiences.

In the field of architectural heritage and more specifically in the field of virtual reconstructions, starting from historical documentation, it seems evident that alongside geometric modelling, the presence of diverse data and documents prefigure the need for the definition of an informative model that should assist the geometric modelling and that should make explicit the series of processes related to the critical interpretation of data and information available [McCurdy 2010; Apollonio, Giovannini 2015; Brunke 2017]. Different interpretative and cognitive processes can be considered similar to algorithms "a procedure used to return a solution to a question through a set of well-defined instructions" [Tedeschi, Andreani 2014]. The difference from the mathematical algorithm definition is that, in this case, the set of instructions are generally not stated and that the interpretative algorithm can generate several outputs (diverse hypothetical reconstructions) starting from the same series of input (knowledge available).

A Three-dimensional model became then, a digital architectural representation of the  $n$  digital representations that can be generated by human processes of interpretation. Analyzing the type of input of the three-dimensional reconstruction process, we can see how these interpretative processes are linked to the qualitative and quantitative values of the available documentation. This type of data and information support both geometric and informative modelling, considered as two indivisible and inter-related components of the same process. An example of that is the common practice of using the semantic architectural structure to digitally create the parts of a 3D model according to logics proper of the architectural field and to use digital architectural elements as reference objects to connect additional information [De Luca 2013; Giovannini 2017; Quattrini, Battini, Mammoli 2018]. A digital architectural representation can be, then, considered as a visual and graphical expression of an interpretative activity and a constitutive element of knowledge production. This assumption is valid not only for 3D models but also for all human objects of production that can be manuscripts, sketches, drawings, maquettes, etc. These pre-existing data can then be used for information modelling and three-dimensional modelling enriching diverse Levels of Knowledge (LoK).

## Knowledge Representation in Architecture

Applications of Artificial Intelligence (AI) to Cultural Heritage (CH) have been developed with a varying fortune to produce innovative tools for documenting, managing, and visiting cultural heritage. From the representation of cultural history, digital semantic archives, tools to support visitor's interpretation, augmented reality and robotics, the application of AI has been applied to the whole humanistic area. In the Architectural Heritage field, AI is commonly used for storytelling, restoration analysis and 3D model classification. AI is also used to develop ontologies [1] to allow computers to perform automated reasoning about data and information all over the world. Software Engineering, on the other hand, started to use conceptual modelling as a representation of a system to describe concepts. Tools for designing and creation of online visualization of data, according to the rules that govern the web in the past, and more recently the semantic-web cannot avoid the use of Information modelling to manage and structure data and information. In the case of digital architectural representations, the text analysis and the source where architecture is represented in a bi-dimensional way are enriched by three-dimensional information derived from the digital acquisition or three-dimensional modelling. The recent need

for interoperable processes that characterize most of the research on documentation and representation of architectural heritage has emphasized the occurrence of various approaches. Some studies analyze conceptual modelling to define and reorganize the information and material available for the comprehensive use of a digital asset. The theme of processes in digital modelling is useful to trace choices, decisions on three-dimensional models using visualization codes [De Kramer 2020; Giovannini 2020; Apollonio, Gaiani, Sun 2013]. Declaring the accuracy or reliability of 3D models [Apollonio et al. 2017; Bianchini, Nicastro 2018] including those obtained using tools and algorithms (for example in the case of digital survey or photogrammetric acquisition) is a practice mostly used in approaches for geomatics and Building Information Modelling applied to Heritage (H-BIM) [Maiezza 2019; Garagnani 2013; Quattrini, Pierdicca, Morbidoni 2017]. Resource-based 3D modelling considered as interpretative process, differs from digital acquisition where reality-based data can be considered as formal derivation of the original object. Both modelling processes are in relation since the 3D reality-based data, if present, affects the modelling and validation process of the derived resource-based model. Standards and models for information modelling including conceptual ones have long been in use in the cultural heritage sector: the CIDOC Conceptual Reference Model (CRM) standard [2], the ISO 21127:2014 also known as CIDOC-CRM, often associated with the controlled vocabulary of the Getty Institute (AAT) [3], is the most used ones. Recent trends demonstrate that ontologies and conceptual models are not that different,

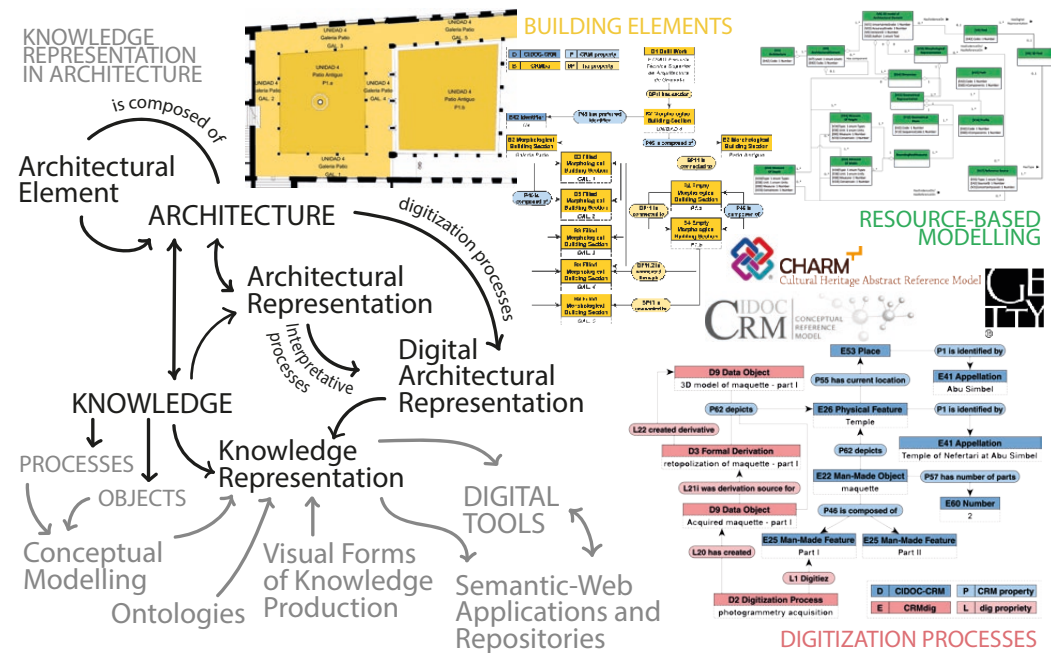


Fig. 1. Conceptual data modelling overview. On the top, conceptual modelling of H-BIM object classes using CRMba extension. On the top-right, resource-based modelling processes using CHARM model. On the bottom-right a conceptual model for the reality-based 3D modelling process using CRMdig extension. On the left, conceptual representation of knowledge in the Architectural field.

and that combined can allow standardising the documentation of cultural heritage. In the archaeological field the Cultural Heritage Abstract Reference Model (CHARM) [4] is an ontology for cultural heritage expressed in Conceptual Modelling Language (ConML) [Gonzalez-Perez et al. 2012]. The Extended Matrix (EM) [5] is a visual language of knowledge representation in the field of virtual reconstructions with a stratigraphic approach [Demetrescu 2015]. In the architecture, engineering and construction (AEC) industry, the reference standard is the Industry Foundation Classes (IFC) data model [6], a metadata schema capable of describing architectural semantics and making Building Information Modelling (BIM) models interoperable between different software solutions. The IFC guarantees the management of geometry but it does not allow the addition of customized information outside the context of the construction industry. Nevertheless, some emerging research proposes an IFC classification for architectural heritage asset

[Diara, Rinaudo 2020] or an architectural heritage semantic 3D documentation for the reusability of 3D city models [Noardo 2018]. To establish a dialogue between the architectural field and the cultural heritage assets a recent study proposes a conceptual model based on the CIDOC–CRM standard to describe a building in its parts, as encoded by a BIM software using the CIDOC–CRMba extension [7], developed to describe built archaeology [Parisi, Lo Turco, Giovannini 2019]. With that model, it was possible to describe the morphological elements that characterize a building but it fails in describing the link between the geometric parts and their spatial coordinates. The conclusion was partially acceptable if we think that the CIDOC–CRM was born to describe assets about museum collections and not about architecture.

## Conclusions

Considering the diverse research conducted, the possibility of creating conceptual models capable of managing three–dimensional data and descriptive metadata on the documentation of architectural heritage is still missing. The CRM–dig [8], a CIDOC–CRM extension, is a model capable to manage the complexity of the reality–based data acquisition, but it does not clarify and explain the relationships between the source used, the data extracted from it and its use for geometrical modelling. The IFC, on the other hand, can be used to describe geometric information of BIM or H–BIM models. The challenge is to create an efficient data model that allows semantic traceability of data. A novel semantic organization of data is necessary for the development, of platforms, analysis tools and algorithms able to manage structured data, make queries for different purposes in complementary disciplinary domains emphasising their combined potential. There is a need for a common conceptual model that reflects the complexity of the three–dimensional modelling process. Conceptual modelling should focus on the representation of architecture in all its forms (drawings, surveys, digital models) and should represent both digital and physical properties. A conceptual reference model for the digital representation of architecture (fig. 1) should first identify the architectural evidence, built, or only represented ones, the parts of which it can be composed and how these can be digitally represented. The knowledge about an architectural asset is also composed of a set of resources that also need to be digitized and that contribute to the creation of the “architectural” digital asset. Then the relationship between digitized resources and three–dimensional modelling can take place by mapping diverse interpretative and modelling processes creating different levels of knowledge. The knowledge produced, can then be used by digital tools able to read the conceptual grammar of the asset: an information system in which three–dimensional models and historical documentation is collected and organized. To reuse data, data models are necessary and even if they do not follow standards, they must at least be stated because this is how computational technologies and machine can see the human world.

## Notes

[1] Ontology is the theory and the Information Model is the application. Information modelling is here intended as “a representation of concepts, relationships, constraints, rules, and operations to specify data semantics for a chosen domain of discourse. The advantage of using an information model is that it can provide sharable, stable, and organized structure of information requirements for the domain context.” [Lee 1999]

[2] The CIDOC Conceptual Reference Model (CRM). <http://www.cidoc-crm.org/> (March 2021)

[3] Art & Architecture Thesaurus (AAT) – Getty Research Institute. <https://www.getty.edu/research/tools/vocabularies/aat/> (March 2021)

[4] Cultural Heritage Abstract Reference Model (CHARM) – INCIPIT, CSIC. [www.charminfo.org](http://www.charminfo.org) (March 2021)

[5] The Extended Matrix formal language for virtual reconstruction processes. <http://osiris.itabc.cnrit/extendedmatrix/> (March 2021)

[6] Industry Foundation Classes. <https://www.buildingsmart.org/standards/bsi-standards/industry-foundation-classes/> (March 2021)

[7] An extension of CIDOC CRM to support buildings archaeology documentation. <http://www.cidoc-crm.org/crmba/> (March 2021)

[8] An extension of CIDOC CRM to encode “provenance” of digitization products. <http://www.cidoc-crm.org/crmdig/> (March 2021)

## References

- Apollonio Fabrizio I., Fallavollita Federico, Giovannini Elisabetta C., Foschi Riccardo, Corso Salvatore (2017). The Reconstruction of Drawn Architecture. In *Studies in Digital Heritage*, 1, 2017, pp. 380-395.
- Apollonio Fabrizio I., Gaiani Marco, Sun Zheng (2013). Characterization of Uncertainty and Approximation in Digital Reconstruction of Ch Artifacts. In *Proceeding of Le Vie dei Mercanti XI Forum Internazionale di Studi*, pp. 860-869.
- Apollonio Fabrizio I., Giovannini Elisabetta C. (2015). A Paradata Documentation Methodology for the Uncertainty Visualization in Digital Reconstruction of Ch Artifacts. In *SCIRES-IT-SCientific REsearch and Information Technology*, 5 (1), pp. 1-24.
- Bianchini Carlo, Nicastro Saverio (2018). The definition of the Level of Reliability: a contribution to the transparency of Heritage-BIM processes. In *Dn-Building Information Modeling, Data & Semantics*, 2, pp. 45-49.
- Boccon-Gibod Par H., Golvin Jean-Claude (1990). Le Grand Temple d'Amon Rê a Karnak Reconstitue Par l'ordinateur. In *Les Dossiers d'Archeologie*, 153, pp. 8-19.
- Borghini Stefano, Cariani Raffaele (2011). Virtual rebuilding of ancient architecture as a researching and communication tool for Cultural Heritage: aesthetic research and source management. In *DISEGNARECON*, 4 (8), pp. 71-79.
- Borra Davide (2004). Sulla Verità Del Modello 3D. Un Metodo per Comunicare La Validità Dell'anastilosi Virtuale." In *EARcom04 Tecnologie per Comunicare l'architettura. Proceeding of the eArcom 4*, pp. 132-137.
- Brunke Luca (2017). *Uncertainty in Archaeological 3D Reconstructions*. Master Thesis, University of Leiden.
- Dell'Unto Nicolò, Leander Anne-Marie, Dellepiane Matteo, Callieri Marco, Ferdani Daniele, Lindgren Stefan (2013). Digital reconstruction and visualization in Archaeology: case-study drawn from the work of the Swedish Pompeii Project. In *Proceedings of the Digital Heritage*, 1, pp. 621-628.
- Demetrescu Emanuel (2015). Archaeological Stratigraphy as a Formal Language for Virtual Reconstruction. Theory and Practice. In *Journal of Archaeological Science*, 57, pp. 42-55.
- Diara Filippo, Fulvio Rinaudo (2020). IFC classification for FOSS HBIM: Open Issues and a schema proposal for Cultural Heritage assets. In *Applied Sciences*, 10 (23), pp. 1-23.
- Frischer Bernard (2006). New directions for cultural Virtual Reality: a global strategy for archiving, serving and exhibiting 3D computers models of Cultural Heritage sites. In *Proceedings of the Virtual Retrospect 2005*, pp. 168-175.
- Garagnani Simone (2013). Building Information Modeling and real world knowledge: a methodological approach to accurate semantic documentation for the Built Environment. In *Proceedings of the Digital Heritage*, 1, pp. 489-496.
- Giovannini Elisabetta C. (2020). Workflow for an evidence-based Virtual Reconstruction: the marbles of the Ciborium of the Early Medieval Monte Sorbo Church. In *ISPRS Archives*, 43, pp. 1395-1402.
- Giovannini Elisabetta C. (2017). VRIM Workflow: semantic H-BIM objects using parametric geometries. In Emler Tommaso (ed.). *3D MODELING & BIM. Progettazione, Design, Proposte per La Ricostruzione*. Roma: DEI Tipografia del Genio Civile, pp. 212-229.
- Gonzalez-Perez Cesar, Martín-Rodilla Patricia, Parcero-Oubiña Cesar, Fábrega-Álvarez Pastor, Güimil-Fariña Alejandro (2012). Extending an abstract reference model for transdisciplinary work in Cultural Heritage. In Doder Juan Manuel, Palomo-Duarte Manuel, Karampiperis Pythagoras (eds.). *Metadata and Semantics Research*. Berlin, Heidelberg: Springer, pp. 190-201.
- De Luca Livio (2013). 3D Modeling and Semantic Enrichment in Cultural Heritage. In Dieter Fritsch (ed.). *Photogrammetric Week*. Berlin: Wichmann Verlag, pp. 323-333.
- De Kramer Marleen (2020). Relict-Interpolated-Extrapolated-Speculative: an approach to degrees of Accuracy in Virtual Heritage Reconstruction. In Fotis Liarokapis, Athanasios Voulodimos, Nikolaos Doulami, Anastasios Doulami (eds.). *Visual Computing for Cultural Heritage*. Cham: Springer International Publishing, pp. 409-422.
- Lee Y. Tina (1999). Information Modeling: from design to implementation. In *Proceedings of the Second World Manufacturing Congress*, pp. 315-321.
- Maiezza Pamela (2019). As-built reliability in architectural HBIM modeling. In *ISPRS Archives*, 42, pp. 461-466.
- McCurdy Leah (2010). *Visualising Architecture: The Experience of Creating Virtual Reconstructions*. Master Thesis, University of York.
- Noardo Francesca (2018). Architectural Heritage Semantic 3D Documentation in Multi-Scale Standard Maps. In *Journal of Cultural Heritage*, 32, pp. 156-165.
- Parisi Piergiorgio, Lo Turco Massimiliano, Giovannini Elisabetta C. (2019). The value of knowledge through H-BIM models: historic documentation with a semantic approach. In *ISPRS Archives*, 42, pp. 581-588.
- Quattrini Ramona, Battini Carlo, Mammoli Raissa (2018). HBIM to VR. Semantic Awareness and Data Enrichment Interoperability for Parametric Libraries of Historical Architecture. In *ISPRS Archives*, 42 (2), pp. 937-943.
- Quattrini, Ramona, Roberto Pierdicca, and Christian Morbidoni (2017). Knowledge-Based data enrichment for HBIM: exploring high-quality Models Using the Semantic-Web. In *Journal of Cultural Heritage*, 28, pp. 129-139.
- Reilly Paul (1991). Towards a Virtual Archaeology. In *Proceeding of the CAA90. Computer Applications and Quantitative Methods in Archaeology 1990*, pp. 132-139.
- Tedeschi Arturo (2014). *AA, Algorithms-Aided Design: Parametric Strategies Using Grasshopper*. Brienza: Le Penseur Publisher.

## Author

Elisabetta Caterina Giovannini, Dept. of Architecture and Design, Politecnico di Torino, elisabetta.caterina.giovannini@polito.it