Digital & Documentation

V5

From virtual space to information database

edited by
Francesca Picchio

PROSPETTIVE MULTIPLE

STUDI DI INGEGNERIA
ARCHITETTURA E ARTE

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Francesca Picchio

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Digital & Documentation

Vol. 5

From Virtual space to Information database

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The volume consists of a collection of contributions from the seminar "Digital & Documentation: From Virtual space to Information database", realized at the University of Pavia on the day of September 19th, 2022. The event, organized by the experimental laboratory of research and didactics DAda Lab. of DICAr - Department of Civil Engineering and Architecture of University of Pavia, promotes the themes of digital modeling and virtual environments applied to the documentation of architectural scenarios and the implementation of museum complexes through communication programs of immersive fruition. The fifth Digital and documentation conference was also the inaugural event of the first Pavia DigiWeek, held from 19 to 23 September 2022 in Pavia.
The event has provide the contribution of external experts and lecturers in the field of digital documentation for Cultural Heritage. The scientific responsible for the organization of the event is Prof. Francesca Picchio, University of Pavia.

This publication is made with the contribution of DICAr, Department of Civil Engineering and Architecture of University of Pavia, through the joint research of the experimental laboratories DAda Lab - Drawing Architecture Document Action and PLAY - Photography and 3D Laser for virtual Architecture LaboratorY.

UNIVERSITÀ DI PAVIA

DICAr DIPARTIMENTO INGEGNERIA CIVILE ARCHITETTURA

DAda LAB DRAWING ARCHITECTURE DOCUMENTACTION

DAda Lab - Drawing and Architecture DocumentAction

PLAY Photography and 3D Laser for virtual Architecture LaboratorY

PLAY - Photography and 3D Laser for virtual Architecture laboratorY

The event "Digital & Documentation, V.5" has seen the participation of professors, researchers and scholars from University of Pavia, Politecnico di Torino, University of Rome "La Sapienza", University of Palermo, University of Catania, Politecnico di Milano, University of Ferrara, University of Florence, University of Basilicata, University of L'Aquila, University of Salerno, Gdańsk University of Technology (Poland), Nanyang Technological University (Singapore), Universitat Politècnica de València (Spain), University of Salerno, University of L'Aquila, Lublin University of Technology (Poland), Cracow University of technology (Poland), University of Cordoba (Argentina).

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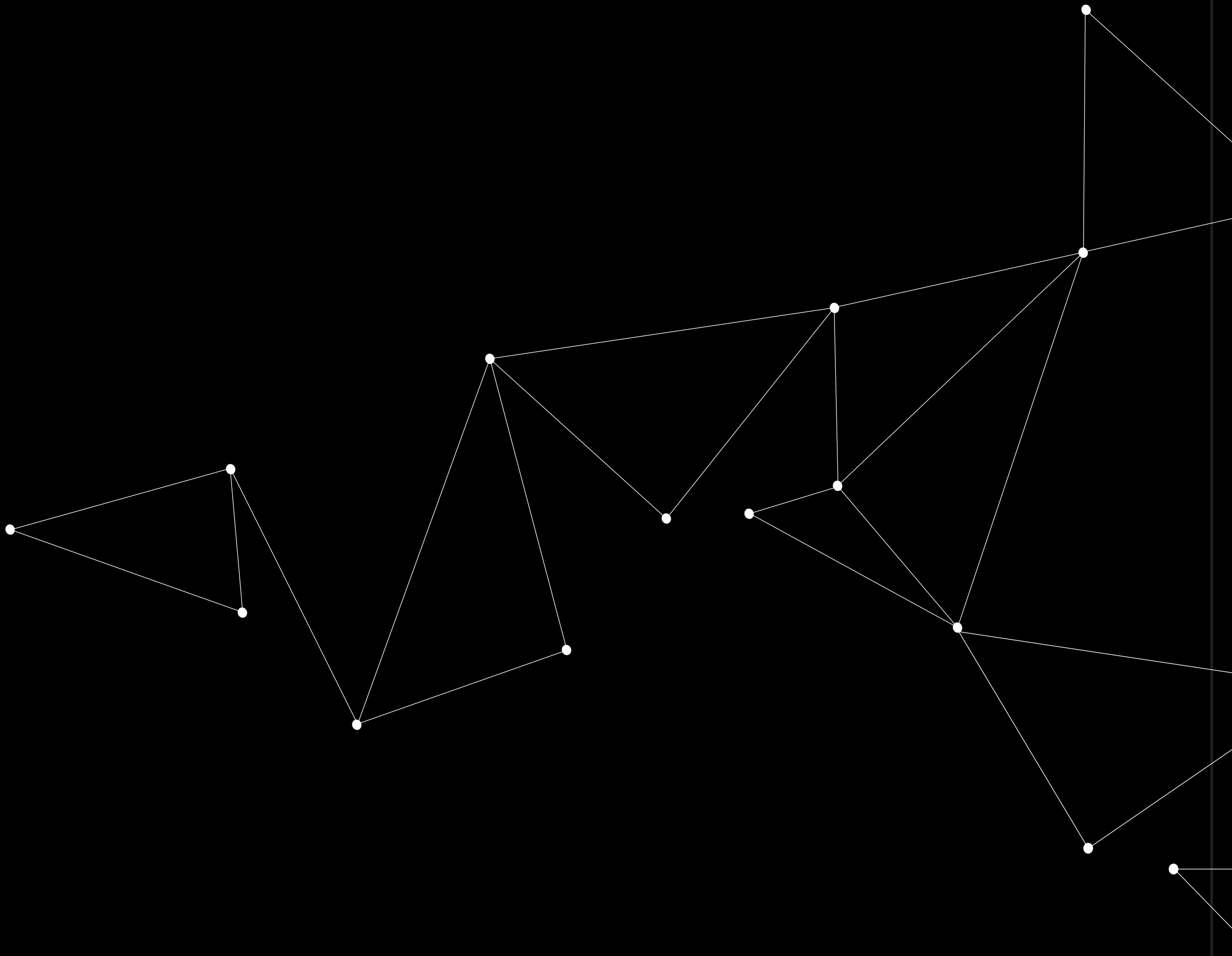


Presentations

FOREWORD

Francesca Fatta
President of UID - Unione Italiana Disegno

The digitization of Cultural Heritage involves not only engaging in critical and interpretive processes of analysis but also utilizing tools and technologies, thereby requiring specific technical skills. The science of representation, therefore, finds itself more than ever in a position to merge humanistic and technological disciplines in a holistic vision, in a continuous renewal and updating of communicative methods and tools.
Drawing represents the world by re-presenting it as a duplicate on the plane of the image. Whether for an existing reality or a design intention, there is always the need to understand the complexity of space and architecture, which over time has manifested in ever-evolving languages and techniques, from painting to photography, from cartography to satellite maps, to the most current interactive information systems.
Today, virtual reconstructions allow for the remote analysis of distant landscapes, knowledge of endangered heritage, and the revelation of archaeological sites no longer visible by reconstructing their original form. At the same time, expectations for the quality of digital products describing built heritage and enabling analysis and investigation at different scales are growing.
Models and information systems, constituting repositories of knowledge, simulation scenarios, and spaces of interconnection and interaction, have assumed an importance that is now an essential goal for all projects aimed at describing cultural assets. However, the volume of information constantly generating new products and the updating of tools and technologies capable of generating them prompt reflection on the "future" of these digital information products. How many of these digital outputs truly represent advancements for research in the field? In which direction is the virtual world moving? What are the most effective procedures for controlling and verifying digital duplicates? And how do different variations of virtual three-dimensional representation support the management of the built environment at various scales?
Researchers working in the field of architectural representation must consider and discuss the implications of the term "digital." In this regard, focus is required on the enormous amount of data we can produce, their actual quality, and the use of this information to structure new and increasingly in-depth knowledge that should be not only an endpoint but also the beginning of deeper consideration.

There is primarily an ethical factor that concerns the role of digitization in the sustainable development of cultural heritage, making it available to visitors from anywhere and at any time effectively and efficiently. Digitization can be seen not only as an action but also as a process. This means not limiting oneself to simple preservation, cataloging, and dissemination of heritage, but also considering aspects that arise from the enjoyment and engagement of an increasingly diverse and extensive audience.
I thank the researchers involved in the context of the Digital & Documentation Conference, now in its fifth edition, which provides further scientific space for these considerations. Each contribution presented here is an additional opportunity to reflect on the many aspects that contribute to defining the field of architectural representation, on digitization for the purpose of preservation, knowledge, and dissemination, as well as for the correct use of digital content, for accessibility and enjoyment that will generate positive social impacts.
I hope that the results of this research can further stimulate a critical sense of the evolution of the academic discipline of Representation to look towards the future in a proactive and confident direction.

Sandro Parrinello
Scientific Responsible for Pavia DigiWeek 2022 and for D&D Conferences

The Digital and Documentation conference has aimed to foster a debate on the adaptation of digital duplicates through several transformation processes to establish flexible readings for heritage analysis. The fifth edition of D&D, an event held in Pavia in September 2022, once again saw the participation of professors and researchers in the field of drawing and representation, hailing from prestigious national and international universities. This interdisciplinary audience, from different experiences, allowed for a comprehensive exploration of practices concerning the production of methodologies linked to the documentation, enhancement, and management of existing heritage.

This year, it seemed appropriate for this event to serve as the opening of Pavia DigiWeek, a week entirely dedicated to the multidimensional aspects of the "Digital," spanning from Architecture to Engineering, and from territory to building. The Pavia DigiWeek event aims to provide an advanced educational experience on the opportunities, arising from the application of digital skills in the field of Architecture and Engineering, stimulating interdisciplinary experiences in the implementation of Digital Content and Virtual Reality for Cultural Heritage management.

Within this week, organized from September 19th to 23rd, 2022 by the Department of Civil Engineering and Architecture at the University of Pavia, a huge program of conferences, events, exhibitions, and social gatherings was curated to bring the public closer to the reality of Digital Practices and their advanced potential. This initiative aimed to foster the open sharing of cultural and creative content linked to Digital Twins and Digital Humanities for Cultural Heritage.

The European digital transformation approach, recommended for the sustainability of Cultural Heritage, inevitably reflects the scientific contribution that universities can provide in the field of digital strategies for Heritage knowledge, design, and communication. Today's challenge revolves around hardening a foundation of knowledge and research for young students, citizens, and professionals to interact and collaborate with the fields of creative industries and virtual products while applying the languages and practices of digitization and content enhancement.

The field of Architecture and Engineering has long pursued the convergence of several disciplines, acknowledging the joint contribution of knowledge in surveying, restoration, architectural history, building technologies, Cultural

Heritage policies, and territorial planning. This integration is considered essential education for informed users to learn how to interact and contribute to the sustainability of global Heritage.
Digital environments and virtual spaces continue to be developed and enriched to meet the needs of society, providing an increasingly realistic and multidimensional reproduction of contents ranging from architectural artifacts to urban and territorial scales. In the last years, the pandemic crisis has accelerated the utilization and sharing of cultural and creative content, spanning from Digital Twins to Digital Humanities, museums, architecture, and the construction industry. The potential linked to the advancement of digital technologies and content in professional and social sectors can be expanded and enriched, creating an educational ecosystem that bolsters international excellence in Digital Cultural Heritage technologies.
The digital models and products presented on this occasion, both for the D&D conference and as outcomes of the training workshops organized within the PaviaDigiWeek, have enlightened some proposals to establish systems of interaction between users and heritage, across different forms of the architectural-engineering paradigm. Configured as extensions of human intelligence, even if with some communicative limitations that seem increasingly exceeded, these models try to explore the characteristics and values of architectural heritage. They outline reading systems for existing objects and implementation systems for information, capable of showcasing activities directly correlated to heritage, thereby adopting a dual identity of the “real” and the “digital”.
Moreover, these three-dimensional models and databases, flexible in their configurations and research objectives, underscore an additional aspect. Within the multitude of data generated, the technologies used to produce them and the practices to manage them, arises a pressing need to structure a knowledge process. This will have to be such that the available technologies can selectively capture only the essential data, building a cognitive framework of information relevant to the description of that specific context. In this sense, digital images and 3D models are evolving into increasingly augmented and practical tools, generating essential direct and synthetic data for knowledge generation. Consequently, a harmonious integration of models and metadata could constitute an informative and interactive database, serving as an assumption for preserving the historical memory of Cultural Heritage.

FOREWORD
DIGITAL TOOLS BETWEEN VIRTUAL AND INFORMATION REALITY

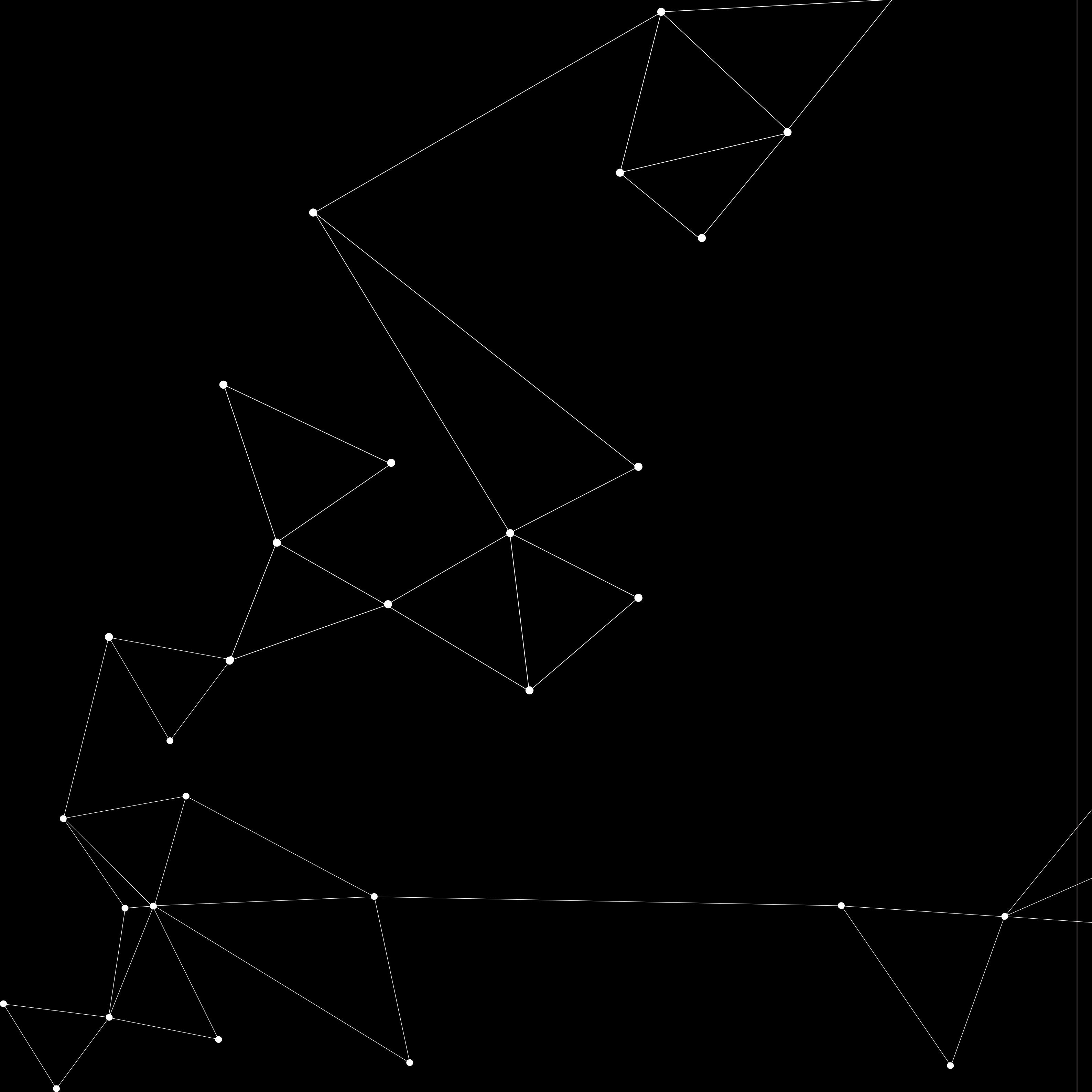
In the Digital Era, the image has emerged as the primary tool of communication. From the early days of analog representation to sophisticated interactive 3D models and printed prototypes, narrative processes have evolved through the logical and procedural approach of design.
In this context, the importance of selecting an effective and specific graphic language becomes increasingly evident in the realm of knowledge, management, and dissemination of cultural heritage. This language must be capable of translating the complexity of a physical space, capturing not only visible but also intangible information, and preserving its memory over time. This evolution is driven by an exponential progress in digital documentation techniques and technologies, becoming more advanced and capable of intricately replicating investigated objects. The transformation of architectural elements into a virtual form detached from their context facilitates control and unrestricted accessibility. Consequently, once rendered virtual, cultural heritage can experience a new existence where its integrity endures the passage of time, and its potential remains largely unexplored.
The current demand for immersive or interactive 3D digital products, serving diverse purposes such as education, museums, and design, reflects the increasing value of digital design in these sectors. Current modes of representation, shaped by ongoing cultural transformation, enable exploration of the past and projection into future scenarios and simulations. These expressive forms not only enrich spaces with invisible information but also engage the observer, making them an active participant in understanding and disseminating collected information.
The evolution of theories and methods for creating informative or educational digital images of cultural heritage is an ongoing process, one that both anticipates and follows technological and instrumental advancements. In this context, the fifth edition of the “Digital and Documentation” conference represents an opportunity for comparison and exchange, particularly advantageous for young researchers. The event, returning to Pavia after four years and held as part of PaviaDigiweek2022, the University of Pavia’s first digital week, offers a chance to host distinguished speakers from both Europe and beyond Europe. The participation of these speakers has provided a broad and multidisciplinary perspective on digital tools for enhancing cultural heritage. The audience, comprised of representatives from various universities with diverse specialized competencies, contributed to making the discussions stimulating, especially with the presence of over 60 students from different degree programs and doctoral studies.

This volume gathers the outcomes of a day of discussion and training on the utilization of digital tools to comprehend and preserve cultural heritage. Young researchers present case studies that focus on two current themes: the perception of heritage through virtual design and its renewed management through three-dimensional information systems.

The paper presented, stemming from research conducted with scientific and methodological rigor, are organized into two distinct sections that constitute the core of this fifth volume: “PART 1 - Perception: Virtual Spaces, Simulations, and Interactions” and “PART 2 - Information Databases and Information Systems for Architecture.” In the first part, authors explore the evolution of design over time, from analog past to digital present, from static to dynamic. They address issues related to the representation and understanding of illusory and vanished spaces, as well as the new opportunities offered by virtual and augmented reality platforms. Techniques for digitally reconstructing past environments that are no longer visible are examined, and the importance of architectural surveys for acoustic simulation and utilization of UNESCO heritage elements and sites at different scales is discussed. In all these cases, one finds themselves immersed in a process that, through the virtual, allows for rediscovery or initial exploration of the surrounding reality.

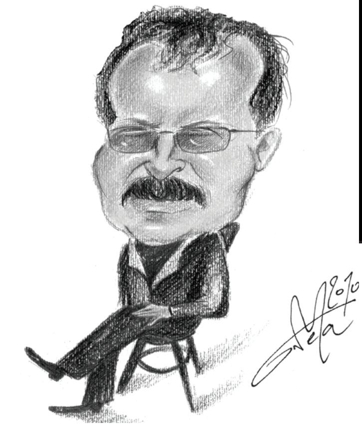
The second part of the volume delves into the advantages derived from the increasingly widespread use of databases and information systems in the field of architecture. It explores the communicative and collaborative potential of digital repositories and web platforms. Furthermore, it examines the construction, potential, and future prospects of three-dimensional BIM and GIS models, tools that enable sustainable and more precise management of buildings and territories. Throughout, the guiding thread of design remains constant, taking on various forms and modalities, guiding the activities of documentation, modeling, and digital reproduction of heritage. Despite their separation, the two parts of the volume intersect through the interaction between virtual and informational systems, prompting new reflections on potential evolutions of representation and opening new avenues for simplified and efficient management of cultural heritage through untapped digital strategies.

Francesca Picchio
Organizer of the D&D 2022



Part 1

PERCEPTION: VIRTUAL SPACE, SIMULATION AND INTERACTION



keynote speaker

Jacek Lebiedź

Gdańsk University of Technology - Poland

M.Sc. Eng. in Computer Science from the Faculty of Electronics at the Gdańsk University of Technology, M.Sc. in Mathematics from the Faculty of Mathematics, Physics and Chemistry at the University of Gdańsk, and Ph.D. in Computer Science from the Faculty of Electronics, Telecommunications and Informatics at the Gdańsk University of Technology, where he is now a deputy head of the Department of Intelligent Interactive Systems.

He was a co-initiator and co-designer of the Immersive 3D Visualization Lab, which he is currently a head of. His current research focus has been computer graphics and virtual reality.

01 VIRTUAL REALITY AS A TOOL FOR DEVELOPMENT AND SIMULATION.

Research projects and experience of the Gdańsk University of Technology

Abstract

By supporting the human imagination, virtual reality technology can be applied in almost every human activity. This is evidenced by the cooperation of the Immersive 3D Visualization Lab with specialists representing such different professions from architects and artists, astronomers and chemists, through historians and museologists, criminologists and military educators, mechanical and ship engineers, up to physicians and psychologists. The results of this cooperation are presented with an emphasis on architectural applications including not only building prototyping. New applications are welcome.

Introduction

Virtual reality (VR) is a technology that allows the user to “soak” (immerse himself) into the digital world [1]. From more technical point of view, virtual reality can be defined as high-end user-computer interface that involves realtime simulation and interactions through multiple sensorial channels: visual, auditory, tactile, smell, taste [2]. Therefore such a technology can be adapted to many different applications concerning various professions. Sometimes the term “virtual reality” is abused for applications using smartphones or typical personal computers equipped with monitors, keyboards, mice and perhaps joysticks. In this case, user is aware of and keeps control of the physical environment. Sometimes such solutions are called non-immersive virtual reality. In contrast with it, immersive virtual reality uses more sophisticated devices (VR devices) and in consequence it isolates (cuts off) a user from the physical environment. In the rest of the paper we will use the term “virtual reality” in the sense “immersive virtual reality”.

Nowadays, immersive virtual reality is very often identified with VR headsets worn by users on their heads. In spite of VR headsets’ weight (a user wears on their head about half a kilogram of optoelectronic device), VR headsets become more and more popular. No wonder at it – they have a lot of advantages. They are relatively cheap (their prices are similar to the prices of personal computers) , have a small size (they can be kept in a drawers) and consume short of energy (so much like smartphones). Unfortunately a VR headset is an appliance exactly for one person, because other people cannot be visible. Moreover a user cannot see their own body and handheld controllers. He or she is extracted from their physicality. VR headsets can provide users only with virtual substitute (avatars) of their own body, controllers and other people looking and moving artificial. If we want to place a few users in one virtual environment, we must apply a few VR headsets connected by distributed interactive simulation putting avatars under cooperating or competing users.

VR headsets are optoelectronic devices where screens and speakers are fastened to the user’s head. For that reason such devices are also called head-mounted displays (HMD). Their functioning can be described as attaching the signal (image and sound) generators to the sensory organs (eyes and ears). When the user is turning or sloping their head, the processor controlling the headset must recognize this movement and generate new image and sound fit for the timely position of the head. This process lasts only fractions of second, but human organism can feel delay even unconsciously. Probably, this is a reason of very frequent cybersickness appearing at VR headsets’ users – fundamental disadvantage of VR headsets.

Cybersickness is much rare when using CAVE-type systems (CAVE Automatic Virtual Environments) – another VR technology. CAVE-type system can be defined as a room were its walls are screens showing images usually supplied by projectors. More formal definition says that CAVE-type system is a multi-person, multi-sided, high-resolution 3D environment that is used for viewing virtual content in an immersive interactive setting. Users inside the CAVE are surrounded by 3D images of virtual scene. In other words, the sensory organs (eyes and ears) are surrounded by the signal (image and sound) generators from all sides. A user should wear on their head only light 3D glasses (known from 3D cinemas) for separating stereoscopic images and directing proper image to each user’s eye. When the user is changing position of their head, the image is waiting on each wall-screen for their glance. Although a CAVE’s computer is tracking the position of the user’s head in similar way like a headset’s processor, but changes of an image generated from the user’s perspective are on every part of each screen much subtler, because they concern only progressive user’s head motion, without consideration of rotation.

CAVE-type systems are very expensive (a few screens combined by a frame, a few 3D projectors controlled by some computer cluster, additional subsystems like speakers and tracking), need a large space (room-size CAVE and projectors outside on each side) and consume a lot of energy (kilowatts). They still have advantages comparing with VR headsets. Several people can be present at the same time in a CAVE and can participate together in a single virtual reality session. Each user can see other participants and can communicate with them in natural way (voice, gesture, touch). Moreover, he or she is in virtual world with their own body and physical controller held in their hand. CAVE-type virtual reality can be treated as augmented by users' body with physical clothes, shoes, and hand-held objects.

Comparing CAVE-type systems to VR headsets we can say that their relation is analogical to the relation between supercomputers and computers. Computers and VR headsets are enough for many applications, but supercomputers and CAVE-type systems give us appropriately bigger computing performance and greater use comfort. In case of CAVE-type systems one can additionally say about deeper immersion in virtual reality.

Immersive 3D Visualization Lab

The survey of different use of virtual reality will be led on the case of the Immersive 3D Visualization Lab (I3DVL) and its applications developed in collaboration with various institutions and research centers [3]. The Immersive 3D Visualization Lab is placed at the Faculty of Electronics, Telecommunications and Informatics of the Gdańsk University of Technology (Poland). The basic installations of the lab are CAVE-type systems featured by various levels of immersion. Therefore software development in the lab consists in testing of implemented VR application first on a simplified CAVE, next on more complicated one, and finally on the most immersive one. Such a sequence of CAVE-type systems constitutes specific software product line [4], which has allowed the I3DVL team and cooperating students (preparing their engineer diploma projects, group projects, and MSc diploma projects) to develop about one hundred VR applications.

The most immersive CAVE-type system of the lab is a virtual reality cubic full CAVE (called BigCAVE, Fig. 1) with six square walls 3.4 m × 3.4 m that are screens: four vertical walls, where one of them is a gate, a floor and a ceiling. 3D images projected on all screens are generated from the user's perspective (head tracking) and displayed by use of 12 rear projectors (two per wall). A front 3D projector in auditorium shows additionally user's view for external observers. Users can wear alternatively two kinds of stereoscopic glasses: passive (Infitec) or active

Fig. 1 - BigCAVE.

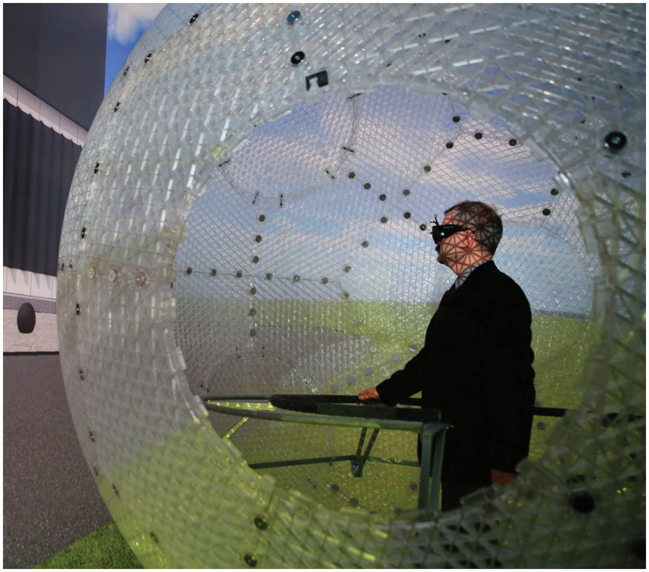


Fig. 2 - Spherical walk simulator inside the BigCAVE (photo: Dorota Patschull).

(shutters). Surround sound is provided by 8 speakers and a subwoofer. Inside the CAVE a user can walk from wall to wall, but for far dislocation he or she can navigate through virtual space using more or less specialized controllers.

The most unconventional controller is a freely revolving transparent sphere (Ø 3.05 m), supported on rollers (something like an omnidirectional hamster wheel capable of accommodation a human user, Fig. 2) enriched with a motion tracking system. A user's gait causes the sphere to rotate and triggers changes in the computer rendered 3D images generating an impression of motion in virtual space.

In the lab, there is also another CAVE-type system which is probably the most popular CAVE architecture in the world. It (MidiCAVE, Fig. 3) has four walls: front vertical wall 2.1 m × 2.1 m with rear projection, left and right vertical walls 1.3 m × 2.1 m with rear projection, and a floor 2.1 m × 1.3 m with front projection. 3D images on all screens are generated

Fig. 3 - MidiCAVE.

Fig. 4 - Body motion tracking system in the MidiCAVE.

Fig. 5 - MiniCAVE.

from the user's perspective (head tracking). Users should look at 3D images by stereoscopic passive glasses (Infitec+) and can hear surround sound. Inside the CAVE a user can walk from wall to wall, but for far dislocation he or she can navigate through virtual space using hand-held controllers. Simulations in this CAVE can by supported by enhanced body and finger motion tracking systems (Fig. 4).

The next CAVE-type system in the lab is a small CAVE consisting of four stereoscopic monitors 27": three vertical walls and a floor. This device (MiniCAVE, Fig. 5) is only for one person (more precisely – for their head) and serves mainly for testing developed applications. As formerly, 3D image is generated from the user's perspective (head tracking), navigation is accessible by hand-held controllers and surround sound is present. A user should wear stereoscopic active glasses (shutters). On account of small size of this device, it can be treat as transportable CAVE system. We visited a few events with it.

Applications of virtual reality in the I3DVL

Probably the most popular application of virtual reality is virtual prototyping. Architectural and urban prototyping seems to be the most obvious. In the I3DVL we developed a few such applications. The oldest one prepared in cooperation with the Faculty of Architecture at my university presents three projects of the development of the western frontage of the Coal Market in Gdańsk (Fig. 6). The existing and designed buildings were modeled in 3DStudio. In this application we can switch between three propositions of arrangement, we can change the time of the day (day/night), we can walk and teleportate to different points of the market and the roofs of surrounding buildings [5]. Other urban prototyping applications concern project of the development of the vicinity of the Vistulamouth Fortress (Fig. 7), project of the development of the vicinity of the Water Forge in Gdańsk Oliwa, and project of the development of the town of Czarna Woda [6, 7]. These applications were prepared in cooperation with the Academy of Fine Arts in Gdańsk and their scenes were modeled in SketchUp. As an example of architectural visualization can serve virtual visiting of the I3DVL building (Fig. 8), where we can enter the virtual CAVE and recursively participate in the next level of virtual visiting of the I3DVL building (like in the movie "Inception").

Very similar prototyping is connected with art. A few years ago we organized the opening and closing of an exhibition "Implosion" by an artist from the Academy of Fine Arts in Gdańsk. During these two events, the virtual sculpture prototype was presented in the CAVE for exhibition visitors and a year later, the sculpture was physically made as an element of small architecture in Gdańsk Wrzeszcz (Fig. 9). Of course, prototyping can be used for other design disciplines like vehicles or machines constructing (Fig. 10).

Virtual reconstruction is similar to prototyping, but concerns old, very often no longer existing objects

Fig. 6 - Virtual development of Coal Market in Gdańsk – BigCAVE.

instead of designed new ones. If reconstructed object still exists, virtual reconstruction can be supported by 3D scanning. For instance, in the I3DVL there was developed Vistulamouth Fortress reconstruction (Fig. 11) on the basis of photogrammetry made by the Faculty of Civil and Environmental Engineering at my university in cooperation with the Museum of Gdańsk. Another example of historical architectonical reconstruction is visualization of history of changes in the interior of the sacristy in the gothic St. Nicholas church in Gdańsk (Fig. 12). The sacristy was modeled by the Faculty of Architecture at my university in cooperation with the Dominican Monastery, who is the church user and owner. In cooperation with the Lviv Polytechnic National University, the monument to the Polish king Jan III Sobieski have returned virtually in the CAVE from Gdańsk to Lviv (Ukraine), where it was situated

Fig. 7 - Virtual development of the vicinity of the Vistulamouth Fortress – BigCAVE.

Fig. 8 - Virtual visiting of the I3DVL building – BigCAVE.

Fig. 9 - Physical sculpture which was virtually presented during opening of exhibition "Implosion".

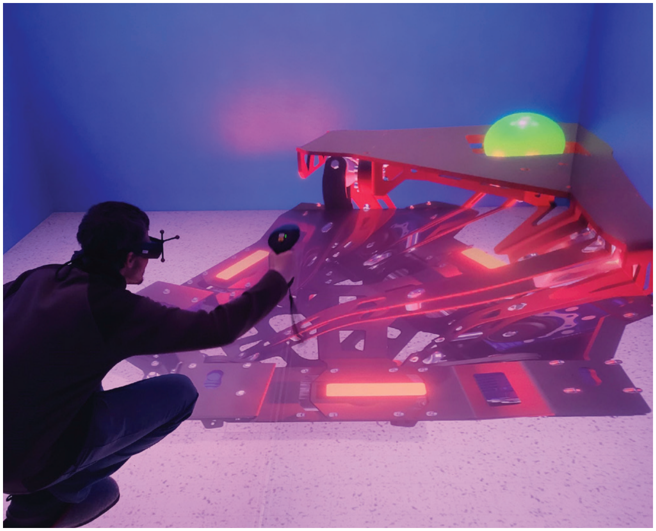


Fig. 10 - Virtual prototype of the Stewart platform – BigCAVE.

Fig. 11 - Virtual reconstruction by photogrammetry of the Vistulamouth Fortress – BigCAVE.

Fig. 12 - Virtual reconstruction of the sacristy in the gothic St. Nicholas church in Gdańsk – BigCAVE.

Fig. 13 - Virtual placement of the monument to the Polish king Jan III Sobieski in Lviv – BigCAVE.

Fig. 14 - Virtual reconstruction of the Amber Room – BigCAVE.

originally before the II World War (Fig. 13). The monument was scanned by Polish-Japanese Academy of Information Technology in Warsaw. Other examples of virtual reconstruction are medieval Kashubian port in cooperation with the Museum of the Puck Region, the Amber Room (Fig. 14) in cooperation with the Museum of Gdańsk, and panoramic visit in Scottish Café in Lviv in cooperation with Lviv Polytechnic National University.

Virtual reconstruction can concern contemporary objects and scenes too. For instance, there were implemented in the I3DVL visualization of an arranged occurrence (crime or accident) location in cooperation with Forensic Laboratory of the Provincial Police Headquarters in Gdańsk. It shows new efficient method for creating digital police archives. Another example of virtual reconstruction is an application for 3D medical imaging (MRI, CT, PET, USG, Fig. 15) in the CAVE prepared in cooperation with the Medical University of Gdańsk. Virtual tourism, exhibitions and museums are in a sense virtual reconstruction too. In order to presenting cultural heritage objects their virtual reconstruction is needed. The I3DVL can show 44 million years old Gierłowska's Lizard, that is inclusion in amber from the Museum of Gdańsk. This multiple zoomed in the CAVE reptile was scanned using tomography by the Warsaw University of Technology [8].

The next kind of VR applications is education. Different school disciplines can profit by virtual reality. In the I3DVL we can find astronomical, biological, chemical, medical, physical, technical and even mathematical visualization. We can penetrate virtually two Solar Systems implemented in cooperation with Integra AV company (former) and Polish Space Agency (latter), various Galaxies developed in cooperation with MAE company and Polish Space Agency, various proteins prepared in cooperation with the Faculty of Chemistry at my university, organ (e.g. foot) anatomy – result of cooperation with Integra AV company and the Medical University of Gdańsk, refinery (Fig. 16) modeled by Tapptic company, Menger Sponge fractal (i.e. 3D Sierpiński's carpet), 3D projections of 4D hypersolids (e.g.

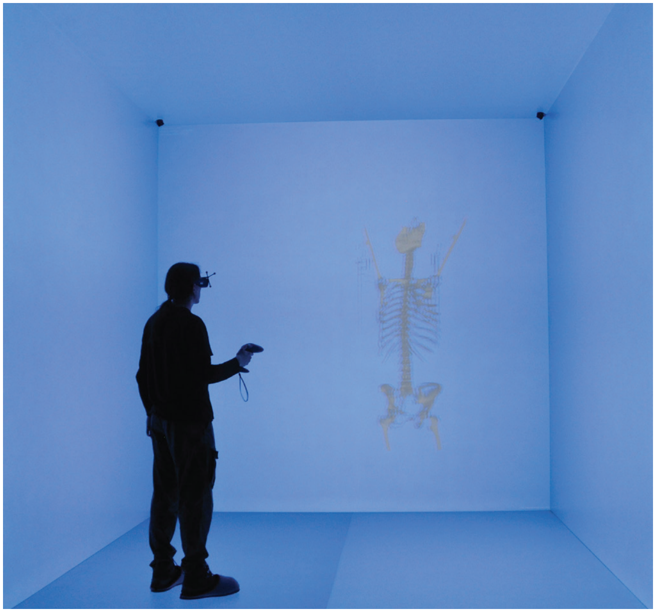


Fig. 15 - Virtual 3D medical imaging – BigCAVE.

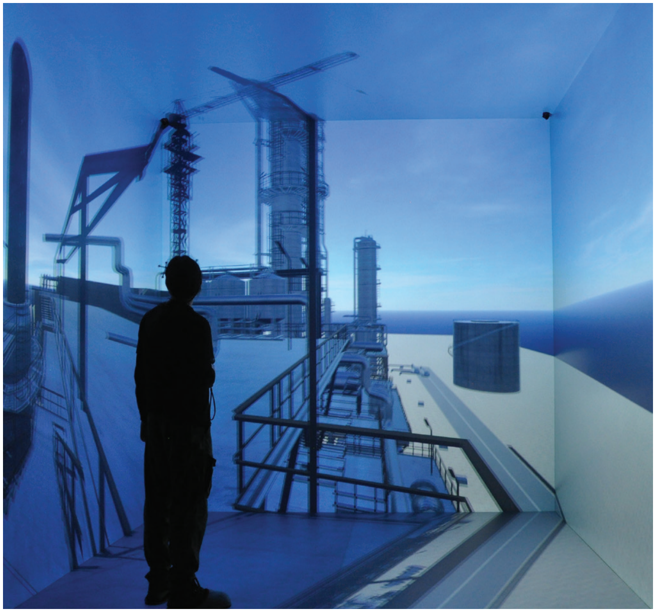


Fig. 16 - Virtual refinery – BigCAVE.

tesseract = 4D hypercube), and Wikipedia pages 3D graph. However visualization is the simplest form of education. More sophisticated VR applications require interaction with a virtual world. A virtual chemical lab allows students to led in the CAVE safe chemical experiments (Fig. 17). Two different virtual chemical escape rooms "smuggle" to them some theoretical knowledge concerning chemistry. These interactive chemical VR application were developed in cooperation with the Faculty of Chemistry at my university.

Virtual training is a next example of interactive education, but it is worth distinguishing because of its wide range. It seems that every job can be train with use of virtual reality. The I3DVL have various such applications: ship survey simulator, which is adaptation of DNV company application (industrial inspection training and examination), parachute jump simulator – result of cooperation with the Gdynia Maritime University, Polish Space Agency, Integra AV and Squadron companies, shooting trainer simulator programmed in cooperation with the Faculty of Mechanical Engineering and Ship Technology at my university, drone operator trainer simulator, distributed simulator of helicopter marshalling implemented in VBS environment (military/homeland security training and operations [9]), robot assembling adjusted for CAVE (Fig. 18) by Heilbronn University of Applied Sciences (Germany), lunar-Martian rover simulator (Fig. 19) developed in cooperation with Polish Space Agency and MAE company (technical training), firefighter trainer simulator (Fig. 20), and evacuation trainer simulator consulted by the War Studies University in Warsaw (crisis management). Such virtual training applications very often have form of a game – therefore they are called serious games. Scientific visualization is in a sense connected with education. For instance, mentioned above



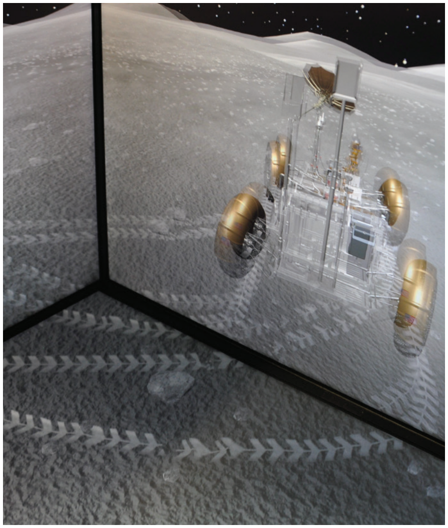
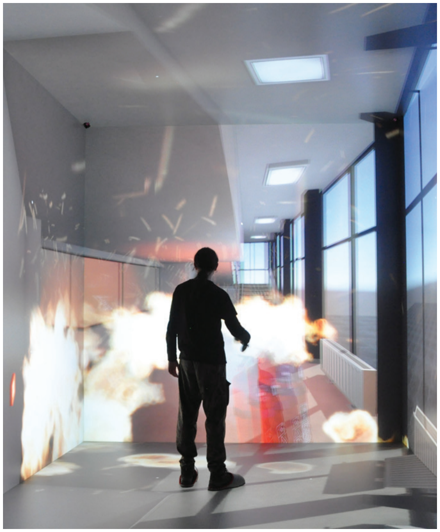
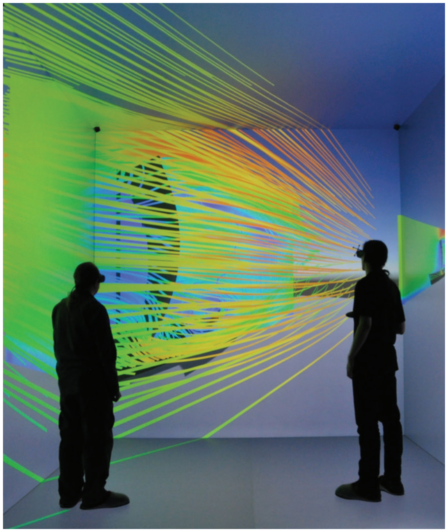
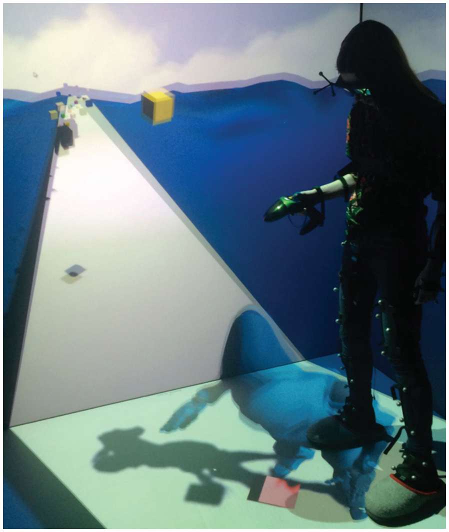





Fig. 17 - Virtual chemical lab – BigCAVE (photo: Alena Rudaya).
Fig. 18 - Virtual robot assembling – BigCAVE.
Fig. 19 - Lunar-Martian rover simulator – MiniCAVE.
Fig. 20 - Firefighter trainer simulator – BigCAVE.
Fig. 21 - Virtual aerodynamical tunnel – colored stripes show air flow – BigCAVE.
Fig. 22 - Virtual rehabilitation in balance disorders – MidiCAVE.

proteins visualizer can be used both in education and in research. However, some other VR application in the I3DVL are dedicated rather research than education: air flow (Fig. 21) – result of cooperation with DNV company and the Maritime Museum in Gdańsk, or wave interaction on a marine object implemented in cooperation with the Faculty of Mechanical Engineering and Ship Technology at my university. Linking together phenomena and behaviors modeling and simulation with visualization we obtain very interesting tool for research in physics, chemistry, biology, medicine, psychology, sociology and other science branches.

Virtual reality can support medicine in other ways too. 3D medical imaging was mentioned above, but the I3DVL can run also medical virtual trainer simulators like paramedic trainer simulator implemented in cooperation with Visus VR and Integra AV companies and exploration of a hospital operating room prepared by Integra AV company as a tool for planning of medical operations. Very interesting medical VR applications concern diagnosis and rehabilitation. Using elaborated in the I3DVL applications physicians can support diagnosis and rehabilitation in balance disorders – result of cooperation with Department of Biomedical Engineering at my faculty. Unstable visual virtual environment allow to check whether a patient has problems with balance. Some other VR games allow a patient to perform exercises that help keeping their balance (Fig. 22). Another example of rehabilitation VR applications are arcade games developed in cooperation with the Medical University of Gdańsk and the Faculty of Mechanical Engineering and Ship Technology. They supports rehabilitation of muscles in muscular dystrophy through repetition of given hand gestures in such scenarios like wizard casting spells by gestures or Beat Saber.

The last but not least kind of VR applications described in the paper is support of psychology. Virtual reality gives psychologists a new tool for supporting treatment and for research. Using special prepared VR applications the I3DVL and the SWPS University of Social Sciences and Humanities led measurements of the immersion degree when using different VR devices (VR headsets, CAVEs). Very promising VR applications are these ones that support phobias treatment, e.g. treatment of acrophobia (fear of heights, Fig. 23) and arachnophobia (fear of spiders, Fig. 24) which were consulted with the SWPS University of Social Sciences and Humanities [10]. Virtual reality can also be used for addiction or posttraumatic stress disorder syndrome (PTSD) treatment. Other VR applications serve psychologists for simulation of psychical diseases like depression simulator developed in cooperation with the SWPS University of Social Sciences and Humanities or for influencing human behavior like shaping pro-ecological postures (Fig. 25) prepared in cooperation with the University of Gdańsk. VR applications can be also used for memory stimulation (another cooperation with the SWPS University of Social Sciences and Humanities) and advertising effectiveness analysis (Poznań University

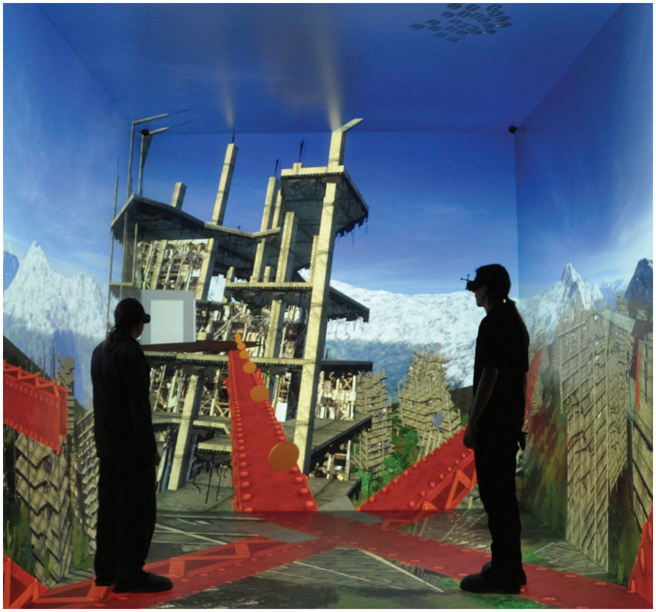


Fig. 23 - Treatment of acrophobia (fear of heights) by support of virtual reality – BigCAVE.

of Economics and Business) [11]. Another very interesting psychological VR application is measurement of morality of human behavior – result of cooperation with the SWPS Humanistic University. Moreover the I3DVL in cooperation with Nlightnin company tried to use human emotions to control visualization. Experiment finished with success would allow e.g. cancer patients to improve efficiency of their therapy. However this problem needs further research.

VR related issues

Unfortunately, there is troubleshooting with VR applications. Above all, Interaction with virtual world is very often problematic: it is not common, often unnatural, e.g. moving with the joystick instead of the legs. User may get lost without some preparation. Another problem is cybersickness common for headsets, but fortunately rarer for CAVE-type systems. Errors of assets modeling represent separate problem with using virtual environment. 3D graphic artists have to pay attention to different aspects of 3D modeling: naming rules, hierarchy of models, texture mapping, object modeling, game engine project organization etc. [12]. Development of useful VR application needs cooperation between programmers, graphic artists and clients (architects, educators, psychologists etc.).

Conclusions

Virtual reality can find its application in almost every human activity discipline. In the paper there were presented various VR application developed in the Immersive 3D Visualization Lab for different disciplines, from architecture and art, astronomy and chemistry, through history and museology, criminology and military education, mechanical and ship engineering, up to medicine and psychology. The I3DVL is waiting for you in order to undertake new endeavors on the basis of virtual reality.

Fig. 24 - Treatment of arachnophobia (fear of spiders) by support of virtual reality – BigCAVE.

Fig. 25 - VR game shaping pro-ecological postures in town – BigCAVE.

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keynote speaker

Davide Benvenuti

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Associate Professor of digital animation at NTU ADM School of Art Design and Media Singapore since January 2013. Graduated with a master's degree in architecture at Florence University he has been engaged by Disney, DreamWorks, and Ubisoft. Among his credit list:
"Assassin Creed Black Flag", "Assassin Creed III"," Assassin Creed Revelation"; "Assassin Creed II" (Ubisoft Singapore); "Sinbad Legend of the seven seas"; "Sprit stallion of the Cimarron" (DreamWorks)
Senior Animator at Disney animation Australia from 1995 till 2006 he worked on many direct to DVD titles and feature film including "The jungle Book II"," Peter Pan Retour to Nederland", and "Bambi and the great Prince of the forest". Winner of The Gold Award for Digicon6 2018 in Singapore with his 3D animated film "Apple of my eye" he is currently working on his second short film "Summer tale"; part of his ongoing research on tool development for 2D animation.

02 FROM DRAWING TO ANIMATION

The creation of virtual places and the development of storytelling for constructing narrative paths through drawing

Abstract

The relationship between environment creation and storytelling is a topic that is seldom discussed. Looking at how architecture could relate to elements of storytelling is easy to forget that "Visual storytelling displays a history of the past, an identity for the present, and a story for the future … Architecture is an ever-present form of visual storytelling. The built environment can capture a place's history and tell that story through space. Architecture forms a visual, spatial link between the past, present and the future, becoming a point in the timeline of a place and culture." [11] Animation is also a medium of visual storytelling that, like painting, illustration, and cinema, is constantly inspired by reality. The graphic research and the necessity to give the spectator recognisable references often combine strong iconographic images with recognisable locations.

With animation, artists and storytellers can overcome the limits of photography; the "real" frequently becomes a simple starting point to be modified and re-conceptualised with alterations dictated by the stylistic needs of a story.

Stylistic considerations often mediate the need to be truthful to reality. Animation, since its inception, has explored graphic languages and techniques: artists like Tyrus Wong, Mary Blair, Eyvind Earle, Gerald Scarfe, Ronald Searle, Ken Anderson, Morice Noble, Hayao Miyazaki, Lorenzo Mattotti, and even Salvador Dali have contributed with their unique and different visions to the creation of memorable images.

This paper will address the relationship between animation and the location study. It will illustrate how understanding architecture and exploiting illustrative style can be combined to develop storytelling through appropriate design methodologies. The paper will, in the end, showcase the graphic research undertaken by the author for a specific project within this framework.

Introduction

Animation as an art form can transport the viewer inside a story to another time and place. This dimension, real or fantastic, is created by combining background design and the sequential juxtaposition of images to support the storytelling. The scenographic element establishes the scale and atmosphere, giving the audience the interpretative key to relate to the story.

Animated films have enormous variations in technique from flat-painted images, 3D elements or miniature models, as in stop-motion animation.

Regardless of the technique, to create locations, designers often need to refer to real places or periods, understand art history, and make design choices to ultimately construct the virtual space where the action will take place.

It is an established practice that designers and illustrators are involved in a project by a director at the beginning of each production. It is common for the designer and director to be the same person, especially for short films. While the creation of the preliminary illustrations is not concerned with technical requirements, the layout and the scenography are specific activities that deal with how the film appears on the screen, defining geographical and historical references, the camera movements and establishing the overall cinematography of the film. Many animated films own their success not only to well-developed narratives but to unique locations that are engraved in the public's imagination, so much so that sometimes these locations become more "real" than the reference they were taken from one has to look no further than the Disney's Park where drawn scenography becomes actual locations.

Whatever the type of story, real or imagined architecture represents a reference point that cannot be ignored when conceiving an imaginary location. Whether photo-realistic, fantastic or highly abstract, the architectural element helps define the reference scale between character and environment, inserting a piece of familiarity that allows the viewer to identify with the character and the story.

Places of Architecture in Animation

For their extraordinary visual impact, many iconic landmarks and buildings have been used in animated films. They have been re-interpreted graphically through the lens of famous illustrators and designers from London in Disney's *101 Dalmatians* to the fairy tale land of *Sleeping Beauty* to the Italian coastal riviera in Pixar's *Luca*.

A unique landmark in his own right, the Neuschwanstein Castle, built in Bavaria in the late nineteenth century, and elements borrowed from the Hohenzollern Castle inspired the princess's castle in Disney's *Sleeping Beauty* (Disney, 1959). Eyvind Earle, the film's art director, was inspired not only by elements present in such architecture but also by post-Renaissance art, characterised by vertical elements traceable in the architecture and design of all the background elements of the film, up to the details of the vegetation. By design, the original castle of Neuschwanstein is a place of "fairy tale" with a scenographic apparatus that the Disney artist fully exploited.

Looking at the film, it is also possible to recognise the presence of graphic entities in the series of tapestries, *The Hunt for the Unicorn*, late fifteenth century.

In his autobiography, Earle wrote: "I began practising doing sleeping beauty's forest scenes. After all, my favourite artists were Albrecht Durer, Van Eyck and Bruegel, and all gothic art, and "The Hours of the Duke de Berry... I wanted stylised, simplified gothic. Straight, tall perpendicular lines like gothic cathedrals. "[14]

In the details of many sets of the film, it is clear how the architecture is deliberately excessive; references to the real object are not precise and significantly borrow elements from the paintings of Durer, Bruegel, Van Eyck, and Botticelli but also go a step further by adding contaminations from Persian miniatures and even Japanese art as Earle admits in the same book.

Sleeping Beauty represents a milestone in the aesthetic evolution of Disney films. In his first feature, *Snow White* and the Seven Dwarfs 1938, the iconographic elements were typical of the nineteenth and twentieth centuries, reworked for the film by illustrators Gustaf Tenggren and Kay Nielsen in the mid-fifties, thanks to competition from studios like Warner or UPA stylised characters and backdrops that investigated a different graphic sensibility emerged.

References to real places are too many to make an exhaustive list, from Sylvain Chomet's Dublin in *The Illusionist* (2010) to the Paris of Pixar's *Ratatouille* (2007).

The villages of Reiquewihr and Ribeauvillé in Alsace inspired the little town in *Beauty and the Beast* (Disney, 1991) with precise references to eighteenth-century France and, in this case, the style of the French painter Jean-Honoré Fragonard.

Two Japanese Onsen buildings constitute a starting reference for Hayao Miyazaki's settings in the film *Spirited Away* (2001). The popularity of the film, in Japan and abroad, has meant that many Onsen claims to be the source of inspiration when the film does not precisely reproduce any place. Miyazaki combined several elements of the original architecture typical of traditional buildings creating a unique look for the central Onsen, where most of the story takes place.

Other films by Ghibli studio accurately reconstruct Japanese locations, like the feature *The Wind Rises* (2013), set in Japan before World War II or in Isao Takahata's *A Grave for Fireflies* (1988), a detailed and realistic description of the effects of the bombing of the Japanese city of Kobe.

The Yoygogi Kaikan Building, a recently demolished building that stood in the Shinjuku district of Tokyo, is the set for the climax of the film *Weathering with you* by Makoto Shinkai (2019). The building is represented in the film as it was, with minimal alterations from the original. In Japanese animated films, with Shinkai at the forefront, the actual reference is often delivered with a hyper-realistic touch, referencing places of modern Japan; scenes of everyday Tokyo portrayed in the film had "fans to descend on locations from the film, " forcing production staff to plead with them not to disturb residents following complaints about their behaviour." Ref

Style

In an animated short film, style can be the product of a single person's artistic vision, whereas, in feature productions, the style becomes the combination of a team effort. Companies choose from within or invite one or more external artists to contribute with their ideas till the art director and director agree and settle around a common aesthetic idea. Comparing backgrounds from different production helps understand how style and attention to period and location information can determine the visual outcome of an animated film.

Backgrounds from Disney's *Saludos Amigos (*1942) present a stylised and almost abstract use of vibrant colours, subtly alluding to South American references. It seems almost abstract art compared to the detailed rendering for the *101 Dalmatians* that instead do not allude but precisely reference a location. Disney's *Bambi (1940) is* inspired instead by Chinese Song dynasty paintings. In contrast, Warner Brothers' shorts featuring *Willy the Coyote and Beep Beep* (1960 ca.) have their roots in the commercial graphic art typical of the sixties, with colours and types of images much closer to modern art.

We can compare the backdrops of Chuck Jones's "What's *Opera Doc" (*1957) with their look curated by Morice Noble, loosely referencing stage opera and oversized architectural clues to those of *Mister Magoo's Christmas Carol*, where the space and location allude to a Broadway stage. All these films, produced by different companies, reveal the clear intent to propose a unique and recognisable style; the places represented do not exist; still, by analysing the images, we recognise elements that allude to design and architecture that recall graphics forms allowing the viewer to reference a period and location.

Architecture becomes a design element in *Cinderella's* (Disney, 1950) background. A distorted scale in the architectural elements and decors places the realistically designed characters in a distinctly vertical world. *Alice in Wonderland,* and *Cinderella*, own their look to Mary Blair's illustrations. They are remarkably abstract, thanks to a series of design elements, vibrant colours, and contrast between light and shadow, creating an abstract but somewhat believable fantasy world.

As previously mentioned, Disney's *101 Dalmatians* is an interesting example in this context: the storytelling dictates that the action takes place in contemporary London, and a fairy tale-style fifties-London would not have worked. Ken Andersen, the art director, adopted a different approach, conducting extensive research on the interiors of specific elements of a Terrace House in London. These investigations created a sense of contemporaneity through the reproduction of the design and furniture typical of a house in the hills of Primrose in 1950, the period in which the film is set. On the other hand, the idea of style is present thanks to the influence of English illustrator Ronald Searle's graphic style and extensive use of black ink pen strokes.

In the animated film *The Aristocats (1970),* all the architectural elements allow the spectator to understand where the action takes place, that is, in Paris. The drawing style shares many similarities with 101 Dalmatians and is still in line with a very modern graphic and drawn-in sensitivity, even if the use of colour is different, where the latter uses a flatter colour approach than the second. The historical Café de la Paix and the Eiffel Tower are featured in the film; in scenes from the film, one recognises the attention to detail that makes the house of Madame, the owner of the cat's protagonists, well anchored to the Parisian atmosphere of the early twentieth century.

The Layout

The layout in animation can be defined as the union of narration and composition; it is the art of placing moving images within a frame so they can flow in front of us in real time for a story's sake.

The cinematography in animation results from a close collaboration between the artists who design and create the various scenographic elements and the technicians who design and manage the complex camera movements, real or virtual, through which the artwork eventually becomes storytelling on the screen. Layout overlaps large areas with the various section of animation production and addresses a multiplicity of problems: story, framing and lighting, defining photography, cinematography and establishing the set design.

Just as animation finds its place between cinema and illustration, layout represents a bridge between design and cinematographic language. The layout artist is the one who guarantees filmic continuity by organising the various elements of a background so that they support the action.

When designing environments for an animated film, it is necessary to design not only the area in which the character moves but is often essential to visualise what is outside the camera. This need often leads to realising real projects, with plans and elevations, miniature models of buildings or even small urban plans that allow the cinematographer to get an idea of the imaginary location. It is essential that the picture is visually well-composed and gives precise information. As part of a moving image, the background is rarely the protagonist but supports the story; sometimes reduced to simple details; an unwritten rule is that a scene should look empty until the character is inserted.

Early animation and live-action directors studied the great painters of the past: Rembrandt, Vermeer, and Gustav

Doré. These artists knew that their images were pictures that told a story in a moment of life frozen in time. A film composition not only tells a story in isolation, but the relation between the parts ultimately contributes to the overall storytelling as we define motion not only for the characters but also in a more general sense of movement through space. Everything in the composition, from the position to the size of the characters to the relationship of the figures to the frame and each other, contributes to the meaning. How many times can the camera become storytelling moments, from the multiplane aerial views of Geppetto village in Disney's *Pinocchio* (1940) to the flight through over mediaeval Paris and Notre Dame in Disney's *Hunchback of Notre Dame(1996)?*

In *101 Dalmatians,* furniture and apparel in the kitchen scene are shaped like those of Victorian terrace houses in an era when light and heating were gas. Each element is adequately represented in its functional integrity. Presenting the apartment of the protagonist provides us with all the necessary information. Every detail reinforces the concept of the bachelor with his head in the clouds: from the messy object casually laid all over the floor at the film's beginning to the scores sheets left lying, giving clues over Roger's line of work to the mountains of unwashed teacups. In the Hunchback of the Notre Dame, the architecture is central to the plot, and every effort was made to recreate the church interiors and external features; the filmmakers created 3D models of the church to allow Quasimodo the main character absolute freedom of movement as he climbs the bell towers and the spire.

In a Tom and Jerry cartoon or a Willy, Coyote cartoon, the spatial relationship between the various elements is not fundamental to the success of a "gags", so continuity is not necessary; on the contrary, in a longer format film, the viewer must build a mental map that can tie him to that imaginary world.

When creating a background for the animation, it is necessary to pay particular attention to the scale relationship between the subject and background elements (steps, railings, furniture etc.).

Even in the case of an animated film, where nothing exists or needs to be correctly functional, if the elements are not well organised, the viewer will get confused and might start focusing on what does not work at the expense of what is essential, like the story and the characters. Designing a master plan gives an idea of the whole setting, and the composition of the space defines what objects the camera sees at every change of point of view.

Even in the case of a hand-drawn film, as soon as the camera moves, the illusion of a 3D space is created; artists use several tricks to ensure that the background is not perceived as a static plane, often creating separate layers for the foreground middle ground and background to accommodate parallax effects, depth of field and all those features that the audience expects from modern cinematography.

Computer-generated images allow the artists to free themselves from the flat page and create multi-dimensional backdrops. If 3D can free the artist from certain technical limitations, the freedom to create complex camera movements must serve the chosen medium's aesthetic characteristics.

Currently, it is common to use software such as SketchUp to create and design environments more efficiently and realistically, thanks to the ability to draw from a vast library of pre-packaged objects that can then be reassembled and reimagined, according to a specific style, allowing for experimentation by, for example varying the point or by simply helping to draw a problematic perspective. Even with all this technology at our disposal, it is sometimes appropriate to contain camera moves to respect aesthetic consistencies. For example, it is possible to achieve a depth of field by blurring elements in the distance or the foreground. However, sometimes, it is possible to resort to graphic solutions by omitting details or working on chiaroscuro values.

Project Showcase

The stylistic references for the project presented as a showcase are two famous Disney productions already mentioned, the *101 Dalmatians* and the *Aristocats,* both set in Europe and featuring highly recognisable graphic styles marked by specific geographical locations, respectively, contemporary London and Paris. Both films, especially the first one, reference the work of English illustrator Ronald Searle (1920–2011), famous for his covers in *life* and other international magazines.

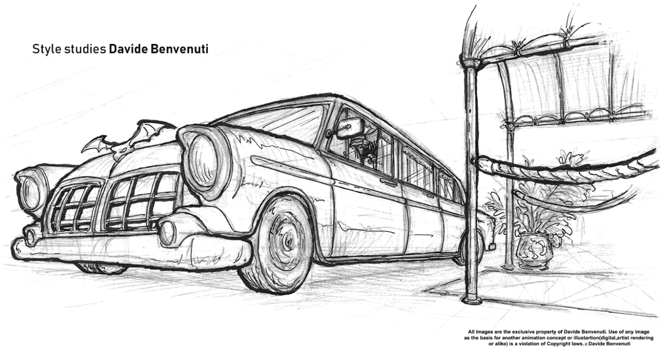
Even at a superficial glance, the *101 Dalmatians* reveals *an innovative* style and a very different look for a Disney film; the settings are accurate and finessed in line drawings and then coloured in washes of colour, which suggest the overall mood of the scene in a sketchy way.

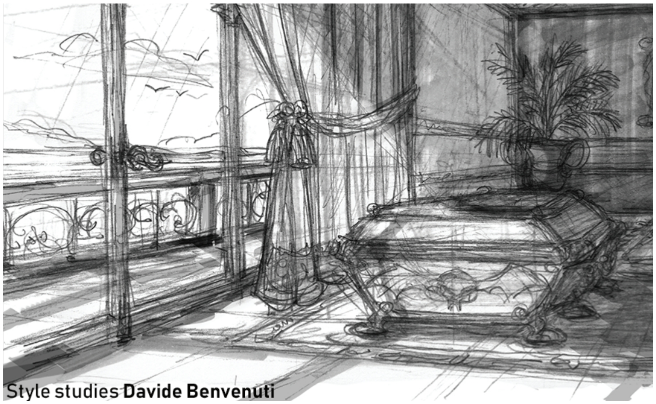
Thanks to the newly invented Xerox machine (the ancestor of the photocopier), the artworks were directly transferred from paper to acetates, allowing for more graphic and fresh drawings so that characters and sets visually belonged to the same world.

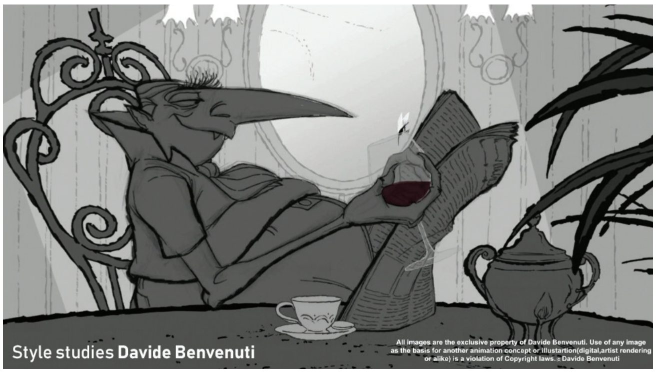
The leap in quality was primarily due to the artistic director of the film, Ken Anderson, who, together with other staff members, such as Tom Oreb and Milt Khal, modernised the style of the studio by referencing the trends of illustration and graphic research of the 50s and 60s, which in turn had absorbed the trends of the modern paintings of the second post-war period.

As already mentioned, the other point of reference for the project we are presenting is Ronald Searle's work. The first step was, therefore, to study Ronald Searle's style.

Searle enlisted in the Royal Engineers of the British Army at twenty-one. At the beginning of World War II, he arrived in Singapore on 12 February 1941. Singapore surrendered to Japanese troops two days later, and Searle was then taken, prisoner. He survived and returned home in 1946. During his captivity, he produced many drawings that he took back to England, documenting his time as a prisoner of War.


Style studies **Davide Benvenuti**


Style studies **Davide Benvenuti**

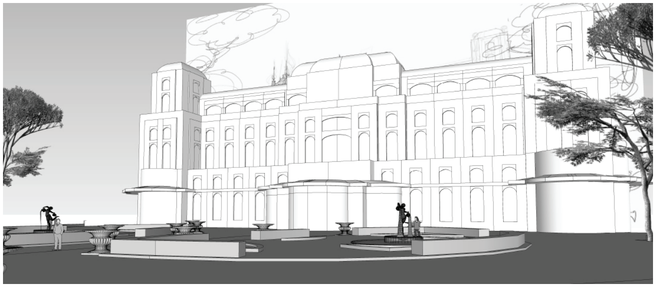

Style studies **Davide Benvenuti**

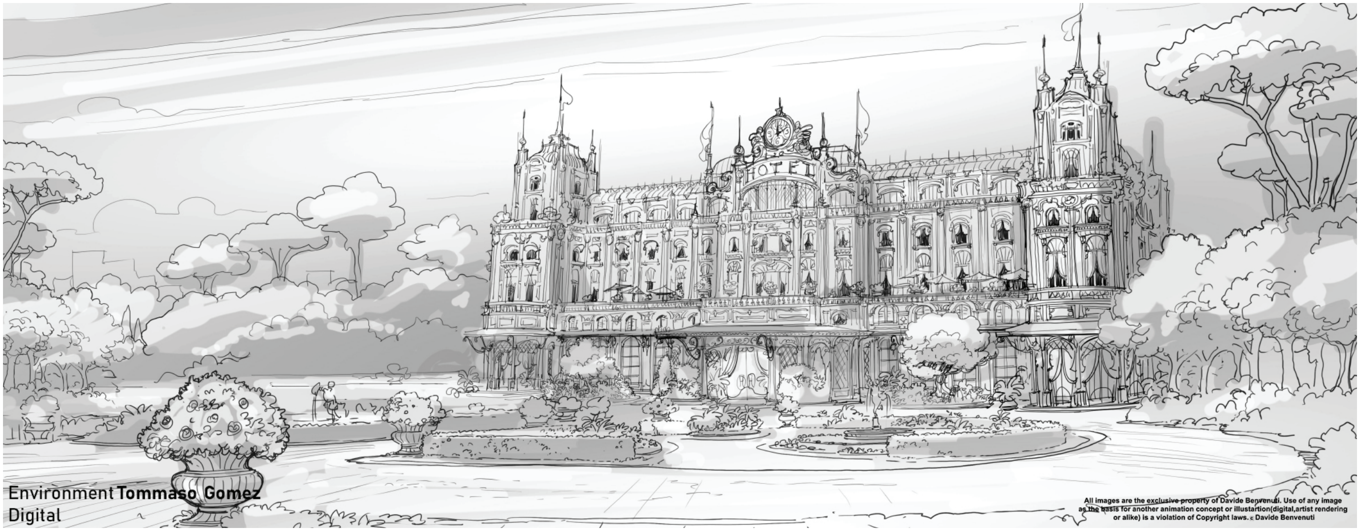
His drawing style was undoubtedly the result of his POW experience: Searle had to learn a new style of drawing directly with ink without first sketching in pencil; this gave rise to a peculiar, graphic, and spontaneous way of producing images. Ronald Searle became international renown for working on the covers of international magazines like the New Yorker of Le Monde and producing countless illustrated books.

He influenced a generation of illustrators, designers, and animators: in the case of Italy, it is sufficient to refer to animation from Bruno Bozzetto, countless designs of animations made for the Caroselli, up to the Tuscan cartoonist Fremura.

In 1958, during his first trip to America, Searle visited the Disney Studios and befriended many artists working on 101 *Dalmatians*. Although the British artist did not participate in the film directly, the film adopted his style. Remaining in contact with the artistic director, Searle contributed to the film, although not officially, with notes on London and the Regent Park area.

For the project's storyline, the mid-sixties Italian Riviera was





Environment **Tommaso Gomez**
Digital

chosen as a central character, Count Dracula. The intent is to create a short comedy narrative that places the character in an unusual environment.

The first step for the project was to visualise possible situations and places that suggest character moments and interaction with the environment. In this case, Count Dracula is not in his typical handsome vampire disguise but is a grumpy middle-aged gentleman who would like to read his newspaper and drink blood out of a wine cup.

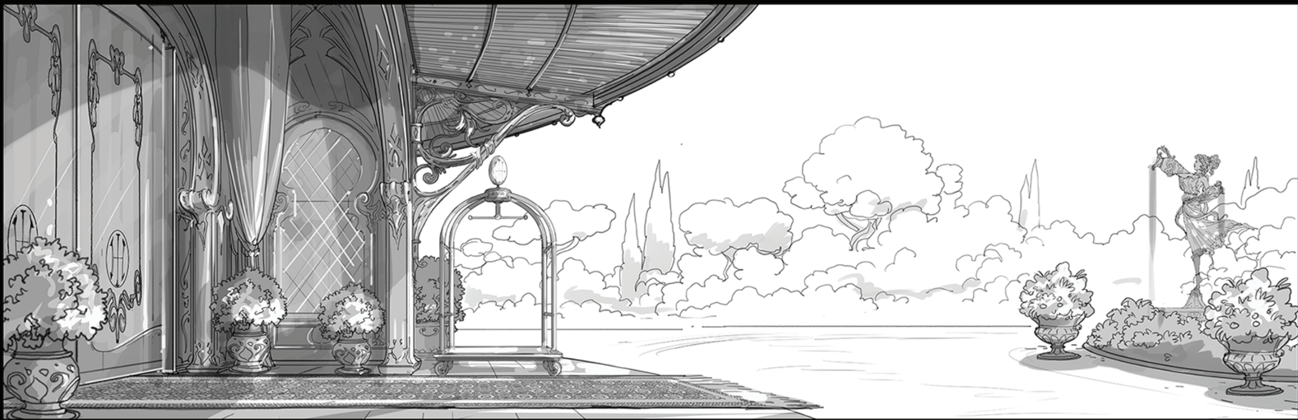
In a project of this nature, one of the first tasks is to settle on a visual style that mediates between the referenced stylistic choice and something original.

Studying Searle's artwork, the first thing that became obvious was that the work has a strong common denominator, characterised using ink pen lines of different thicknesses and that he sometimes employed mixed techniques like markers, watercolours, or gouache.

During this research process, colour was discarded in favour of black and white, a choice consistent with the historical period of the film, set in the sixties; a choice was made to focus on Searle's peculiarity of thick and thin ink work on paper to create an atmosphere that can recall the classic black& white films of Dracula with Bela Lugosi's as a protagonist (1931). (Fig. page 38).

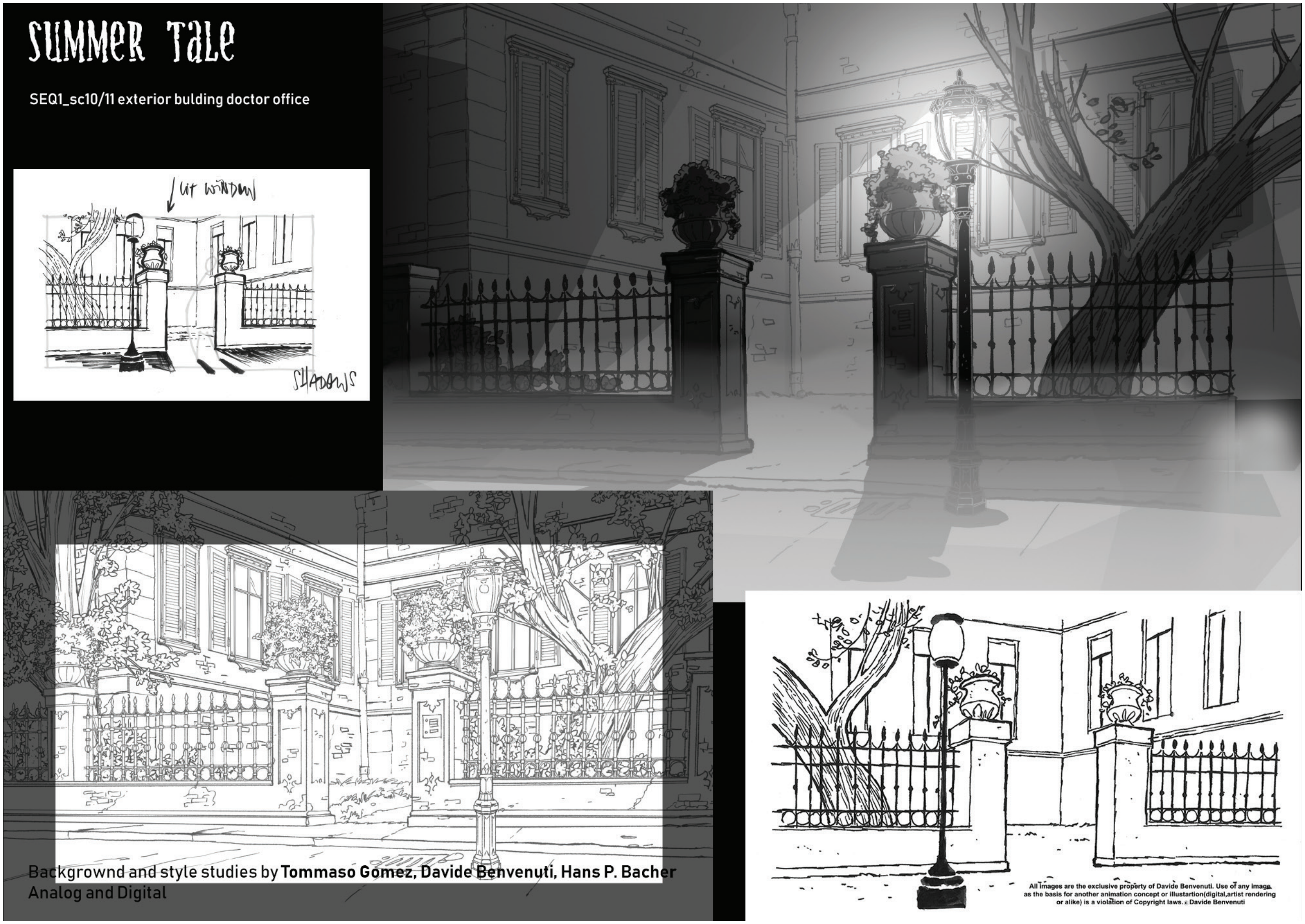
Backgrownd study **Tommaso Gomez ,Simone Borselli & Davide Benvenuti**
Analog and Digital

SUMMER TALE



Backgrownd and Style study **Davide Benvenuti,Tommaso Gomez**
Analog and Digital

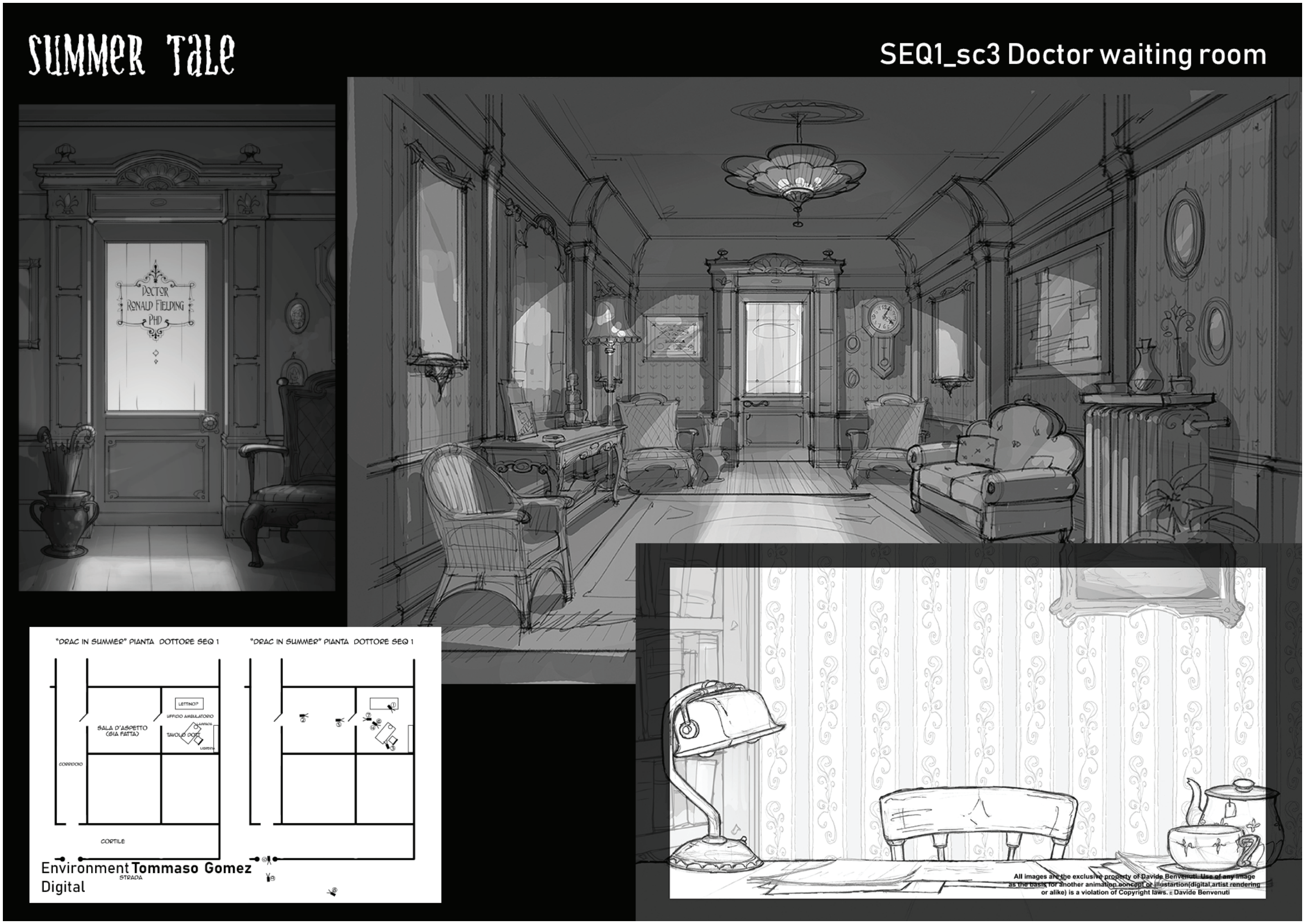
The central piece of architecture where the action takes place is the focus of the research or the film settings. Two real locations serve as inspirations, the Grand Hotel of Cesenatico and Grand Hotel di Rimini Italy (Fig. page 39); these large structures are similar in their architectural structure, and scenographic appearance and are highly recognisable in Italy's Romagna Riviera. The Grand Hotel in Rimini – built in 1908, was designed by the South American architect Paolo Somazzi. It featured two domes adorning the roof, but a fire damaged the building in July 1920, destroying the domes. The Hotel was severely damaged during the War and reconstructed in 1950. The rooms are still decorated with Venetian and French antiques

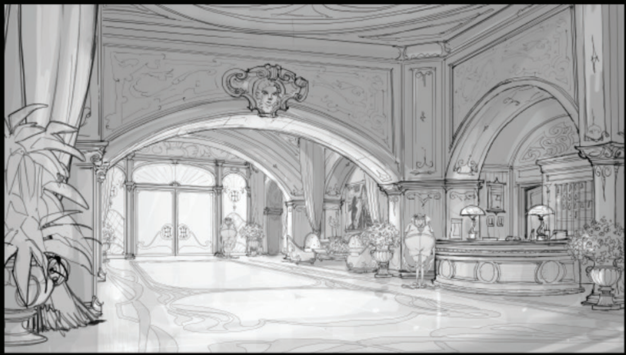


Backgrownd and style studies by **Tommaso Gomez, Davide Benvenuti, Hans P. Bacher**
Analog and Digital

of the 18th century, and the original wooden floor (parquet) and Venetian chandeliers have been restored. Federico Fellini's film *Amarcord* featured the Hotel, and Roberto Benigni also used it as a set for his film *Johnny Stecchino* (1991). The use of stills taken from Benigni's film has allowed for useful visual references, primarily to focus on furniture, floor design and space in general.

The final Hotel designed for the project does not intend to reproduce Cesenatico or Rimini but blends it by reworking elements of both to create a recognisable and evocative building. (Fig. page 39); 3D models were created using SketchUp to facilitate the drawing process and help with complex perspective issues; this was particularly relevant with






Environment Simone Borselli & Davide Benvenuti
Digital


SUMMER TALE
Environment Tommaso Gomez
Digital
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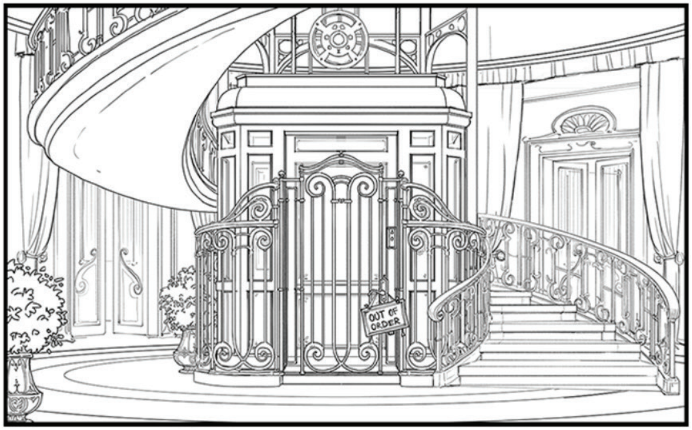
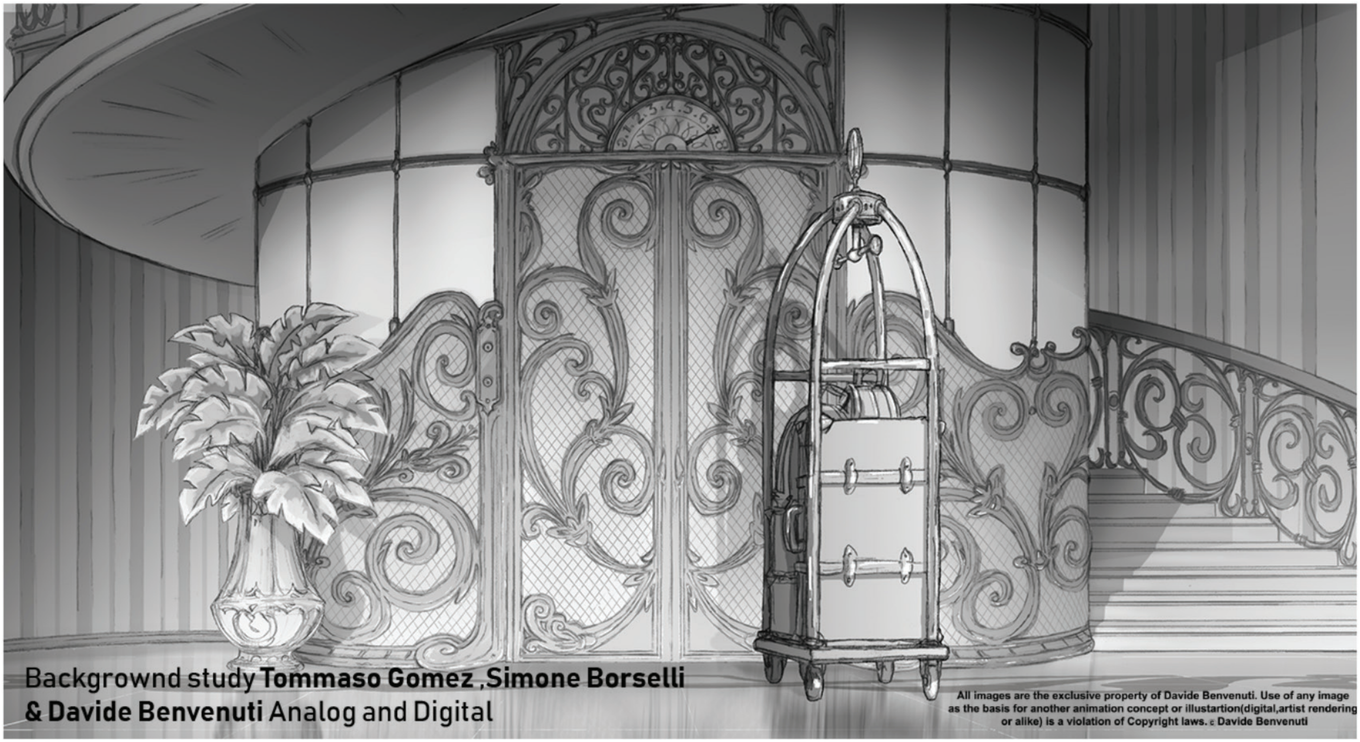
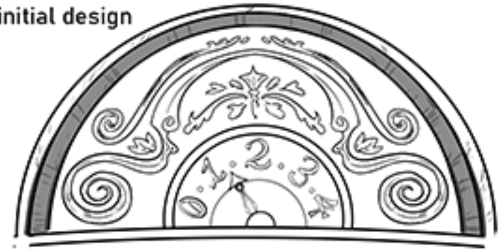




Backgrownd study **Tommaso Gomez ,Simone Borselli & Davide Benvenuti** Analog and Digital initial design



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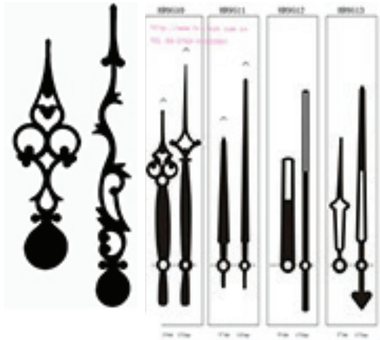
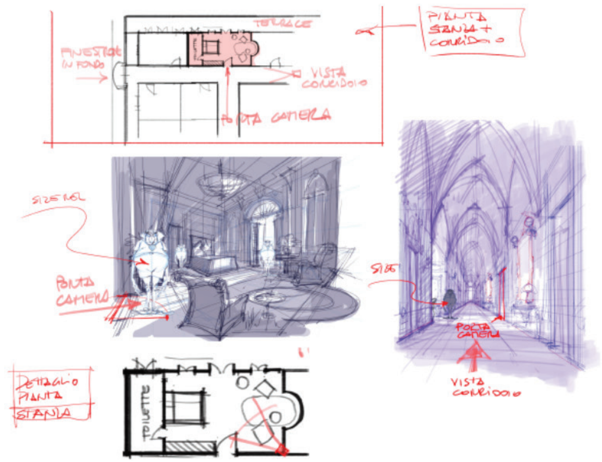
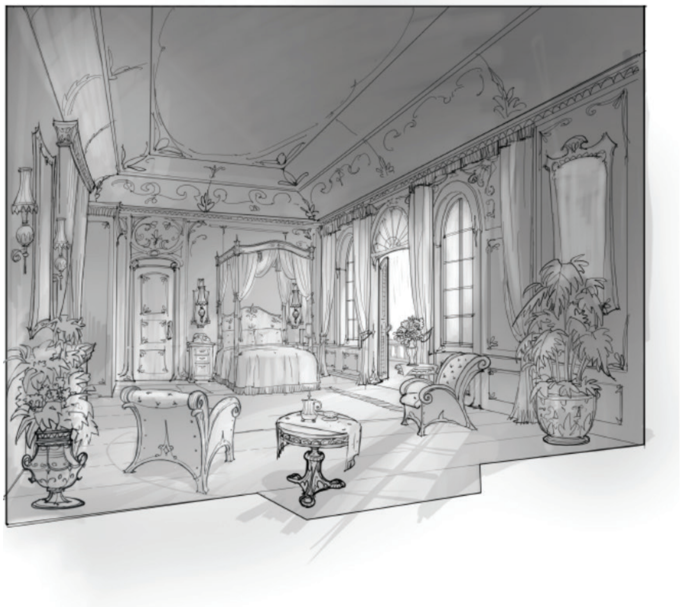
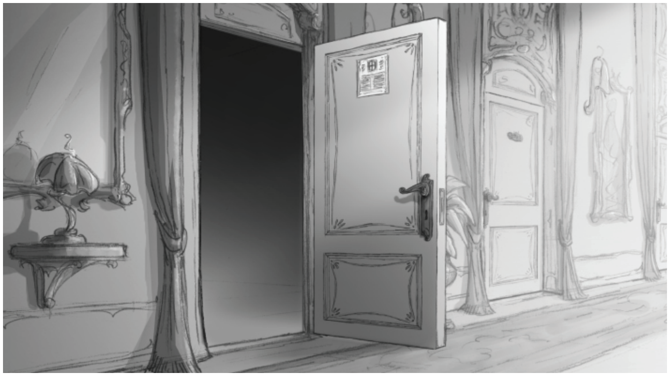


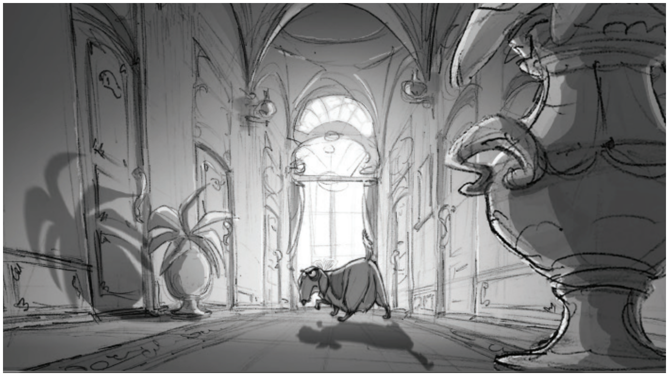


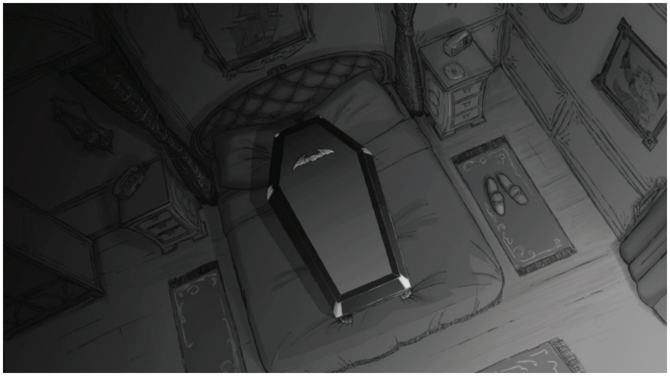
Backgrownd and style study **Tommaso Gomez**



the view of the Hotel front and for the interior design and visualisation of the lift area and the bedrooms. (Fig. page 47). One of the project sequences centres on Count Dracula's arrival at the Hotel; for this reason, it was necessary to carry out a detailed study of the entrance. Some illustrations were created early to explore a point of view and possible camera angles; once the look of the Hotel was finalised in a subsequent development, more architectural features were added to the sequence; in the image (Fig. page 41), it is possible to see the canopy that protrudes from the building without supports. Two cast-iron canopies of the same type, one in Florence and the other in Paris, were taken as a reference and then exaggerated in proportions to obtain the desired effect.
A coherent design approach that inserts Searle's style in characters or elements of the background is central to the project. It is present even subliminally in as many elements as possible. For example (Fig. page 41); depicts the study on the fountain located in front of the main entrance of the Hotel. The Greek statue of the Dancing Satyr inspires the first sketch; the second to the left is the image made by the set designer, who somehow maintains the posture and general line of action of the initial sketch and the final image that makes the female figures more of a Searle's character.
The first sequence of the film is set in a doctor's office. Typically, the work happens in a parallel fashion. The set designer needs to understand elements concerned with the perspective point of view to create a functioning composition that is then decorated with additional elements. The image features a document used to plan the buildings' interior, defining the place's geography used to plan the camera moves.
Fig. page 43 shows the environment of the Doctor's waiting room with various objects of the interior design of everyday use that makes it look "lived-in".
In this case, it is a rich scenography with many details that overpower a character. However, in this specific case, it becomes part of the film's storytelling, as it performs a specific narrative function by introducing the spectator to the office's atmosphere.







In the case of the exterior of the building Fig-XX, the designer deliberately chose to reference the poster of the live-action film *The Exorcist* (the short film *RunAway Brain* Disney 1995 also used the same ploy). In this case, the background plays with an added value to a subliminal reference to a well-known horror film. The image contains preliminary studies of composition, where lights and shadows are used as solid compositional elements. Reducing some parts of the background details facilitate reading and maximises the visibility of the action Fig. page 42.

For an animated short film, a sequence is often conceived starting from a central concept; Fig. page 48 is the visual exploration that is then divided into individual scenes through a storyboard. In this case, the sequence features a comical situation where the character must carry heavy suitcases for a long flight of stairs as the elevator is faulty. Once the succession of events has been established, it is advisable to plan the geography of the final set. Different parts of the upstairs floor plan are subdivided, like the corridor, the entrance, and the view of the room interior.

As production progresses, the designer may be called upon to develop elements in detail, which can be simple objects or parts of an environment that prove essential to the storytelling.

The elevator is one of the central elements of the atrium of the Hotel Fig. at page 45. It was initially only partially defined, but as the story evolved, it became a more critical narrative element needing a closed look. The basic idea is that of a central elevator around which a staircase leading to the various floors develops. The initial visual reference was the Hotel George V in Paris. However, the result did not meet the intended expectations, as this type of lift has a gate to access the cabin's interior, which would have complicated the story unnecessarily. An elevator whose door opens conventionally was adopted, with a door design reminiscent of New York's Art Deco elevators. We have therefore committed a geographical impropriety solely for aesthetic/storytelling purposes.

The image in Fig. at page 46 shows the detailed study and various iterations of the elevator. Other images show the design development of specific objects, in this case, the phone; through photographic references, in this case, a phone with an antique feeling was first used; this concept was then abandoned in favour of something slightly more modern like the example in Fig. page 50.

Conclusion

Designers in every field must assemble many inputs and reorganise them to suit the desired storytelling, whether working on a background for an animated film or designing an actual building. Both disciplines have in common the element of movement through space.
In this paper, we have presented a series of examples related to an animated short film that featured specific references to geographic and spatial elements and discussed how the study of locations and its implementations in a real-world example could successfully marry design intent, storytelling, and the study of architecture. The paper has discussed some examples where the interdisciplinary intersection between architecture and animation has established a connection with reality for the audience and further argued how the knowledge of architecture and art history has been employed in the past and present of animated cinema. In the future of the Digital Humanities disciplines, the interdisciplinary connections between apparently unrelated disciplines need the codification of methodologies that both scholars can adopt in the humanities and practitioners in animation and architecture.

Acknowledgement

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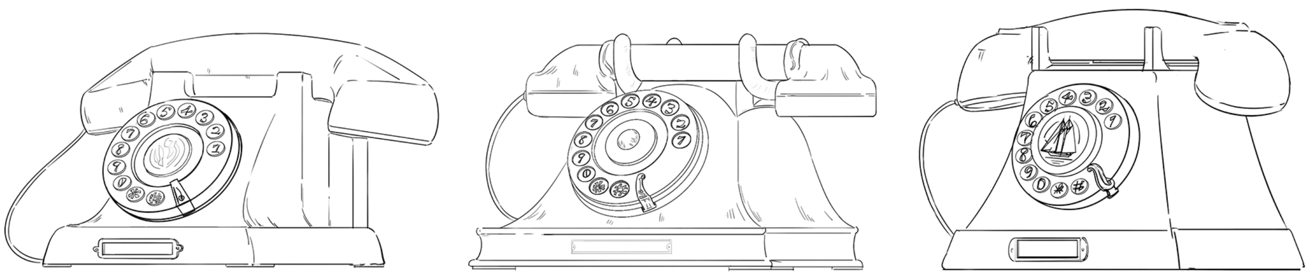
The author also likes to acknowledge the support of Nanyang Technological University (NTU) and the School of Art Design and Media (ADM) of Singapore.
All illustrations presented in the paper are a work in progress and preproduction work for the upcoming film "Summer Tale" and a covered by copyright. For references to the example highlighted in the first part of the paper, please refer to the site: https://animationbackgrounds.blogspot.com/.The article was first published in part in the book *Manuale di reppresentazione per il design* by Prof Stefano Bertocci 2021 DIDA Press. This article presents a substantial revision with updated sections and images.



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03 SPATIAL PERCEPTION IN ARCHITECTURAL PERSPECTIVES: VISUALIZATION THROUGH AR E VR SYSTEMS

Abstract

Those who observe a painted, drawn, carved, or sculpted perspective perceive three-dimensional spaces and environments that are not, however, present in reality. Similarly, the user using VR and AR systems perceives spaces and elements that are not physically tangible.
These technologies allow, through the use of three-dimensional models, to simulate scenarios and interactions with strong communicative power that introduce themes such as the perception of illusory spaces, thanks to their fundamental characteristics such as immersiveness and interaction, through which the user comes into contact with virtual scenarios.
The paper presented intends to reflect on this analogy, relating it to the suggestive aspect that quadratures could arouse in the viewer of the time, deceiving the eye and dilating space, and the interest that new technologies stimulate in the contemporary viewer.
This relationship allows us to make the most of the perceptual component of these experiences and to reflect on the contribution these technologies can have in the study of Architectural Perspectives.
This paper discusses some applications and consequent reflections arising from different case studies, which have different dimensional characteristics and made with different techniques.
In particular, it aims to bring to light the different types of interactions that the user can get from the use in new technologies if they are applied to the chosen theme. And again, understand how, through perceptual experience, illusory space can best be represented with the selected digital tools.
The use of these instruments for the study of Architectural Perspectives is intended to represent the innovative contribution that this study proposes, relating to the suggestive aspect that quadrature could arouse in the viewer of the past, deceiving the eye and dilating the space, and the interest that new technologies stimulate in the contemporary viewer, capable of astonishing and showing new realities.

Introduction

Perceiving space is a simple yet complex exercise involving the senses. This exercise is practiced every day and in every context because a right understanding of the environment around us is necessary. Therefore, when we are faced with systems that simulate spatial effects, our brain generates a response, which is always mediated by our experiential background.
This kind of response is obtained when looking at Architectural Perspectives[1], a figurative genre, which aims, through the use of perspective, to trick the eye by representing three-dimensional environments.
Just as perspective, which found its codification and wide use in artistic production in the Renaissance[2], aimed to surprise the viewer by deceiving the eye and arousing awe, Virtual Reality and Augmented Reality[3] also want to surprise the user by catapulting him or her into virtual scenarios (Fig. 1).
Because of the vast heritage that makes up the genre, case studies will be used that differ in their characteristics and peculiarities: the *Sala dei Centro Giorni* (Fig. 2a), painted by Giorgio Vasari in 1546[4], is a large frescoed room; created in the same period are the wooden inlays of the choir of San Domenico realized by Fra Damiano Zambelli (Fig. 2b), composed of individual images of more modest dimensions[5]; even smaller in size are those of the perspectives contained in Andrea Pozzo's treatise (Fig. 2c), which, by date is situated later in time, 1700[6].
The viewer observing live perspective images is strongly influenced by what their eye perceives as a dilated space, i.e., a virtual space; this also occurs in other similar ways in AR and VR applications in which the viewer is convoluted by virtual three-dimensional content. So, the purpose is to explore the relationship between quadratures and immersive systems, reflecting in particular on the perceptual implications they have.
But in addition to this function, the use of these tools, in the proposed research, aims to the investigation and deep understanding of the relationship between real and illusory space through the creation of a digital model[7] representing both (Fig. 3).

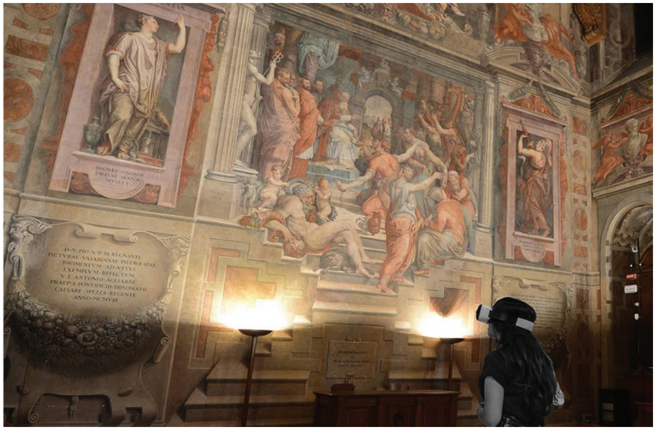
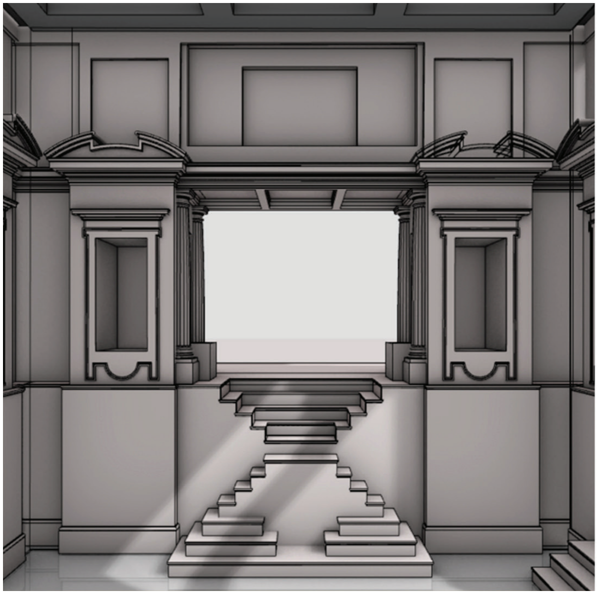
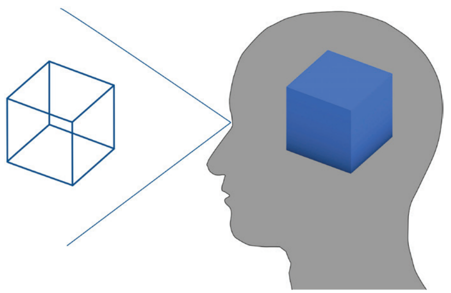


Fig .1 - The viewer inside the Sala dei Cento Giorni (left) and the user viewing the same Sala in Virtual Reality.
Fig. 2 - The works chosen as case studies: a) Sala dei Cento Giorni, Palazzo della Cancelleria, Rome; b) sixth inlay of the Dossal of the Choir of San Domenico, Bologna; c) Figure 81 of the second volume of the treatise Perspectiva pictorum et architectorum by Andrea Pozzo.
Fig. 3 - Three-dimensional model representing the perspective space of the case studies.



AR and VR for the study of cultural heritage

AR and VR technologies are part of the ITC a macro-group that includes the set of information technologies; but more specifically they are part of those immersive technologies that focus on the user experience and we find them along with other types of tools such as Spatial Augmented Realty, Video Mapping, and Mixed Reality just to name a few[8]. These tools are in the context of Cultural Heritage conventionally and increasingly used for communication and valorization phases. AR and VR make it possible to simulate scenarios and interactions with strong communicative power that introduce themes such as the perceptual contribution of the viewer to the artworks. This is because their key feature is the immersiveness and interaction through which the user comes into contact with the virtual scenarios. Neurobiology states that the nervous system developed as a response to input from the surrounding environment[9]; the objects around us we see through countless perspectives, under different lighting conditions and at ever-changing distances, nevertheless, we are able to understand their absolute form because it is the mind that actively contributes in vision by providing "added value" to the images we receive from the outside world. A similar process happens when viewing two-dimensional images, whether painted or drawn or the result of virtual projections, that simulate three-dimensional spaces (Fig. 4). Just as the artist knows that they cannot take for granted the understanding of the imagined space in their mind and therefore must always reiterate it, through visual method[10], in the same way those who approach the use of new technologies must always take these rules into account for effective perceptual impact. Much has been written[11] about the use of these technologies applied to Cultural Heritage by framing the topic and emphasizing the potential that these tools have with in the communication. There are many researches that make use of these tools for the representation and enhancement of Cultural Heritage, such as the work done on the basilica of Santa Maria di Loreto[12] in which different strategies are introduced to delve into different aspects of an architectural monument; in this study different technologies are used to highlight, in a systematic and visual way, information of various kinds. Or again, in the work[13] done on the Scoletta del Carmine in Padua, the potential of different Virtual Reality tools are tested, with different degrees of immersiveness, on the painted perspectives within the environment. The two systems presented possess different characteristics in terms of the degree of immersiveness and thus in the way one interacts with and perceives the dilated space (Fig. 5).



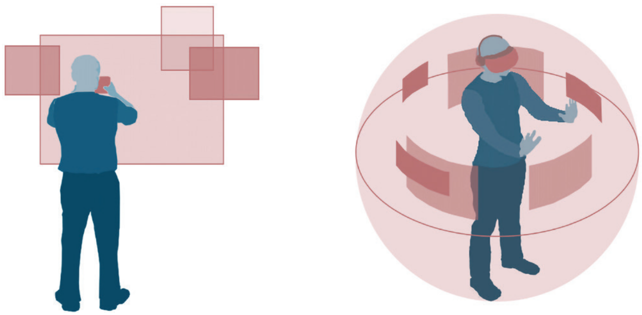


Fig. 4 - A two-dimensional image can be interpreted as three-dimensional.
Fig. 5 - AR systems (left) have low immersiveness compared to VR systems (right), because in the latter case digital content surrounds the user.

Perception in AR systems

The quadraturist work, with its different levels of reading, makes it possible to study the relationship between two-dimensional and three-dimensional elements, as is the case, for example, in experiments that make use of Augmented Reality, overlaying the two-dimensional perspective image with the three-dimensional model it represents. Taking advantage of this type of technology and associating it with architectural perspectives, the relationship between 3D information content and target becomes fundamental, the latter represented by the work itself becoming part of the model, without which the information content would lose relevance. The perspective image used as a target represents an added value in this reading: the use of the target is no longer just a recognition marker, whose function is therefore no longer just relegated to the orientation of the digital content with reference to the camera.
In systems that exploit Augmented Reality, interaction is always mediated by the device that stands between the real environment and the augmented experience. In this case the user manages the point of view with which the models are shown and visual contact with the source work is possible, which in the analyzed cases becomes the activating target of the technology. The three-dimensional model arises from the perspective image and is in continuity with it and is its spatial transposition. This reinforces the link between perspective and AR that sees the centre of projection as the virtual chamber, the picture plane, on which the image is formed, as the target, and the model as the augmented content (Fig. 6).
On this we can reflect on the position of the model with respect to the picture plane, which in the classical perspective can take on infinite positions, but which we can trace back to three cases, whereas in the default AR the model always projects in front of the target (Fig. 7).
In order to achieve a perceptual effect similar to the second case, in which the model straddles the picture plane, it is

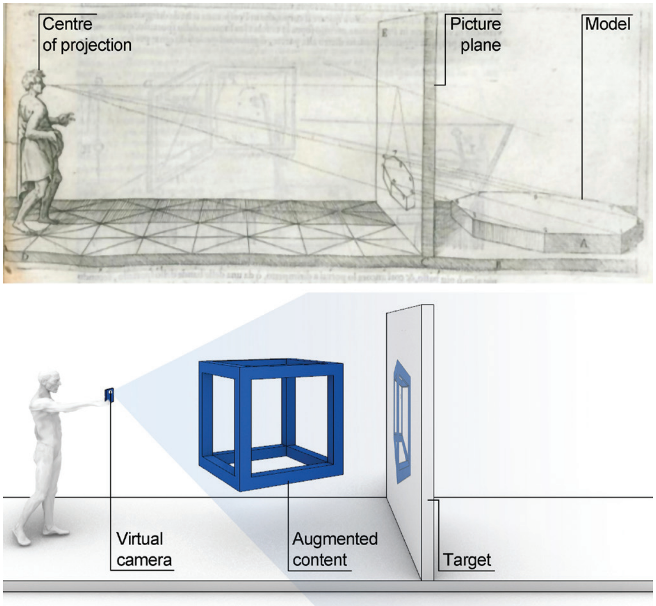


Fig. 6 - Comparison between perspective (top) and Augmented Reality (bottom).

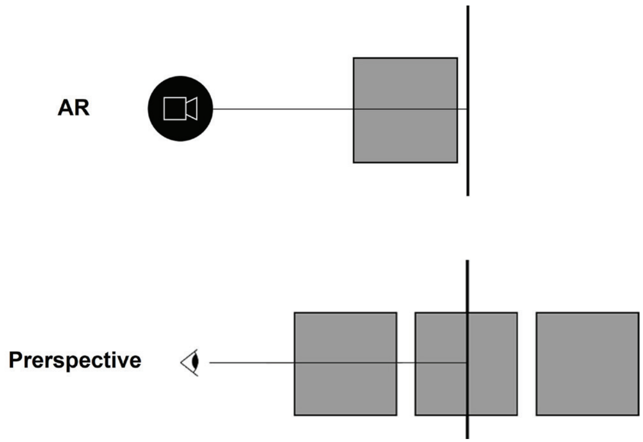


Fig. 7 - Comparison of spatial configurations: in perspective the model can be ahead or behind the picture plane, in AR it automatically projects in front of the target.

possible to integrate parts of the target into the virtual model so that they serve as a perceptual reference. This occurs in the *Sala dei Centro Giorni* model in which the parts in the model coincident with the partitions have been textured, in the true-form parts where the model is on the picture plane. This allows us to perceive the staircases in front of the target and the scene behind (Fig. 8).

Again in an inlay of the choir of San Domenico in Bologna, the urban scene seems to unravel within the wooden framework of the backrest. Without modification by projecting Augmented Reality the model would seem to come out of the perspective image. In this case, in addition to integrating part of the target within the model, the backside was screened as is done in photographic sets and a front screen was created that extends beyond the frame (Fig. 9).

These two strategies thus make the impression that the model of the urban scene develops beyond the frame. The sense of perspective breaking through is thus possible if one fully exploits the relationship with the target by integrating parts of it within the model (Fig. 10).

Fig. 8 - AR experiment on the Sala dei Cento Giorni.

Or the experimentation conducted on figure 81 of Andrea Pozzo's treatise, which through AR makes explicit the perspective decoding by revealing the position of the observer in space. It is possible to exploit the potential of the tool by designing interactions that allow the user, once the device is placed in the centre of projection, to appreciate the collimation between perspective image and three-dimensional model (Fig. 11).
Augmented Reality represents an overlay of content of the existing reality. In this case, the "additional" information that is added to the reality of the work will be precisely those contents processed by means of the interpretative phase and in particular the relationship between the two-dimensional image of the fresco and three-dimensional space restituted.
If Augmented Reality always maintains contact with reality, so it has a type of interaction that is not very immersive, Virtual Reality is the type of technology that guarantees the gratest immersiveness and is able to involve to a greater extent the perceptual aspects in the observation of perspective images and three-dimensional models.

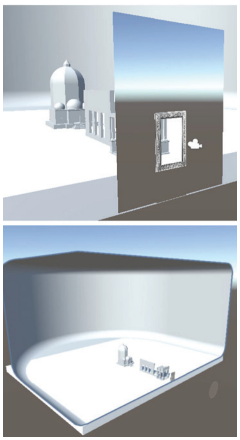


Fig. 9 - Stratagems used to simulate perspective breakthrough.
Fig. 10 - AR experimentation on the inlay of the choir of San Domenico.

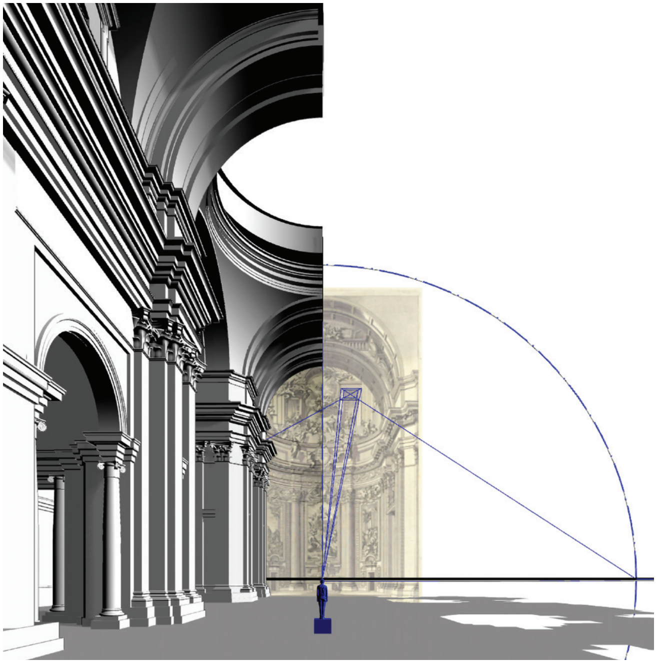


Fig. 11 - AR experimentation on the page of Andrea Pozzo's treatise.

Perception in VR systems

Speaking of VR refers to a type of immersive technology, enjoyed through a visor, glasses or helmet, with which it is possible to observe virtual environments with a 360-degree view. Two types of experiences can be distinguished; the first exploits panoramic images and the second allows spatial interaction within a three-dimensional model.
Both systems, however, are mediated by the use of a visor. This element generates a series of reflections related to the perceptual aspect: basically, the type of technology tends to want to trick our brains, and for this reason there can often be a feeling of estrangement or disorientation for the user; the experiments conducted also reflect on this aspect.
The *Sala dei Cento Giorni*, due to its characteristics, i.e.,

perspective images surrounding the viewer on the four walls, is the perfect subject to conduct the experiments and test the differences between the two systems.
The features focused on during the applications are the particular characteristic of the *Sala*: it, in fact, has a very high horizon compared to that of a viewer. This aspect strongly influences the perception of the painted architectural space because when observed, the planes that our brain would like to interpret as horizontal appear slanted to us (Fig. 12).
For this purpose we make use of two versions of the three-dimensional model of the illusory spaces. Thus obtaining two models: a realist one, more closely matching an ideal model, and a surrealist one with slanted planes, more similar to what the user of the room perceives in the frescoes (Fig. 13). These two versions of the model subsequently were visualized through VR systems to understand the different perceptive implications.
Obviously, perspective is the method most comparable to human vision; the VR comparison becomes immediate in which the viewer is tricked by an image that simulates the sensation of being in a three-dimensional environment.
Thanks to the use of 360° images, acquired on site and digitally created with the help of the three-dimensional model, it is possible to experiment in Virtual Reality, the perceptive aspect that the observation of the perspectives and the model of the illusory space causes in the viewer in different notable positions.
The experimentation consists of setting up a panoramic tour through specially created spherical images, each with the purpose of highlighting specific reflections on aspects of the *Sala*: the possibility of observing and comparing different configurations, moving from one version to another in which the different models replace the frescoes allows for a deep understanding of the relationship between the parts. Or again, it is possible to observe the models and frescoes from certain points of view, such as from the viewer's height or the horizon height of the perspectives (Fig. 14).
What is noticeable is that the VR project with panoramas needs a clear reference system for navigation to help the user not only move from one configuration to another but also to predict the

Fig. 12 - The horizon of the painted perspective, in red, and the horizon of an observer in the Sala, in blue.

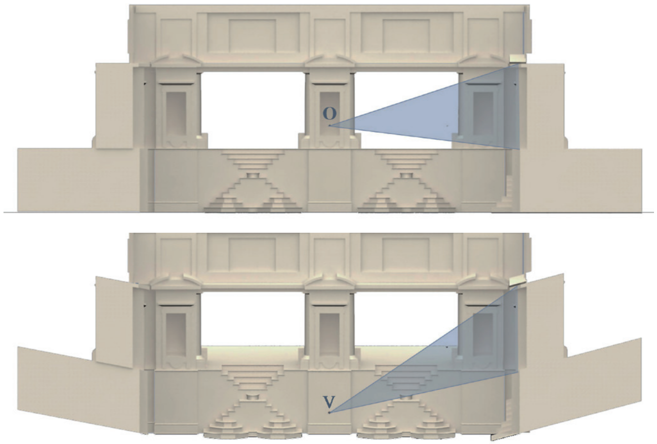


Fig. 13 - Realist and Surrealist model of the Sala dei Cento Giorni.

simulated movement, or change in the model that interaction with hotspots produces.
In this type of system, since these are static images, focusing on details or certain aspects is favored. Even by graphically editing on panoramas (Fig. 15).
Then there are the dynamic VR applications that take advantage of real-time rendering technology to be able to navigate three-dimensional models; in this case the user, in addition to wearing a visor, is also equipped with sliders or joypads that allow them to manage movement within the model. Interaction is greater

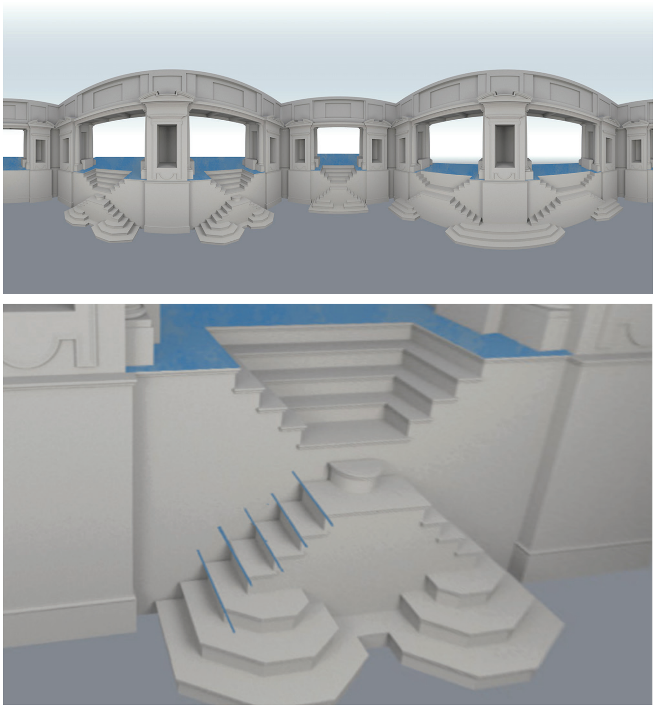
Fig 14. Panoramic exploration of the Sala, the image shows a configuration in which the model of a wall is inserted into real space.

Conclusions

The decision to exploit the potential of these two technologies, AR and VR, is motivated by the recognition in these tools of a direct connection with perspective: both are obviously related to the concept of projection, but in addition, Augmented Reality has similarities between its elements (camera-centre of projection, target/picture plane) that it is useful to deepen and highlight or again in Virtual Reality where the because it is possible to move within the digitally created space, thus allowing for multiple points of view (Fig. 16).

By navigating the realist model at the two altitudes, it is clear how at the viewer's altitude the horizontal plane in which the scenes take place would not be visible. Although the second assumption is more fitting with the painted perspective images, the viewer has a strong sense of estrangement because they perceive that they are walking on an invisible plane or possess an unrealistic height.

On the other hand, if one wants to try to climb the sloping steps of the surrealist model this will not be made easy by the system that simulates physical laws to mimic the effect of gravity. The realist steps, however, are walkable, coming to observe the illusory space model as if the user were one of the characters in the stories.



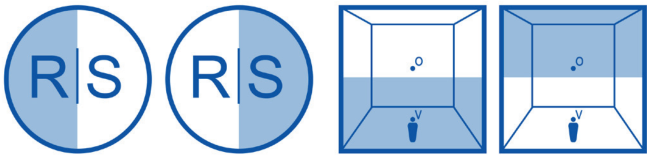


Fig. 15 - Graphical elements that aid in the perception of the navigable models.

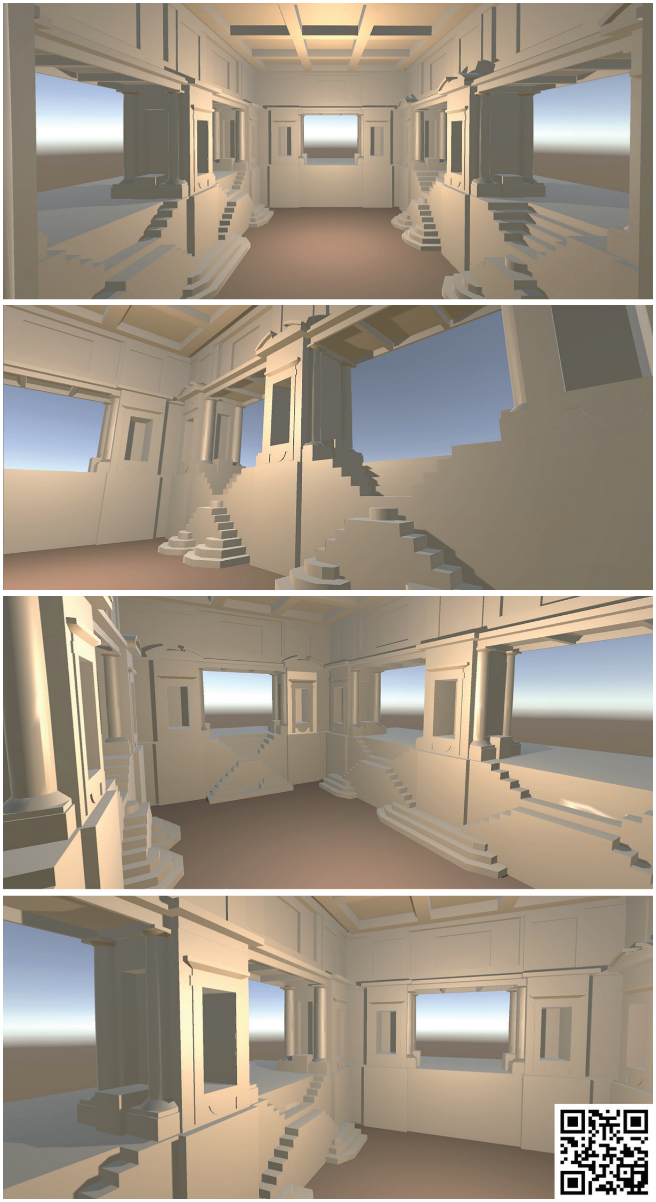


Fig. 16 - Views of the model exploration in real-time mode.

role of the observer- centre of projection can be deepened. These experiments are strictly designed to interpret and provide new keys to interpret the architectural perspective, therefore, not posing themselves with the sole purpose of valorization, considered as the final and communicative phase of the whole project, but mainly as a tool for understanding the phenomenon, allowing to explore, in the true sense of the word, and to interact, although this is done virtually, with the different instances of the works under consideration. In conclusion, we can say that Virtual Reality and Augmented Reality have suitable characteristics for the exploration of architectural spaces, but the perceptual implications of the applications need to be kept well in mind. In addition, it is shown to be necessary that the perspective characteristics of the works be well understood to create efficient applications.

Notes

[1] Valenti, 2014, 2016.

[2] Camerota, 2006.

[3] Li et al., 2018.

[4] Fasolo, Mancini, 2014.

[5] Fasolo, Camagni, 2020.

[6] Fasolo et al., 2021.

[7] The models presented in this contribution are obtained by prospective restitution. For a more in-depth discussion on this methodology, see Inzerillo 2014.

[8] Of course, with technological advancement, the definitions of these technologies are becoming more and more blurred, and often the various experiences overlap.

[9] Casale, 2018.

[10] Arnheim, 1986.

[11] Among the many, they include Ippoliti, Meschini, 2010 e Luigini, Panciroli, 2018.

[12] Rossi, 2018.

[13] De Rosa, 2020, p. 225.

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04 REVEALING THE INVISIBLE: DIGITAL SIMULACRA AND VIRTUAL USE OF LOST ARCHAEOLOGICAL HERITAGE

Abstract

After more than two decades of debate, nowadays, scientific research in the field of archaeology involves not only the application of the natural sciences but also the support of the latest information technology. As a result, archaeological excavations and virtual archaeology have become part of a unified methodological and cultural process, enabling the production of numerous digital outputs, thus providing a clear understanding of the data obtained from excavation campaigns. Focusing on the topic of archaeological representation, the contemporary scientific debate is currently addressing the development of an accurate methodological protocol regarding the implementation of digital visual simulation of antique contexts. The critical issues related to the digital representation of archaeological contexts are heightened in the case of "invisible landscapes", that are no longer accessible or no longer exist and whose documentation took place in recent times carried out through analogue tools and under emergency conditions.

Digital models, used as valuable cognitive tools, complemented with the latest immersive virtual reality technologies, provide the opportunity to recreate and explore an archaeological excavation whose placement within its original landscape is no more visible, as it belongs to a dynamic environment that changes over time. The greatest challenge lies in understanding these transformations and in the digitally graphic translation of the archive material, which is not always spatially and temporally relocatable within the original scenery. The activity of graphically synthesising information is aimed at defining new communication strategies for the narration of inaccessible sites through the development of virtual applications whereby drawings and textual content become interactive. As a result of the operational workflow, the digital product is not just a mere representation in a virtual world but becomes a valuable tool for further research, as well as for promoting awareness and reconnection with the past by imbuing the space with new meanings.

Introduction

Archaeological areas and ancient artefacts have an important role in the definition of the historical evidence of a land, so much so that *archaeological sites and museums are considered places where historical and artistic memory is preserved over time [...] contributing to the dissemination of knowledge*[1]. The cultural relevance of archaeological heritage requires the scientific community to constantly and continuously reflect on the subject of its representation and the use of drawing as the main tool for codifying evidence of the past, so as to make it *from imaginary to existing in our understanding*[2]. At the same time, documenting and transforming heritage components into data useful for its management and preservation is part of a digitisation process that is constantly renewed by technological development. Documentation of archaeological heritage is a useful tool for both the acquisition of information and its evaluation based on logical reading and reconstruction criteria. The data acquisition and processing methodologies applied are changing and transforming thanks to the possibilities offered by digital technology. (Fig.1) The development of new technologies makes it possible to obtain increasingly reliable data, from a metric and qualitative point of view, as well as to plan and organise databases according to the management and enhancement purposes of the site. In this way, the descriptive potential of archaeological contexts manifests itself in the realisation of parallel scenarios and alternative modes of use, especially when dealing with sites in a fragile condition or when their knowledge is fundamental to the understanding of the evolution of the urban fabric in which they are located. (Fig. 2)
Unfortunately, current documentation practices do not fully meet the needs of representing heritage that has evolved and changed over time, or environments that no longer physically exist and are only known through historical descriptions or illustrations. This type of invisible heritage, identifiable for archaeological sites of minor relevance or of which little

Fig. 1 - 'e-Archeo' project, promoted by the Ministry of Culture and ALES S.p.A., in collaboration with several Italian universities and CNR (Italian National Research Council). https://e-archeo.it/.

information is available, is part of the many archaeological contexts in which systematic or occasional investigations have made it possible to document and recover a small part of the architectural, artistic, historical and sometimes archaeological traces. This is due to several heterogeneous aspects of the archaeological documentation: the complexity of ancient contexts or the very nature of the material collected during excavation campaigns, which is often heterogeneous and not perfectly preserved. [Christillin, Greco, 2021]. Moreover, the recovered archaeological data is not always matched by full public enjoyment, as it is often limited or completely impeded [Giannotta et al., 2014]. The result is a fragmented or absent type of information, completely inaccessible and totally unknown. The resulting invisibility contrasts with the cultural and informational value that an archaeological site should have and highlights the need to define a new form of communication related to the representation and reconstruction of invisible contexts. The structuring of a method to narrate through digital visual simulation systems the dynamic context of an excavation of which few traces remain has been one of the objectives related to this area of research. It is important to develop a graphical model that makes explicit the interconnectedness of the data used for the reconstruction of fragmented or destroyed archaeological contexts, making explicit the disappeared landscape. (Fig.3).

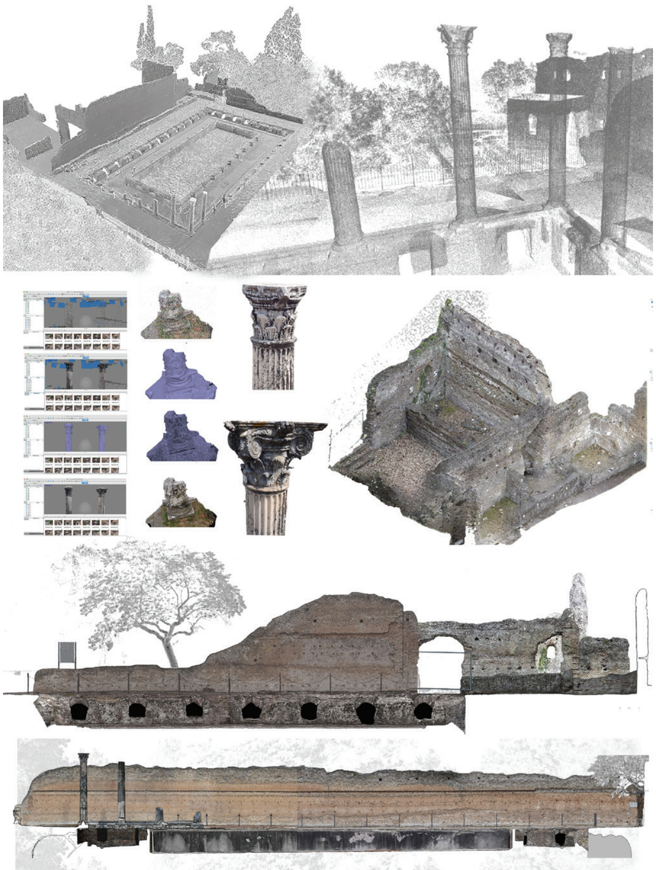


Fig. 2 - The documentation project by University of Pavia, University of Florence and University of Bologna for the digital representation of Hadrian's Villa, Tivoli.

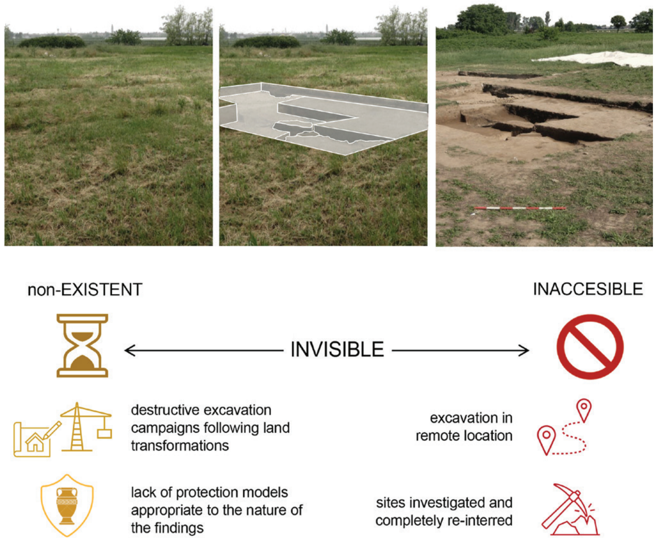


Fig. 3 - Inaccessibility and non-existence of archaeological sites.

Three-dimensional models as knowledge and representation tools

Digital technologies used in the field of heritage representation have radically changed techniques and tools derived from centuries-old drawing traditions. Digital plans and sections have taken over from perspective representations, providing a new medium through which to construct three-dimensional digital models. *In the process of visual transposition, based on the use of digital tools, drawing loses its expression as a direct consciousness of the sign because the meaning goes beyond the graphic matter by incorporating algorithms and graphic libraries of objects, defined through categories and parametric data*[3]. While previously three-dimensional representation was left to the use of perspectives or material models, from the 1960s it became possible to replace these iconic forms of three-dimensional representation with views of digital models, despite the fact that the processes were still limited by the calculation capabilities of the computers of the time. *With the introduction of digital modelling, the way we see objects and their representations has changed. [...] The introduction of 3D digital models links drawing even more closely to construction, first verifying it in a virtual environment and then allowing the operator to carry out the necessary verifications in a desktop environment; in this way drawing once again becomes an experimental synthesis between imagination and image formation that, by overcoming the barrier of reality, opens up a new way of thinking and thus of building*[4]. In this digital context, a new evolutionary process in the representation of architecture is emerging, still in progress, which aims to re-examine the role of drawing through the use of digital three-dimensional models as tools of figuration and knowledge[5]. *For knowledge is not simply perception, just as perception is not simply described by representation. The modelling process, i.e. the model, could be understood as one of the possible ways of replacing reality in perception with a more complex element*[6]. Modelling therefore means representing reality as a structured reproduction, both on a subjective and standardised level. (Fig. 4). From this it can be deduced that the iconic, perceptive and geometric value of a space or object is only consolidated when their representation is transformed into a vehicle of information: in the specific case of three-dimensional representations, when the characters of materiality, spatiality and volumetry can be understood through the development of a model. In the last twenty years, digital three-dimensionality is one of the key features of the communication and information trend. Thanks to the use of three-dimensional models, the

Fig. 4 - An early form of enhancement of representational tools is related to the development of CAD software, which, acting as electronic drafting machines, are used to produce digital drawings and models. Basilica di Siponto, Project by Edoardo Tresoldi, 2016.

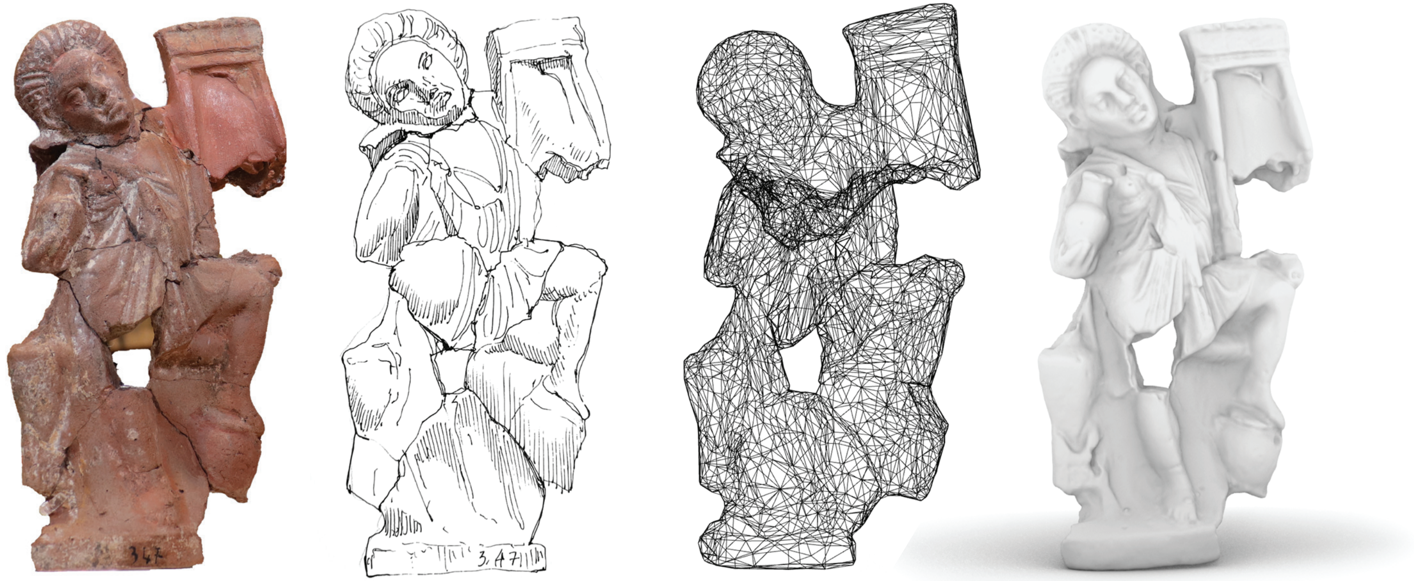


Fig. 5 - The use of three-dimensional models as visual symbols and vehicles for the transmission of graphic information characterises many interventions related to the enhancement of cultural heritage, confirming how virtual systems take on new meanings and functions, amplifying the value of the information potential of the resulting applications. Above, different representation of an ancient artifact of Arpocrate statue.

aim is to recover the cognitive structures that characterise knowledge processes, connecting the cognitive aspect with the emotional one, finally overcoming what Arnheim called *the pathology of Western thought*, the split between abstract concepts and the visual elements that produced and accompany them[7]. For this reason, it is through the in-depth study of issues related to three-dimensional digital representation that it has been possible to develop descriptive geometric representations as tools for reconstructing an archaeological context that is no longer accessible (Fig. 5). A reconstruction is not only represented as a simple animated image that brings distant epochs back to life, but becomes a cognitive tool that allows, starting from the archaeological datum, to build a particular connection with the past. [Pietroni, Ferdani, 2021]. Therefore, a digital model can become a mediating space, constituting itself as a representation of an archive of heterogeneous information, becoming a participatory tool in which the curator, the artefact and the user are in dialogue with each other. In this dynamic process, the digital model becomes an element that formalises interpretations and moments of the past and accompanies archaeological science in its active role of mediation between discovery, material remains and society, responding to the first real need in the care of archaeological heritage: to stop the inevitable and constant process of decay and disappearance through tools of representation and knowledge. (Fig. 6).

Digital modelling procedures and experiences: from reality-based models to reconstructive methodologies

If three-dimensional digital models can be considered as a meeting point between the worlds of Representation and Simulation, then all methodologies leading to the creation of such models can be considered as a field of experimentation and research for the improvement of knowledge and analysis of the invisible heritage. Unlike digital documentation methods with reality-based techniques, from which it is possible to reconstruct the geometric and material complexity of any existing artefact, the application of virtualisation methods of something that no longer exists presupposes the application of a different type of operational workflow. An in-depth a-priori analysis of the historical and iconographic information of the asset is required, as well as the archive of data obtained from the documentation phase, integrated with the use of the rules of architectural representation modified according to construction techniques[8]. While workflows for virtual reconstructions of existing objects are mostly technologically or logistically demanding, a virtual reconstruction of objects that no longer exist adds tasks such as interpretation and inclusion of historical, documentary or photographic sources. The digital model obtained at the end of the reconstructive modelling process is a representation that can be easily modified, depending on the variations proposed by experts in the various fields. Moreover, the resulting flexibility allows the model to constitute itself as the starting point for a new process of shared knowledge.

Regarding reconstructive practice, modelling techniques depend on the archival data on which the reconstructions are based. In general, 3 macro-areas of application can be defined[9]:

1. Reconstruction from a comprehensive digital archive containing three-dimensional databases of point clouds and photogrammetric 3D models, supplemented by digital drawings of plans and sections. [Picchio et all, 2022]. In this specific case, the reconstruction of the excavation is considerably advantaged, even though there are considerable problems in managing the huge amount of data collected during the excavation campaigns and in the digital representation of the multiple documented phases, which are often overlapping (Fig.6). To provide adequate digital support for the specific project objectives, the modelling process was supplemented by post-production and reverse modelling activities that ensured an easily usable, metrically and morphologically reliable and constantly updatable final product (Fig.7).

Fig. 6 - The large amount of data that characterises any archaeological investigation has led to the extensive use of digital systems for the documentation, management and cataloguing of archaeological excavation data, aimed at a comprehensive understanding of the data. Thanks to the integrated survey methodologies between digital Terrestrial Laser Scanner systems and SfM photogrammetry techniques, the reading of stratigraphies is more organic and efficient, providing the possibility of reconstructing excavation volumes, surfaces and structures in three-dimensional space.

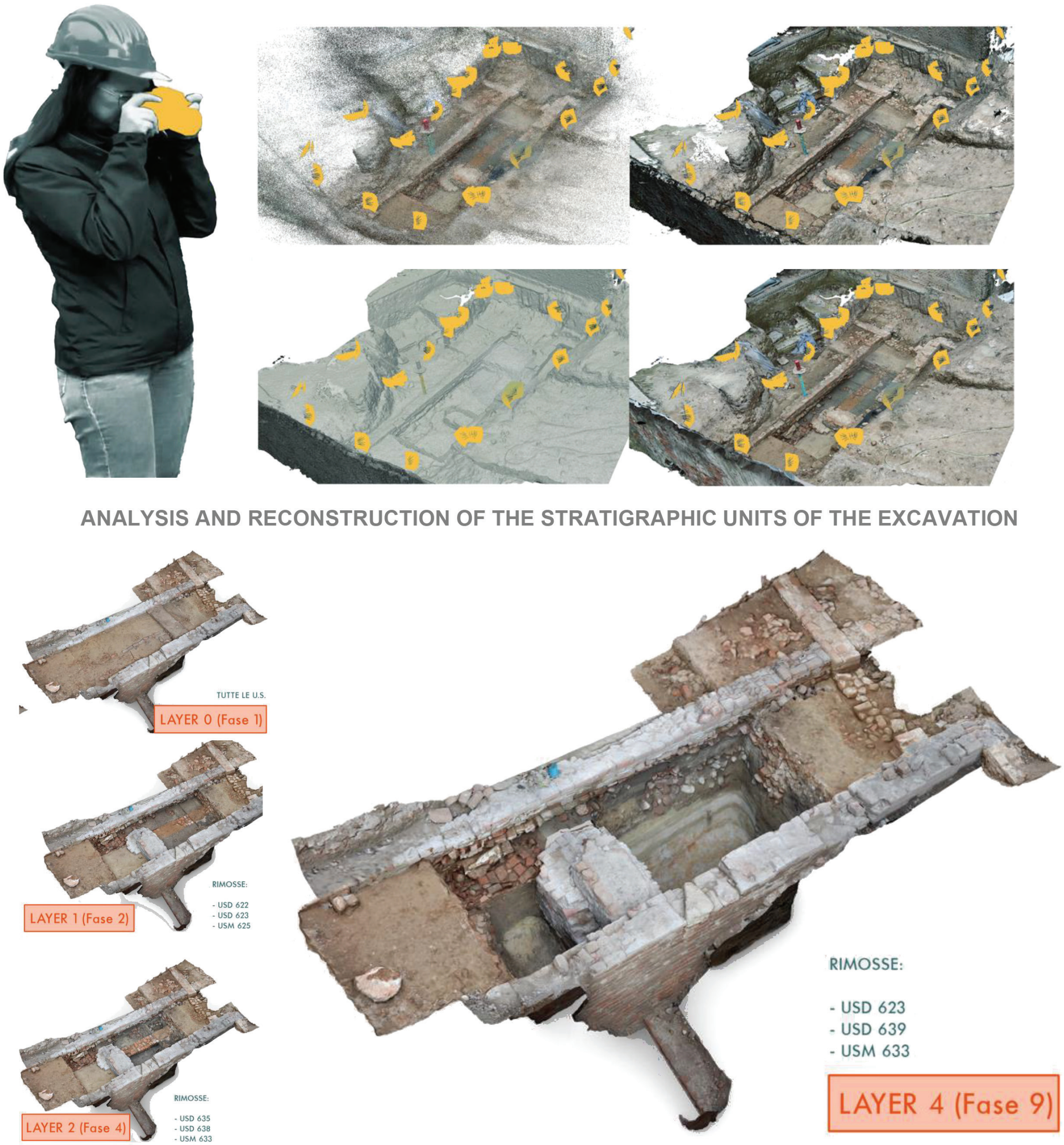


Fig. 7 - The three-dimensional outputs resulting from the integrated documentation activities provide a highly descriptive reading of the excavation phases, from which more information related to the geometric, chromatic and material characteristics of the archaeological artefact can be understood and evaluated.

2. Reconstruction from a partially complete digital archive, consisting mainly of documentary photographic images, not acquired for the purpose of photogrammetric modelling and digital drawings of plans or sections [Galasso et all, 2021]. In this specific case, the reconstruction of the excavation took place according to different operational phases, which allowed the extrapolation of an outline three-dimensional model from the two-dimensional drawings through extrusion actions of the polylines and curves of the vector drawings. The result was an outline model that allowed an easier understanding of the site and the excavation phases thanks to an unprecedented visualisation of the same in three dimensions (Fig.8). The overall model supported the visual description of the excavation process and the documentation of the archaeological site, highlighting the continuity of the structures present in the subsurface at different depths and facilitating the understanding of the excavation activities that took place over time.

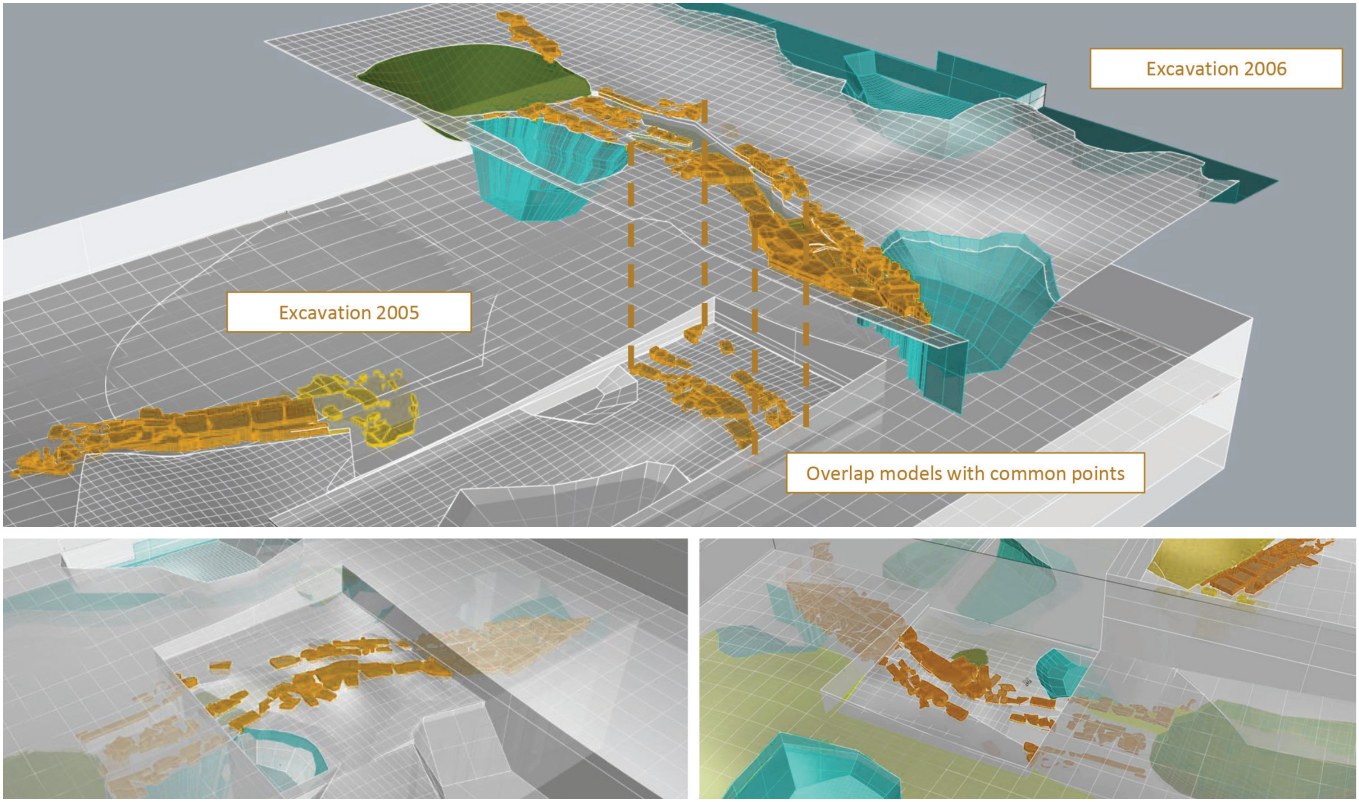


Fig. 8 - At the end of the processing of the individual elements modelled for each excavation campaign, the alignment and overlap within a unique management system have been prepared. The common homologous points between one excavation and another have been used to refer individual models on a single digital platform to define the Stratigraphic Units. This made it possible to obtain discreetly reliable and plausible overlaps from a volumetric and spatial point of view of the entire excavation.

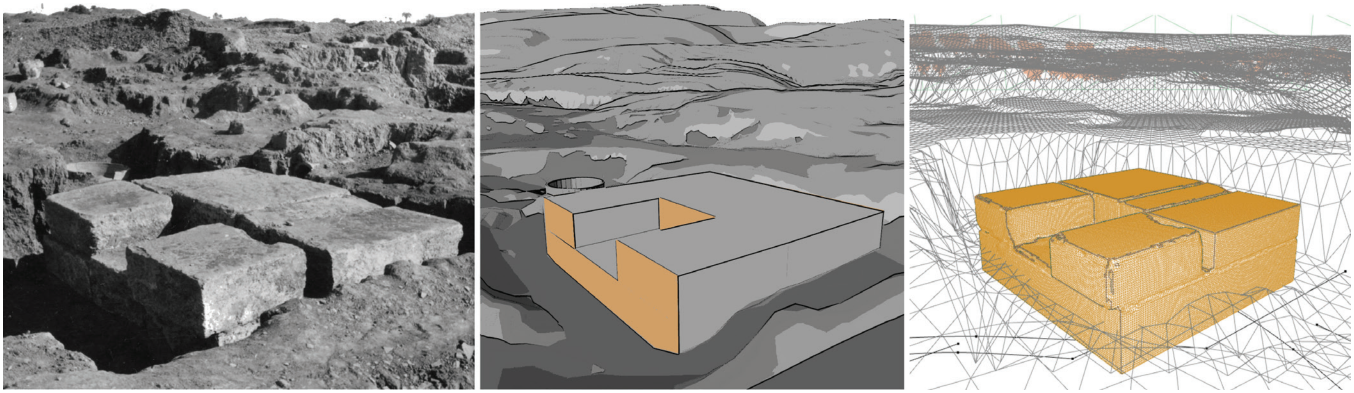
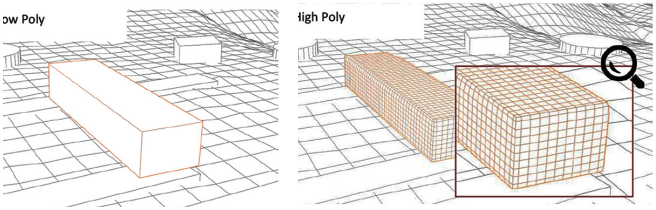


Fig. 10 - Views of the excavation model, obtained from both detailed digital sculpting of structures and extensive digital sculpting of the entire area.

3. Reconstruction from an incomplete non-digital archive, in which there are analogue photographic images documenting the excavation, but no details of the structures, most often in black and white, and unreliable graphic drawings, mostly drawn up by hand without the aid of digital tools [Parrinello et all, 2022]. In this specific case, the rough model was developed through extrusion actions from the graphic drawings (Fig.9). The compound model was detailed at a later stage through digital sculpting actions based on the analogue photographic images. In particular, each image of the archive was broken down into three levels of depth: the first floor, in which the excavation structures are present, the second floor, identified by the main volumes and the



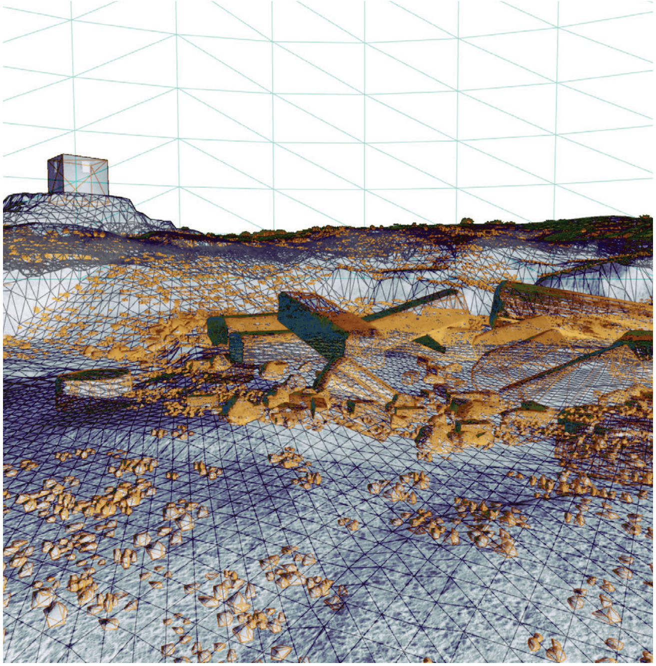


Fig. 11 - The definition of levels of detail appropriate to the archive data made it possible to obtain a multi-scale representation, with different levels of modelling depth depending on the interpretation of the source information and the purposes to which the model must respond.

Fig. 12 - View of the integrated model of the different levels of detail, from the architectural scale to the excavation area.

Figg. 13-14 - Three-dimensional reconstruction of the excavation of Arsinoe, destroyed following the urban expansion of the city of El-Fayuum, Egypt. The virtual excavation becomes a new place to rediscover archaeological finds, excavation activities and, finally, the history of the area.

surrounding terrain, and the background, i.e. the landscape skyline. Thanks to the presence of some landmarks easily identifiable between different images, it was possible to optimise the digital sculpture of the rough model, matching it to the different angles and views available with virtual cameras. The result is a model that reproduces in three dimensions only what was represented by a photograph. The listed methods of representation can be integrated and organised according to multiple levels of detail, emphasising the potential of three-dimensional models: the representative comparison of metadata between 'real' and 'virtual' space is directly re-presented through a 3D digital info-graphic container [Galasso, 2022]. Thanks to the use of three-dimensional models, the physical space is drawn through new communicative languages, promoting the development of a critical reading of its forms and relations to arrive at a synthesis of the information necessary for its representation and use on interactive platforms (Fig.10).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Conclusion

The ability to spatially configure 'lost' environments defines a new frontier of technologies related to visual communication. This happens not only because of the communicative power of an increasingly dematerialised and 'mouldable' design in its digital form, but above all because of the ability to produce outputs that are characterised within digital spaces. This process of digital reconfiguration generates new approaches to the interaction between the individual and space and, consequently, a new demand in terms of products and performances related to digital communication. It follows that the use of digital applications for the three-dimensional reconstruction of invisible archaeological contexts represents an extraordinary means of research, promotion and enhancement: it highlights the potential of perceptive knowledge, contextualising and reworking spatial information and mental maps. In this way, the infographics obtained during the excavation operations and the models elaborated in the post-production phase will not only consist of photo galleries and reference sheets, but will constitute a significant support for the representation and understanding of environments that can only be restored through a virtual configuration. (Figg. 11-12). The integration of the different outputs, combined with the development of an interface dedicated to the visualisation and interaction between the user and the digital space, will allow the design of an application through which different levels of in-depth content can be accessed. Through these content modelling and utilisation strategies, discretized digital products take the form of a new form of visual translation of processed information. The user is offered the opportunity to interact with multimedia products that become containers of new realities, making the process of information and investigation more engaging and stimulating (Figg. 13-14).

Notes

[1] Cit. Ragni, 2008, p. 6

[2] Cit. Hookk 2014, p. 647

[3] Cit. Amoruso, 2012, p. 93.

[4] Cit. Garagnani, 2008.

[5] In the field of design, the model, or maquette (Maldonado, 1992), is used to see the development of buildings in advance and makes it possible to assess not only the architectural validity, but also aspects related to the composition of spaces and their perception. The function of the model is no longer only to represent and communicate a project, but also takes on a simulative value.

[6] Cit. Garagnani, 2008. Referring in some respects to the theory of images described by Edmund Husserl in his Fifth Quest for Logic, in his work the Austrian philosopher and mathematician moves his critique against representation in the sense of depiction, placing himself in direct opposition to those who claim that the image or sign of a real subject is, in certain circumstances, exactly corresponding to the image that individual consciousness possesses of it.

[7] *Perhaps the real problem was more fundamental: a split between sense and thought, which caused various deficiency diseases in modern man*. cit. Arnheim, R., 1969. p. V

[8] *Any architectural reconstruction always starts with clues, which may be of varying complexity: sometimes there may be remains, the presence of ruins, the guidance of drawings or accurate representations, such as photographs, archival documents and written descriptions.* Cit. Verdiani, 2017

[9] The reconstructive practices listed are sketchy and in continuous development. In particular, the contribution presents case studies of inaccessible or destroyed archaeological excavations related to research projects conducted within the DAda-LAB research laboratory of the University of Pavia, in collaboration with multiple national and international organisations and institutions.

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05 PROJECT AURA:

ACOUSTIC SIMULATION OF THEATRE HALLS FROM DIGITAL SURVEY TO VIRTUAL RECONSTRUCTION

Abstract

The issue of acoustics is an increasingly debated topic in the fields of digital documentation and Cultural Heritage preservation, especially in contexts such as theater halls, churches, and auditoriums. These acoustic characteristics change over time and thus contribute to structuring the historical memory of a place, playing a fundamental role in the perception and fruition of the built environment. Indeed, the acoustics of an architecture is an intangible consequence of its construction and the design choices made on the materials and furnishing systems that will constitute the truly tangible elements of the Architectural Heritage.

On these theoretical aspects has thus moved the European project AURA – Auralisation of Acoustic Heritage Sites Using Augmented and Virtual Reality, co-funded since 2021 by Creative Europe, whose aim is to explore the potential of auralization – a technique for simulating the acoustics of a given place within models – by combining it with the three-dimensional-visual representations of the virtual environment based on accurate digital surveys.

For this purpose, three emblematic European case studies were thus examined – the Konzerthaus in Berlin (DE), the Teatro del Maggio Musicale Fiorentino in Florence (IT) and the Opera and Ballet Theater in Lviv (UA) – for each of which an appropriate methodology dedicated to digitization and virtual reconstruction was conceived, with the aim of obtaining reliable assets on which subsequent auralization processes could be set and, following these, to develop multisensory, reliable and high-performance 3D models both in terms of graphic rendering and virtual fruition, and in terms of acoustic simulation.

Introduction: the AURA project

The development of modern technologies had a substantial impact on the Cultural and Creative Industries (CCI), which take advantage of its potential to explore new performative horizons, create new business models and attract ever-new and dynamic users [Bertocci et al., 2021]. The COVID-19 pandemic has highlighted the urgent need to develop alternative ways to access to cultural and artistic heritage. The AURA – Auralisation of Acoustic Heritage Sites Using Augmented and Virtual Reality project, co-funded by the Creative Europe call since 2021, aims to explore the potential of auralisation[1] to create immersive virtual experiences that combine both visual representation and acoustic simulation.

The project is designed to deliver an immersive experience where the user can interact with the environment and experience how the perception of soundscape is influenced by architectural space, and how at the same time soundscape influences the perception of the built environment. Acoustic simulation experiences are generally built around a listener, while architectural visualisation experiences revolve around an observer. These immersive experiences stimulate a single sense, thus limiting the user's perceptive possibilities of the represented object. The acoustic of an environment plays a fundamental role in perception. The creation of Virtual Acoustic Environments (VAEs) [Kato et al., 2008] makes it possible to bring back to life the acoustic experience of places that no longer exist, or to compare the acoustic of distant places in a virtual environment [Eley et al., 2021]. Beyond the physical aspect of the acoustic phenomenon, the perception of a site soundscape carries a heritage value that needs to be documented and archived [De Muynke et al., 2021]. This was spotlighted by the 2017 UNESCO resolution 39 C/49, "The importance of sound in today's world: promoting best practices", which complements the concepts and principles of safeguarding that were introduced with the "Convention for the Safeguarding of the Intangible Cultural Heritage" in 2003. Thanks to technology advancements, it is now possible to develop new applications that allow for both audio and visual content integration. AR and VR applications enhanced the user experience, as they allow development of new interaction systems between the user and the virtual experience, creating an immersive system that takes full advantage of the dissemination potential of ArcViz and Acoustic experiences [Borisov et al., 2022].

The AURA project explores three emblematic European case studies: the Berlin Konzerthaus (DE), the Teatro del Maggio Musicale Fiorentino (IT) and the Lviv Opera and Ballet Theater (UA). An appropriate digitisation and virtual reconstruction methodology has been developed for each of the theatres to create reliable 3D models from a graphic rendering and digital accessibility perspective, as well acoustic. Selecting three different case studies

Fig. 1 - The AURA European project, its partnership and the three case studies: the Konzerthaus in Berlin (DE) , the Teatro del Maggio in Florence (IT) and the Solomiya State Academic Theater of Opera and Ballet in Lviv (UA).

from an acoustic, functional, and architectural point of view was essential to define a reliable and replicable methodology. The project analyses a contemporary building, the Teatro del Maggio Fiorentino (2011), to address issues related to contemporary technologies and materials; a neoclassical-style 1980s reconstruction, the Konzerthaus in Berlin (1984), to address problems associated with the combination of different materials, such as reinforced concrete, wood and decorative stucco; and finally an architectural typology present throughout Europe, represented by the Italian-style theatre with the neo-baroque features Lviv Opera and Ballet Theater (1900), which presents the limitations of architectural and decorative structures when it comes to acoustic. The project, completed in December 2022, sets guidelines for the creation of multi-sensory virtual experiences to make the auralisation of cultural spaces easily accessible and applicable in the future. (Fig. 1).

The importance of acoustic in cultural heritage safeguarding strategies

The strategies to investigate and safeguard cultural heritage, both tangible and intangible, lean towards a greater integration and use of acquired data, often heterogeneous and from different research fields. A growing sensitivity towards a more ephemeral and fragile aspects of heritage – such as its acoustic features – leads to the development of new methodological protocols that reinterpret and integrate approaches already consolidated by each individual discipline. The new frontiers of digital surveying, 3D modelling and rendering applied to built heritage allow the recreation of a digital copy of the investigated object, preserving its image over time and making it widely accessible through mixed reality technologies (MR). Similarly, the auralisation processes [Kleiner et al., 1993] – which had been already employed in acoustic design for several years – have been integrated by visually accessible models that contextualise sound experiences. For research projects on acoustic heritage – particularly those that investigate the acoustic of an archaeological site or a damaged or destroyed building – a well-balanced integration of acoustic and visual aspects is necessary[2]. One exemplar is EVAA (Experimental Virtual Archeological Acoustics), an umbrella project that gathers multiple sub-projects on heritage acoustics research, virtual reality and real-time auralisation. Amongst the case studies investigated by the research group coordinated by the Sorbonne University of Paris, that forms part of the Past Has Ears project (PHE 2020-2023)[3] [Katz et al., 2022], is the Cathedral of Notre Dame, then further explored by the Past Has Ears at Notre-Dame project (PHEND 2020-2024) [Eley et al., 2021] [De Muynke et al., 2022]. The acoustics of Notre Dame is considered an essential part of its intangible heritage, particularly as it may have played a fundamental role in the development of musical practices during the Middle Age. The study compares the current internal acoustics, following the fire of 2019, with that recorded by archival acoustic measurements, particularly those acquired in 2015 during an investigation campaign for the virtualisation of the UNESCO heritage site. This comparison also allows for monitoring the effective acoustic correspondence of the restoration project during the construction phase and verifying the accurate restoration of the original atmosphere.

The AURA workflow: developing a methodology for VR and acoustic simulation of theatre halls

As mentioned earlier, the very purpose of the project is to exploit the potential of the three different case studies to define a methodological workflow for VR and acoustic simulation of theater halls that can be replicated and applied at the European level for the virtualization of other venues as well (Figg. 2-3).

This methodological workflow, mostly common to the three cases, included an initial phase focused to digital surveying using terrestrial laser-scanner (TLS) instrumentation – and in one case also through Structure from Motion (SfM) photogrammetry techniques – in order to ensure a reliable metric basis for the next step concerning the 3D modeling of the main halls.

At the same time, a semantic subdivision of the furniture and architectural elements that constitute the main halls, together with a classification of the related constructive materials, was also carried out. Based on this, each material was also classified acoustically through on-site investigations and studies on technical documentation, and properly matched with the specific acoustic parameters[4], in order to develop a parametric acoustic database useful for subsequent auralization processes. Along with these studies, a series of photographic surveys of the various materials present were also carried out for their sampling intended for the creation of photorealistic textures for mapping the 3D models.

The next phase involved the actual virtual reconstruction of the theater hall. This was carried out through specific 3D modeling processes based on the morphometric assets developed from the digital survey and the semantic and materials subdivision. The 3D models were then also subjected to specific mapping and texturing operations in order to optimize their graphical rendering for *ArchViz* simulation.

Next, a preparatory phase to auralization processes was carried out, aimed at creating a parametric and coded database within which the various elements and their respective constructive materials could be associated with the values of the acoustic parameters identified in the preliminary on-site studies.

Finally, the operations related to auralization and virtualization of the theatrical venues – which, however, will not be explored in depth within this paper – were carried out by exploring the multiple potentialities offered by *Unity* platform. Indeed, this Game Engine allows both the creation of virtual and immersive 3D environments and, through a specific plugin, also their auralization.

All of these methodological experimentations thus made it possible to develop an easily replicable workflow for the creation of immersive multisensory VR experiences intended for different types of users. Indeed, the last phase of the project involved a series of testing activities on users in order to verify the actual response and contribution offered by the auralization of 3D models developed according to this workflow.

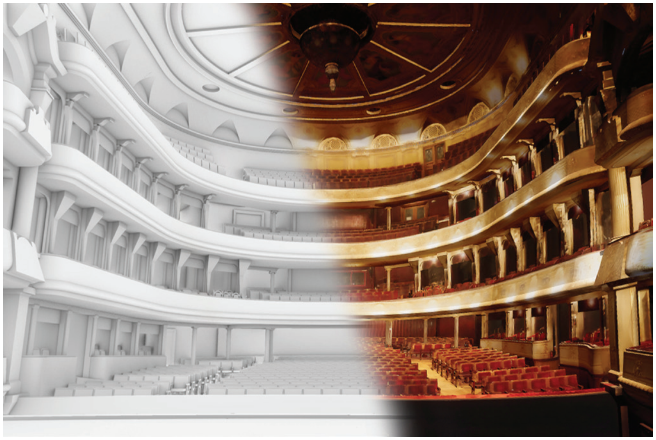


Fig. 2 - Concept of Aura project. The main hall of the Lviv Opera House depicting the interaction between the two 3D models: on the left the one intended for auralization and on the right the one for visual rendering.

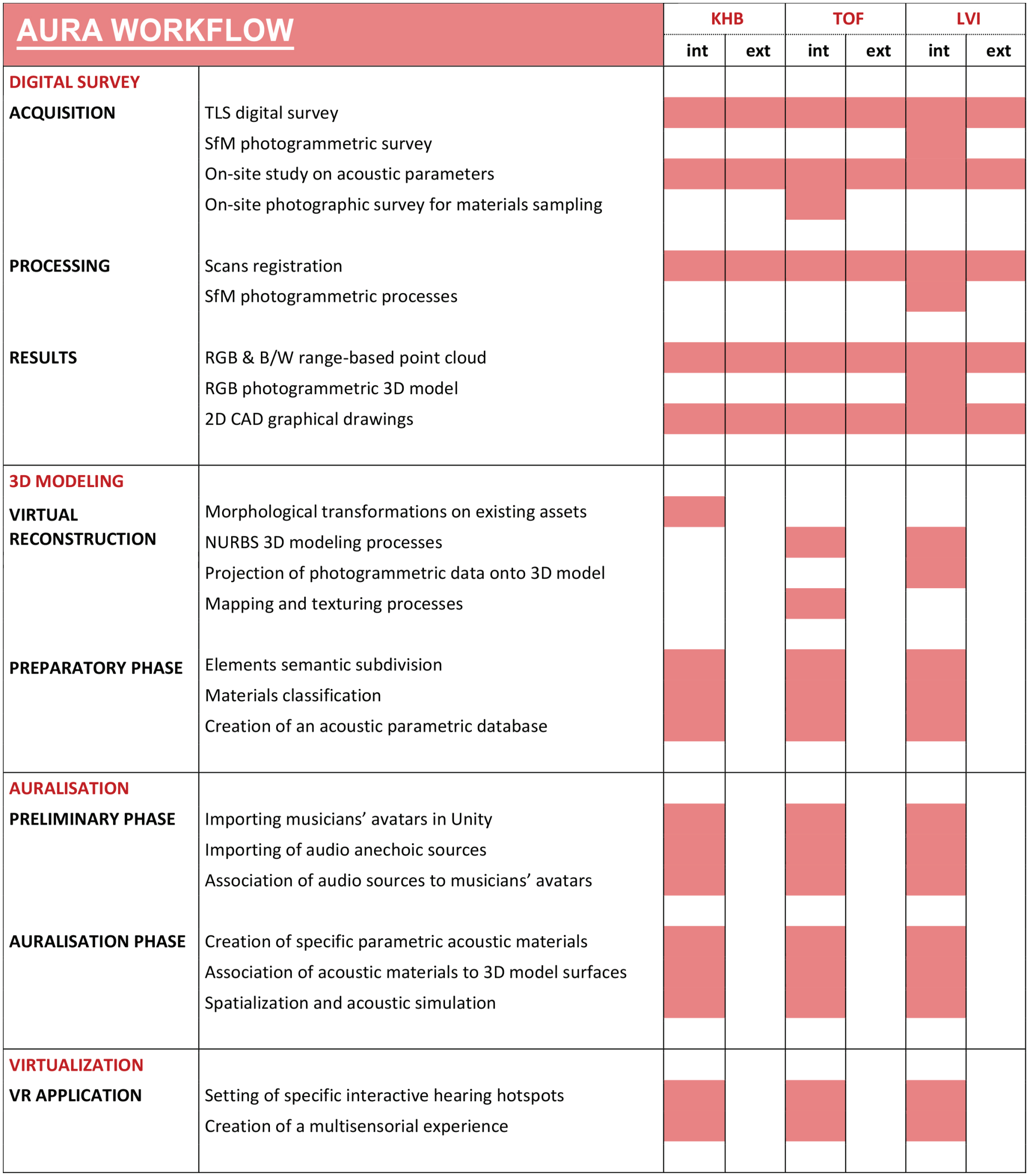


Fig. 3 – Methodological workflow of the activities carried out for each case study.

The digital survey for a reliable virtual reconstruction of the three case studies

The project's first step is digitizing the built heritage through appropriate technologies that ensure a reliable virtual morphometric reconstruction. Specific and different digital survey campaigns were thus planned for the documentation of the three case studies (Fig. 4).

Data acquisition activities for the Berlin Konzerthaus began in September 2021 and included laser-scanner surveys. Two different TLS instruments were used, a *Z+F Imager 5016* and a *Faro Focus*^{M} *70*, both with phase difference technology. Specifically, the first one was used to acquire 220 RGB color scans related to the exterior environments of the Konzerthaus, its foyer and main hall, while the second one was used to acquire 300 B/W scans of corridors, stairwells and service areas (Fig. 5).

Fig. 04 – Digital survey acquisition activities of the three case studies and panoramic views of the colored point clouds of their exterior areas.

Likewise, the digital documentation activities for the Teatro del Maggio Musicale Fiorentino – conducted in early 2021 – involved the use of the same TLSs, through which were acquired respectively 180 RGB color scans of the exteriors, its foyer and main hall, and 110 B/W scans for corridors, stairwells and service areas (Fig. 6).
The digital survey of the Lviv Opera House required instead two different temporal tranches. During the first campaign – conducted as well in early 2021 – geometric data of main hall, foyer, and corridors were acquired using a *Leica C10* laser scanner. Since the 160 scans were captured in B/W, a SfM photogrammetric survey of the hall was combined for color data acquisition. At the end of 2021 a second digital survey campaign was planned, through which missing data from the exterior areas and again some interior spaces were integrated with 160 RGB color scans acquired using a *Faro Focus^M 70* (Fig. 7).
All of these laser-scanner surveys have thus provided a large amount of data, which have been subsequently imported and processed within a specific point cloud management software, *Leica Geosystems Cyclone*, through which the main phases of filtering, registration, checking and processing of the point clouds were developed.
The results of this first step have thus provided a set of highly descriptive and reliable three-dimensional metric assets, from which both morphometric and chromatic-material information could be extracted and used for the development of graphical-technical supports necessary for the subsequent modeling and auralization steps.
In parallel to these digital data documentation activities, the methodological workflow included a series of on-site studies on the constructive materials and their acoustic properties, investigating the values of the above-mentioned acoustic parameters necessary for subsequent auralisation processes within the chosen Game Engine plugin.
For this acoustic survey, visual examinations were conducted [Pompoli et al., 2000], through which it was possible to attribute to the acoustically significant materials present in the main hall

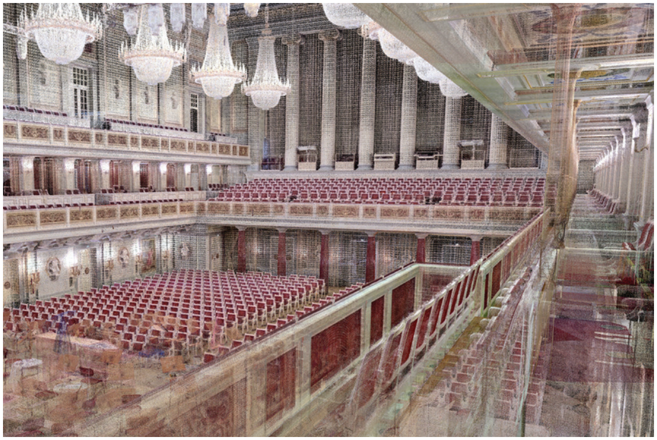


Fig. 05 – Colored point cloud of the main hall of the Berlin Konzerthaus developed from laser-scanner surveys.
Fig. 06 – Colored point cloud of the main hall of the Teatro de Maggio developed from laser-scanner surveys

their respective acoustic characteristics – in terms of scattering and average coefficient of sound absorption and diffusion at low, medium, and high frequencies – relying on data found in acoustic technical reports, scientific publications, and acoustic simulation software such as *Odeon*[5] and *Ramsete*[6] [Bartalucci et al., 2018].

Processing of 3D digital-twins for auralization and visualization purposes

The processing and post-production phase of the acquired data was developed by pursuing two complementary and methodologically propaedeutic objectives for the auralization and visualization of the three venues. The first aimed at creating highly descriptive 3D models of the main halls based on the geometric results of the digital survey. The second regarding the semantic subdivision of the various architectural elements to enrich the morphological contents with information relating to the investigated acoustic parameters.

Specifically, regarding the first aspect, the highly reliable metric data obtained through point cloud post-production processes were used to virtually develop the digital-twins of the various case studies following two different reconstructive methodologies (Fig. 8).

For the cases of the Teatro del Maggio and Lviv Opera House, morphometric data from the respective point clouds were extracted and, through a careful data discretization, used for the development of 2D drawings in *CAD* environment in order to create a geometric basis for modeling each element of the main halls. These drawings[7] were then imported within *McNeel Rhinoceros* modeling software where they were used as metric support for the creation of the 3D model of the halls and each of their components[8], exploiting the management and precision potential of NURBS geometries.

For the Berlin theater, on the other hand, an existing 3D model made available by the Konzerthaus institution was used. However, since it did not metrically reflect the real dimensional aspects, specific morphological transformations based on the point cloud data were carried out within *Rhinoceros*.

Similarly to the modeling one, a dual approach was also followed with regard to the mapping methodology of the 3D models developed. For the cases of the Konzerthaus and Teatro del Maggio, surfaces mapping was based on textures created from photographic samples of real materials (Figg. 9-10).

Fig. 07 – Colored point cloud of the foyer and main hall of the Lviv Opera House, developed from laser-scanner and photogrammetric surveys, respectively.

For the case of the Lviv Opera House, on the other hand, a different methodology was tested. The NURBS model developed for the auralization processes, was overlaid with an identical one in the form of a mesh textured by projecting onto it the photogrammetric data developed within *Agisoft Metashape Pro*. In this way, within *Unity*, both the acoustic simulation developed by the auralization of the NURBS model and the realistic graphical rendering of the photogrammetric mesh were guaranteed.

In parallel with the modeling processes, a semantic subdivision of the elements present and their relative material classification was also carried out. After preliminary on-site studies of the materials, all the elements in the main halls were divided and categorized within the 3D models into typological categories, and for each, a different virtual and coded material was associated. This process thus led to the creation of an acoustic database in which each category is associated with a set of ID codes, a material, various numerical-dimensional data, and most importantly, the corresponding acoustic parameters previously investigated (Fig. 11). The values of latter will then be associated with the various surfaces of the 3D models and will become the basis for the development of the auralization processes (Fig. 12).

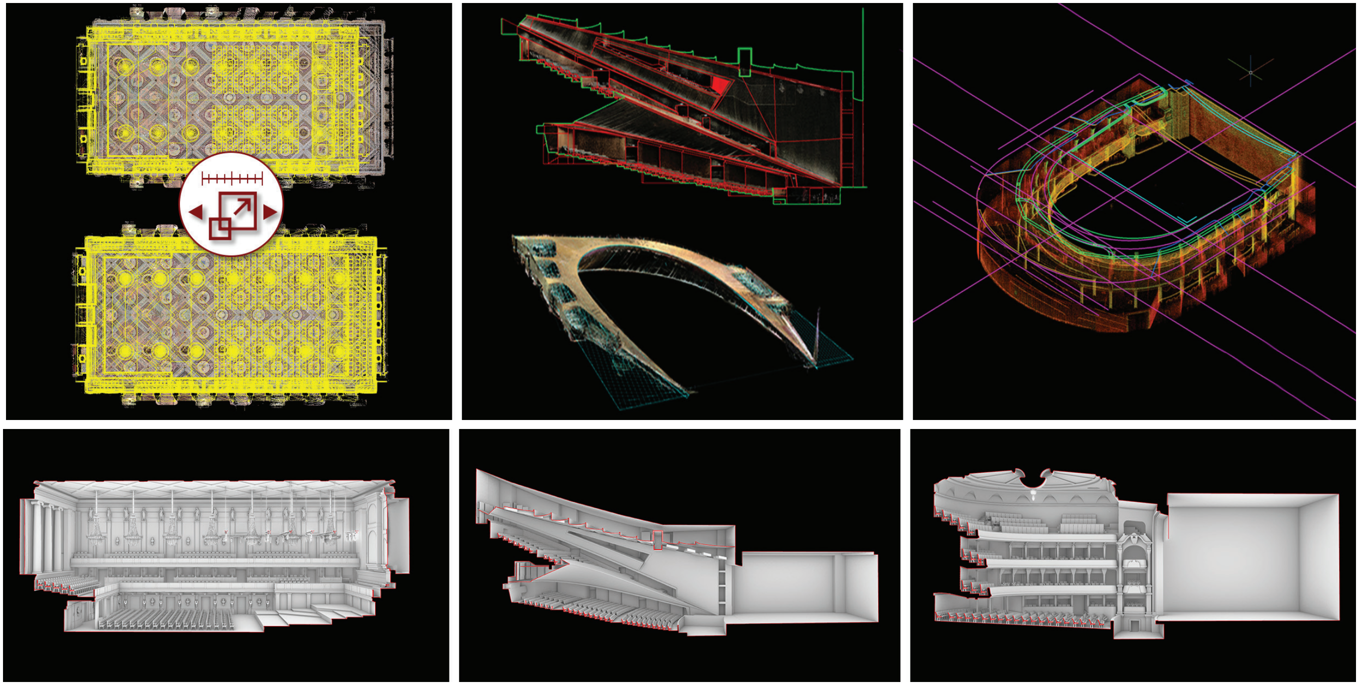
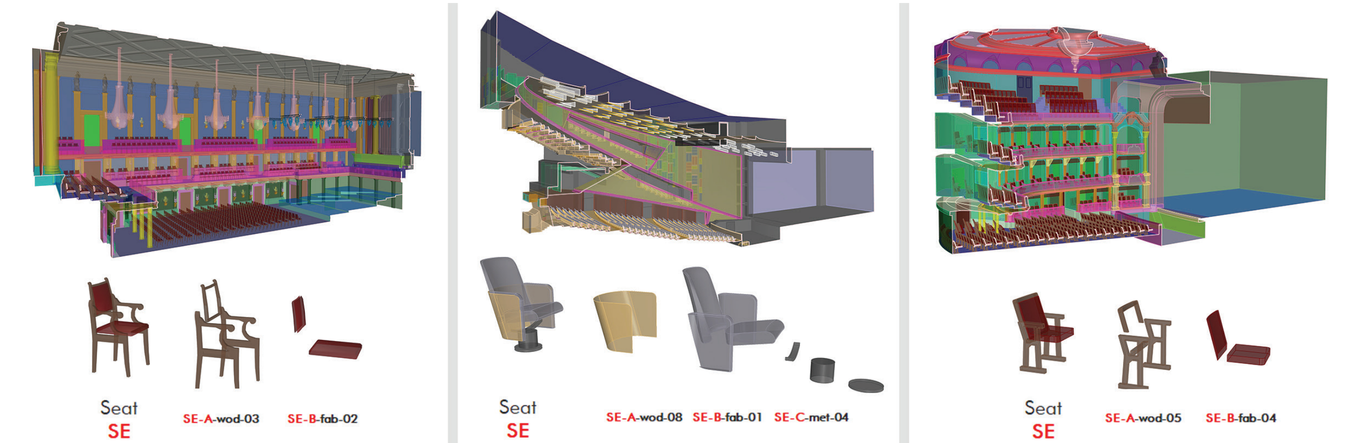


Fig. 08 – Overview of digital processing and different methodologies used for virtual reconstruction of the three case studies.
Fig. 09 – Panoramic view of the textured 3D model of the main hall of the Berlin Konzerthaus.
Fig. 10 – Panoramic view of the textured 3D model of the main hall of the Teatro del Maggio.



ACOUSTIC DATABASE

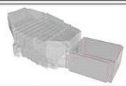
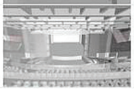
ID	Element description	TYP	Element Type / Component description	MAT	Material description	Material RGB code	POS	NUM	SRFE	SRFT	LFA	MFA	HFA	S	LFT	MFT	HFT
AB	Acoustic Background	A	Stage 01 vertical acoustic background	abg-01	Acoustic background 01	191,191,255		-	-	873,44	0,30	0,50	0,70	0,50	0,00	0,00	0,00
		B	Stage 01 fly acoustic background	abg-02	Acoustic background 02	63,63,255		-	-	374,12	0,50	0,70	0,90	0,50	0,00	0,00	0,00
		C	Shell 01 wooden surfaces acoustic background	abg-03	Acoustic background 03	0,0,255		-	-	8,72	0,15	0,07	0,05	0,10	0,00	0,00	0,00
		D	Shell 02 slanted walls acoustic background	abg-04	Acoustic background 04	0,0,191		-	-	10,50	0,15	0,07	0,05	0,10	0,00	0,00	0,00

Fig. 11 – Semantic subdivision of the elements and classification of the materials present in the three case studies for the creation of a parametric acoustic database.

Development of multisensorial and virtual experiences

The research required several tests to develop multisensory virtual experiences of the three venues that could simulate visual and acoustic reality simultaneously. The test results identified *Unity* as the most suitable virtual platform for this sort of real-time applications. In fact, in addition to the ArchViz of the developed 3D models, this Game Engine allows through a specific plugin called Steam Audio the development of all auralization processes: importing of audio sources, setting of acoustic materials characterized by the values of the investigated parameters and the association of these with the respective surface materials of the imported 3D models (Fig. 13).

In order to make the visual-acoustic experience more realistic, in each of the three theaters an orchestra

composed of 3D avatars of real musicians was placed, and each of these was associated with its respective audio source recorded individually in an anechoic chamber and making it virtually audible in a spacialising way. In fact, within the Unity-Steam Audio editor, it is possible to set the sound three-dimensionally so that the volume changes with the distance from the sources and with the acoustic properties of the various materials present (Fig. 14).
Thus, the three multisensory and virtual experiences were developed within Unity in the form of VR Apps. In each of the three theaters, even the least experienced user will thus be able to navigate the main hall by moving to specific and defined positions (e.g., front row, balcony, stage...) and decide which instrument of the orchestra should be played by simply activating the respective musician[9] (Fig. 15).
This integrated and immersive approach, in which photorealistic visualization and acoustic rendering are combined with direct and simulated user interaction, aims to significantly develop new ways of communicating and disseminating Acoustic and Cultural Heritage.

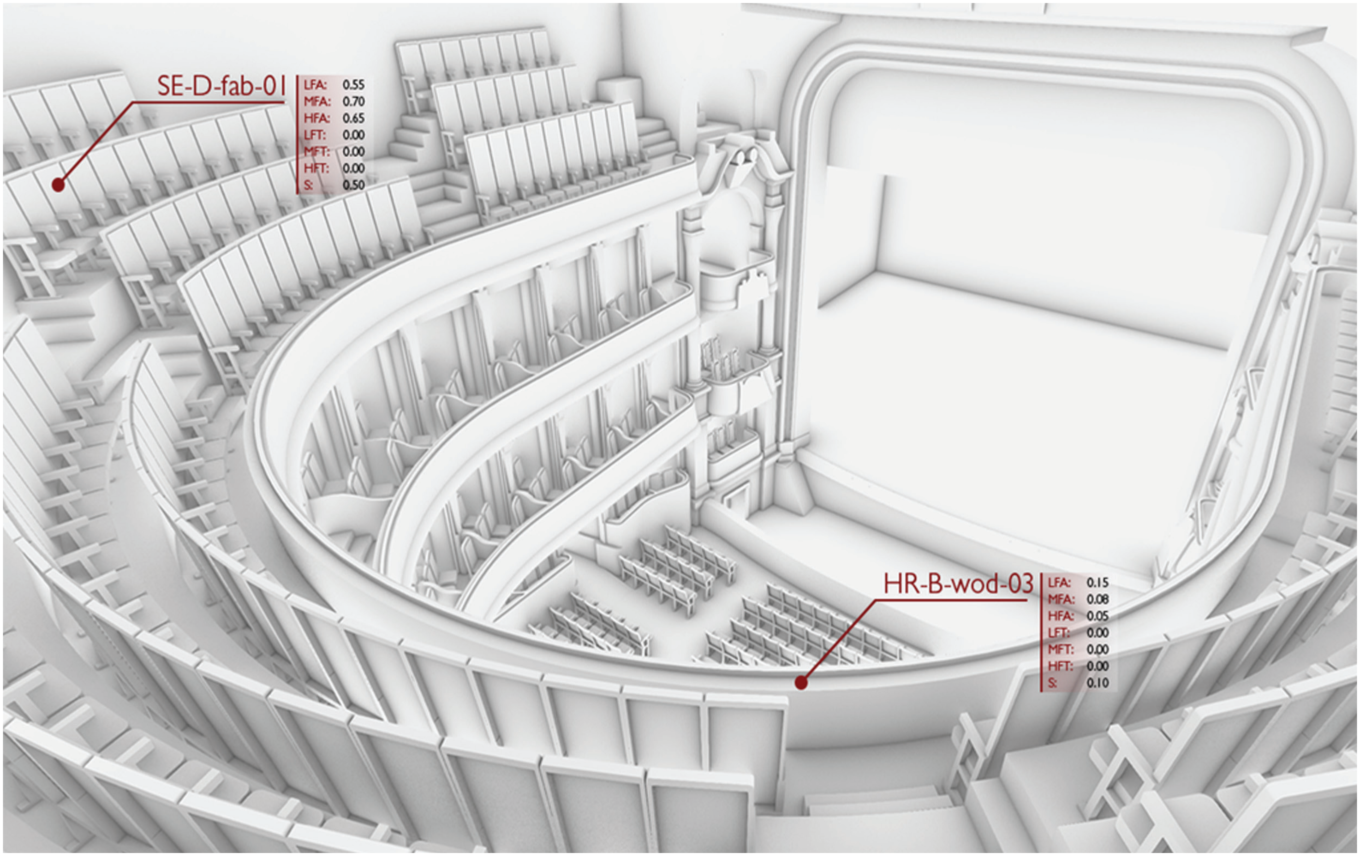


Fig. 12 – Example of acoustic data enrichment within the 3D model of the main hall of the Lviv Opera House aimed at auralization processes.

Conclusions

The results of the AURA project confirmed that precise digital survey campaigns are necessary to develop 3D models that investigate the relationship between space and acoustic.[10] The geometric-morphological aspects of the models, as in the case of the hall of the Konzerthaus in Berlin, deeply influence the sound rendering of the auralised models [Schauer et al., 2022]. Through correct data acquisition and accurate sampling of materials and related acoustic parameters, these tools allow the documentation of both the material aspects of the built heritage and the intangible features related to the soundscape of the investigated entity. Furthermore, using these tools in architectural design offers a unique opportunity to explore and test acoustic in the preliminary stages of the project, thus informing the choice of the best materials and technological solutions both from a technological and an aesthetic point of view. One of the AURA project's objectives is to investigate the possible use of auralised 3D models in the architectural and acoustic design field. The project featured a user testing phase designed by Vie en.ro.se. Ingegneria S.r.L., which collected feedback from musicians, designers and the general public to offer insights on the pros and cons and potential use [Bellomini et al. 2022].

The project also entailed the organisation of a multidisciplinary university workshop on the theme of auralisation, which involved 20 students from the Department of Architecture of the University of Florence. The students took an active part in the "transfer of knowledge" phase, assisting in defining an approach to disseminate methodological steps to a user base of technicians and architects. Notably, the adopted methodologies have proved to be a possible integration in acoustic and digital survey classes, training the Next-Gen of architects and building engineers to be sensitive to issues related to acoustic heritage. These matters are tightly interlinked with BIM (Building Information Modeling) and collaborative design approaches. Together, these disciples create a connection between design and IT skills to create immersive experiences that are beneficial during the design and development phases of the architectural project, as well as in the documentation and protection of the acoustic heritage.

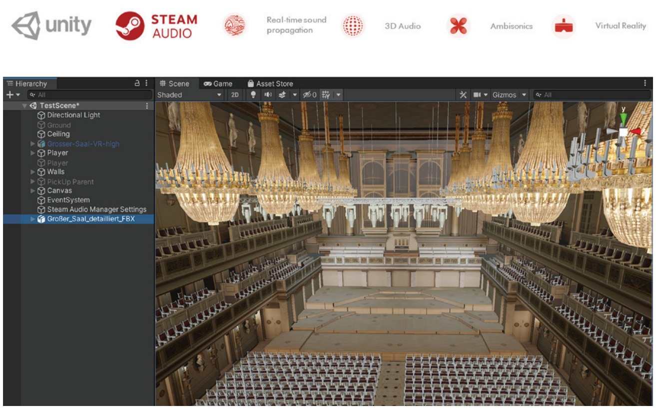


Fig. 13 – Importing main hall models within the Game Engine Unity platform and acoustic processing using the Steam Audio plugin.

Fig. 14 – The three Apps for multisensory experiences and their virtual navigation using VR devices.

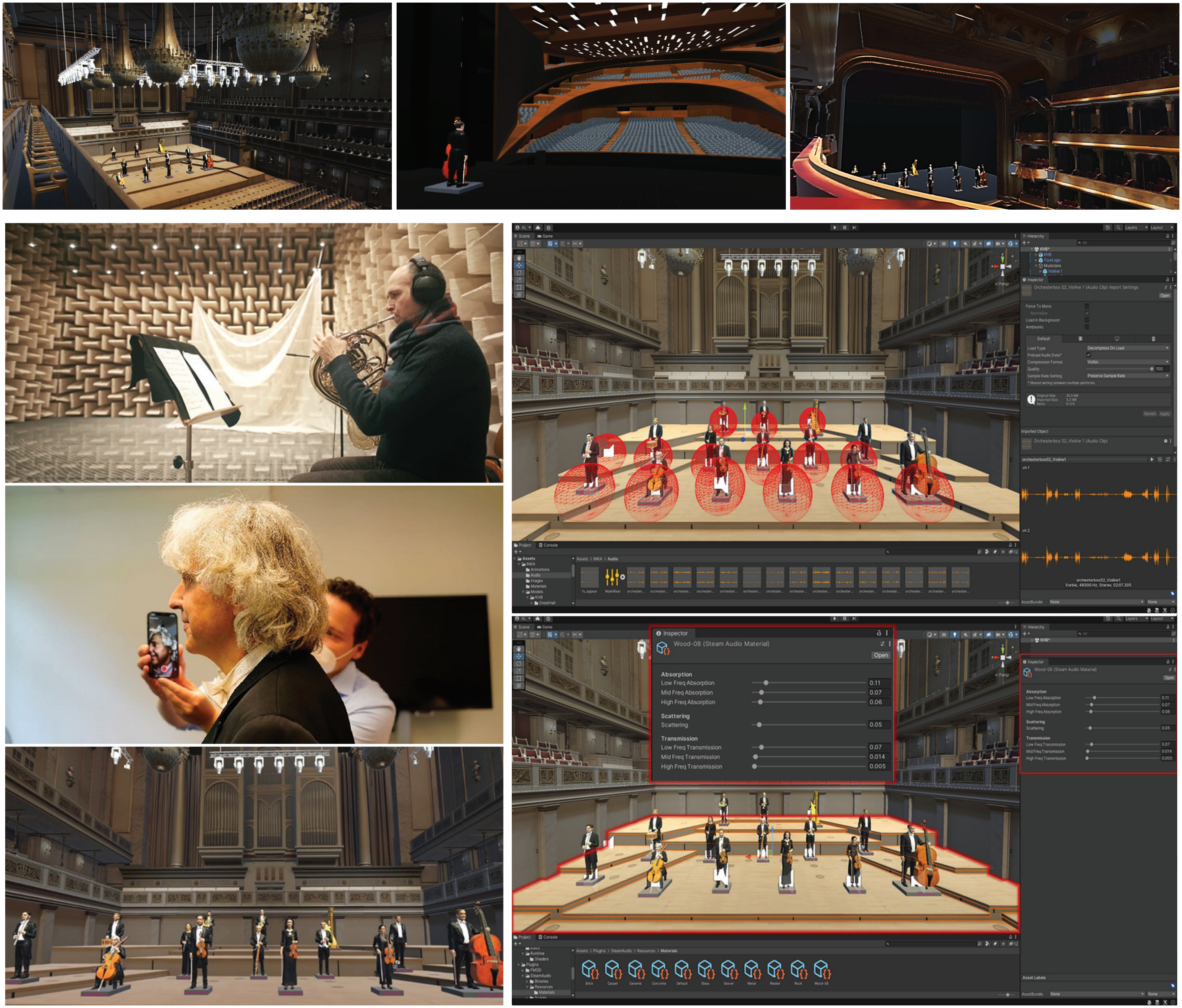


Fig. 15 – On the left, phases of sound acquisition of each instrument, SfM survey of the respective musicians, and insertion of the orchestra within Unity. On the right, auralization processes.

Acknowledgement

Andrea Lumini wrote the paragraphs "The AURA workflow: developing a methodology for VR and acoustic simulation of theatre halls", "The digital survey for a reliable virtual reconstruction of the three case studies", "Processing of 3D digital-twins for auralization and visualization purposes" and "Development of multisensorial and virtual experiences"; Federico Cioli wrote the paragraphs "Introduction: the AURA project", "The importance of acoustic in cultural heritage safeguarding strategies" and "Conclusions"

AURA is a project co-funded by the Creative Europe program led by the Berliner Gesellschaft für internationale Zusammenarbeit mbH (BGZ), in collaboration with the Hochschule für Technik und Wirtschaft in Berlin (HTW), the Department of Architecture (DIDA) of the 'University of Florence (UNIFI) and the Lviv Polytechnic National University of Lviv (LPNU, supported by musical institutions such as the Konzerthaus in Berlin and by marketing partners such as Vie en.ro.se. Ingegneria Srl in Florence, the Lviv Tourism Development Center of Lviv (UA) and Magnetic One of Ternopil (UA).
For further information, see the website of the European project https://www.aura-project.eu

The credits of the activities carried out by the respective technical partners of the AURA project are briefly presented. The HTW team, coordinated by Prof. J. Sieck, was responsible for the auralization of the models and the development of apps for their virtualization and use. The team of UNIFI-DIDA, coordinated by Prof. S. Bertocci, has carried out the activities of digital survey and data processing, as well as the 3D modeling of the theaters. The UNIFI-DIEF team, coordinated by Prof. M. Carfagni, has dealt with the preparatory investigation for the auralization of the values to be assigned to the acoustic parameters. The LPNU team, coordinated by Prof. I. Savchyn, carried out the first digital survey activities, TLS and SfM, of the Lviv case study. The Konzerthaus musical institution provided the textured model of the Berlin theater.

Notes

[1] Auralization is a technique that simulates the acoustics of a real place within a virtual space.

[2] Noteworthy: ERATO projects (2003-2006), focused on the theme of archaeoacoustics for the analysis and comparison of the acoustic properties of ancient Greek and Roman theatres [Rindel et al., 2011]; ECHO project (2013-2018), investigating the issue of acoustics and the integration with digital survey and 3D modelling for the development of virtual experiences [Katz et al., 2019].

[3] PHE – "Past Has Ears" is a research project financed by the JPICH 2019 call, which investigates and develop a methodology for archeoacoustic investigations through heritage sites in France, Italy and UK.

[4] The acoustic parameters considered for auralisation are essentially three: sound absorption and transmission frequencies (low, medium and high) and scattering.

[5] https://odeon.dk

[6] http://www.ramsete.com

7 For some instances with complex geometry portions of the decimated point cloud was imported directly, and from it, through specific algorithms and cross sections, the three-dimensional surfaces were extracted.

[8] For the Maggio case study, in addition to the architectural elements of the hall, the entire acoustic reflection system, such as dispersing panels or acoustic curtains, was also modeled, as well as of the furniture elements, such as the seats, whose wide presence (more than 1700) is extremely relevant in the acoustic study of the hall and, consequently, in the auralization processes.

[9] The orchestra consists of static mesh models made by SfM photogrammetry of real musicians, and includes: two violins, a viola, a cello, a double bass, a flute, an oboe, a clarinet, a trumpet, an harp, a drum, a piccolo flute, a bassoon and a horn.

[10] A number of researches focuses on the direct use of surfaces generated by meshing the point cloud, following a good data simplification process [Foschi, 2022].

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06 FROM SURVEY TO SIMULATION OF A VIRTUAL SPACE: UNESCO World Heritage sites in South East China and Archaeological Heritage in Basilicata

Abstract

This contribution is the result of long time cooperation between UNIBAS-School of Architecture and FZU-School of Architecture and Urban Rural Planning and between UNIBAS Schools of Architecture and of Specialization of Archaeological Heritage in Matera.
It aims to shed some light on exploration of more economical preventive conservation methods of large heritage sites. The development of survey technologies has contributed to the progress of heritage conservation. Thus, the conservation of large sites has formed a certain amount of accurate and systematic processes, significantly improving accuracy while reducing labor costs, also useful as reference for other heritage sites with similar characters.
Chinese case studies are both located in the UNESCO Mixed Heritage Site of Mount Wuyi (Fujian region). One, Chengcun Han City, is a large archaeological site to be surveyed and putting in value. The other regards the "cliff-burial", an ancient funerary ritual during which the dead were buried high on the cliffs overlooking rivers. The log coffins (hanging coffins) were used to be left in natural caves, excavated grottoes, or on woodpiles. Due to their size and impervious location, these were a good starting point to explore the feasibility of combining digital survey methods with tilt photography and remote sensing technology. The research aims to explore a safe and low-cost surveying method that can acquire and process the maximum amount of detailed information in a short time. Efficient and practical digital survey methods can be applied to other heritage sites, which could contribute not only the cultural heritage protection but also to the studies in ethnic migration and cultural assimilation field.
Moreover, the relations between archaeology and architecture were dealt with, by investigating the documentation as objective and scientific basis on which to operate. In the need to act directly on cultural heritage to ensure its transmissibility, theoretical and methodological, multi-disciplinary and strategic approach to the quality of graphic restitution was explored through an in-depth study of the cultural and evocative value of the representation.
European case studies in Greece and south Italy (Basilicata region) focus on graphic documentation for archaeological, artistic and monumental heritage to experiment Virtual Archaeology and Virtual Restoration.

Knowledge and protection of the UNESCO Mixed Heritage Site of Wuyi Mountain: Chengcun Han City and the Cliff-Burial cases study[1]

Chengcun Han City in Mount Wuyi, Fujian Province, is known as "Pompeii of China", the only surviving city of a Western Han Dynasty (202BCE-8CE) in South China, which has been lost and preserved for more than 2000 years. It was listed in the mix UNESCO World Heritage in 1999. The city site survey was mainly based on archaeological excavation and square grid survey and a close-up photogrammetry was carried out during the first trial dig in 1958. The site map was completed by the Bureau of Cultural Heritage based on the digs and the onsite underground exploration between 1958 and 1980. The digital survey of the site is still challenging for two main problems: firstly, the massive size of the site, which covers an area of approximately 480.000 m^2 and cannot rely entirely on remote sensors; and secondly, its location in the remote rural areas causes a lack of labor force. (Figg.1-2).

To figure out the first problem, a hierarchical conservation management strategy is developed in this study with the Social Network Analysis (SNA). To solve the second problem, a mapping routine could be established using UAV inclined photogrammetry technology. (Fig.3).

During the recent two decades, SNA has been commonly used in archaeology for classifying, processing, and quantifying relationships in the process of establishing a site value system. Nowadays, the application of UAVs used in the large-scale site is more concentrated in surveying and mapping, agriculture, forestry, power industries, ecological protection, and large-scale disaster prevention. The Chengcun Han City's topography is complex, and the road system is irregular, but there is still a clear spatial separation at the high platform of the site left by the buildings, and the terrain is flat. When planning the flight route, the "LocaSpaceViewer" software was used to export the KML file of the survey area, import it into the DJI GS PRO ground control station, plan the flight route by the mapping aerial photography mode within the survey area, and set the overlap rate of the UAV heading and side direction to over 80%. As the entire complex of buildings at the site is organized in groups, the flight path around the site was centered on the palace area and the northern part of the city gate (the ancestral memorial site). (Fig.4).

DJI PHANTOM4 was used to acquire the site's tilt and vertical image data. The images came with POS data, and the characteristic points of the site-building clusters themselves were used as image control points. The coordinates of the image control points were measured with a total station. Context Capture 3D modeling software was used for modeling. The image data taken by the UAV was imported to realize the image association of control points, solving the problems of aerial triangulation based on the tilt photography of light and small UAVs, realistic 3D models, and accuracy evaluation of buildings in 3D scene models, which significantly reduces the workload of archaeological research. Further generating large-scale topographic maps provides essential data to guide archaeological site investigation, BIM model application, and site protection planning. (Fig.5).

Based on the value of SNA, a survey routine for Chengcun Han City Site was developed. Compared to traditional satellite remote sensing, the high timeliness and high flexibility of UAVRS technology provides the possibility of long-term monitoring of dynamic changes in the site. The monitoring process was carried out as follows:

- image acquisition;
- graded protection;
- data Preprocessing;
- information extraction.

Fig. 1 - Distribution of exploration area of Chengcun Han City site.

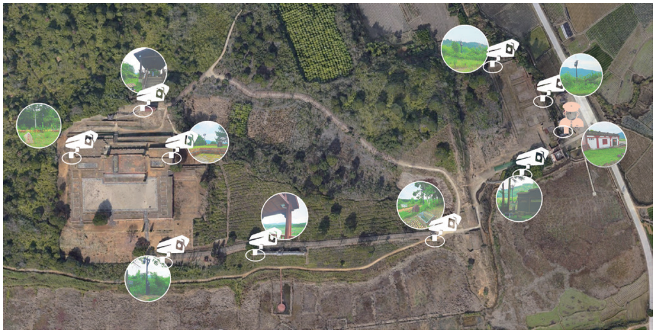


Fig. 2_Plan view of the status of site monitoring.

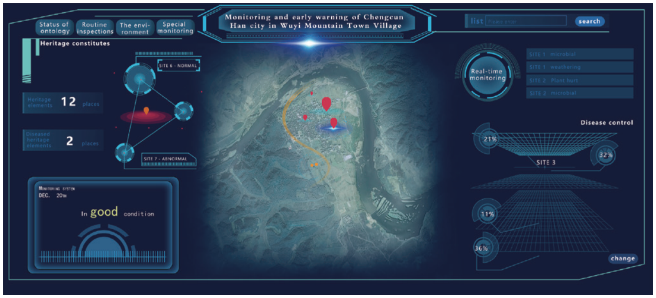


Fig. 3 - Monitoring and visualization of Chengcun Han City.

The “cliff-burial” was an ancient funerary ritual once popular in Far East Asia, and nowadays, still in practice in some remote areas of Southeast Asia and Pacific Islands. To preserve historical information of the hanging coffins is significant in the fields of ethnic migration and cultural assimilation. (Fig.6).

Since the cliff-burial sites are usually located on the escarpments overlooking the rivers and with great slope, e.g., the Jinji Cave site in Mt. Wuyi has a height up to 30-50 m (Zeng, Yang, Fu 1980), the Luoping River sites (Badong County, China) and the Tabon Cave site (Palawan Island, Philippines), some coffins are as high as 100-200 m above the water (Chen 1992), the conventional 3D survey such as ground laser scanning and traditional aerial photogrammetry is less practical. (Figg.7-8).

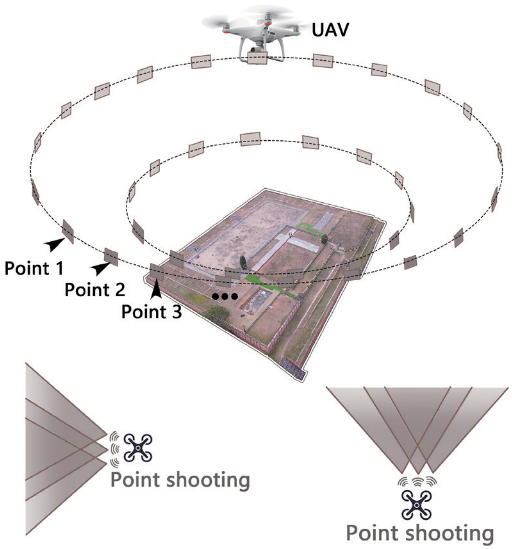


Fig. 4 - Flight schematic of the drone in point-of-interest surround mode.

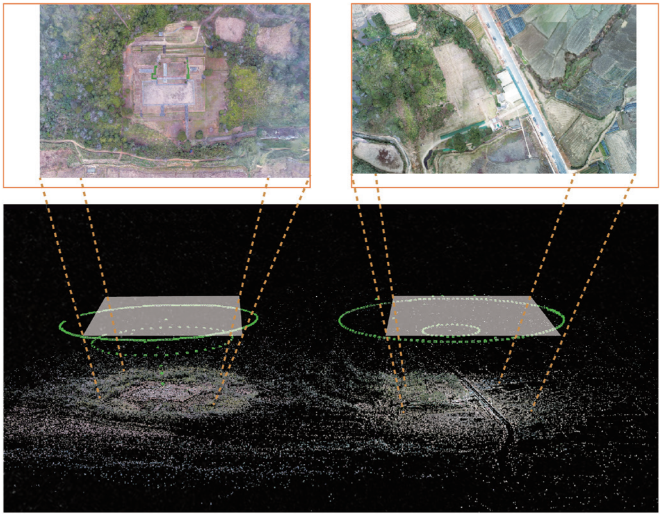


Fig. 5 - Point cloud map of circular flight.

The most recent major comprehensive survey of hanging coffins in the Mt. Wuyi was carried out in August 1979, and the results showed that 18 relic sites with more than 19 coffins had been severely damaged over time, leaving no coffin intact *(Cultural Heritage Group of Chong'an County Culture Museum 1982)*. Due to the limitation of the technology available in South China in the 1970s, information on the specific cliff height, location, coffin form and remains of each relic site is mostly recorded in vague description without accurate documentation.

In comparative experiments with remote sensing measurement techniques, the UAV surveying requires the least amount of field operation time for building elevation measurement compared to total station equipment and 3D laser scanning, while the accuracy of the model obtained is higher compared to total station, adjusting with the accuracy of the 3D real scene model to be constructed, and more flexible than 3D scanning (Li 2019). The UAV photogrammetric data are found using in the reconnaissance and documentation on slopes, cliffs, high dams, and other similar terrains. Nevertheless, the environment of the waterfront cliffs arranges the total station equipment and laser scanner even more difficult as the traditional aerial photography requires large, long-range fixed-wing UAV equipment, but the complex environment of high slopes and the space limitations of cliff projects do not allow for large UAV equipment to be brought down. As such, small-sized rotary-wing UAVs equipped with single lens are more suitable for photogrammetry on slopes or cliffs and the use of UAV oblique photogrammetry should enforce the following processes: site survey, route planning, flight operations, and data post-processing (Ye 2019).

Currently, two major types of photogrammetry are in use on small-sized consumer drones: the conventional oblique photogrammetry and the nap-of-the-object photogrammetry, which is a new photogrammetry method invented in 2018, affords a method for grasping high precision images of vertical surface by segmenting intricate terrain into units (Tao, Zhang, Duan, Ke, Xi, He

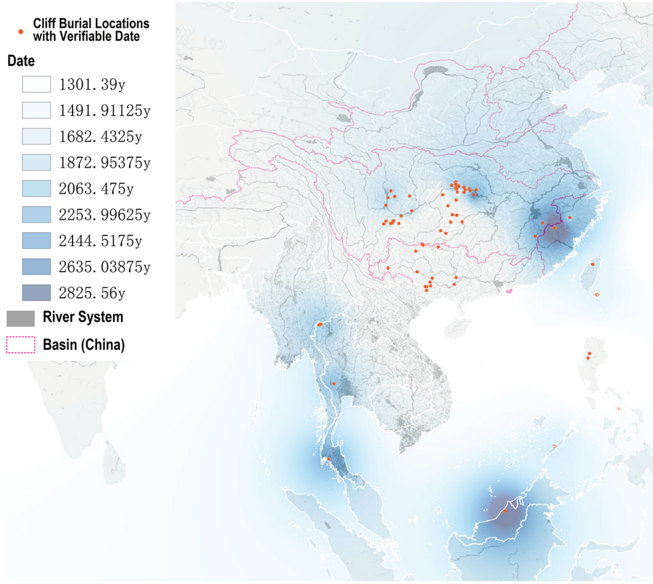


Fig. 6 - Spatial-Temporal Graph of Global Cliff-Burial Sites.

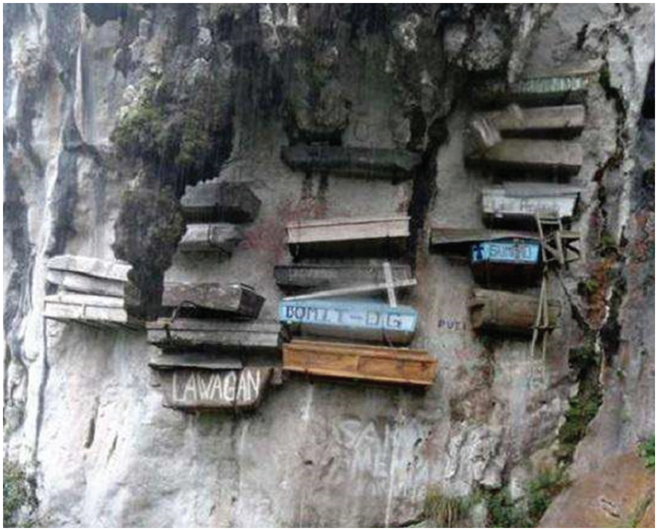


Fig. 7 - Cliff-Burial Sites of Sagada, Philippines.

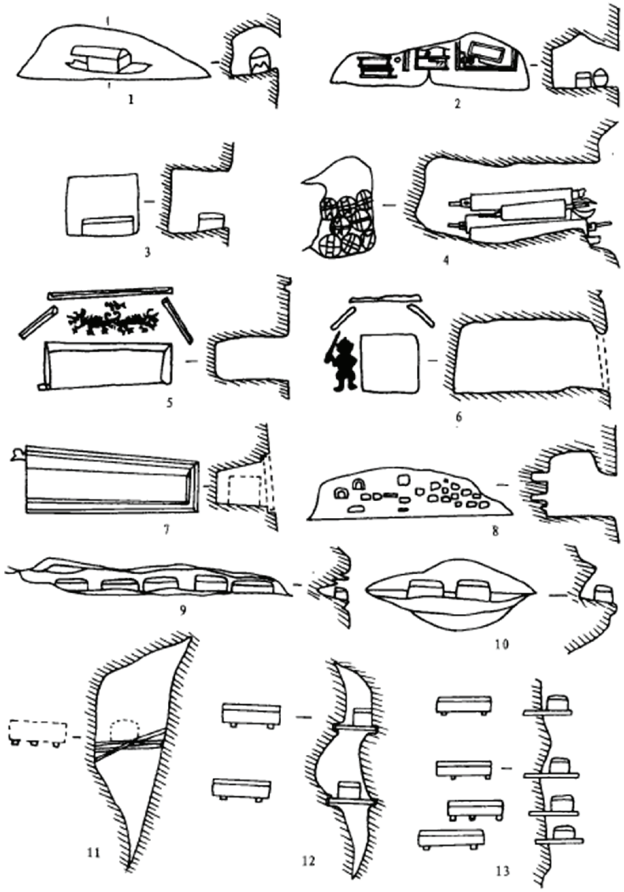


Fig. 8 - Diagram showing the different forms of cliff burial places (Wu 1999) p. 316, Fig.1.

2021; Tao, He, Xi, Liu, Niu, Duan, Zhang 2019). Both techniques have their own advantages and disadvantages and should be utilized in conjunction with the specific terrain when digitally researching. Compared to oblique photogrammetry, nap-of-the-object photogrammetry enables efficient acquisition of sub-centimetre or even millimetre ultra-high resolution images of the ground (e.g. landslides, dams, high slopes, etc.) or the surface of artificial objects (e.g. tall ancient buildings, landmarks, etc.) and thus implement the fine-grained 3D reconstruction (Tao, He, Xi, Liu, Niu, Duan, Zhang 2019). The nap-of-the-object photogrammetry provides an excellent means of digitally researching cultural heritage on the precipice, but is not suitable for large scale DOM and DSM geographic information acquisition for surrounding environment. In the modeling of high dam in hydropower project, 3D modelling incorporating oblique photogrammetry and nap-of-the-object photogrammetry enables effective fine-grained, high-resolution modelling of elevations, steep slopes and shaded areas (Zhang, Wu, Shang, Lyu, Wang 2021).

This study thus explores the possibility of using UAV with substantial improvement in survey accuracy, range and flight control. With the help of SfM (Structure from Motion) algorithm, the key results are expected as follows: first, the current situation of the hanging coffins on the cliff in terms of size, shape, coffin cover and coffin body preservation status, etc.; second, the accurate location of the coffins referring their geographical environments, such as the location of the cliff or cave, the structure of the supporting structure, etc., and other hanging coffins in different caves, such as the stacking mode of coffins and the layout of cliff caves, etc.

The former cliff of Baiyun Temple located in the west of Mt. Wuyi was selected as the main subject of a digital survey by UAV photogrammetry and reconstructed by DJI TERRA software based on SFM-DMVR algorithm. The UAV type used in this stage was the DJI Spark Pro as a mid-

priced consumer drone, whose size and weight are also suitable for carrying in hilly environments for cliff-burial survey.
The nap-of-the-object photogrammetry was used in the first step as the main tool to scan the coarse model of the Baiyun Temple site to obtain not only the basic cave dimensions, the approximate shape of the objects in the cave, but also the placement position and angle of the object.
To meet the possible requirements of a higher precision model, the next step was to plan a refined photogrammetric route with Waypoint Master (WPM) software. For a wider image range, which is key for improving model accuracy in photogrammetric 3D digitization, we tried to determine the UAV camera declination, elevation and horizontal with the information such as size, shape and coffin position obtained from the coarse model. (Fig. 9).
The hanging coffins at the Baiyun Temple cliff-burial site have been damaged and lost, while most of the better-preserved sites such as Jinji Cave are in a forbidden zone, where UAVs are not allowed to take off without a special flight permits due to an air traffic control. The current research, therefore, includes ground data collection and preliminary research test of the Jinji Cave site, and proposes a detailed plan for UAV flights and photogrammetry once permission was granted.
The spatial pattern of cliff-burials from southern China to SE Asia has a variety of types; in section, the cliff-burial caves in Mt. Wuyi (especially the Jinji Cave site) region are predominantly shallow, inwardly concave, and the coffins are placed in a direction roughly parallel to the cave openings. Using this as a base paradigm, we selected a building elevation opening with no flight restrictions as the simulated environment for the Jinji Cave site testing, the color and orientation of the elevation and the height of the opening being consistent with that of the Jinji Cave site. A solid model of a coffin made of similarly colored cardboard was also placed in the simulated cliff cave. The test was set by setting the UAV’s elevation position, distance to the cliff face and camera rotation angle to test whether it could effectively record the coffin form and position information in this Jinji Cave site-like environment. (Fig.10).
By adjusting the angle of pitch and deflection of the lens, and the point at which they adjust the angle, we could derive two imaging means each for the vertical and horizontal directions, in response to the specificity of the spatial environment of the cliff-burial. In a simulation based on a similar environment, we designed experiments to investigate the effect of three different close-in photogrammetry methods on the data obtained from photogrammetry of cliff burial sites, using a combination of different experimental group. Trial flights at Baiyun Temple have shown that elementary hand-controlled flights facing a cliff-burial cave environment can be sufficient for initial information acquisition. At the same time, based on the results of the simulated test in similar environments, we have derived an accurate survey trajectory based on the elevation position and scale of the cliff cave, and the more efficient pitch and rotation angle of the UAV.

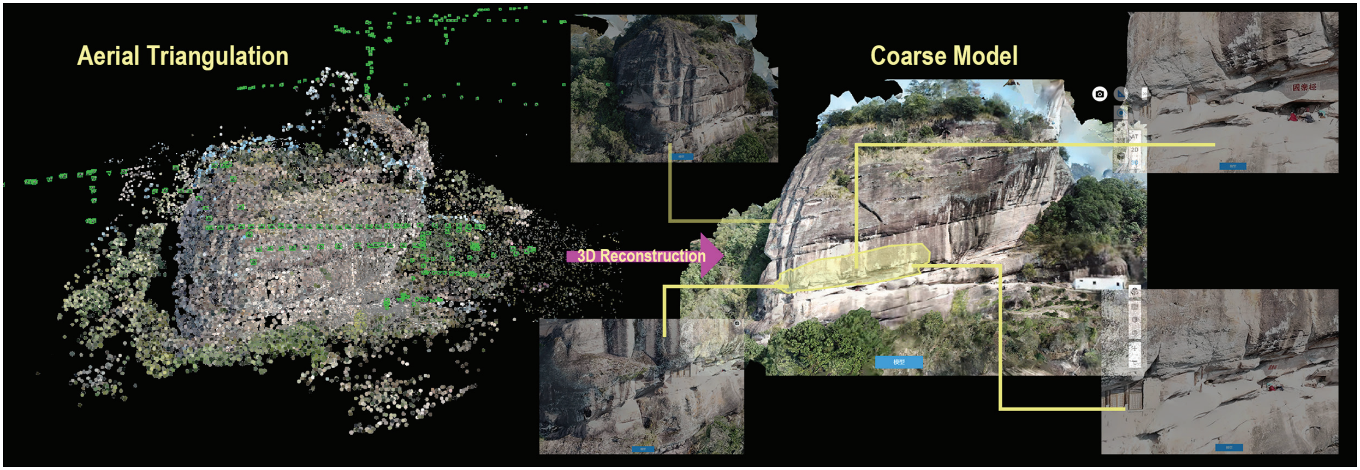


Fig. 9 - Coarse Model Results of the Baiyun Temple Site Based on the Nap-of-the-Object Photogrammetry Data.

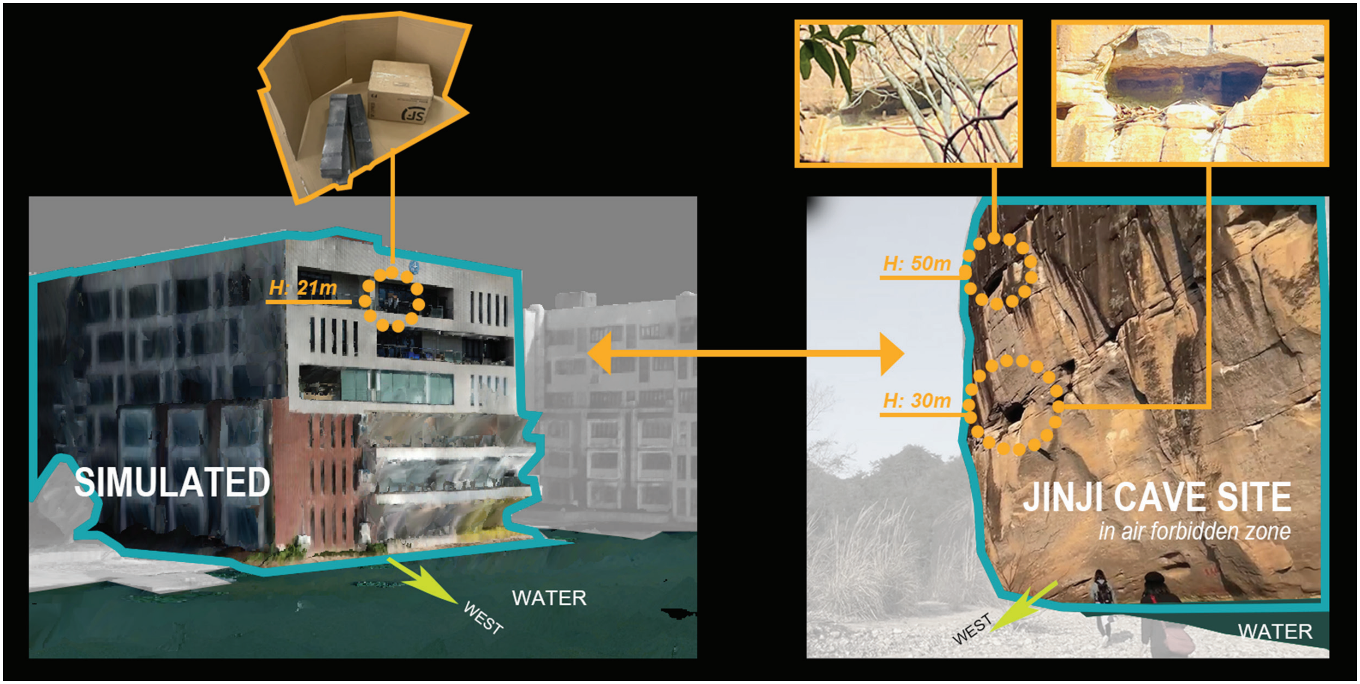


Fig.10 - Simulating Tests for Jinji Cave Cliff-Burial Site.

Virtual Archaeology and Virtual Restoration as tools for knowledge and communication. Cases study in Greece and southern Italy[2].

This work is part of the results of a doctoral research[3] on the topic of knowledge and scientific communication through the experimentation of original methods of graphic language of documentation, investigating advanced acquisition, archiving and representation tools for cultural heritage.
The gap between technical drawings and dissemination products is increasingly thinner due to the specificities of digital information systems, capable of capturing the shape and physical characteristics of an asset in all its dimensions. The digital survey, fulfilling the dual function of documentation and interpretation, assumes the role of support for the investigations carried out on the cultural property. This allows archaeologists to be able to analyze, in a more detailed and punctual way, preserved horizontal and vertical deposits, as in the case of the investigations carried out at the archaeological site of Kastrì-Pandosia (Ionian coast of Epirus, Greece) where the use of Structure from Motion (SfM) techniques directed subsequent investigations in the study of the archaeological evidence found on site (Fig.11).
The possibility of extending the dimension of archaeology into digital space is the basis of a new scientific process of virtualization, able of transferring the correctness of metric, geometric, historical, and archaeological data into digital space, increasing the construction of virtual models to preserve memory and disseminate knowledge.
Virtual Archaeology and Virtual (or Digital) Restoration allow information recovery interventions on virtual images or scenes. It aims at reconstructing the initial condition of the artifact's appearance from an archaeological trace.
The experiments made possible the virtual reconstruction of ceramic artifacts at the archaeological site of Karabournaki

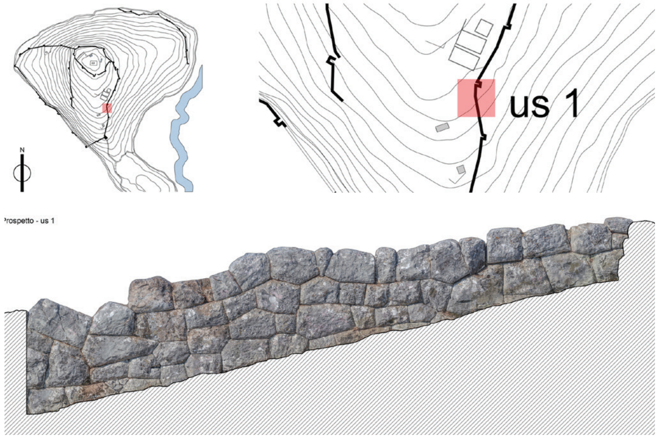
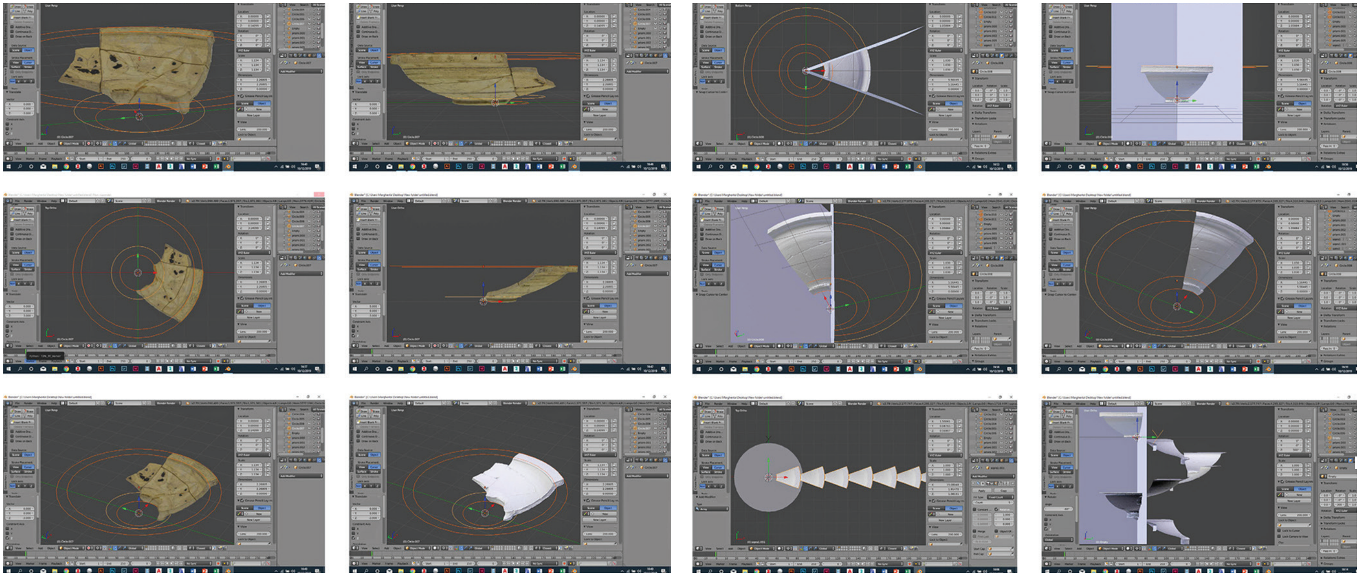


Fig.11 - Instrumental survey and terrestrial photogrammetry of the wall structure USM1 at the archaeological site of Kastrì Pandosia. Edited by Margherita Tricarico.

(GR) (Fig. 12) and the virtual reconstruction of the medieval fortified settlement at the archaeological site of Satrianum (Tito, PZ).
The long twenty years' path of knowledge and excavations[4] of the vast medieval fortified settlement of Satrianum, carried out by the SSBA-Unibas, has made it possible to build up a large and detailed documentary corpus testified by numerous finds[5]. This work led to the definition of a "knowledge model" of the entire archaeological site and specifically of the religious complex[6].
The process of synthesizing the collected data was carried out together with the archaeologists in charge of scientific management and made it possible to retrace all the historical and settlement phases of the complex. It was decided to represent the Angevin phase (1246-1435) of the episcopal complex because, characterized by a decisive renovation following the earthquake of 1273, it represents the moment of the greatest transformation of the entire complex that is still evident in the structures.



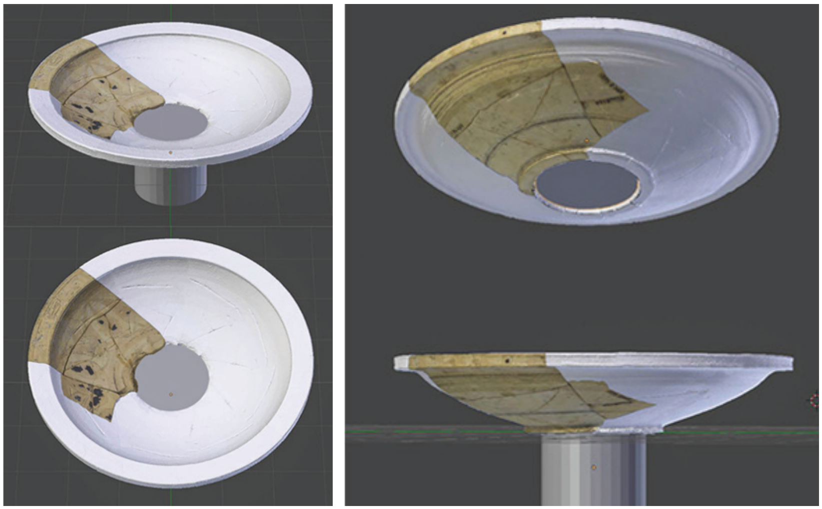


Fig.12 - The different stages of three-dimensional reconstruction of the Karabournaki plate in its integral form. From the photogrammetric model of the real object to the virtual model. Screen extracts from Blender 3D, processed by Margherita Tricarico.

Fig.13 - Digital reconstruction of the floor of the church of Satrianum, emerged after the archaeological excavations in 2006. Re-elaboration by M. Tricarico. SSBA Archive, UNIBAS, Matera.

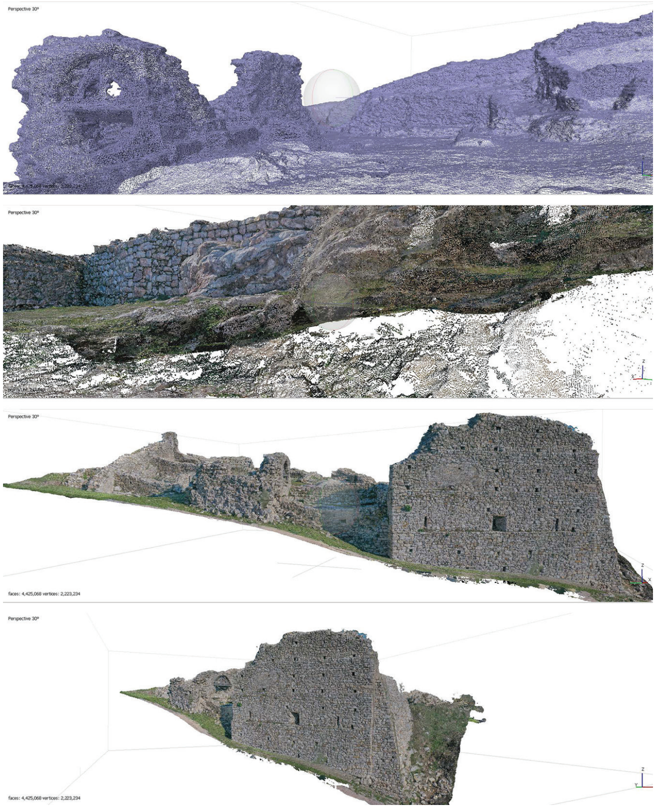


Fig.14 - Photogrammetric processing. Point definition, acquired to allow a detailed reading of the wall textures. Processed by M. Tricarico.

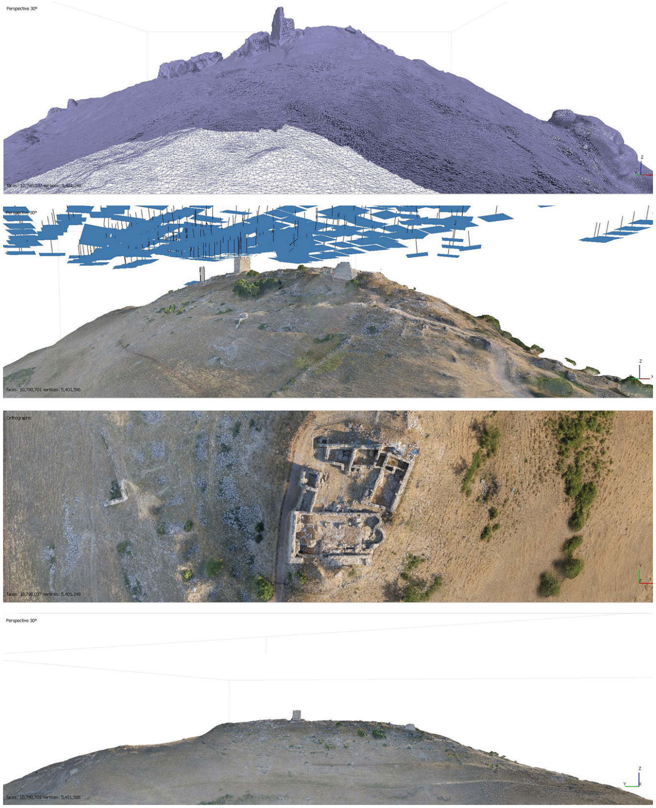


Fig.15 - Photogrammetric processing. Landscape definition, acquired for the understanding of the natural morphological system of the entire high ground. Re-elaboration by M. Tricarico. SSBA Archive, UNIBAS, Matera.

The surveying activity coincides partly with the process of studying documentary sources and analysis found in historical research, and partly with all that information still "found on the body of the monument"[7], found by direct analysis of the state of conservation of the artifact such as the survey, stratigraphic reading of the elevations, and data from archaeological excavations. The valuable data from the excavation of the cathedral that began in 2006, describes the internal components of the horizontal walking surface, bringing to the surface part of the pavement, various burials, the small frescoed altar, the ground attachment of the pilasters, and the perimeter walls, were covered, at the end of the excavation, to preserve them. Therefore, the digital reconstruction of the church floor that emerged in 2006 was carried out using archive photos and documents that, as they were not acquired through

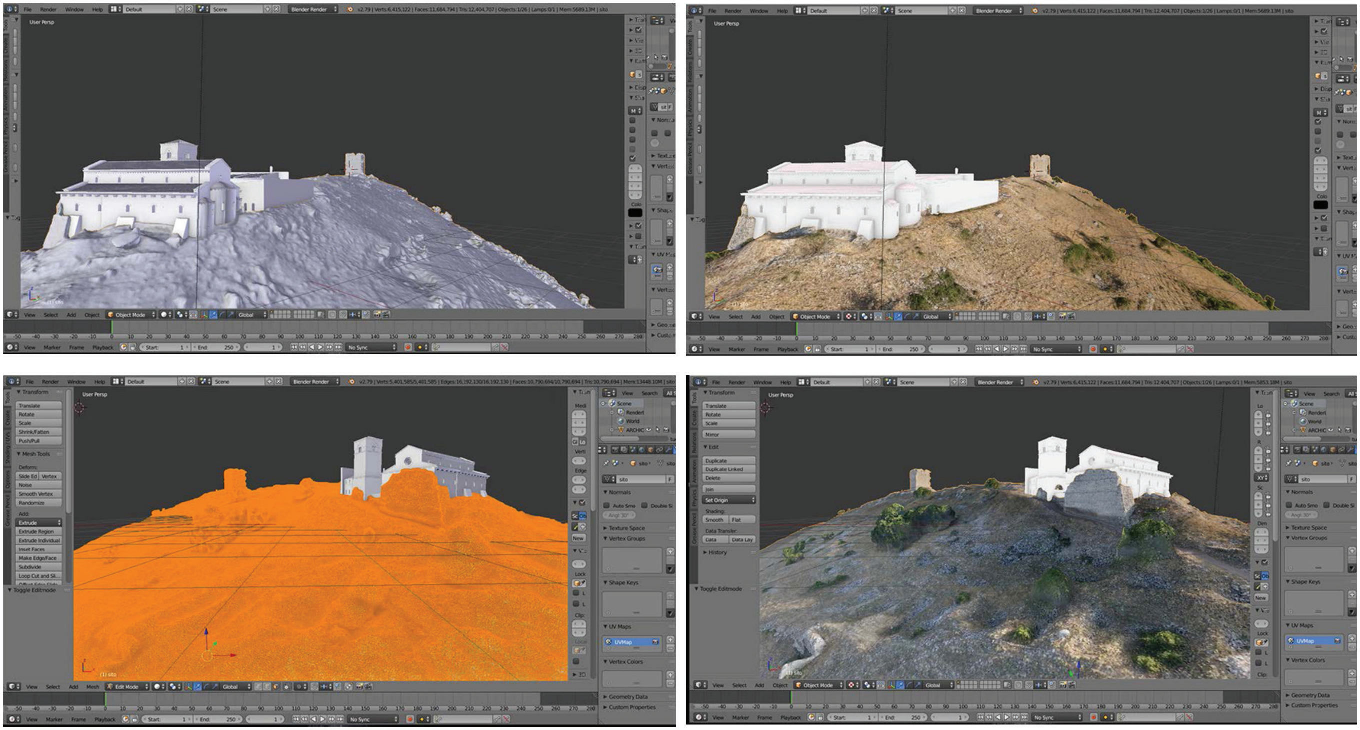
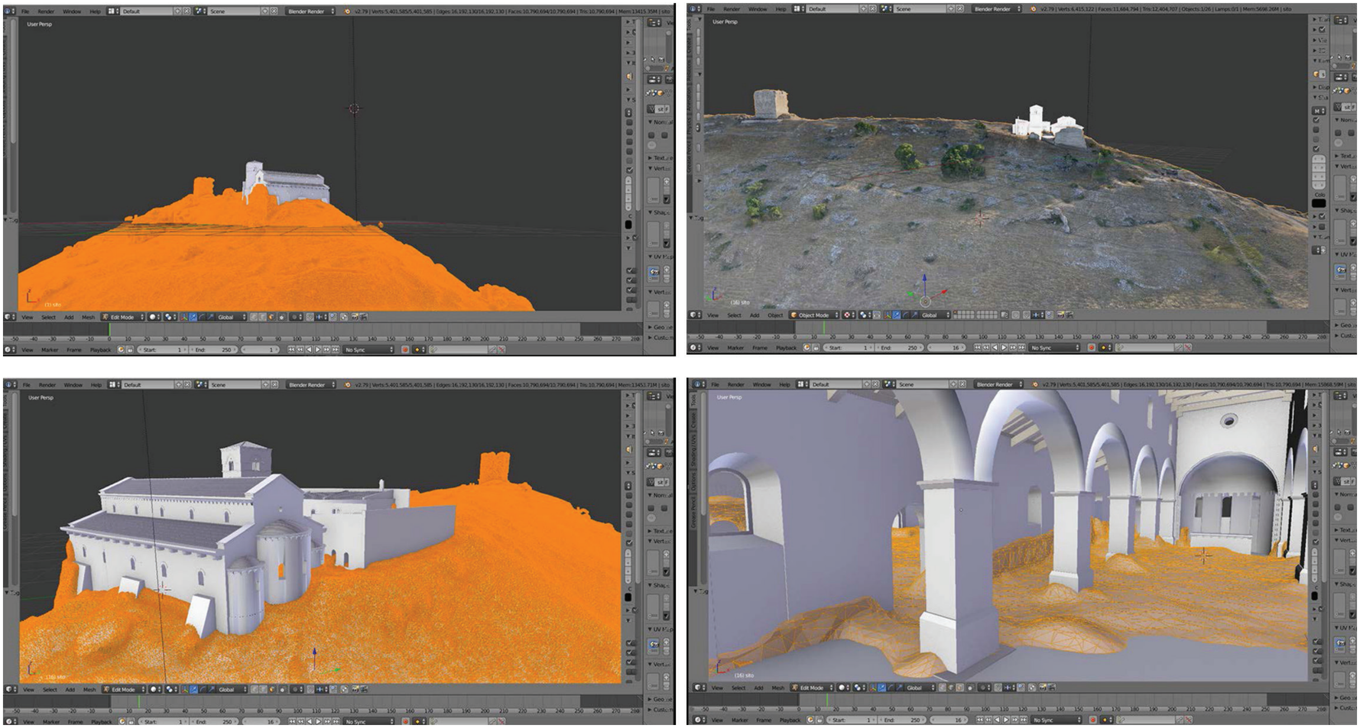


Fig.16 - Manual modelling process. Assembly between virtual model of the actual state and virtual model of the reconstructed artefact. Elaboration by M. Tricarico.

the photogrammetric process, made the reconstruction particularly complex (Fig. 13).

Photogrammetric acquisition procedures aimed at conducting purely archaeological analyses, follow a method aimed at the restitution of two-dimensional photo plans. This allows archaeologists to interrupt the acquisition of photographs between one elevation and another or between the elevation and its horizontal projection, to obtain single files referring to individual stratigraphic wall units (USM). This procedure, however, was not valid to produce a reliable database for a single complete 3D model designed to capture depths, angles, and connections between one elevation and another. A new acquisition through Image-Based Technologies was therefore deemed necessary, conducted using drones, GIS technology, and professional cameras, divided into two acquisition phases: the first one to allow a detailed reading of the wall textures, carried out in the religious complex; (Fig. 14) the second one for the landscape definition and understanding of the natural morphological system of the entire elevation. (Fig. 15)

The joint use of the two technologies ensured the construction of a reliable database for metric documentation of the entire complex. The acquired data were processed



using different software[8], thus managing the obtained database of information and being able to return in graphic form the architectures under investigation. The techniques of Image-Based Technologies are followed by those of Hand Made Modeling that make it possible to interact with the virtual model of the buildings, to restore the formal unity of the artifact (Fig. 16) through the reintegration of missing parts[9].
Everything that the survey, previous graphic and photographic documentation, written sources (epigraphic, numismatic, and literary), and archaeological research needed in terms of integration, such as certain heights and stylistic or spatial considerations, was investigated through the study of typological comparisons of the architecture and decorations of other religious complexes built in the same period in the regional context[10].
The experiments were carried out by integrating photogrammetry data with three-dimensional modeling[11] were used to elaborate a comprehensive information system that combines the metric precision and color aspect of the digital survey with the critical description of its virtual reconstruction.
The result is defined in virtual restoration as a "verification model", i.e. the tool for understanding the structural and

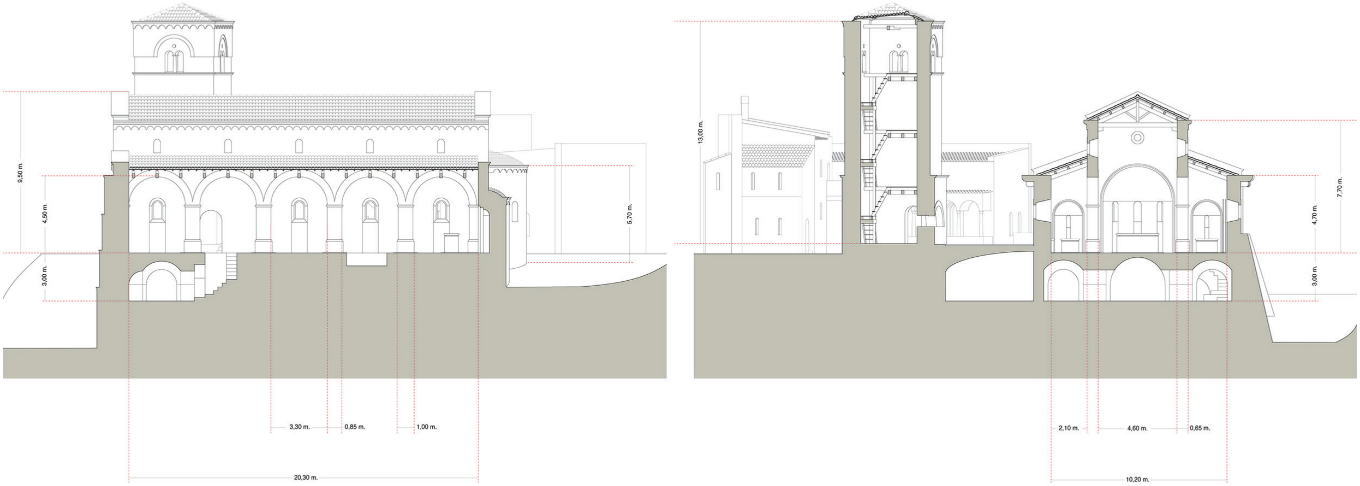


Fig.17 - Virtual reconstruction of the medieval fortified complex of Satrianum. Longitudinal section (A-A’) and cross section (B-B’) of the Cathedral, extracted from the three-dimensional virtual model. Elaboration by M. Tricarico.

functional logic of a monument (Fig. 17). It represents a verification of construction solutions for a scientific evaluation of the sources available to archaeologists and their interpretation. This phase of experimentation can be defined as “final” in archaeological research normally undertaken in the field and in the laboratory, i.e. the confirmation of what has been imagined through study and analysis, but it can also be a step in the work in progress observed from another point of view (Fig. 18).
The choice of modeling the lost form in a simplified manner concerning the complexity of the shapes and materials of the real space made it possible to produce graphics from which direct information could be derived, clear in the understanding of what has been preserved and what has been critically hypothesized (Figg. 19-20).

Fig.18 - Virtual reconstruction of the medieval fortified complex of Satrianum. Sequence of three interior views of the cathedral, taken from the same transversal axis, one for each nave in the direction of the apses. Edited by M. Tricarico.

Fig.19 - The medieval fortified complex of Satrianum, aerial view of the east elevation. Photo insert of the reconstructed virtual model. Elaboration by M. Tricarico.

Conclusions

The results on the simulations and their application on different cases study in Europe and China, not only demonstrate not only demonstrate the feasibility of digital survey tools for UAV photogrammetry, but also suggest operational details for the heritage sites in terms of imaging methods, reflecting the differences between the application of photogrammetry in other environments.

The preservation, management, and valorization of archaeological, artistic, and monumental heritage go through their concrete usability. This is one of the main aspects on which the research is focused. Thanks to the use of several combined techniques and tools, the research aims to optimize the level of information, with the necessary objective of raising awareness of the extent and relevance of the cultural heritage and making the enjoyment of the heritage more participatory and considered.

Notes

[1] Edited by Prof. Arch. Xin Wu and Ph.D. Arch. Marianna Calia.

[2] Edited by Ph.d. Arch. Margherita Tricarico.

[3] Doctoral Fellowship P.O.N. Research and Innovation 2014-2020, European Social Fund, Action I.1 "Innovative Doctorates with Industrial Characterization". Tutor Prof. Arch. Antonio Conte, Prof. Francesca Sogliani.

[4] Since 2000, the SSBA-Unibas under the direction of Prof. Massimo Osanna, has undertaken in-depth archaeological surveys and research on the entire area surrounding the high ground, obtaining an initial overall reading of the entire settlement network, which stretches from the Protohistoric Age to the Archaic Classical and Roman periods. In 2006 archaeological investigations began on the plateau dominated by the medieval tower, aimed at bringing to light the vast fortified medieval settlement of Satrianum. These investigations have made possible to acquire an initial restitution of the structures of the cathedral and the adjoining rooms, which were used as an episcope. The archaeological investigations, which are still ongoing, are directed by Prof. Francesca Sogliani.

Fig.20 - The medieval fortified complex of Satrianum, view of the eastern profile of the hill with the Norman tower and the episcopal complex. Photo insert of the reconstructed virtual model. Elaboration by M. Tricarico.

[5] Gargiulo B., Annunziata E., *La storia di un butto. La mensa, le monete e un terremoto dalla cattedrale di Satrianum* (PZ) (pp. 335-340).

[6] "To achieve optimal levels of historical rigor and truthfulness, any form of computer-based visualization of the past must be supported by solid research, historical analysis, and archaeological documentation". Historical rigor. The fifth principle of the Seville Charter.

[7] Fancelli P., *Indagini preliminari e diagnostica. Rilievo storico-critico delle fasi costruttive*, in Zevi (edited by), *Manuale del Restauro Architettonico*, cit., E13.

[8] Photogrammetric processing was carried out using: Adobe Lightroom, Agisoft Metashape, Blender 3D, and Adobe Photoshop.

9 Limoncelli M., Scardozzi G., *Dalla cartografia archeologica digitale al restauro virtuale: recenti casi di studio a Hierapolis di Frigia* (pp. 75-99).

[10] Such as the abbey of Santa Maria in Banzi, the church of San Michele Arcangelo in Potenza, or the sanctuary of Santa Maria Regina in Anglona. Observing the original planimetric development, not only of the cathedral but of the entire complex, it can also be observed comparisons with numerous coeval French installations, also structured around a central space/court.

[11] Three-dimensional modeling was carried out using: Blender 3D, Archicad, and 3D Studio Max.

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[3] Dimitris R., Sogliani F., Tricarico M., 2019. *Kastri-Pandosia. La città greca fortificata sull'Acheronte* (pp. 182-187), II Simposio UID di internazionalizzazione della ricerca, Bertocci S., Conte A., Dida press, Firenze.

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[6] Sogliani F., Gabellone F., 2010. *The fortified medieval settlement of Rocca Montis Dragonis* (Mondragone, Caserta – Italy) virtually alive, in Proceedings 14th International Congress Vienna Cultural Heritage and New Technologies (Vienna,16-18 novembre 2009), Wien, e-book, pp. 461-472.

[6] Tao P., He J., Xi K., Liu K., Niu Z., Duan Y., Zhang Z., 2019. *Approaching photogrammetry method based on rotor unmanned aerial vehicle*.

[8] Tao P., Zhang Z., Duan Y., Ke T., Xi K., He J., 2021. *Close photography three-dimensional flight path and attitude planning method and device for complex terrains*.

[9] Tsiafaki D., Koutsoudis A., Arnaoutoglou F., Michailidou N., 2016. *Virtual reassembly and completion of a fragmentary drinking vessel* (pp 67-76), Virtual Archaeology Review 7.

[10] Wu C., 1999. *A typological study of cliff burials in south China.* "Acta Archaeologica Sinica". No. 03, p. 311–336.

[11] Zeng F., Yang Q., Fu S., 1980. *A Survey and Preliminary Study on Boat Coffin Burials in Mount Wuyi. Cultural Relics*. No. 06, p. 21–31.

[12] Zhang Z., Wu F., Shang H., Lyu W., Wang J., 2021. *Application of Nap-of-the-Object Photogrammetry and Oblique Photogrammetry in Fine Modeling of High Dam in Hydropower Project. Northwest Hydropower*. No. 05, p. 47- 50+55.

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07 SIMULATION OF SPACE IN PIRANESI'S *CARCERI* BETWEEN ARCHITECTURE, PERSPECTIVE AND PERCEPTION

Abstract

Perspective restitution alone is insufficient to achieve a three-dimensional simulation of the represented space in perspective images constructed without projective rigour, such as Giovanni Battista Piranesi's Carceri. Therefore, a method of spatial analysis - that integrates architectural (graphic analysis), perspective (perspective restitution and principles of scenography), and perceptual (eye-tracking technique) interpretations - is proposed and then applied to the frontispiece of the first edition of the series. The result is a three-dimensional simulation of Piranesi's space, whose perspective view can be compared with Piranesi's perspective. Further axonometric views of the 3D model show the architectural elements directly derived from the etching, those varied for architectural-compositional reasons and those assumed to complete the space.

Introduction

Among perspective views, it is possible to distinguish those that present a rigorous projective construction, that therefore derive from and are constructed according to the method of perspective representation, and others that, while simulating perspective vision, introduce inconsistencies and ambiguities. Among the first group, an excellent example can be found in the work of the quadraturist Andrea Pozzo. In his treatise *Perspectiva pictorum et architectorum* (1693) (Fig. 1a), he

Fig. 1 – (a) Theodor Verkruys, engraving in the 2nd volume of Andrea Pozzo's treatise *Perspectiva pictorum et architectorum*, 1700; (b) William Hogarth, engraving for the frontispiece of the treatise *Dr Brook Taylor's method of perspective made easy*, 1754.

described perspective construction procedures for artists and architects, which he also applied in his masterful architectural perspectives inside some Jesuit churches. The purpose of the quadratures is to create an illusory virtual space, and projective rigour is required to make the deception happen. Studying this type of perspective pictures presupposes a good knowledge of the inverse method of perspective, the so-called perspective restitution, which allows us to reconstruct the three dimensions of the illusory space virtually[1]. However, as mentioned at the beginning, not all perspective views are based on a rigorous construction. Some conceal inconsistencies, more or less overtly, which complicate a possible three-dimensional interpretation of the depicted space, and perspective restitution alone cannot provide an unambiguous answer. An extreme and provocative case is represented by the frontispiece (Fig. 1b), illustrated by William Hogarth, of the treatise *Dr Brook Taylor's method of perspective made easy* (1754) in which the caption reads 'Whoever makes a design without the knowledge of perspective will be liable to such absurdities as are shown in this frontispiece'. Giovanni Battista Piranesi's *Carceri* series ranks in a less extreme position than Hogarth's engraving among the perspective pictures constructed without projective rigour.

The research described here aims to devise a method of analysing and interpreting the space represented in perspective views constructed without projective rigour and applies this method to the frontispiece of the first edition of the *Carceri*, entitled *Invenzioni capric[ciose] di Carceri all'acquaforte* (1749-50) (Fig. 2)[2].

The most important graphical-analytical study of the *Carceri* conducted to date is by Ulya Vogt-Göknil and dates back to the 1950s[3]. Concerning the frontispiece, Vogt-Göknil compared the plans of the two versions of the series. These plans do not seem to derive from an attempt at perspective restitution, nor is the method by which she arrived at these representations clearly explained.

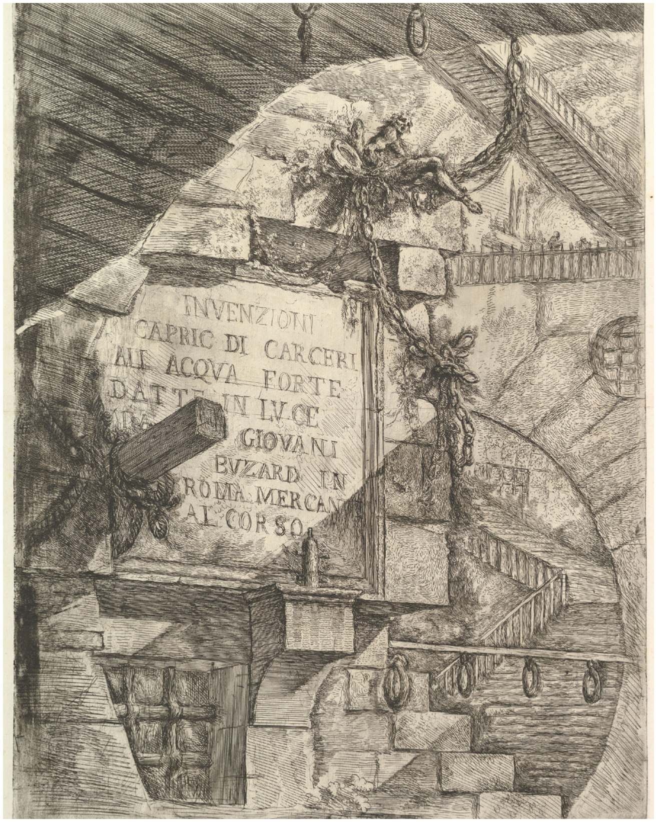


Fig. 2 – Giovanni Battista Piranesi, frontispiece of *Invenzioni capric[ciose] di Carceri all'acquaforte*, 1749-50.

Graphic analysis and simulation of space

The proposed method of study involves the integration of architectural, perspective and perceptual analyses and interpretations, which make it possible to propose a hypothesis for the reconstruction of space thanks to their integration.

Knowledge of the represented architecture is fundamental since perspective images can only evoke configurations known to the observer[4]. For example, a whole series of assumptions are made upstream of the process in perspective restitution, including identifying triorthogonal elements. The architectural study of the frontispiece was conducted through graphic analysis: a method of studying architecture based on drawing and consolidated in the Roman School since the 1950s[5] (Fig. 3). The complex space was broken down into more easily readable drawings, the functional value of which is determined by the relationship between each level and all others. Eight different types of analysis were conducted on the frontispiece (Fig. 4): the re-drawing of the work; the analysis of symmetries (not present), proportional ratios, masses, the relationship between solids and voids, structures, materials and recurring elements (connections, openings, architectural furniture and decoration, anthropic and prison environment). The analysis of the masses revealed the first ambiguity related to the four steps at the lower edge of the plate (Fig. 5). They can be interpreted as parallel or perpendicular to the plane with the epigraph. This ambiguity is the same type attributed to Necker's famous cube, where depth perception is subject to switching. The architectural analyses are interesting both when considering each plate in the series and when comparing all 14 etchings analysed. The visual programming language (VPL) was the tool through which the percentages of the presence of certain elements of the structural and material analysis were calculated (Fig. 6). These graphs unequivocally show that masonry and arches are the elements most present not only in the frontispiece but also in many other plates. Stone predominates among the materials present in all the etchings in the series. The architectural interpretation of the frontispiece suggested which elements to consider in the following reconstructive hypothesis, excluding those not participating in the spatial configuration. It also suggested the composition's triorthogonality and the architectural elements' recognition. The latter helped

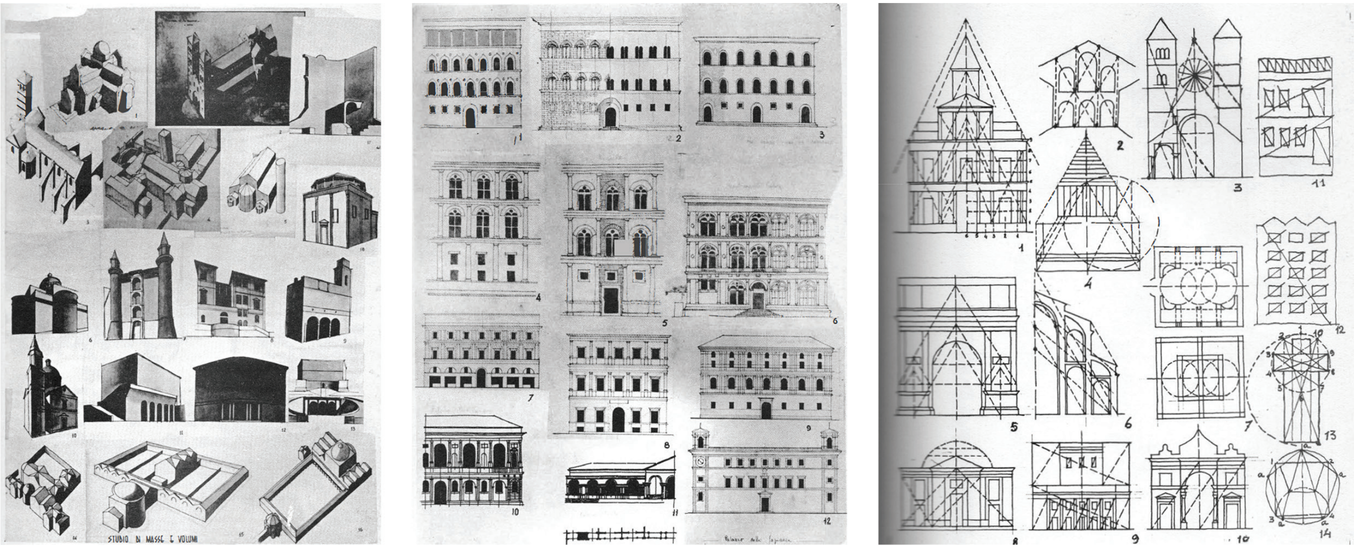


Fig. 3 – Vincenzo Fasolo, a few pages with examples of graphic analysis (Fasolo n.d.).

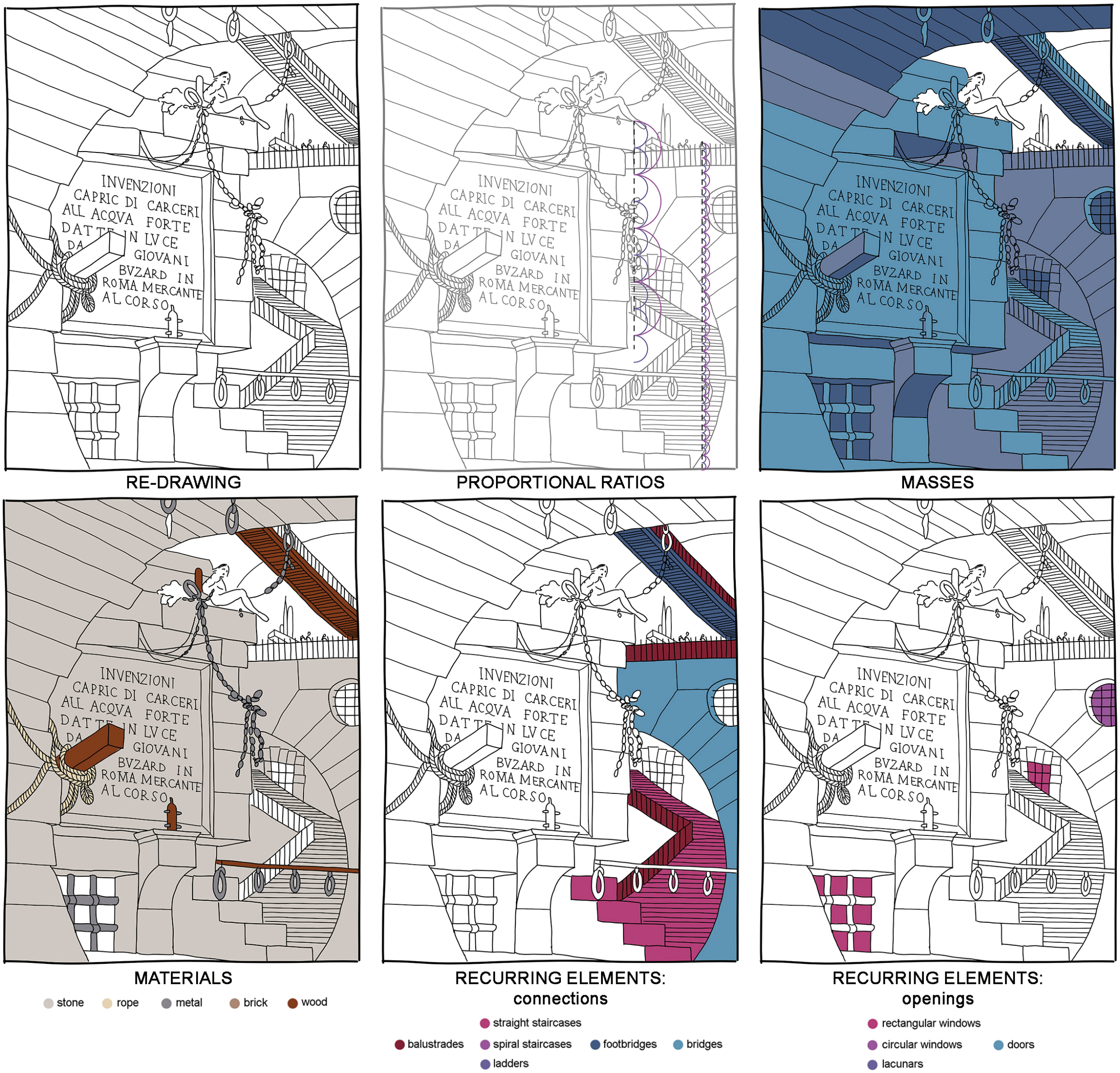
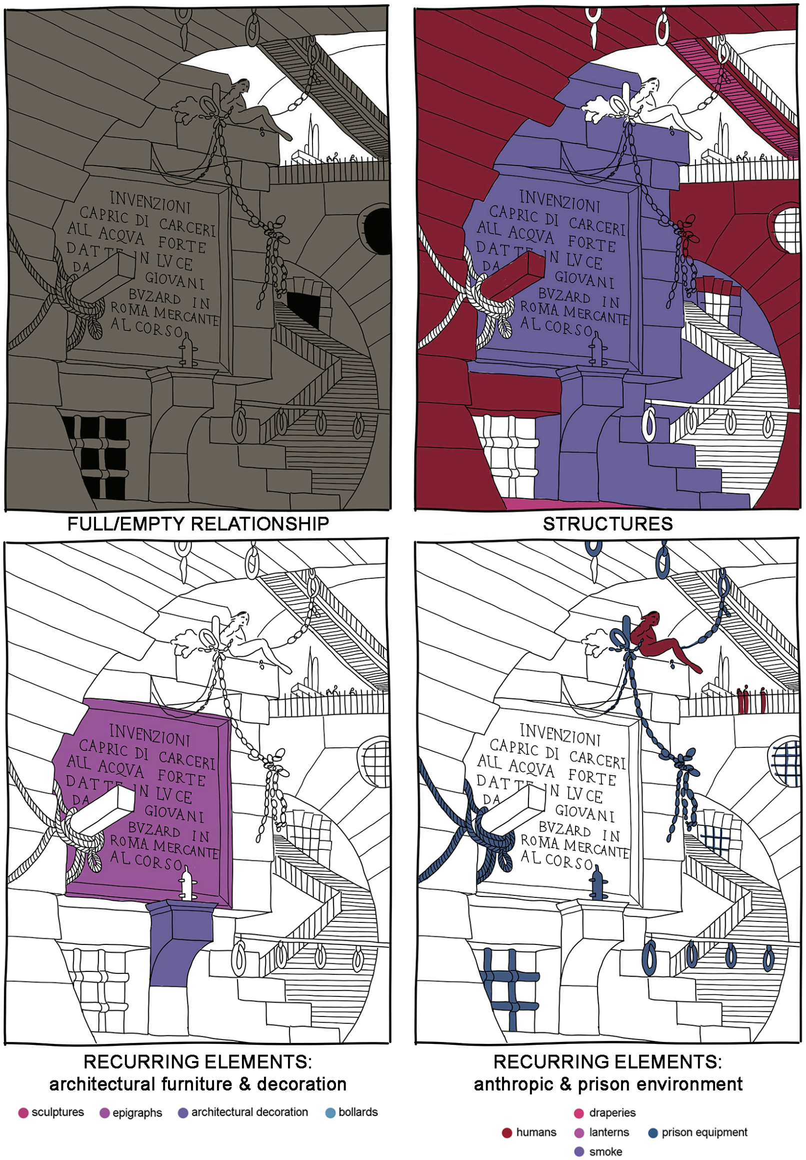
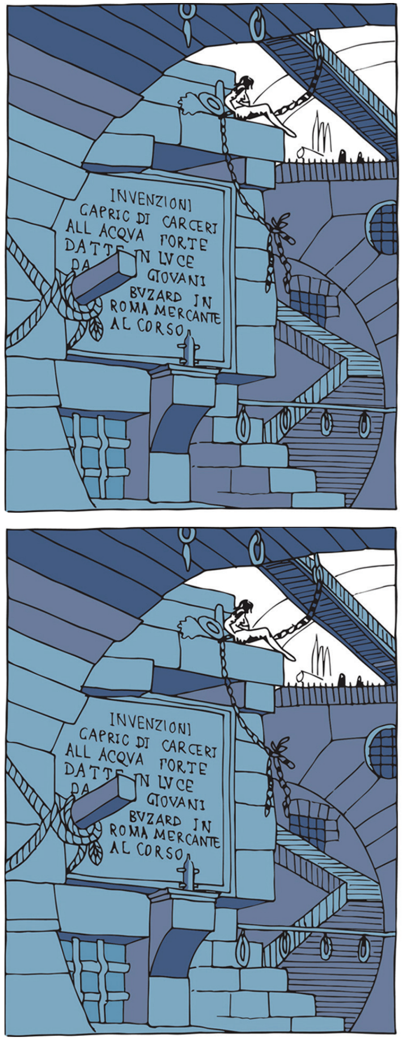


Fig. 4 – Architectural analyses conducted on the frontispiece of the Carceri (graphic elaborations by the author).





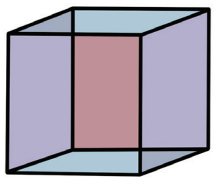


Fig. 5 – On the right, analysis of the masses Analysis of the masses of the frontispiece with the two perceptible versions of the four steps below the epigraph and the famous Necker's cube (graphic elaborations by the author).

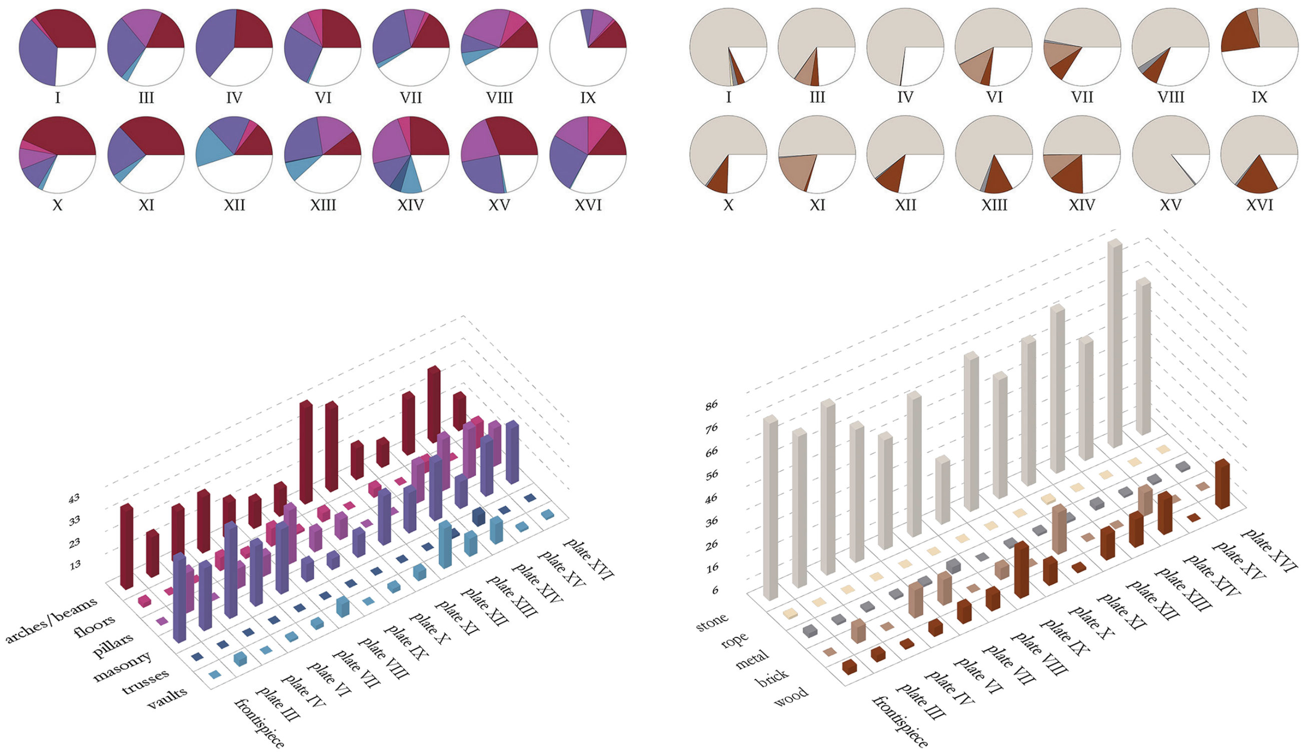


Fig. 6 – Graphs obtained by VPL showing the summary data of the analysis of structures (left) and materials (right) for the 14 plates in the series (graphic elaborations by the author).

First depth plane
Second depth plane
Third depth plane
Fourth depth plane
Fifth depth plane

Fig. 7 – Decomposition of the frontispiece into depth planes (graphic elaborations by the author).

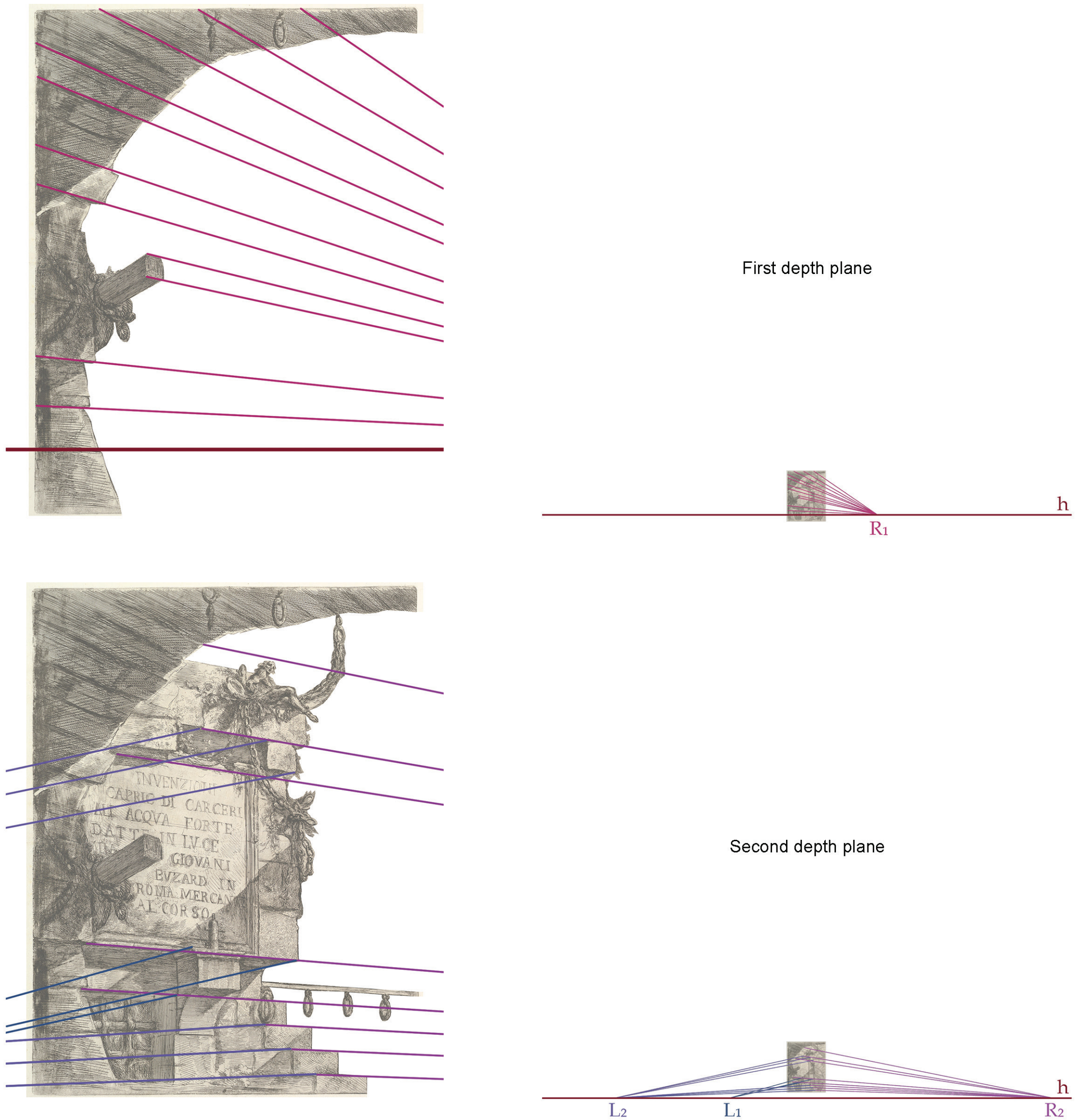
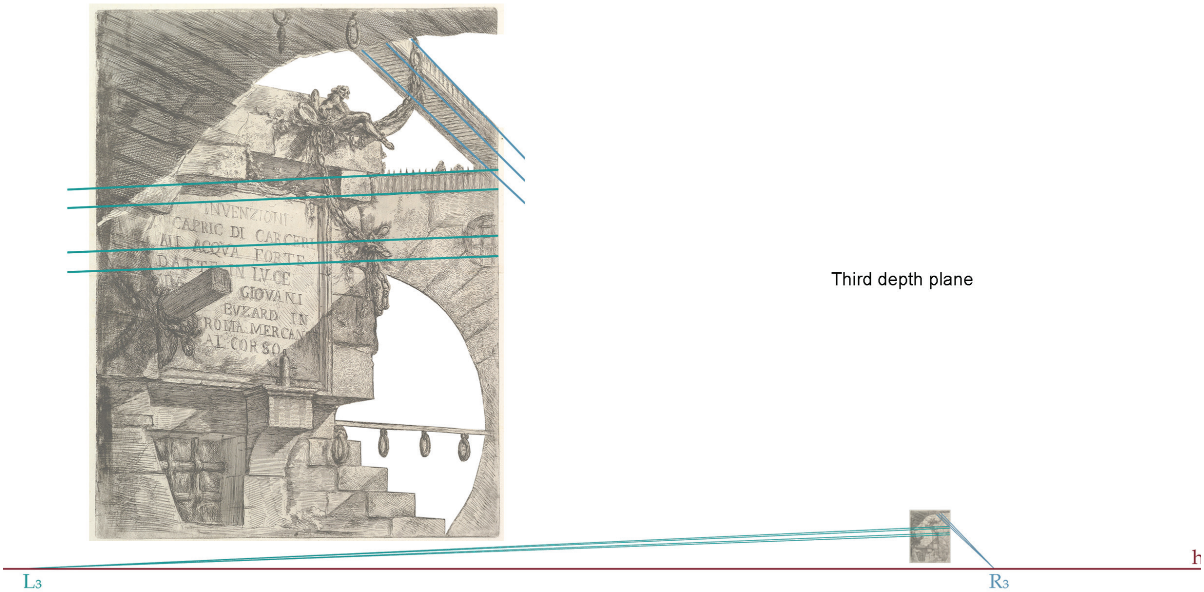
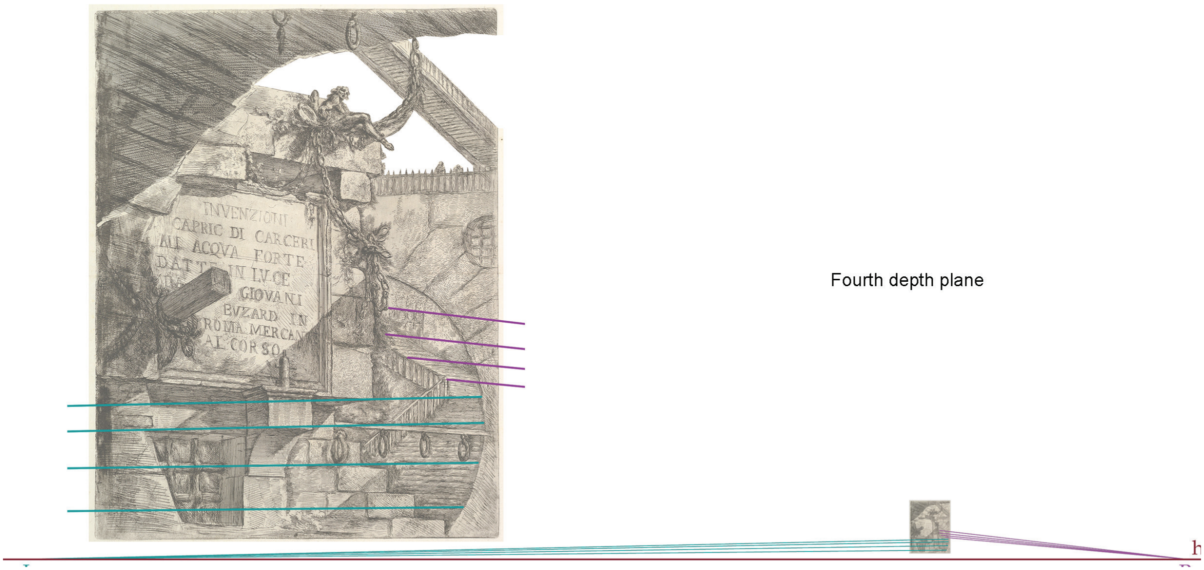


Fig. 8 – Perspective analysis of the depth planes of the frontispiece. All the lines running to the same vanishing point have the same colour (graphic elaborations by the author).


Third depth plane
h
L3
R3


Fourth depth plane
h

present a hypothesis of the development of the space that is not directly visible on the plate.
The perspective interpretation investigates the spatial relationship between the objects represented, using scenography principles and perspective restitution tools wherever possible. From the former, we derive the idea of decomposing the plates into various planes at different depths, as if they were backdrops and stage flats. The decomposition is done by looking for those elements that define limits in the representation and identifying space sectors at different distances from the observer. A perspective analysis of these planes is then performed to trace the main elements of perspective (horizon, vanishing points) as these settings inform about Piranesi's communicative intentions. The frontispiece can be broken down into five depth planes (Fig. 7): the element framing the left margin in the foreground; the architecture with the epigraph; the bridge and the footbridge above; the stairs; the background. The perspective analysis of the individual depth planes (Fig. 8) shows that the horizon's position is not shared: it

Fig. 9 – Alfred Yarbus, eye movement experiments (reworked from Yarbus 1967). The work observed was the painting *An Unexpected Visitor* by Ilya Repin (1884), and each of the seven recordings had a duration of 3 minutes and specific instructions: (1) observe the painting freely; (2) assess the economic condition of the family; (3) propose the age of the people depicted; (4) hypothesise about the activities the family was engaged in before the visitor's arrival; (5) recall the people's clothes; (6) recall the position of the people and objects in the room; (7) assess how long the unexpected visitor had been away from the family.

is contained within the board in the foreground and then passes beyond the lower margin in the subsequent planes. The vanishing points of the horizontal lines also vary. The second depth plane shows a further oddity: the monument with the epigraph, assumed to be triorthogonal, has one right vanishing point, R_2, and two left vanishing points, L_1 and L_2. The left vanishing point splits but not due to a rotation of the triorthogonal element because the right vanishing point remains the same. What has just been described is likely a mechanism Piranesi used to provide greater depth to the block with the epigraph at its lower edge above the shelf.
The perceptual interpretation contributes to finding the spatial configuration closest to that the observer perceives. In particular, an experimental method was used based on the image decoding process, which is implemented by the human visual system continuously and unconsciously. This method involved the recording of eye movements using the eye-tracking technique. The greatest acuity in the human visual system is in the *fovea centralis*, the central part of the retina, so the observation of the eye movement allows us to understand what is attracting an observer's attention moment by moment, and its recording is helpful for perceptual purposes. Alfred Yarbus was the pioneer of this type of study[6]. The Soviet psychologist conducted a series of experiments, which enabled him to understand that, during an observation, the elements on which the gaze lingers most are those the observer considers most helpful in perceiving and understanding the phenomenon. The results of one of his eye-tracking experiments applied to a painting show that the tracking pattern varies depending on the instructions given to the observers, confirming that eye movement varies depending on what the observer unconsciously considers most useful for perceptual purposes (Fig. 9). Yarbus in his experiment performed seven three-minute recordings. He gave specific instructions for each one: e.g. to estimate the economic condition of the family, the age of the persons portrayed, to remember the clothes, and so on. Another factor

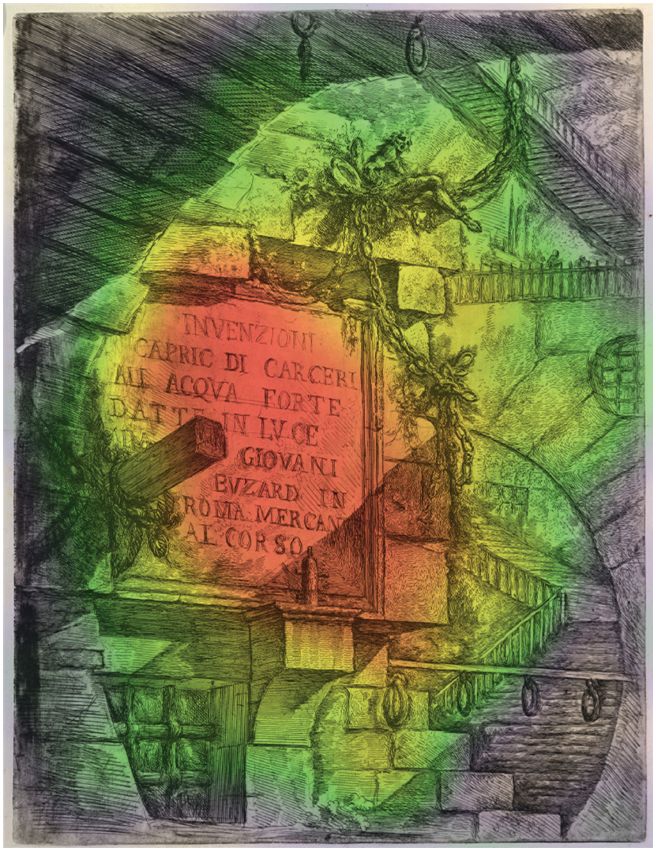


Fig. 10 – Eye-tracking map of the frontispiece (graphic elaboration by the author).

influencing the tracking pattern is the cultural variability of the observers. For this reason, 29 individuals of different ages and cultural backgrounds were involved in the *Carceri* experimentation. Each was asked to look at the frontispiece freely for 20 seconds while eye movements were recorded by a webcam placed above the monitor and processed by a software-based system (GazeRecorder). The resulting output includes an eye-tracking map, whether dynamic or collecting fixations over 20 seconds. The warm tones of the map are associated with the most observed areas of the plate. The free view allowed us to understand which areas were the most attention-capturing so that more attention could be paid to modelling those parts. In addition, the absence of instructions helped us understand whether the points of most significant fixation were the elements selected as ambiguous, for example, the four steps toward the lower edge of the plate. The perceptual interpretation of the frontispiece shows a pattern concentrated on the epigraph (Fig. 10), as was logical to expect. Since the eye-tracking map shows few fixations at the four steps, it seems reasonable to assume that most observers overlooked the ambiguity introduced by Piranesi. In the last part of the test, the group of individuals was asked to look freely at the four steps and indicate which of the two proposed variants came closest to the one they perceived (Fig. 11). The results show that the most selected variant is the one where the steps are perpendicular to the wall with the inscription. Furthermore, it seems that cultural background was not decisive in the choice. Similar results were obtained in percentage terms between individuals with a background in the scientific disciplinary field of Representation (ICAR/17), thus with a specific background on knowledge of architecture and its representation, and all the others. By combining the results of the three levels (architectural, perspective and perceptual) of analysis and interpretation conducted, it was possible to propose a three-dimensional reconstructive hypothesis of the space represented by Piranesi in the frontispiece. The 3D model shows the same perspective view as the etching when observed from the same projection centre (Fig. 12). The horizon height was assumed by choosing the height

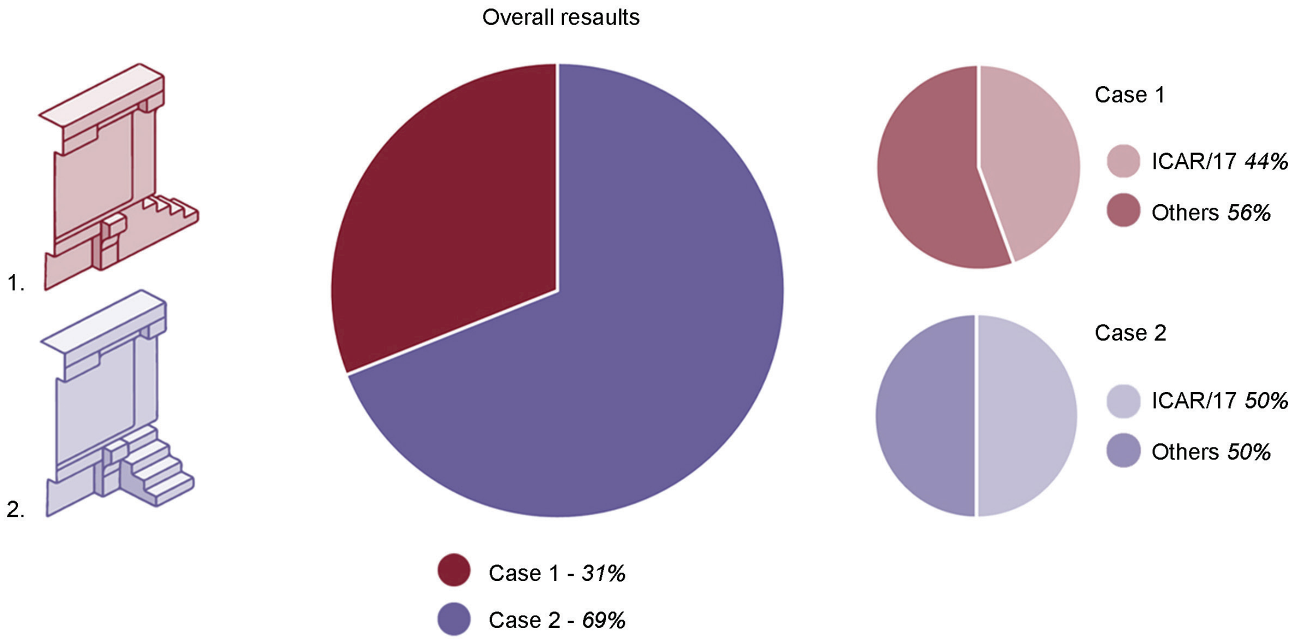


Fig. 11 – Percentages of perception of the two variants of the frontispiece steps (graphic elaborations by the author).

Fig. 12 – Rendering of the 3D model with the reconstructive hypothesis of the frontispiece seen from a projection centre similar to the etching (graphic elaboration by the author).

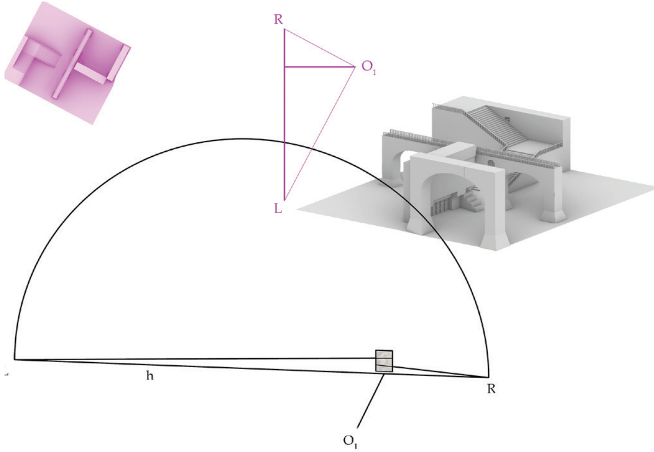


Fig. 13 – Floor plan (in purple) and axonometric view of the 3D model with the perspective setting and position of the projection centre related to the architecture (graphic elaborations by the author).

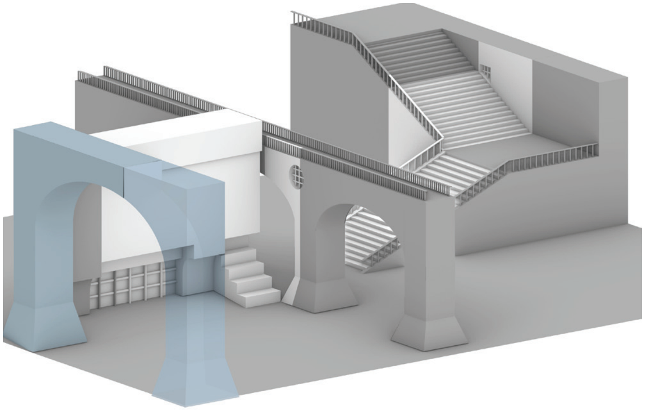


Fig. 14 – Axonometric view of the 3D model with the reconstructive hypothesis in which the colours indicate the level of reliability: the elements deduced from the etching in light grey, the altered elements in blue, the hypothesised elements in dark grey, the omitted elements in transparent blue (graphic elaboration by the author).

most commonly found in the perspective analyses of the depth planes. The position of the projection centre was assumed to be at the intersection of the horizon line and the vertical axis of the plate (Fig. 13). The rendering and the etching do not coincide perfectly due to the series of optimisations required to make the Piranesian drawing consistent. For this reason, some axonometric views of the 3D model show different colours based on adherence to the etching. Elements directly deduced from the plate are in light grey. In blue are those elements modified for architectural and structural coherence. Hypothesised elements not visible within the plate are in dark grey. They have been deduced based on symmetry principles and recurrence from the architectural interpretation (Fig. 14). Given these considerations, the model is one of the infinite possible reconstructive hypotheses since perspective views constructed without rigour do not provide biunivocity between the representation and the represented space.

Conclusions

In order to move from a non-rigorous perspective representation to a three-dimensional reconstruction of the represented space, a path was traced involving the integration of analyses and interpretations in three areas: architecture, perspective and perception. None of these disciplines, individually, would have provided sufficient information for reconstruction, but together they allowed the process of interpretation to be based on the most objective data possible. The main problem in approaching a perspective analysis of the *Carceri* concerns what the literature defined as the multiplication of viewpoints[7]. The solution to this problem was found in breaking down the plates, the frontispiece in this case, into a series of depth planes and analysing the perspective setting of each plane to highlight differences and invariances. This operation, on the one hand, confirmed the general contradiction of the perspective system; on the other hand, it made it possible to 'break down the problem' into small and more coherent portions. The reconstructive hypotheses were based on the recurrences in the analysis of the perspective settings. The analytic study guided the choice of the main elements to base the restitution of space and, first and foremost, the height of the horizon line. In the absence of a pair of vanishing points of at least two mutually rotated triorthogonal elements, the position of the projection centre was hypothesised on an experimental basis at the intersection of the horizon and the vertical axis of the plate. The model was scaled by assuming the size of a human figure: the prisoner above the epigraph. The perspective layout of the reconstruction was chosen so that the perspective image would be faithful to that of the etching: thus cancelling out perspective inconsistencies but not completely distorting Piranesi's 'vision'.

The advancement of knowledge on the subject of the *Carceri* would not have been possible without the attempt to rationalise a space that has very little that is reasonable, a space that fascinates precisely because of its contradictions. There is no risk of belittling an architecture that amazes and disquiets, a space where the gaze is lost and difficult to find again. The result is not intended to replace the artist's imagination or the pleasure of viewing the artwork. The reconstructive hypothesis is not meant to have an emotional response: other interesting outcomes have already been proposed in this sense[8]. The aim was the simulation of the imaginary space. It was achieved by revealing some deception but with the certainty of not undermining the fascination of direct observation of the etching.

Notes

[1] Studies on the subject of virtual reconstruction of perspective views are numerous. Of particular note are the three volumes with the outcomes of the PRIN 2010 research coordinated by Riccardo Migliari on architectural perspectives (Valenti 2014; Valenti 2016 tome I and tome II) and the book *Roma anamorfica* (De Rosa 2018).

[2] This contribution draws its methodological basis from the research conducted by the author during her doctorate (Menconero 2021). This study was further advanced by the publication of a monograph on the subject (Menconero 2022).

[3] Vogt-Göknil 1958.

[4] Baglioni *et al*. 2016, p. 1029.

[5] Fasolo n.d.

[6] Yarbus 1967.

[7] Vogt-Göknil 1958, p. 28.

[8] Grégoire Dupond's videos from 2010 for the exhibition *Le arti di Piranesi: architetto, incisore, vedutista, designer* organised by the Cini Foundation in Venice https://gregoiredupond.com/piranesi-carceri-d-invenzione-2010/; another video by the same author produced in 2020 for the Galleria Nazionale dell'Umbria https://gregoiredupond.com/piranesi-carceri-d-invenzione-300/; the video by the ACE group of the Scuola Superiore Sant'Anna as part of the exhibition *Piranesi. La fabbrica dell'utopia* organised by the MetaMorfosi Cultural Association and curated by Luigi Ficacci and Simonetta Tozzi (here an excerpt https://youtu.be/TYcKiJadgZw); the virtual reality produced by Alessandro Basso (Basso 2018).

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08 DIGITAL ECOSYSTEMS FOR THE VIRTUAL FRUITION OF PORTA AUREA IN RAVENNA

Abstract

The presented study is focused on communicating and visualizing architectural representations through computational and digital methods in the context of transversality and trans-disciplinary knowledge. In particular, the study enlightens the role of digital ecosystems in the communication processes of built cultural heritage, which is intended as a medium for the visualization of the n-dimensional levels of knowledge that can be collected in virtual reconstruction processes according to different kinds of resources.
The study involved different applications and tools for creating digital ecosystems that manage diverse information: digital galleries, 3D models, drawing annotation systems, and a Social Virtual Environment (SVE) platform.
The study focused on the dissemination and virtual musealisation of a monument that is no longer extant and has always aroused the interest of many scholars and archaeologists: Porta Aurea in Ravenna. The Roman Gate was built in 43 AD at the behest of roman Emperor Tiberius Claudius. The existence of large and heterogeneous documentation allows the possibility to investigate the theme of digital ecosystems for museum collections. In particular, digitization processes' role in creating digital environments for different types of fruition: research and dissemination for a large public.
Immersive digital environments can shift the focus from the management of the museum space, the container of the collection, to the exhibition itself. The SVE platform used in the study is a novel solution for developing a digital environment accessible by any web browser. A room dedicated to the Porta Aurea fragments at the National Museum of Ravenna also offers new perspectives on using virtual environments for disseminating museum collections replicating the environment to which they belong. The solution differs from the website, the two-dimensional ancestor of virtual environments, making a novel way of fruition that is no longer passive but active, interactive, and participatory.

Introduction

The Oxford English Dictionary defines an ecosystem as "a biological community of interacting organisms and their physical environment." If we pause to analyze, one of the main aspects of an ecosystem is to consider it as the sum of its constituent elements. Just as a natural ecosystem has inherent rules that are not necessarily perceivable or identifiable, the digital ecosystem is a system that is instead designed and developed with the ambition of permanence over time and eventual implementation. Within a digital ecosystem, the rules are defined in the design phase and are closely related to the end-use type. Therefore, it is necessary to determine what are the goals and objectives of the digitization process of the asset that will be fruited, the kind of target audience, and the types of visualization of the data, whether it is informative, three-dimensional, or reused within a predetermined narrative path.
One of the main benefits of digital ecosystems is to deposit primary resources within a system accessible through different devices and possibly through applications that allow the retrieval of resources in an organized and semantically classified manner.
In the case of cultural heritage, we are witnessing the proliferation of digital data production of various kinds with the advent of massive digitization. Specifically, it should be remembered that "raw" data will have to be reworked and post-processed to reach the end users. How the data is transformed into information or displayed on the Web is only the tip of the iceberg of the digital ecosystem: the front end. The back end is generally hidden but necessary to organize data and information to be easily retrievable.
The paper aims to investigate a possible pipeline for building digital ecosystems in museums. Beginning with the digitization process, which cannot be excluded from the ecosystem design process, digitized objects undergo various transformations, qualitative in resolution, allowing them to be accessible in different ways depending on the software used.
Once the assets of interest have been identified, the digital curatorship is responsible for selecting and classifying the content. Then there is the digitization phase regarding the documentary/archival and physical material. The first acquisition phase is generally carried out using the best quality and most appropriate tools. On the other hand, the information processing phase requires a critical *a priori* analysis depending on the desired output. Generally, the outcome requires a reduction/retopologization of the raw material, both bi-dimensional and three-dimensional. Different versions of the same digital object at different resolutions are developed depending on the final platform. The type of information also changes, is reused, or possibly reorganized depending on the chosen narrative.
In the architectural heritage field, at the content organization stage, there is also a semantic structuring of information related to the architectural features of the building and its architectural elements. In creating digital ecosystems, structuring information is a part of the process that has become unavoidable. The necessity to interconnect heterogeneous data is evident in architectural representation, for example, related to architectural drawings. In analyzing architectural drawings, the granularity of information is relevant, and it is essential to add a diverse semantic level of knowledge. Speaking of iconographic apparatus, i.e., the "complex of representations in the art relating to a given subject"[1] appears reductive in architecture. Classifying resources based on iconographic representations in humanities remains fundamental, especially in the archaeological and archival fields. Leading digital platforms in digital humanities use iconographic recognition and classification to organize their content. These systems generally collect bi-dimensional digitized institutions' contents. In recent years many museums have embraced the digitization challenge, creating three-dimensional digital collections that are unfortunately not linked to the original content.

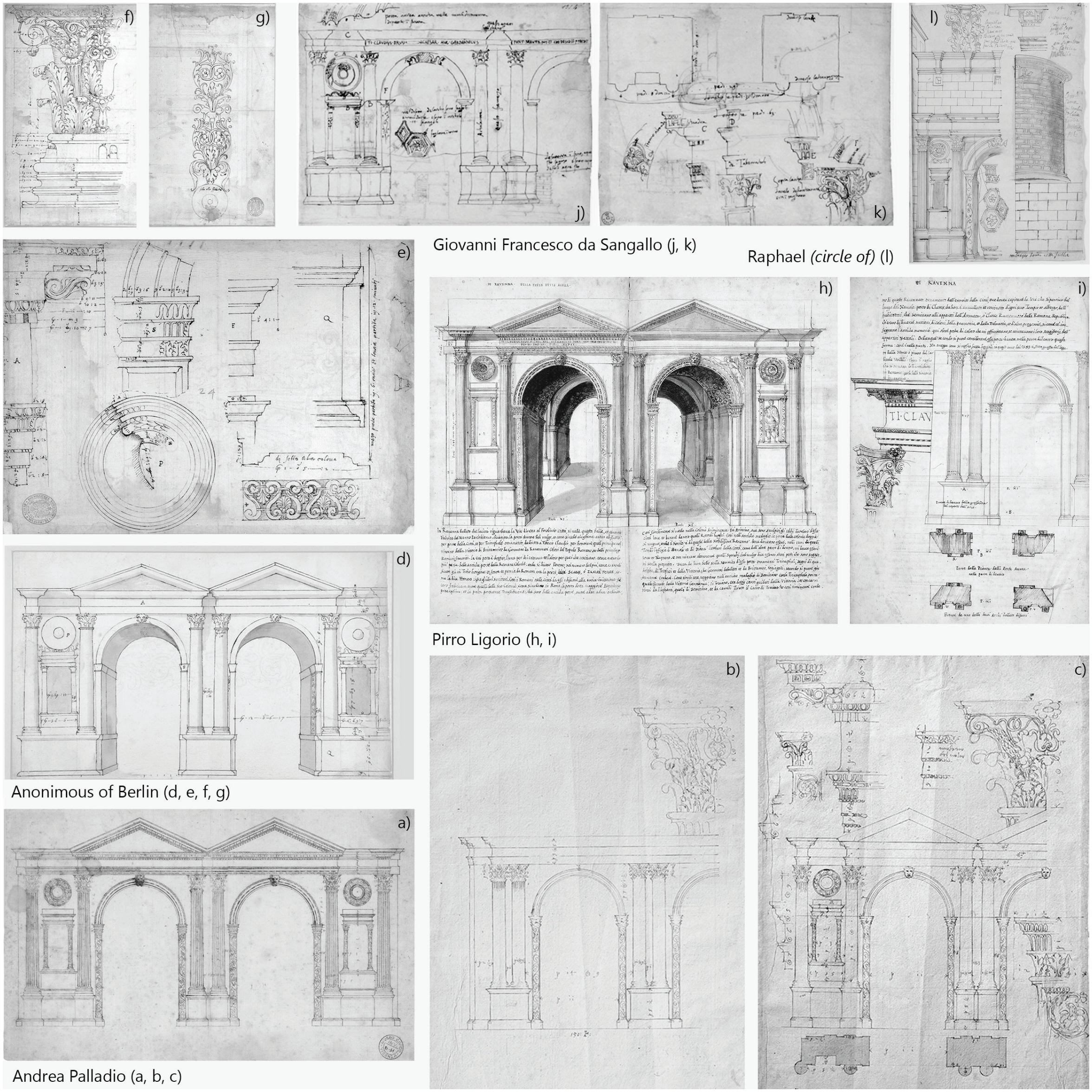


Fig. 1 – Collection of drawings representing Porta Aurea in Ravenna. Image layout by the author.

Porta Aurea: an integrated approach for the creation of a digital ecosystem

This study proposes in an organized manner the digitization processes put in place for the virtual reconstruction hypothesis of Porta Aurea[2]. The paper presents a methodological workflow for the possible use and reuse of digital assets for the virtual fruition of the museum collection of existing architectural fragments and beyond. The research began with the historical analysis of existing documentation regarding Porta Aurea in Ravenna: an ancient Roman gate destroyed in 1582. Today, some fragments remain in the National Museum in Ravenna, and some ruins at the city walls. The events inherent in the architectural apparatus and excavation campaigns at the walls have been extensively investigated by both local historians and scholars who have been involved in analyzing the collection of architectural drawings related to the Roman Gate. (Rossi, 1572; Rosi, 1939; Tosi, 1986; Savini, 1996, 1997; Novara, 2002; Ranaldi, 2015)
The gate was in the past represented by several authors: Giovanni Maria Falconetto (1520), Giovanni Francesco da Sangallo (c.a. 1526), Andrea Palladio (1545), Anonimous of the Raphael circle (c.a. 1150), Anonimous of Berlin (c.a. 1580). (Fig.1)
In recent years, the extensive documentation available has allowed further investigation of the documentary, archival and photographic funds for a virtual reconstruction hypothesis according to the drawings developed by Andrea Palladio. [Apollonio and Giovannini, 2015].
The analyzed and digitized resources belong to different archives and institutions and were part of the data collection and gathering for the dissemination of the study beyond the virtual reconstruction. Other research outcomes related to the semi- automatic generation of Architectural elements and using data, metadata, and paradata for the virtual reconstruction processes were previously published. [Apollonio and Giovannini, 2015; Giovannini, 2017].

The workflow can be divided into three main parts: Data collection, Data Modelling, and Data Representation & Visualization (Fig.2). This research explore the digitization processes and post-processing phase of sources and resources for the creation of a digital environment accessible online. The developed Virtual Reality (VR) is based on the room dedicated to Porta Aurea at The National Museum of Ravenna.
The process involved digital acquisitions of documentary heritage, photogrammetric acquisition of archeological fragments and laser scanning acquisition of the archaeological evidence.
The Data Modelling phase was performed using resources collected and digital acquisition to obtain metric information for the development of both virtual space for VR and digital assets to be displayed using Social Virtual Environment (SVE).
The data representation and visualization phase involved a workflow for digital post-processing of assets to be uploaded and reused through low-cost web applications: Sketchfab and Mozilla Hubs[3]. Hubs is a web-based virtual collaboration platform. (Iglesias, Jenkins and Morison, 2021) Hubs is considered a Social Virtual Reality, an emerging medium that invites multiple users to join a collaborative virtual environment (VE) and can support remote communication in a natural and immersive way. (Li *et al.*, 2021) The platform, developed by Mozilla, was used during the COVID emergency when the virtual space was implemented as a solution for attending conferences and for education purposes (Hagler, Lankes and Gallist, 2022), allowing the creation of digital replicas of real space. The Virtual Reality installation lets users interactively explore a virtual space that hosts several digital 3D models and other digital content. The content for creating the scene can be selected from 3D models available online on the Platform Sketchfab. To enrich the scene and manage diverse content, Mozilla offers Spoke, a built-in scene editor for creating environments to publish Hubs rooms. (Fig. 3)

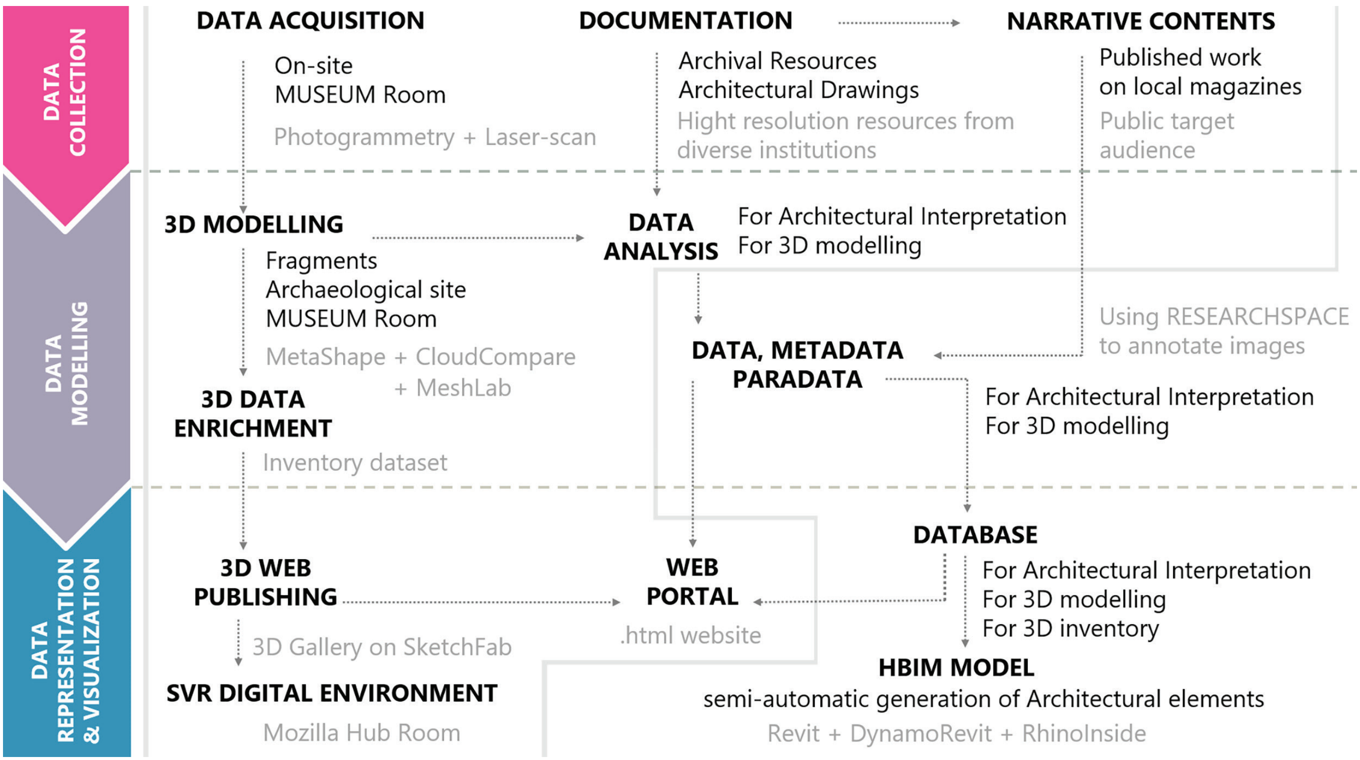


Fig. 2 - Methodological Workflow for the creation of a digital ecosystem, including processes and software.

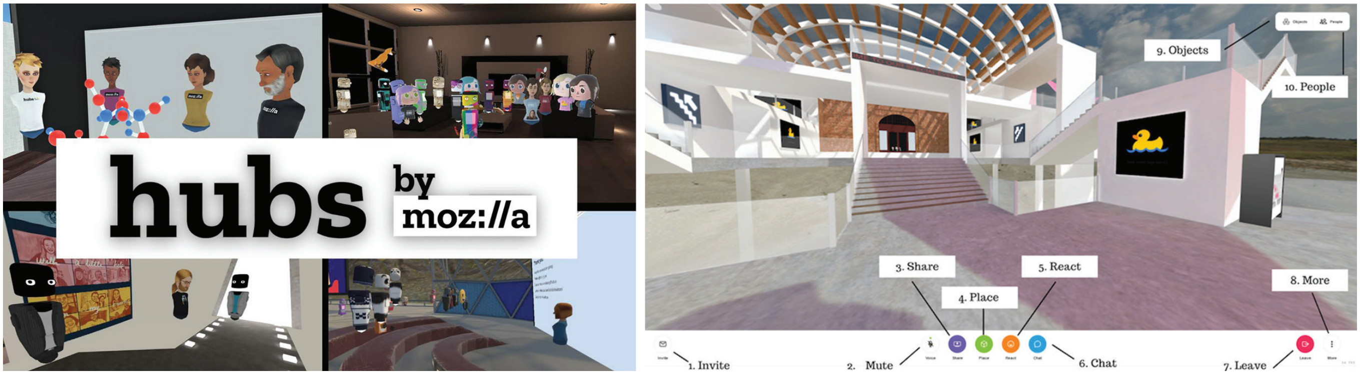


Fig. 3 - Collection of Mozilla Hubs rooms and user interface of a default virtual scene.

Porta Aurea: online repositories and digitization processes for documentary heritage

A preliminary search of the online iconographic apparatus on Porta Aurea was carried out using iDAI[4] (Fig. 4) and CENSUS[5] (Fig. 5), both developed by German institutions.
The two databases are structured differently and seem not to communicate with each other. A comprehensive view of the material regarding Porta Aurea is possible only by cross-referencing the data exported from both portals. iDAI is a two-dimensional digital ecosystem where various resources are organized and classified using specific semantic web tools. Although it proposes itself as a structured platform to collect data of heterogeneous types, it is not very effective in visualizing the contents. iDAI acquires the data from the photographic digitalized archives of the Italian Ministero per i Beni Culturali e Ambientali (MiBACT).
CENSUS proposes a simpler relational scheme that relies on the iconographic recognition within the resource and, in some instances, allows the material, digitized at high resolution, to be viewed more efficiently through a web interface. CENSUS also encodes resources using inventory numbers, making it possible to uniquely identify resources and request them from individual institutions in high definition. In systems of this type, the third dimension is still unfortunately absent. (Fig. 6)

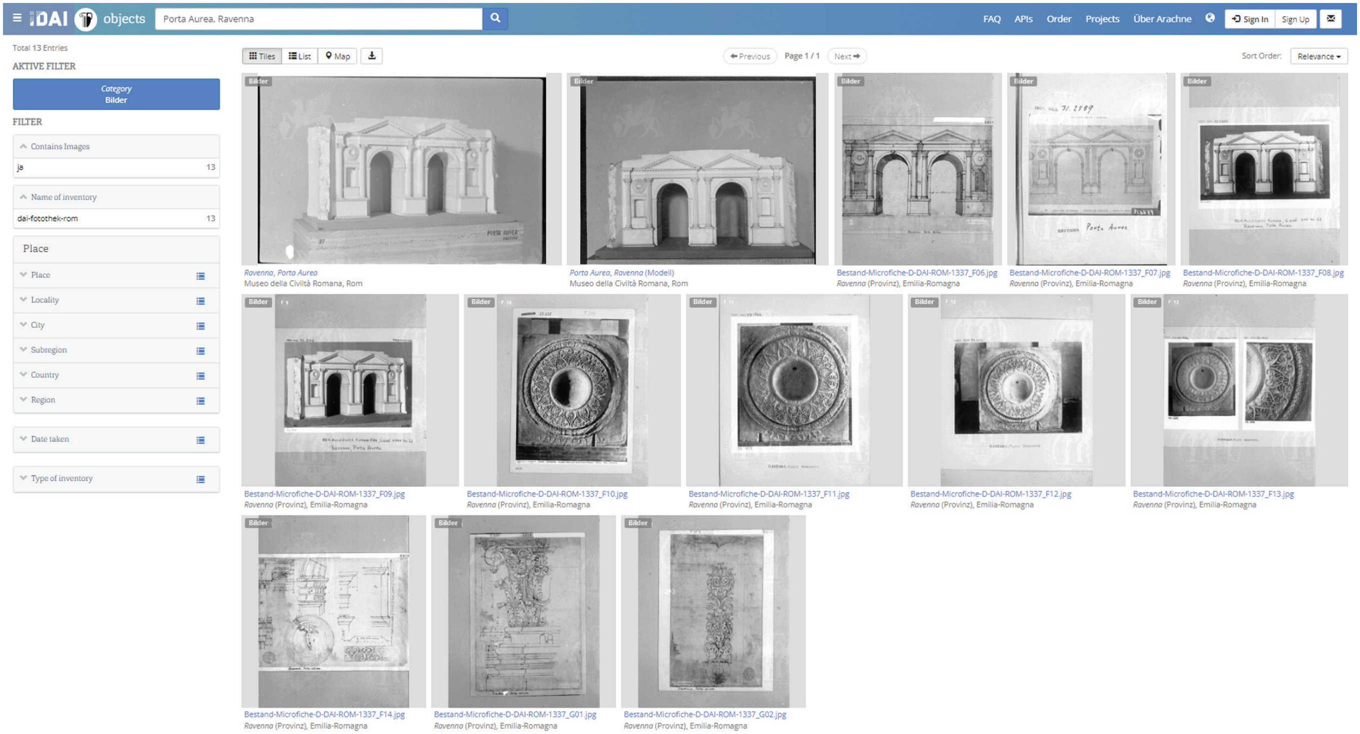


Fig. 4 - iDAI interface with retrieved content about Porta Aurea in Ravenna.

The *Soprintendenza Archeologia, Belle Arti e Paesaggio per le province di Ravenna, Forlì-Cesena e Rimini* also own partially digitalized documentary heritage. For example, archeological reports and survey drawings documenting the excavation campaign supervised by Domenico Maioli on the city wall in 1906-1908. Then, the resources available at the drawing and photographic archives were collected and digitized. During the excavation campaign, new fragments were discovered and are nowadays exposed in the "Sala della Porta Aurea". Each fragment is described in the inventory of the Museum and documented by black and white pictures, part of the photographic archive. Its material was divided as follows:

- 5 images concerning photocopies of the drawings by Palladio[6] and Sangallo[7]
- 24 images concerning excavations at Via di Porta Aurea dated 1907-1908, some published in Rosi (1939) and Savini (1996, 1997)
- 10 images of fragments of the roman gate before the current arrangement, dated 1937-1939
- 56 images, which were digitized during the research conducted. The selected images refer to the present

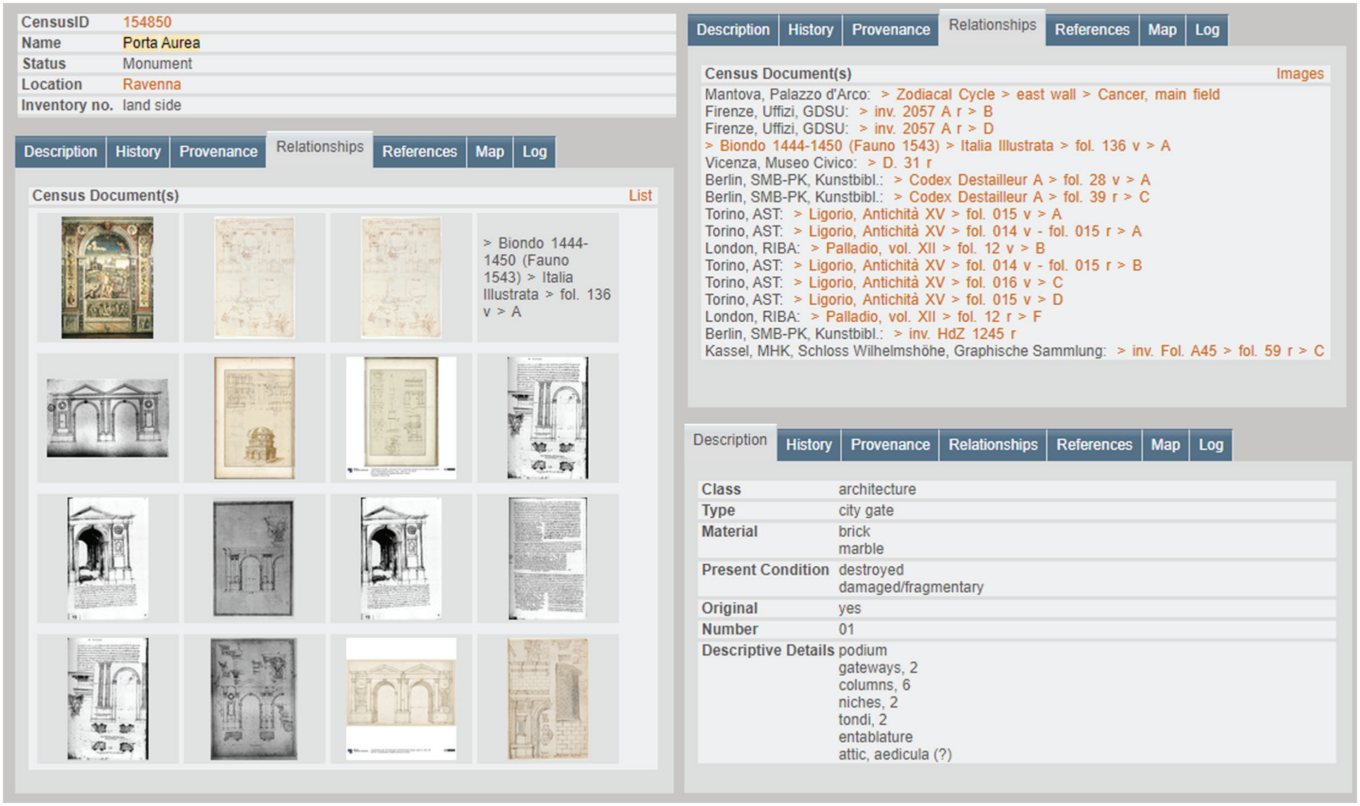


Fig. 5 - Census interface with retrieved content about Porta Aurea in Ravenna. Image layout by the author.

arrangement and are dated between 1978 and 1991. In particular, the objects refer to the “saletta del primo chiostro” now renamed the “Sala della Porta Aurea”.
A Canon EOS-1Ds Mark II with a 100mm lens with a fixed focal length of 50mm was used for the image acquisition. (Fig. 7) An x.rite color checker was used for color balance. The predominantly black-and-white images are on a paper card that is accompanied by a variety of information: the image’s title, the year of production, the location of the find within the Museum, and the inventory number of the original negative from which the photo was developed. There are

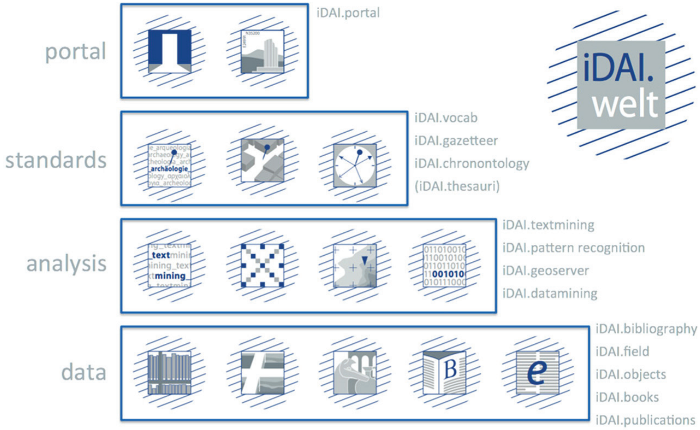


Fig. 6 - Knowledge structure behind iDAI (right)) and data model of CENSUS (bottom). diagrams available on the respective web pages of the online databases.

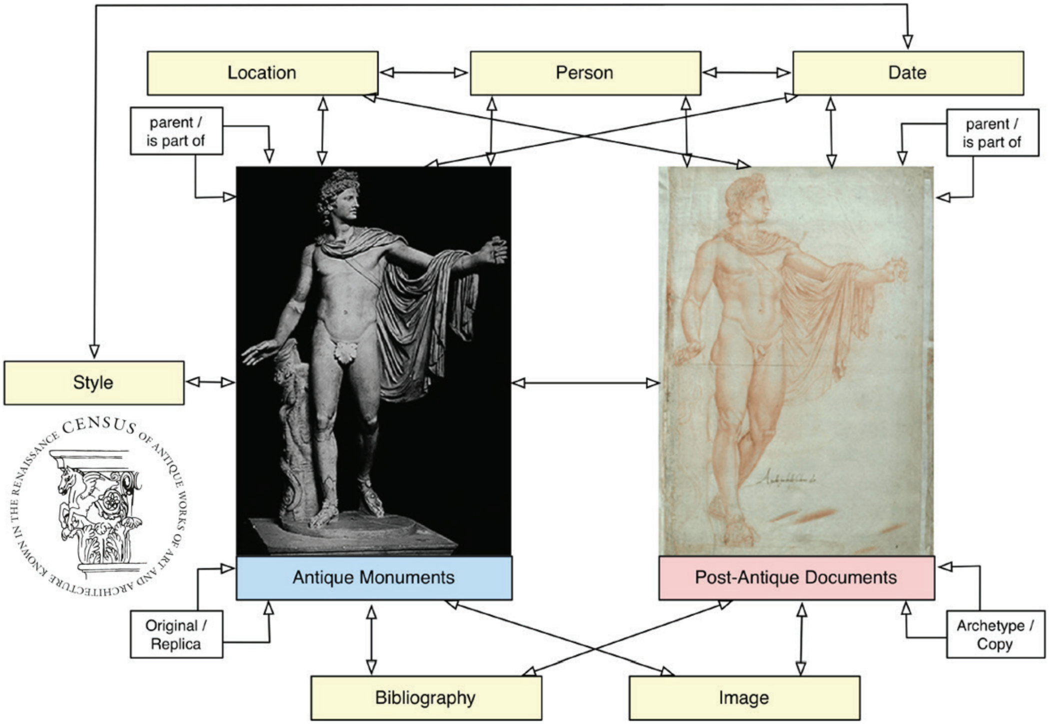


Fig. 7 - Digital acquisition of the photographic archive.

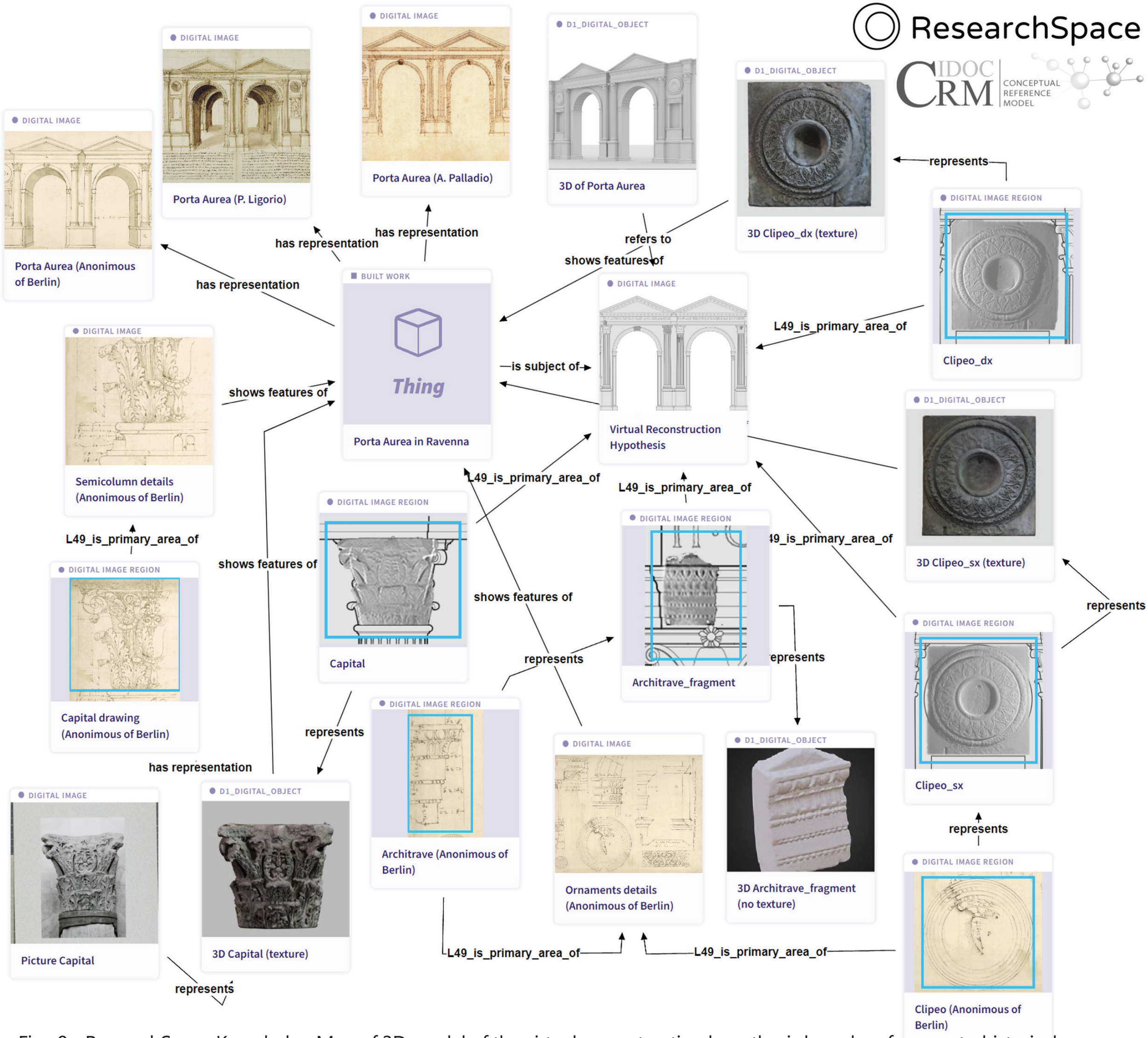


Fig. 8 - ResearchSpace Knowledge Map of 3D model of the virtual reconstruction hypothesis based on fragments, historical sources and drawings. Image by the author.

often annotations on the cards giving the inventory number of the fragment depicted. This information was collected and associated with the digitized source using knowledge patterns for metadata enrichment in ResearchSpace[8]. (Fig. 8) ResearchSpace is a web-based tool used to support research in museums, cultural institutions, and many other institutions that work with cultural collections. It is a platform that is generally used to manage museum collections in a bi-dimensional digitized format with the possibility of being implemented with embedded three-dimensional content. (Giovannini, 2021)

The documentary acquisition campaign considered the drawings drawn up during the Via di Porta Aurea[9] excavations. These are the survey drawing of two circular towers and their respective longitudinal and cross sections. Accompanying the survey drawings is a report on the excavations and a reconstructive hypothesis made by Domenico Maioli. The hypothesis was drawn up on Roman feet based on the drawing by Giovanni Francesco da Sangallo. The drawing archive also contains a second reconstructive hypothesis[10] made by G. Rosi for the execution of a reconstructive model for the *Augustan Exhibition of Romanity in 1937-1938*. (Ranaldi, 2015)The model is now preserved at the Museum of Roman Civilization. (Fig. 9b)

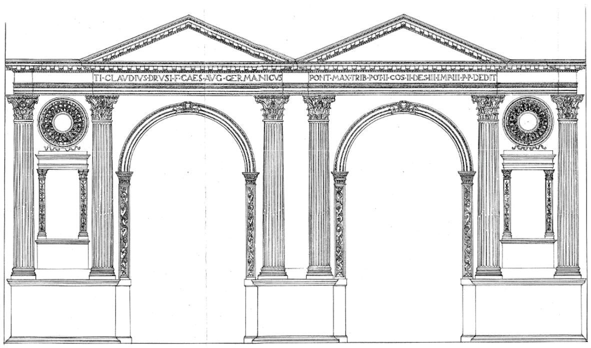
The acquisition campaign complemented the archival and documentary acquisition campaign at the room of the National Museum in Ravenna, which collects the remaining marble fragments as evidence of the monument. The acquisition was made by laser scanner technology with a Leica C10 all-in-one. The digital acquisition was made at a medium resolution to capture the museum space and at a high resolution for the archeological fragments attributed to the monument. (Fig. 10) Some of them were difficult to access because they were high in the walls.

A parallel photogrammetric acquisition campaign was carried out to create a digital gallery of the Porta Aurea artifacts. The acquisition allowed obtaining metrically accurate objects that were scaled according to the point cloud obtained by the laser scanner and were adequately textured.

Data from the inventory and the photographic archive were cross-referenced with data on the museum layout to create a digital inventory into ResearchSpace and identify the location of the various fragments within the room.

According to iconographical and archival resources, the research identified ten fragments that belong to the Roman Gate. (Fig.11)

For each fragment was developed a 3D model with the highest resolution. The points clouds of single objects were



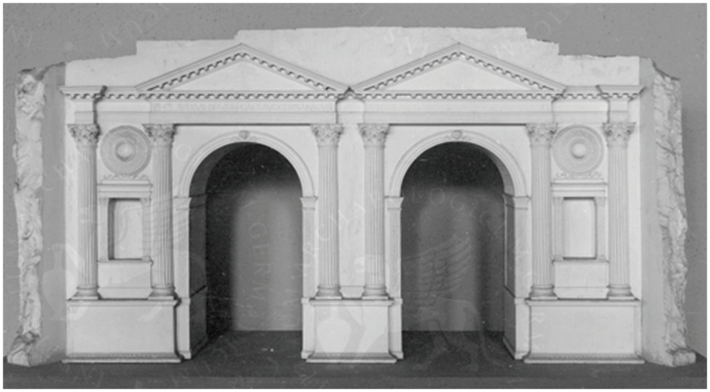


Fig. 9 - Drawing of the reconstructive hypothesis of Porta Aurea by G. Rosi (left) and relative physical model (right - image from iDAI platform).

Fig. 10 - Sala della Porta Aurea at National Museum of Ravenna. Fragments of Porta Aurea. Pictures by the Author.

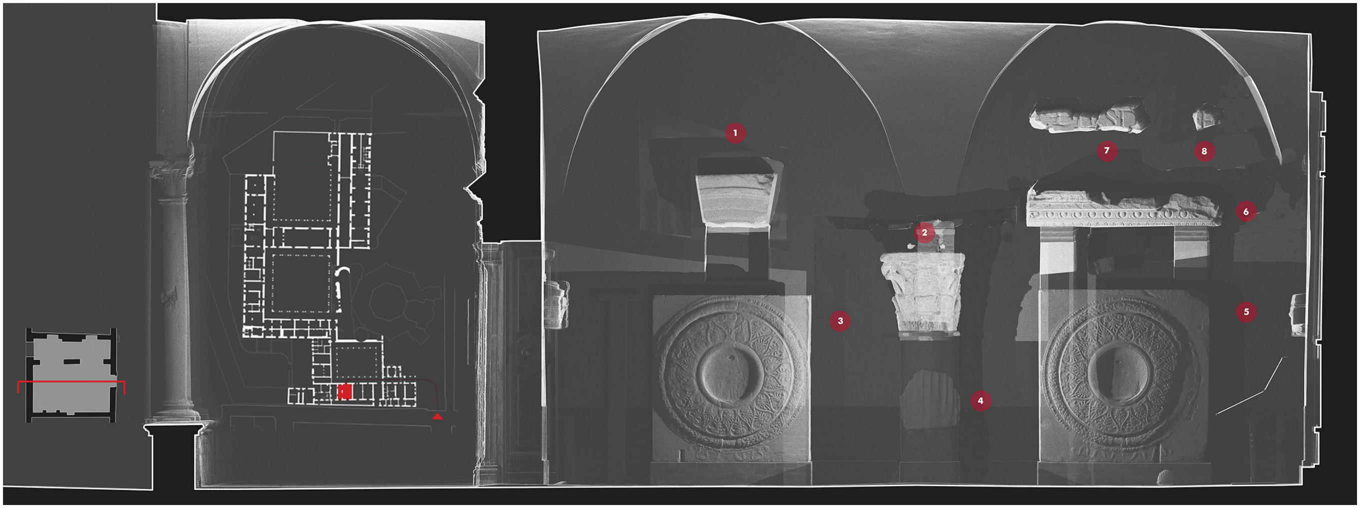


Fig. 11 - Porta Aurea Room at National Museum of Ravenna. Point cloud obtained from Leica C-10. Section of the room with archaeological fragments of the Roman Gate. Image by the Author.

extrapolated from the room's point cloud. Then each point cloud was imported into MeshLab[11] and converted into a mesh using the Poisson surface reconstruction algorithms packed in the software. The 3D models obtained were collected and published online in SketchFab. (Fig.12)
A second digital acquisition campaign was carried out at the walls near Via di Porta Aurea where the remains of the two circular towers that surrounded the monument were found during excavations for the street opening. (Fig.13) The distance between towers matches the measure indicated by A. Palladio in its drawing for the plan of the gate.
This information was used to decide to represent the gate with a double central plinth, one for each semi-column. The solution differs from the hypothesis proposed by G. Rosi, who presumably followed the drawings of the Anonymous of Berlin. His solution presents a single plinth supporting the two half-columns in the middle of the gate.

Creating a digital environment for the online Porta Aurea Room using Hubs

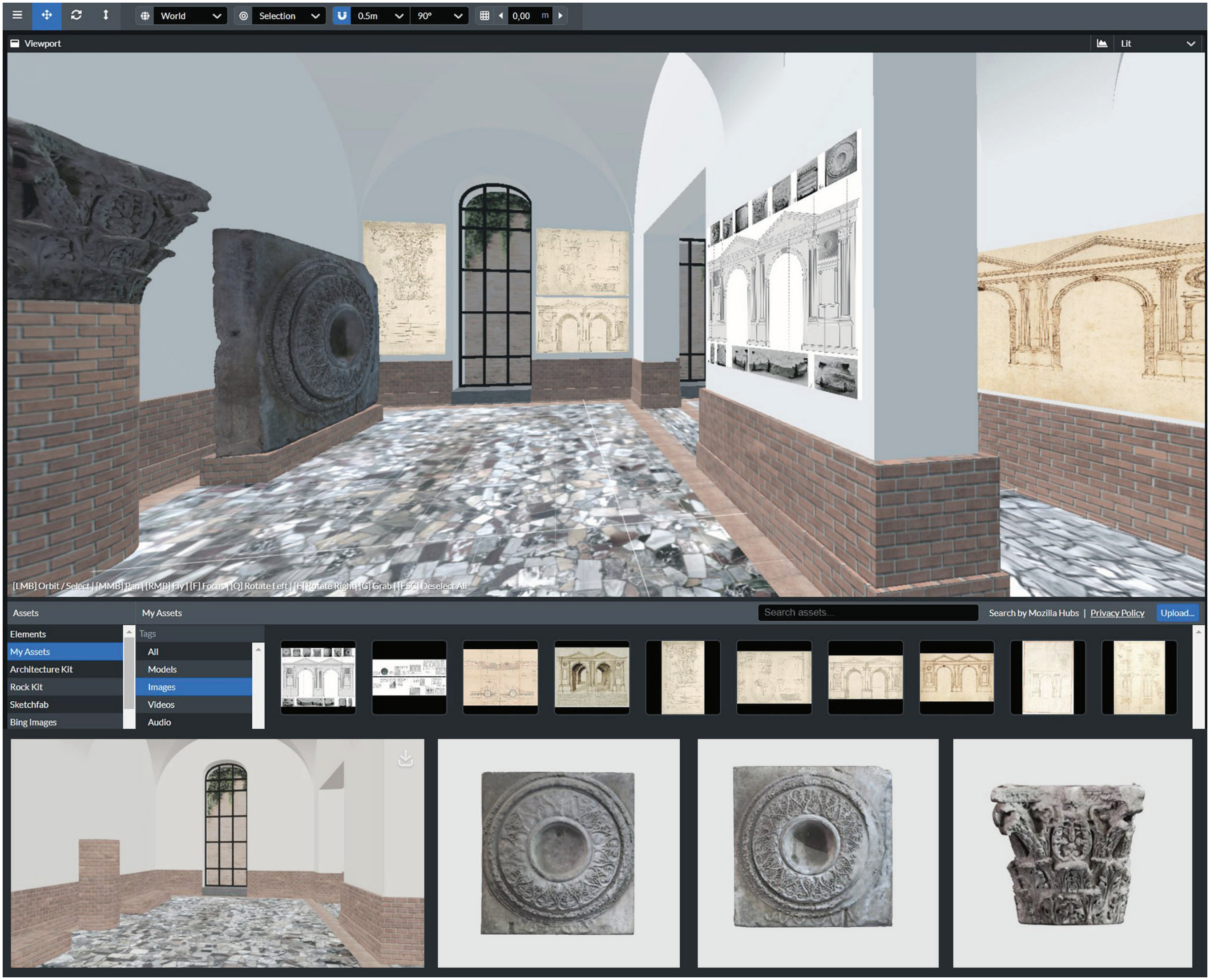
A digital replica of the Porta Aurea room was made to create the virtual environment. The point cloud was used to model the room in a NURBS model, using Rhinoceros. For online optimization and fruition, the model was textured using an image obtained from the photogrammetric acquisition of the room's floors. This choice was dictated by the presence of the *Palladiana,* which makes the space unique and recognizable. In addition, it was chosen to dedicate the room solely to the fragments of Porta Aurea, deleting from the digital model the structures that support other pieces in the real environment.
The textured model was then exported in .obj format and uploaded within sketchFab. The platform's interface allows setting up the VR fruition by arranging the starting point of view to visit the space. (Fig. 14).
The most significant fragments related to Porta Aurea were imported into Sketchfab to be reused in the digital room space and recreate the Museum environment. The 3D models obtained from Metashape were reduced to be imported online with a 75% reduction for texture definition and brought down to 750.000 faces using the Quadric Edge

Fig. 12 - 3D models obtained from Laser scanner point clouds with no textures: capital, entablature and fragment of the archivolt. 3D gallery by the author.

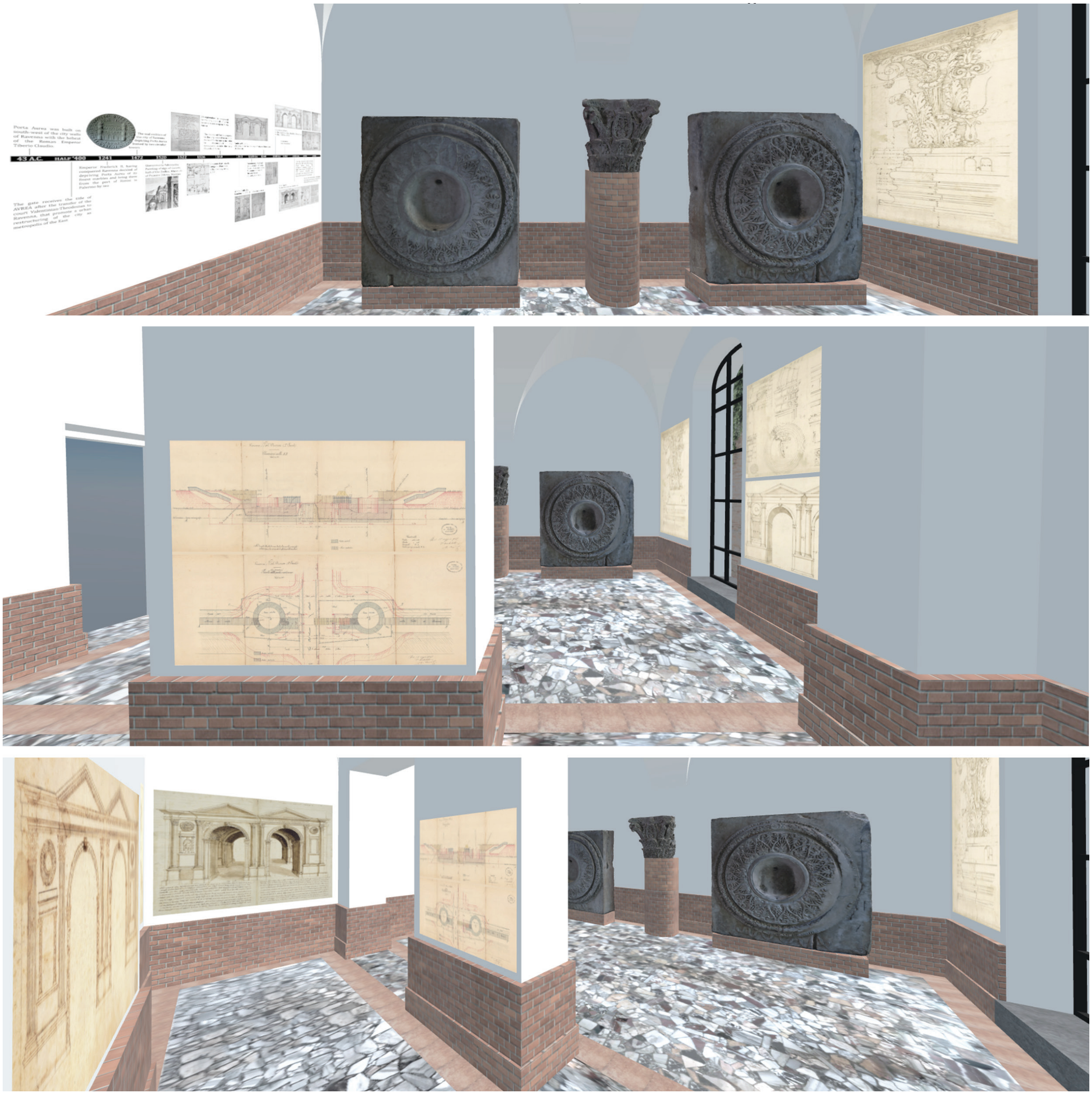
Fig. 13_ Point cloud obtained from laser scanning acquisition. Plan view with dimensions. The Roman Gate was framed by two round towers (bottom). Front view of evidences of the towers with superimposition of hypothetical virtual reconstruction based on A. Palladio drawings and dimensioned using photogrammetric acquisition of fragments conserved in the Museum (top). Image by the Author.

Collapse Decimation (with texture) filter in MeshLab. The filter simplifies a textured mesh using a Quadratic based Edge Collapse Strategy, preserving UV parametrization. (Garland and Heckbert, 1998) This reduction allows for an optimized fit within the maximum of 200 MB set by the platform included in the low-cost PRO version of SketchFab. MeshLab was also used for setting up the origin of the 3D model. These models constitute the core of the digital collection and can then be embedded within any HTML-based application.
Switching from Sketchfab to Spoke subsequently required a second retopologization of meshes. The built-in scene editor allows a maximum of 128MB per scene (*Spoke Scene*). This bottleneck had not been considered during the initial research phase and required a rethinking of the scene. In the first stage, the Spoke scene was planned to contain the ten original fragments. Then, only the most recognizable elements of the monument were chosen: the clypeus and the capital of the semi-column. The models were further reduced to 100.000 faces with a further 50% reduction for textures. At this point, it was possible to fit them within the reconstructed model of the museum hall. (Fig. 15) Spoke allows retrieval of the models from SketchFab using their URL address. The room, imported in Spoke with 3D models, was scaled and reorganized, developing a single scene. The room was then enriched with the iconographic apparatus collected during the research phase. The images were uploaded as separate digital assets, scaled, and organized on the room walls. Because 3D models, images, sounds, and videos can be imported into the scene using a URL address, the drawings, already published online in ResearchSpace, were reused instead of duplicated. The final scene was published online as a Hubs room, and it is possible to navigate within it by knowing its URL address. (Fig. 16)

Fig. 14 - textured 3D model of the Porta Aurea room visualized in the SketchFab 3D editor. Image by the author.



Above, Fig. 15 - Digital asset used for the Spoke Scene. 3D gallery by the author.
In the next page: Fig. 16 - Views of the Porta Aurea Room hosted by Hubs. Spoke scene by the author.



Conclusions

This study proposes a methodological workflow developing a digital environment related to cultural heritage and Museum collections. The VR environment offers a novel way to fruition digital assets for the public. The experience is configured as a parallel activity to access Museum collections. The virtual space, as an access point to broader and more heterogeneous content, goes beyond the limits of the real Museum environment and allows different thematic insights. The amount of data acquired, especially regarding the photographic archive, has not been addressed in the prototype, and their digital exhibition would merit further investigation.

This experimental and prototype phase has highlighted the opportunities offered by the Mozilla Hubs platform and the critical issues related to Spoke, especially regarding the resolution of files, both 3D models and images that were resized to populate the scene. An alternative to this solution is to use the room and 3D models as the basis of the spoke scene and place assets in the room afterward.

A relevant consideration regards Copyright, privacy, conditions, and terms of use of the collected assets. As far as 3D models are concerned, there is no legislation on the subject, and it is clear that the resulting product is the product of the person who took the photos. Regarding the documentary and archival heritage, a serious problem arises since the material, once uploaded, is in the first phase stored on an external server and can then be downloaded by any user who has access to the scene. It is possible to avoid the issue by disabling the default user interaction with image elements.

Finally, it is possible to assert that SVE systems can be employed in the museum dissemination pipeline (Giovannini and Bono, 2023).. The experience is not a surrogate of the Museum visit. The VR experience can follow normal museum activities, allowing the setting up of diverse temporary and thematic exhibitions alongside

Notes

[1] Translated by the author from *Enciclopedia Treccani*, noun *iconografia*, retrievable at https://www.treccani.it/vocabolario/iconografia/ (last visit, January 2023)

[2] The study was carried on in 2013 for the development of the bachelor degree in Architecture with a dissertation entitled "*IN LOCO VRBI DICITVR PORTAVREA: Dal disegno al modello digitale, studio per una ipotesi ricostruttiva della Porta Aurea di Ravenna ai fini della fruizione museale*".

[3] https://hubs.mozilla.com/

[4] iDAI (https://idai.world/) is the portal for digital archaeological knowledge and it was developed by the German Archaeological Institute (DAI), a worldwide networked research institution in the field of archaeology and ancient history.

[5] https://database.census.de/

[6] AFSn 32992, AFSn 32993 e AFSn 32994 copies of Andrea Palladio drawings conserved at RIBA (SD170/PALL/XII/12 recto/verso) and at Museo Civico di Palazzo Chiericati in Vicenza. The drawing (Inv. D 31) represents the facade oriented to the city of Ravenna.

[7] AFS 5-D-9 e AFS 5-D-10 copies of the Sangallo il Giovane drawings conserved at the Gabinetto dei Disegni e delle Stampe delle Gallerie degli Uffizi in Florence. The drawing (2057 A recto) represents a survey of Porta Aurea.

[8] https://researchspace.org/

[9] Savini (1996, 1997) discusses this extensively.

[10] Copies of the drawings can be found within the dossier U8-2670 *"RAVENNA - Progetto di ricostruzione dell'antica Porta Aurea di Ravenna – elaborati grafici"*

[11] https://www.meshlab.net/

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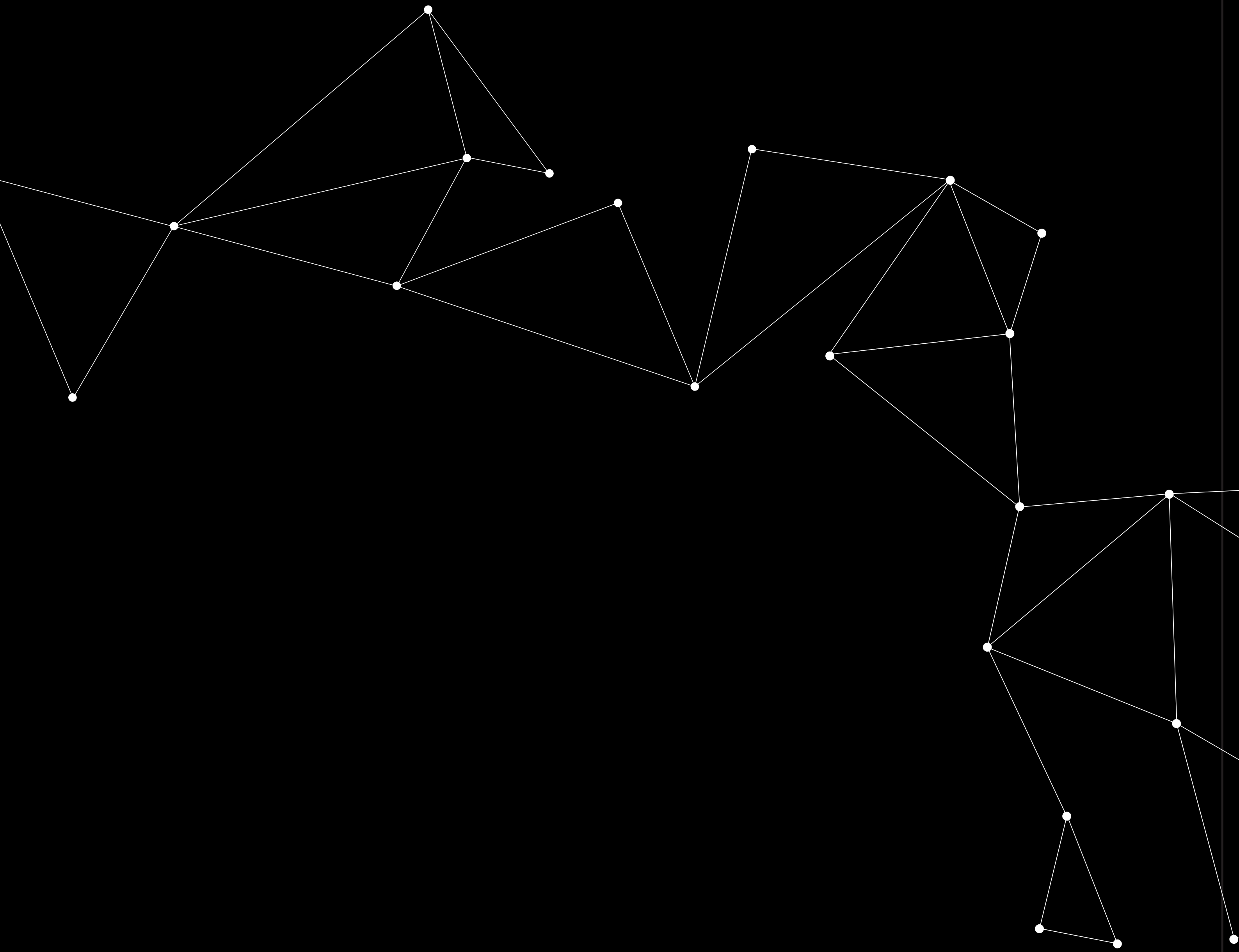
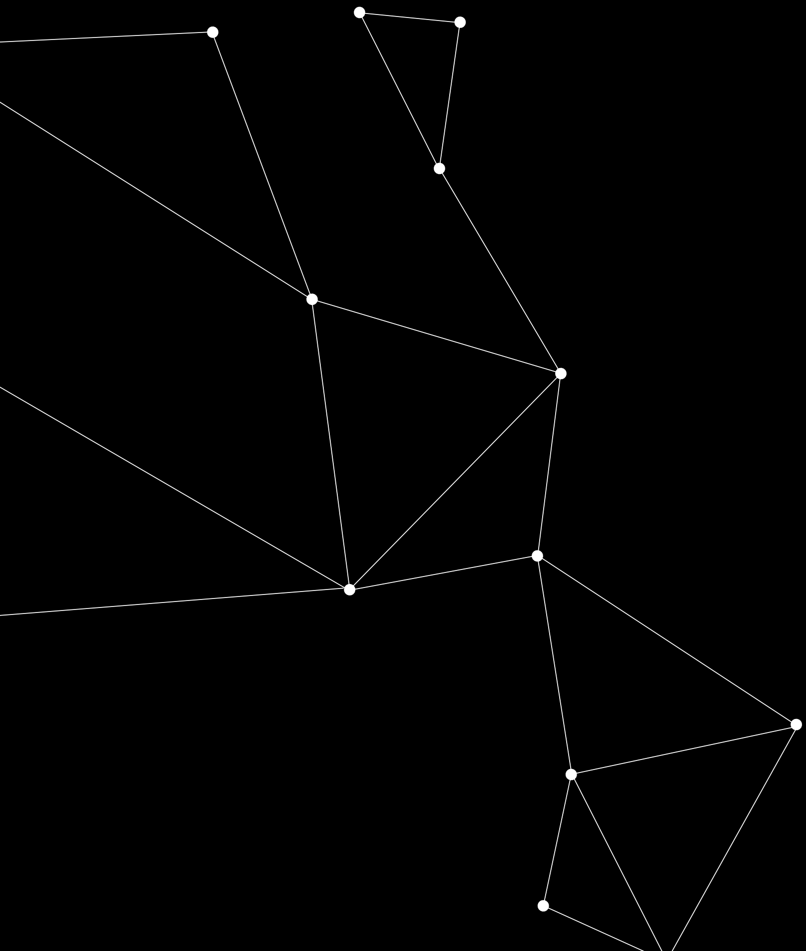


Part 2

Information Databases and Information Systems for Architecture



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09 DIGITAL DOCUMENTATION FOR THE ENHANCEMENT OF BRAZILIAN CULTURAL HERITAGE: MUSEO DO IPIRANGA, PARQUE DA INDEPENDÊNCIA AND MONUMENTO À INDEPENDÊNCIA

Abstract

For this year's bicentenary of Brazil's independence, the DIAPReM research centre and the TekneHub laboratory of the University of Ferrara present the results of the digital documentation of one of the most important monumental complexes in the state of São Paulo: Museo Do Ipiranga, Parque da Independência and Monumento à Independência.
The application of integrated three-dimensional survey protocols and scan-to-HBIM procedures currently provides technicians, researchers, public administration, and citizens with the most complete digital memory of the monumental complex built by Italian architects and engineers in 1922, on the occasion of the centenary of the country's independence. Moreover, the database represents the documentation of the state of the museum before the recent restoration work. The survey databases and HBIM models are finally an inherent part of the valorisation and dissemination project, intended for an audience of non-professionals only, IpirangaDigital.

Introduction

The importance and value of the digital memory of heritage assets has been highlighted, over the last few years, by the increasing dissemination, accessibility, and usability of integrated digital technologies for surveying and representation, particularly three-dimensional, of the cultural heritage as well as the built heritage. Moreover, the digital memory of cultural heritage has emerged into a resource for communication to a large audience as well as for purposes of conservation and maintenance.

As the experience detailed here illustrates, interest in the study topic of integrated digital heritage survey and representation protocols with a view to valorisation and communication to a non-expert audience is expanding both internationally and inside the European Community. Despite the fact that the definition of clear-cut digital documentation protocols appears to be hampered by the uniqueness of cultural heritage, both tangible and intangible, the rapid adoption of key enabling technologies, collaborative visualisation platforms, and machine learning protocols are encouraging studies and applications aimed at involving a large audience. Applications include, among other topics: integrating VR, AR, and

Fig. 1 – Enhancing Brazilian cultural heritage through integrated digital platforms. Monumento à Independência do Brasil, São Paulo, Brasil.

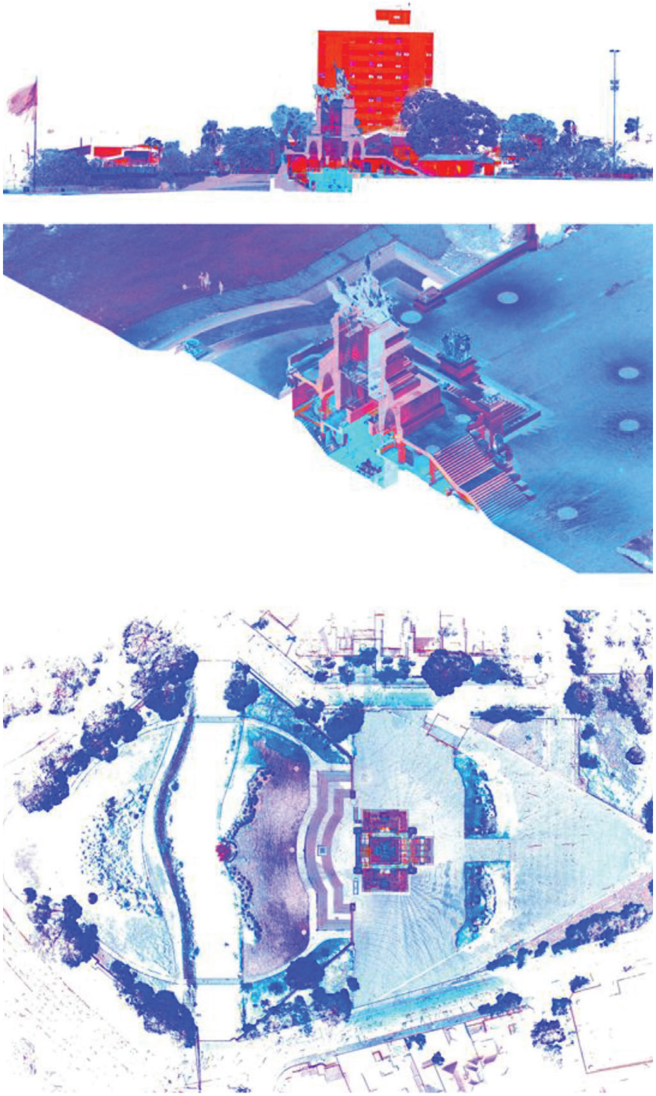
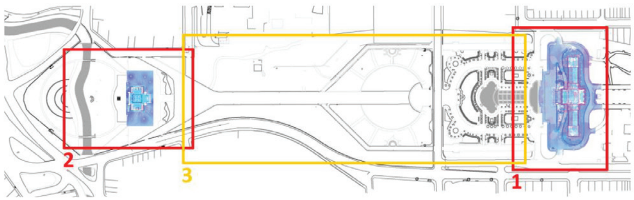


Fig. 2 – 3D integrated digital survey of Museu do Ipiranga, Parque da Independência, and Monumento à Independência, São Paulo, Brasil.

mixed reality technologies to engage a variety of target audiences; integrating digital technologies to support greater accessibility and as a response to fragilities of the target audience; enhancing through gaming activities implemented through digital interfaces and media.
The primary goal of the research project is to pursue an interdisciplinary, integrated, and systematic approach to documenting and enhancing cultural heritage. However, the goal of this study is to define a shared protocol for international and interdisciplinary collaboration for the digital documentation of Brazilian cultural heritage from an architectural and urban scale perspective to support preservation and value-adding initiatives in accordance with a variety of approaches to cultural heritage.

Urban Memorial Landscapes

The Museu do Ipiranga, Parque da Independência, and the Monumento à Independência stand on an area of more than 160,000 square metres that stretches from south-east to north-west along the path of the old Ipiranga river. Overall, the project aimed at building a collective memory around the declaration of Brazil's Independence from Portugal proclaimed by D. Pedro I in 1822.
On the centenary of Independence, in 1922, as part of the celebrations, the Monument à Independência do Brasil was inaugurated, although not yet completed, designed by Ettore Ximenes and Manfredo Manfredi. The completed project had won an international competition



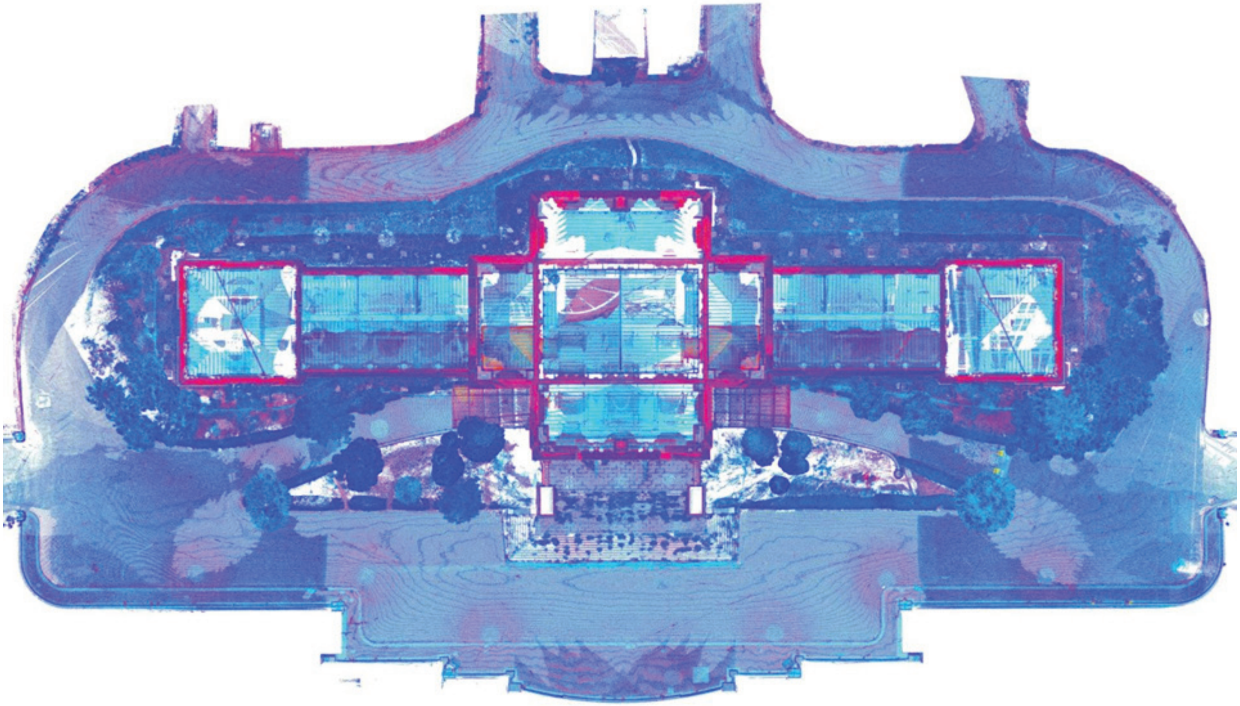
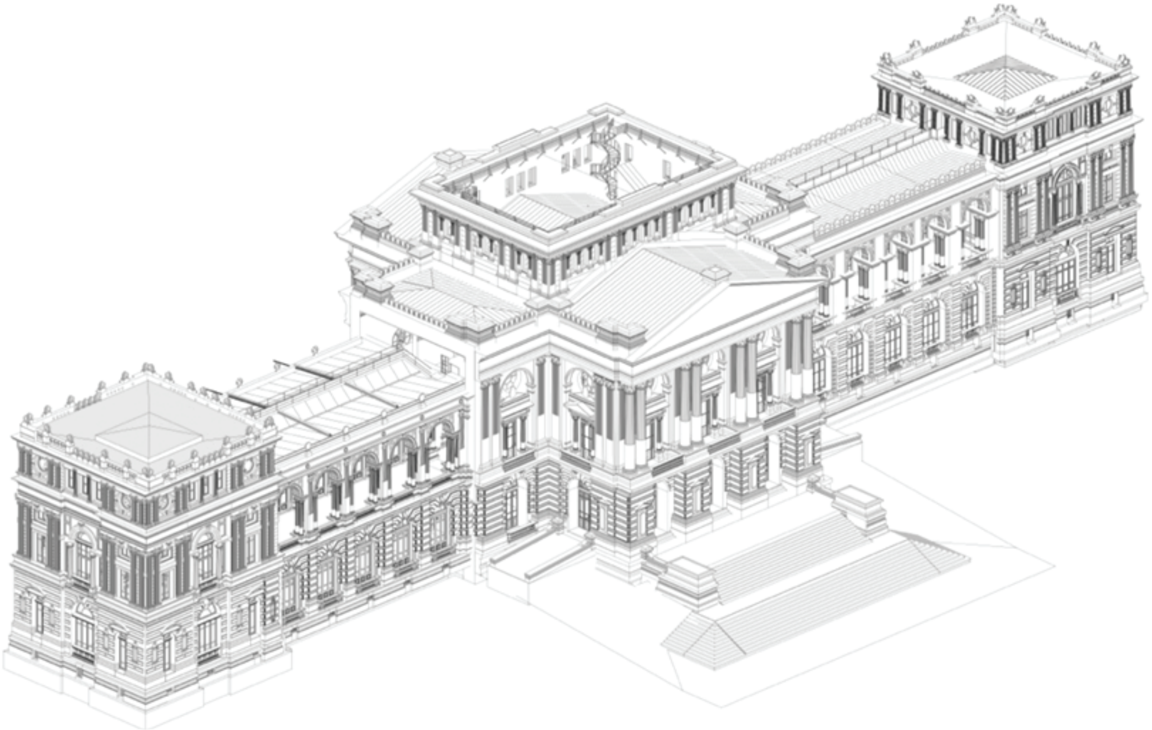


Fig. 3 - (Above and in the next page) Scan to HBIM protocols: Museu do Ipiranga São Paulo, Brasil.

for a monument to Brazilian independence. Completed a few years after its inauguration, the monument underwent major transformations that still characterise it today. In 1952, the crypt was inaugurated, effectively changing the monument into a cenotaph of Emperor Dom Pedro I. Later, in the second half of the 1980s, the monument underwent an initial restoration, following which the interior exhibition space was inaugurated. Prior to the digital documentation campaign carried out by the DIAPReM/TekneHub laboratory in 2018, two further restoration works are carried out.
The construction of the monument completes the landscaping and urban work of the entire area begun in 1884 with Tommaso Gaudezio Bezzi's project for the Museu do Ipiranga. The museum represents the first, in chronological order, architectural landmark in the area.

The museum, which currently houses a collection of over 125,000 artefacts of Brazilian history from the 16th to the mid-20th century, represents, as stated in the preliminary report and recommendations for the Museu Paulista conservation project of 2013, a unique testimony of the irreplaceable values of Brazilian history, architecture and engineering. The Museum is certainly the repository of the national memory linked to São Paulo, built through the epic expeditions of the various local explorers and the pioneering vocation of São Paulo, since colonial times, as testified by the objects, documents, iconography and specimens in the collection.
The building, bound by Brazilian law through the Instituto do Patrimônio Histórico e Artístico Nacional - IPHAN, was closed to the public from 2013 until 2022 to allow for its



total restoration, the purpose of which is, among other things, to preserve the important functions performed by this outstanding architectural example. The inauguration of the new Museo do Ipiranga took place on 7 September 2022 on the occasion of the bicentenary of Brazilian Independence.
The integrated digital documentation provided as a result of the survey campaign conducted in 2018 allowed the management, during the construction phase, of the new entrance built as an hypogeum structure on the south-east front that provided the museum with an access and services area of over 6,800 square metres.
The three-dimensional database developed as a result of the survey campaign therefore remains the digital memory of the museum prior to the restoration and recovery work.

Related Works

The integrated digital survey activity Museu do Ipiranga, Parque da Independência, and Monumento à Independência is part of a broader context of research and technology transfer activities carried out in collaboration with the FAU-USP Faculdade de Arquitetura e Urbanismo da Universidade de São Paulo.
One of the most important places in the history of the State of São Paulo Independence is represented by the monumental and urban complex, which is the focus of the integrated HBIM survey and modeling methodology described. Definitely, the goals of valorizing and understanding the multiple narratives associated

Fig. 4 - Museu do Ipiranga – USP main façade. View of the central projecting pronaos from the monumental gardens overlooking the main building (left). View of the perspective axis in the direction of the Monumento à Independência from the roof of the Museu do Ipiranga (right).

Fig. 5 - 3D integrated digital survey of Monumento à Independência do Brasil, São Paulo, Brasil.

to the cultural heritage under examination combine with objectives of memory conservation, restoration and adaptation efforts, accessibility, and security of the buildings and urban spaces as well.
Moreover, the areas and settings of both the Monumento à Independência and the Museo Do Ipiranga have changed throughout time due to functional adaption needs. Therefore, in order to manage the sites and their changes over time, engineers and architects were the primary target audience for the integrated digital record of the current status of the sites. The digital survey protocols that were implemented were intended to offer, at the same time, sufficient documentation support in order to express the technical and figurative, as well as literary and historical content, related, for instance, to the complex reading of the monument. Moreover, the monument is distinguished by decorative equipment while also exhibiting dimensions like those of monumental architecture. Over time, the monument has undergone incongruous plant and functional interventions that have worsened the internal micro-environmental conditions that are no longer

suitable for the preservation of the emperors' remains. The convergence of the described elements today inhibits the accessibility and usability of a history that is often unknown to the population of São Paulo State.
Then, the implementation of the overall database has made it feasible to carry out training and technology transfer initiatives for regional technicians. In fact, technicians from the H+F Arquitetos studio, which won the open competition for the Museo do Ipiranga restoration, attended a course in Italy in 2018 that was put on by the DIAPReM Laboratory and TekneHub of the University of Ferrara and focused on using the three-dimensional database to verify the various stages of the project and construction site.
The subsequent pandemic crisis postponed the completion of the survey of the park, which will be the subject of a subsequent, although not conclusive, survey campaign during 2021.

Digital Documentation of Brazilian Cultural Heritage

The integrated digital survey and documentation protocol implemented took into account, first and foremost, the conservation and restoration purposes associated with a cultural heritage such as the one described. The monumental dimension on the one hand and the richness of the ornamental and sculptural apparatuses on the other make it necessary, both for conservation purposes and for communication and valorisation, to conduct multi-scalar analyses, from urban scale to architectural detail. The resulting integrated digital survey data must therefore allow the transition to widely different scales of understanding, firstly, and representation, secondly.
Therefore, it was chosen to implement a survey protocol that, based on more than twenty years of experience in the digital documentation of Cultural Heritage, allows the geometric and angular control appropriate to the

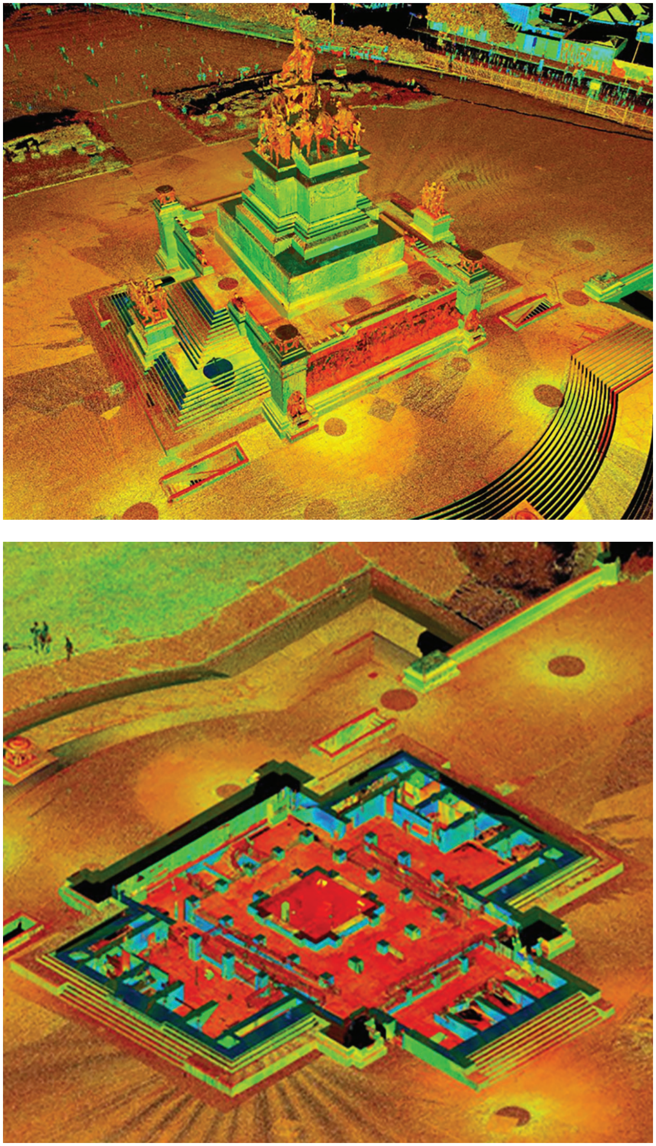


Fig. 6 - Views of the overall point cloud data model of the Monumento à Independência do Brasil, São Paulo, Brasil.

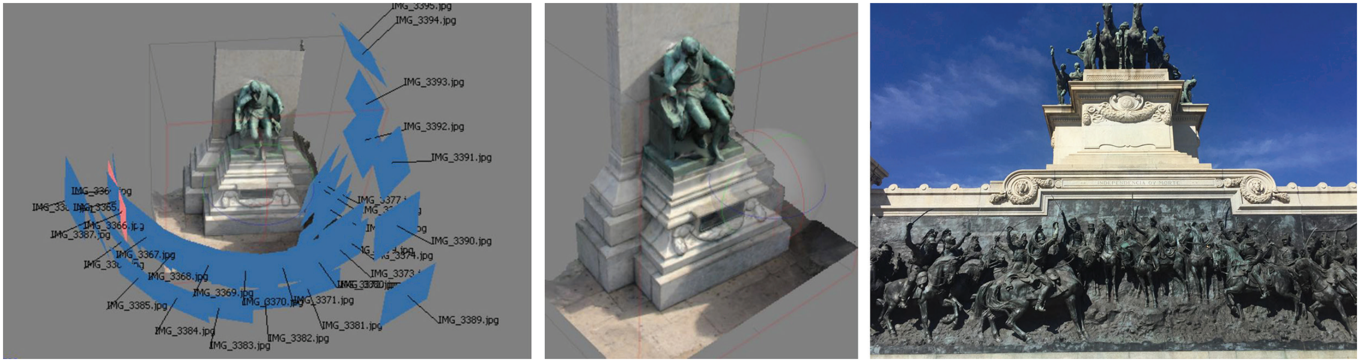


Fig. 7 - Scan to 3D photo modelling procedures: Monumento à Independência do Brasil, São Paulo, Brasil.

accuracy required and at the same time the optimisation of the quality of the digital data in terms of redundancy. To a morphological approach, today favoured by the greater usability of terrestrial laser scanner technologies, an integrated topographical approach was therefore preferred.

The protocol used for the surveys calls for the development of a first-level topographic network, second- and third-level target networks, normalization, and registration of the overall point cloud model to regulate angular accuracy and elevation deformations, segmentation of the overall data model by areas related to the purposes of use, and visualization of data and information within a digital portal. The present use of digital platforms to combine various non-digital and digital data sources is encouraging further experimentation with the dissemination and enhancement of tangible and intangible cultural heritage. However, there are still a great deal of challenges. A purpose of this effort and related work has been identified as improving and promoting the usability of the whole point cloud model as source of data. The developed survey technique is used to verify the accuracy of the digital data in respect to the information system as a whole and the associated two- and three-dimensional forms of representation.

The size and quality of the same information through the various visualisation supports that are currently available and which can be integrated in complex information systems does not yet make it possible to transfer the value of the 3D data source to a wide audience, especially in a dynamic manner. This is true even if the accessibility of the overall cloud database is still guaranteed both within native and open-source environments, even if supported by suitable calculation infrastructures. Consequently, to preserve the multiscalar information content, integration with non-dynamic contents seems to be essential.

Conclusions

Since 2016, interdisciplinary research has been conducted to consolidate integrated digital survey and scan to HBIM protocols of complex architectures subject to restoration interventions as well as enhancement and communication activities. In this regard, the integrated three-dimensional survey, digital modelling, and visualization project of the Museu do Ipiranga, Parque da Independência, and Monumento à Independência exemplified an interesting area of investigation of data and information acquisition

Fig. 8 - Some images of the training and technology transfer activity and results carried out to support the development of the restauration project made by the architects Pablo Herenu and Eduardo Ferroni (selected from the 13 proposals received by invitation) The collaboration with the DIAPReM centre took the form of a period of face-to-face training, at the University of Ferrara, of some of the architects of the firm.

and processing to support processes of modification of urban space as well as conservation and protection of the heritage of memory.

When employed in conjunction with quick surveying techniques, integrated digital surveying technologies, in particular indirect surveying, enable the current situation to allow the capture of large amounts of data in a short amount of time with acceptable levels of accuracy. In a while, as this documentation effort indicates, control and geometric precision are needed for multi-scalar studies related to the conservation, valorisation, and communication of cultural assets and cannot be obtained merely through indirect surveys and a morphological approach. Moreover, the use of the topographic survey along with the Terrestrial Laser Scanner (TLS) survey pursues multiple objectives: first, the verification and control of the geometric and morphological characteristics, from the architectural scale to the detailed scale, with a view to the accessibility and usability of the database created and the subsequent implementations, also carried out with various survey instruments and techniques. The division of the models that follows subsequently aims to provide database accessibility, usefulness in scan to BIM processes, and eventually visualization in integrated digital platforms for communication.

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10 DATA MANAGEMENT, EFFICIENT USE, AND SMART ACCESS TO REALITY CAPTURE DATA VIA WEB PLATFORMS

Abstract

Sharing the output data of a digital survey with other stakeholders can increase its professional and widespread use. How a non-surveying specialist can visualize, interrogate and measure the reality-based models in the three-dimensional space -and not only- without sector-specific software is, for most instances, a significantly challenging problem. The possibility to upload digital survey data on web platforms would allow for greater dissemination and greater exploitation of the capabilities of reality capture technology. The point cloud can be displayed and investigated directly on the web and accessible on any device (laptop, desktop, tablet, or smartphone). The tools for measuring, cropping, annotating, and downloading data are usually included as standard features. Moreover, the different commercial proposals provide many innovative functions: VR interaction, BIM interoperability, automatic scan alignment, and 3D point cloud automatic segmentation and classification. The web-based system solution represents a real revolution in digital data sharing among experts, technicians, and professionals, who can dispose of all the survey data directly on their devices anytime, anywhere, preventing data loss and enhancing user sharing.

This paper aimed to present the characteristics and the potential of some online platforms for direct sharing and management of the point clouds derived from image- or range-based techniques. This preliminary research is presented to underline the pros and cons and identify future developments in this new way of exploiting digital survey data. This approach can be advantageous in the Cultural Heritage field, especially when CAD or HBIM 3D modelling is unnecessary because it is not the final aim. The solution can be to skip the whole complex and time-consuming modelling phase and directly use the point cloud as the 3D geometric base and as a reference for the information repository.

Problem Statement

Several sectors relating to the natural environment, civil engineering, infrastructure, architecture, heritage, and art are involved in the 3D digitization process (Fig. 1) with different aims and purposes [Daniotti et al. 2022; Miceli et al., 2020; Parrinello 2021; Poux et al. 2020, Russo et al. 2023].
In the infrastructural and architectural field, the last hardware and software developments have simplified and speeded up the data acquisition and processing phases, even in the case of complex measurements (surveys with lots of scans, buildings with several floors and complex plan layouts, narrow environments and so on).
Laser scanner equipment types are becoming smaller, lighter, and quicker in field operations, making instrument transportation more flexible, faster, and suitable for different environments. Thanks to on-board real-time elaboration, the data capture phase is becoming quicker and more efficient. Moreover, laser scanners are now commonly equipped with additional sensors (GNSS systems, IMU platforms, tracking systems etc.) that allow users to run a raw pre-registration of the various range scans on-site in real-time while the survey is going on. This aspect primarily ensures that the detected surfaces are under control and that it is easier to determine if the 3D measurement is complete and if it includes all the involved areas. The on-site raw pre-alignment, therefore, simplifies the practical survey activity and drastically reduces the time required for the optimized registration of the scans in-office, optimizing and enhancing the scan-to-pointcloud pipeline. However, the scan-to-HBIM workflow is still a hard-working process even though it is becoming a reference standard in architectural heritage [Semina et al., 2022].
Even in the field of image-based methods, software development related to computer vision techniques has revolutionized the times and flexibility of the photogrammetric data processing workflow. The phases of image orientation and dense machining have been significantly accelerated, simplified, and optimized.
Despite the technological advancements that have

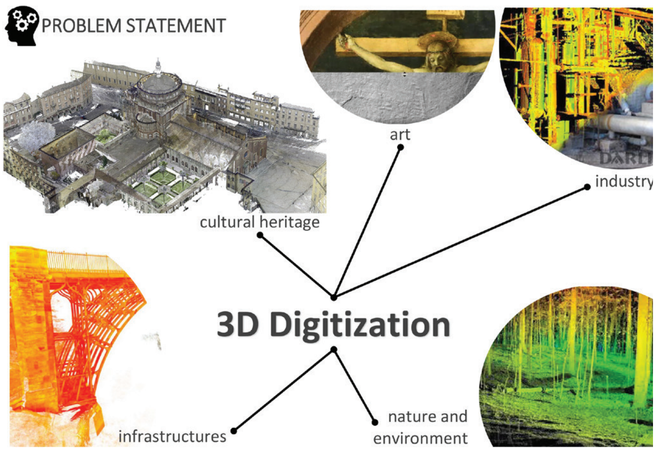

Fig. 1 – Possible fields of interest and applications of the 3D digitization process.

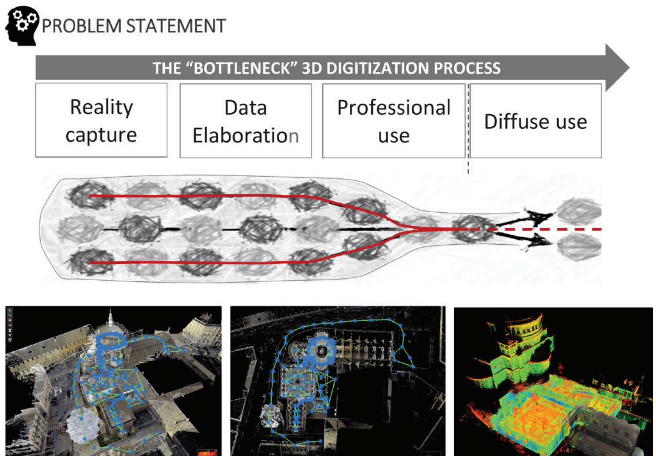

Fig. 2 – The "bottleneck" of the digitization process: diffuse use of reality capture data by users without professional-level hardware and expertise.

improved and accelerated the data acquisition and the processing phase in both image and range-based workflows, the use and management of output data by technical professionals who are not surveyors or 3D experts are still uncommon.

Nowadays, conducting a digital survey is usually simpler than utilizing its results and outcomes. The bottleneck is the practical, efficient, and immediate employment of the reality capture data (Fig. 2).

Indeed, observing the digital survey workflow, the more time-consuming step is the output elaboration, whether a 2D or 3D representation (Fig. 3). Whether using active or passive sensors, the final outcome is a point cloud model that takes a long time and effort to be transformed into a technical 2D drawing or a CAD or BIM model.

The discussion aims to present the characteristics and the potential of some of the web platforms available on the market for direct sharing and management of point clouds from image- or range-based surveys. Indeed, these solutions could facilitate the direct and professional utilization of point cloud models by various specialists (Fig. 4).

The main open issues that seem to hinder the widespread use of digital survey outputs are the following: i) digital data sharing and use require specific software; ii) these types of software are typically not user-friendly for professionals in other fields, and the acquired datasets are usually very huge; iii) the eventually subsequent geometrical CAD or BIM modeling is very time-consuming (above all for built heritage); iv) the 3D modelling implies many open issues about geometrical deviation among metric data and the reconstructed models.

A web-based platform approach can address these problematic aspects because: i) digital data can be shared and used directly through a web browser; ii) no specific software or plug-ins are required; iii) visualization and interaction also with massive data are quick and easy; iv) point clouds can be directly used as geometric and informative reference v) the point model is real scale, and any metric data can be extracted from the point cloud depending on the aim and graphic representation scale. In this context, the web-based platforms for online point cloud management can fill the gap between the digital survey and the widespread use of its outcomes.

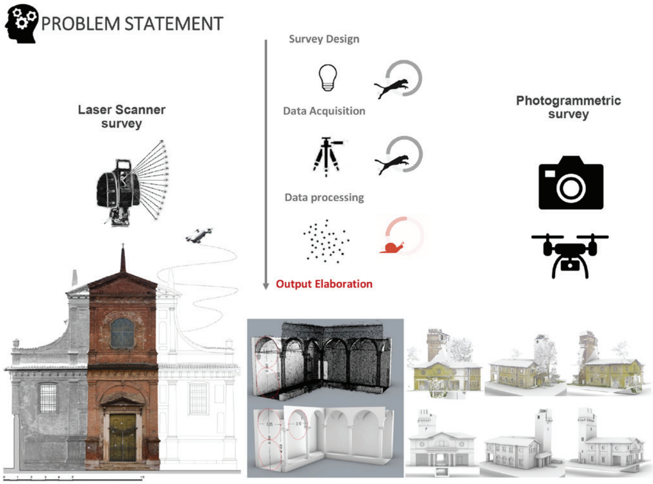

Fig. 3 – Digital survey pipeline.

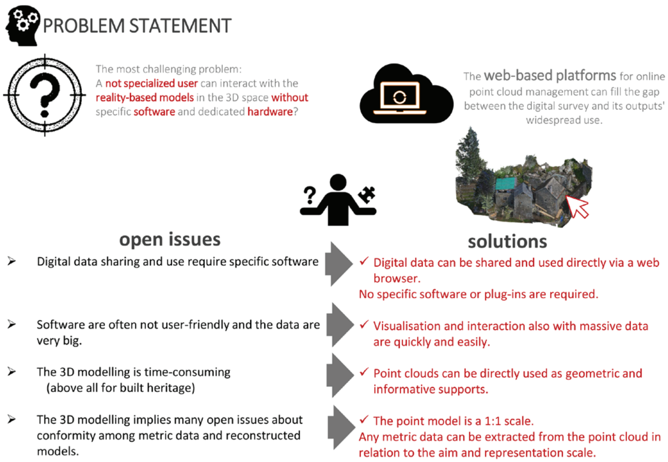

Fig. 4 – Reality capture data use and sharing: problem statement.

State of Art

The significant increase experienced in the latest years in the use of reality capture outputs stresses urgently the need for suitable and easy tools for managing and broadly sharing this kind of data. The web platforms for point cloud data sharing are nowadays the most promising option to address this increasing need.

A web platform for point cloud management is a tool embedded in a website that provides users instruments to view and interact with point cloud data already present in the system, or that can be uploaded by the user. The user can interact with the point cloud by taking annotations, measuring distances, areas, and volumes, cutting cross-sections, and consulting information through databases related to point cloud objects. Whereas generally, for all the web platforms, the module for visualization is performative and achieves a smooth user experience, the "amount of interaction" that is possible with the point cloud depends on the purposes and goals of the platform. This latter aspect is a keystone in the future development of web platforms that promise to evolve from data-displaying tools to fully cloud-based elaboration software, as described later in this paragraph.

VISUALIZER Source Agnostic

Potree

Potree, 2022. Potree. URL https://potree.github.io/
Schütz, M., 2016. Potree: Rendering Large Point Clouds in Web Browsers. TU Wien, Wien.

Fig. 5 – The interface of Potree visualizer and the main tools available.

The visualizer is the main core of the system and is the module in charge of delivering, through rendering and visualization, the 3D data stored in the system. It handles the most resource-consuming operations as point clouds are massive and require to be rendered fast in order to provide usability and a satisfying user experience.

The research on point cloud visualization systems has been focused, since its early stages [Axaridou et al., 2014], on finding more effective ways to index massive point clouds for out-of-core rendering [Bormann and Krämer, 2020] also adapting to the typology of data with semantic-dependent techniques [Discher et al., 2018], in order to get satisfying performances on most of the devices. The main focus of these efforts is directed towards point clouds at a territorial scale, especially massive, country-size ones derived from LiDAR surveys [Martinez-Rubi et al., 2015], which with the actual average hardware resources, represent a real challenge for in-core rendering.

One of the most diffused point cloud visualizer is Potree (Potree, 2022; Schütz, 2016) which originated from the SCANOPY Project [SCANOPY, 2009] and is still under development. Potree is an open-source converter and visualizer based on WebGL that can be used both as a standalone desktop application as well as an embedded tool in websites. The use of Potree for web applications is a common choice both for case studies that involve data at a territorial scale and for experiences at an architectural scale. Potree integrates some basic annotation tools that allow users to take measurements on the point cloud, put point labels with textual descriptions and attachments, and cut sections of the cloud (Fig. 5). Some case studies are useful to focus on possible uses of Potree, as an environment to display architectural reconstructions through point clouds of existing buildings and mesh models of artworks [Bent et al., 2022] and can be used as a renderer in more extended platforms for point cloud management that may also integrate WebGIS visualizers [Quintilla-Castán and Hernández, 2022]. The use of open-

source code can offer several possibilities in terms of adaptability and customization, allowing users to use point clouds as a geometrical basis for various purposes, such as the representation of acoustic features of space [Bergerot et al., 2022].
Aside from the open-source world, several companies are developing web platforms devoted to point clouds as a complementary service to their other products or as their core business. In the first category can be mentioned services such as Leica TruView Cloud [Leica Geosystems AG, 2022] and FARO WebShare [FARO, 2022], offered as additional services to the already established survey instruments and software, in order to enhance the possibilities of data sharing and diffusion by their clients [Fig. 6]. The second category comprehends platforms that propose data elaboration and analysis services based on cloud computing, sometimes starting directly from the data captured on-field. Cintoo [Cintoo, 2022] proposes tools for fully-operational data elaboration oriented to terrestrial laser scanning surveys in a perspective of digital twinning and built asset management. Vercator [Correvate Ltd, 2022] integrates alignment algorithms, automatic

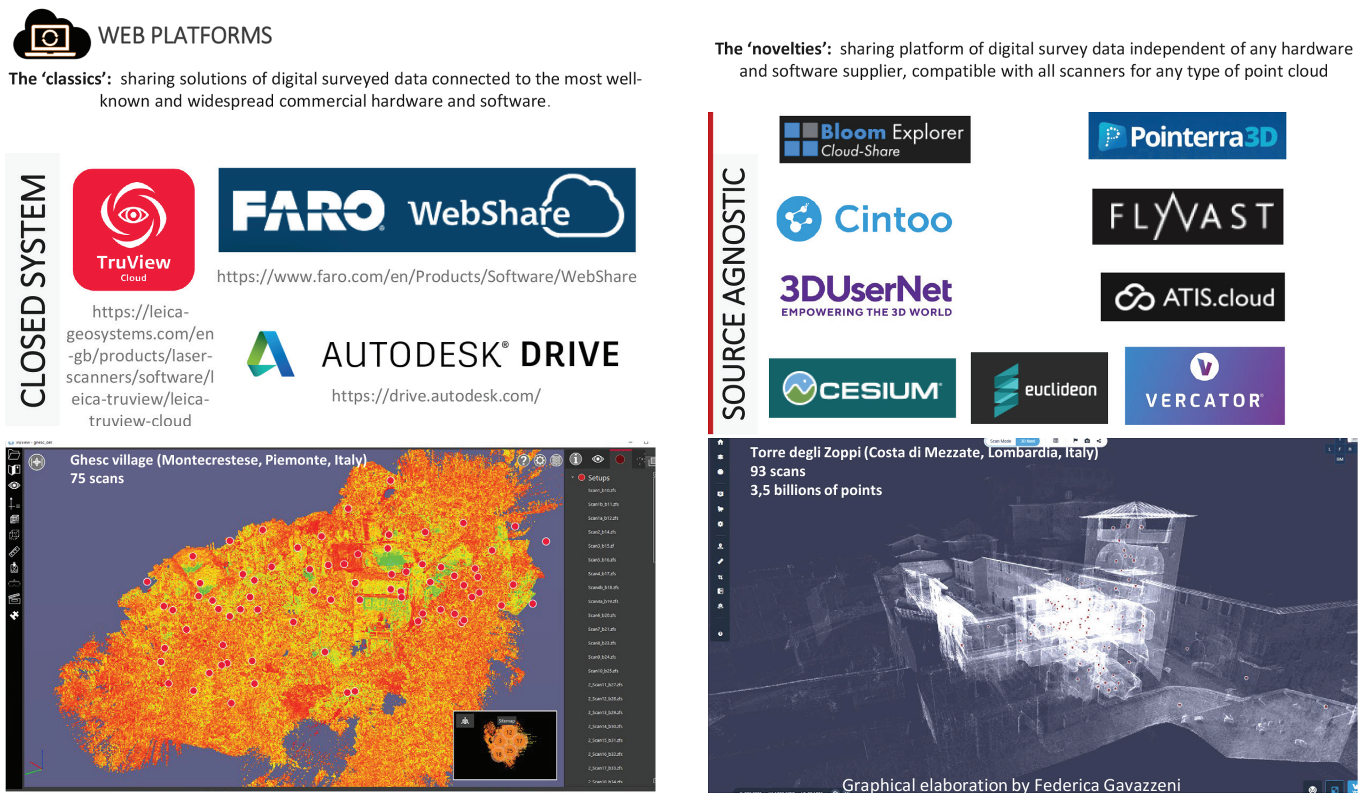

Fig. 6 – Web platforms for point cloud visualization and management can be categorized according to the data origin: specific instruments and software (closed systems) or virtually any possible data (source agnostic).

segmentation objects, and features recognition tools [Selviah, 2018]. FlyVast [Geovast 3D, 2022] is a platform based on the Potree visualizer that was developed to offer Artificial Intelligence (AI) support for geometry recognition [Poux et al., 2022]. NavVis IVION [NavVis, 2023] aims to provide elaboration tools from the beginning of the survey process, aligning cloud-to-cloud the laser scans, sharing the point cloud, and creating deliverables; the platform is integrated and optimized to work with the mobile mapping device [NavVis VLX] developed by the same company. Pointerra3D [Pointerra, 2023] is oriented towards using reality capture data for digital twinning and analysis and simulation based on geometry, offering three different modules with specific features according to the user's needs. Bloom Cloud Engine [Bloom Technologies, 2023] processes a broad amount of point cloud data and offers visualization and annotation tools; it embeds a plug-in to export point clouds to Autodesk products. udCloud [Euclideon, 2023a] is the web platform based on the udStream application [Euclideon, 2023b] which has the main feature to handle massive point clouds, providing basic measurement and annotation tools. ATIS.cloud [ATIS.cloud, 2023] supports a great variety of scanning projects, from terrestrial, aerial and mobile devices, for delivery and visualization of point clouds, including some annotation and slicing tools. Cesium ion [Cesium GS, 2022]

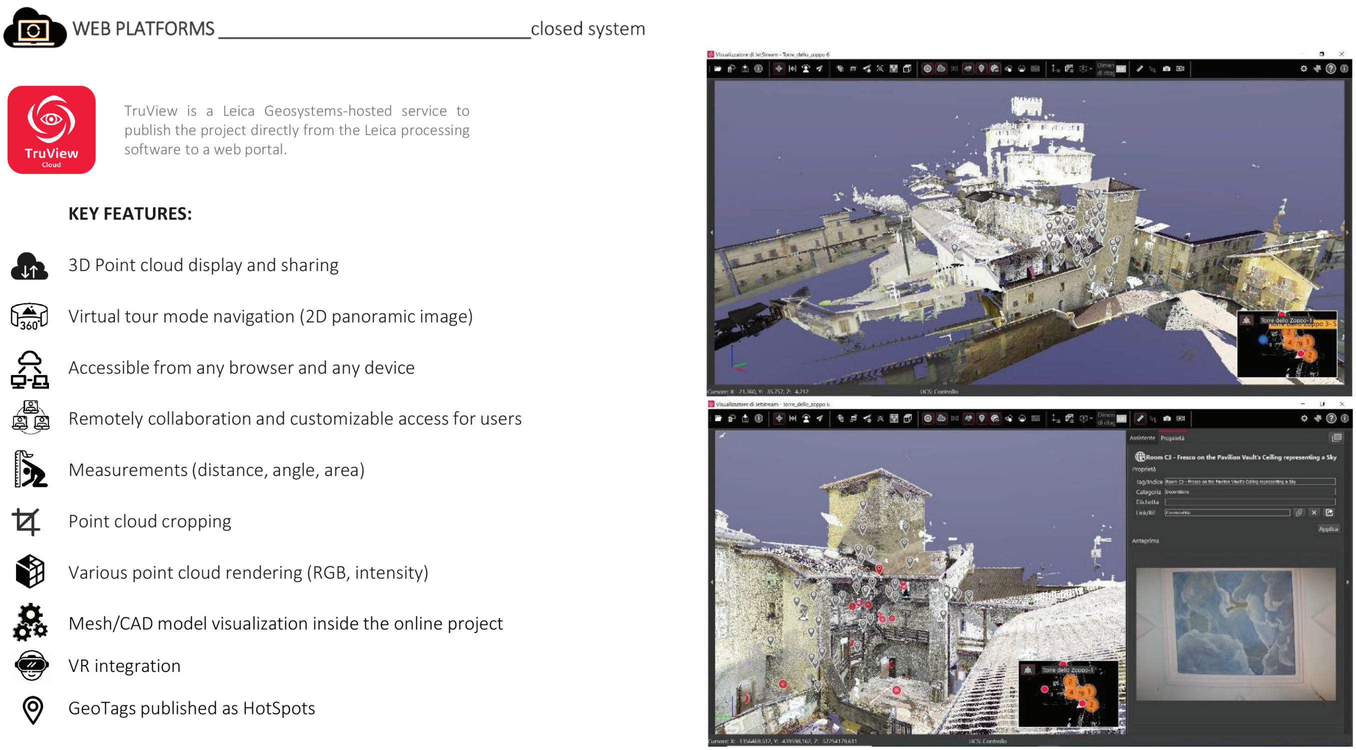

Fig. 7 – Features of the Leica TruView Cloud platform.

is a platform generally devoted to the representation of huge geodata, as point clouds and mesh, but can be used also with georeferenced clouds at the architectural scale. Cesium provides a series of embedded world-scale map and building databases from various sources to be used as standalone or with the 3D data provided by the user.

Web platforms for point cloud visualization and management are nowadays spreading and developing as fast as the request for reality capture increases, leaning towards the possibility of offering data elaboration features, automatized segmentation tools, and enhancing sharing possibilities in order to cover all the needs of professional and non-professional users.

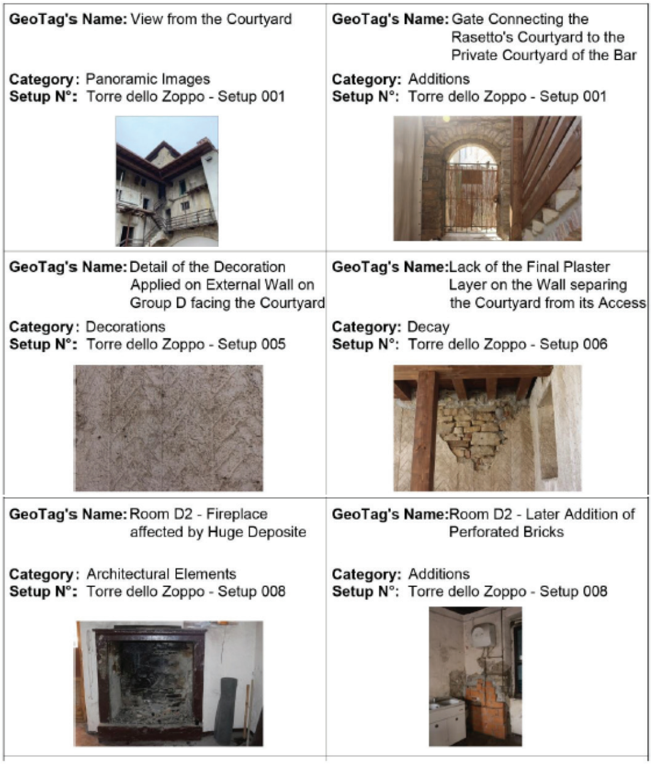

Fig. 8 – An example of the annotation possibilities offered by the Leica TruView Cloud platform.

Experimental case studies

As already specified, two main categories can be distinguished by studying the types of web platforms currently available. There are closed systems of sharing solutions for digital surveys connected to the most well-known and widespread commercial hardware and software. On the other hand, there are agnostic sharing platforms independent of any hardware and software supplier, compatible with all scanners and for any type of point cloud.

In order to test the functionality of both cloud-based platforms for reality data sharing, two sorts of datasets were used. The first dataset consists of data coming only from the laser scanner survey of the *Torre degli Zoppi*. The data were acquired with a single laser scanner instrument during the same survey campaign. The XII-century tower is located in Costa di Mezzate, near Bergamo (Lombardy, Italy). It was surveyed in 2020 using the Lecia RTC360 laser scanner, resulting in a point cloud of 3,5 billion points, composed of 93 scans [Gavazzeni, 2021].

On the other hand, a second dataset is a mixed set-up of data from image and range-based acquisitions collected over the years during the surveys developed in the village of Ghesc. The datasets refer to different years and are related to active and passive sensors. The historical village is located in the Ossola Valley (Piedmont, Italy), and it is characterized by the local stone peculiar architecture. From 2011 to 2017, the village was surveyed with various techniques during recurrent summer schools [Achille et al., 2018; Bolognesi and Fiorillo, 2023]. The final dataset used in this paper is composed of a laser point cloud of 75 scans and a UAV point cloud of roofs and the surrounding terrain [Achille et al., 2017].

Standard and common features among the different platforms are related to: i) 3D Point cloud display and sharing; ii) virtual tour mode navigation using a 2D panoramic image; iii) access from any browser and any device; iv) remote collaboration and customizable access for users; v) direct measurements (distance, angle, area) on the point model; vi) point cloud

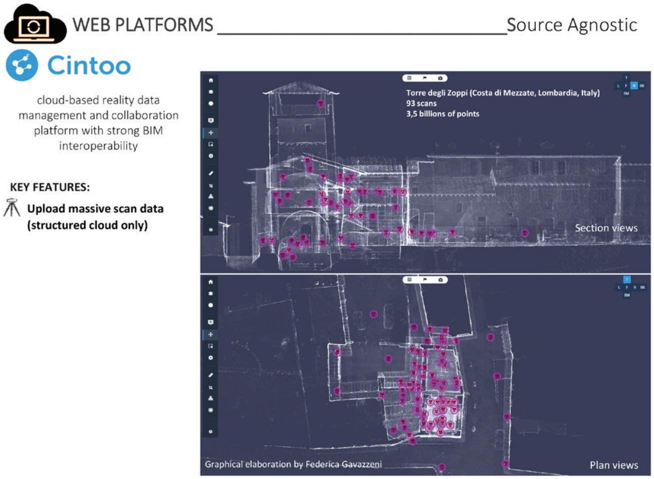

Fig. 9 – Cintoo web platform interface.

cropping or selection; vii) cross-sections extraction; viii) various point cloud rendering (RGB, intensity, elevation); ix) creation of annotations as GeoTags or HotSpots.

This last utility is essential to developing an informative structure that graphically represents information as a link on the point cloud with a specific icon.

Since the *Torre degli Zoppi* digital survey was carried out and managed entirely within the Leica Geosystems hardware and software environment, the acquired dataset was published using Leica True View (Figg. 7-8). True View is a closed system that allows sharing the project directly from the Leica processing software to a web portal. The platform provides an interesting feature related to the mesh or CAD model visualization inside the online project. Moreover, the more innovative resource is the possibility to integrate immersive exploration using Virtual Reality devices.

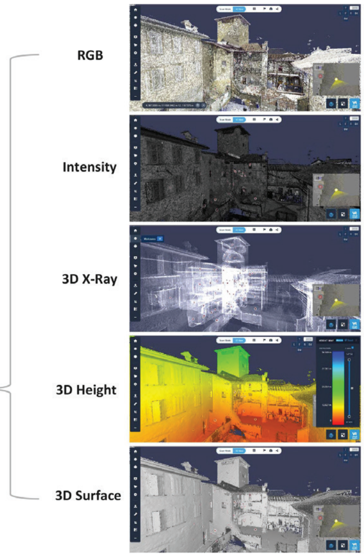

Fig. 10 – Features of the Cintoo web platform.

Fig. 11 – Cintoo rendering modes of the point cloud.

The same dataset was also uploaded on the Cintoo platform, characterized by strong BIM interoperability (Figg. 9-11). The cloud-based management and collaboration platform ensure the upload of massive scan data (structured clouds only). Furthermore, a repository of under-study building documentation (technical documentation and bibliographic research) can also be structured (Fig. 12).
Flyvast and Vercator adhere to the same principle and organizational structure as Cintoo: independently process, manage, publish, and share 3D data. In addition, both ensure the uploading of unstructured clouds, such as those generated by photogrammetric surveys.
These last two platforms share a strong spirit of research by proposing innovative AI-based tools for point cloud segmentation. Innovative and constantly under-development tools for semantic segmentation, automatic classification, and point cloud labeling characterize Flyvast (Figg. 13-14). Instead, as a novelty, Vercator (Fig 15) offers the option to implement an automatic targetless scan alignment.

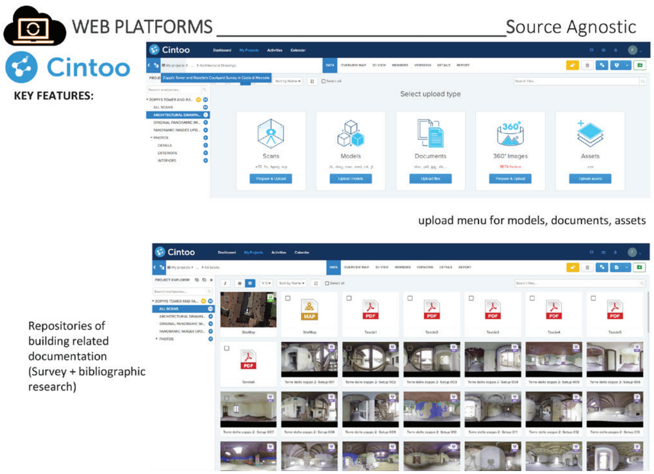

Fig. 12 – Cintoo data management interface.

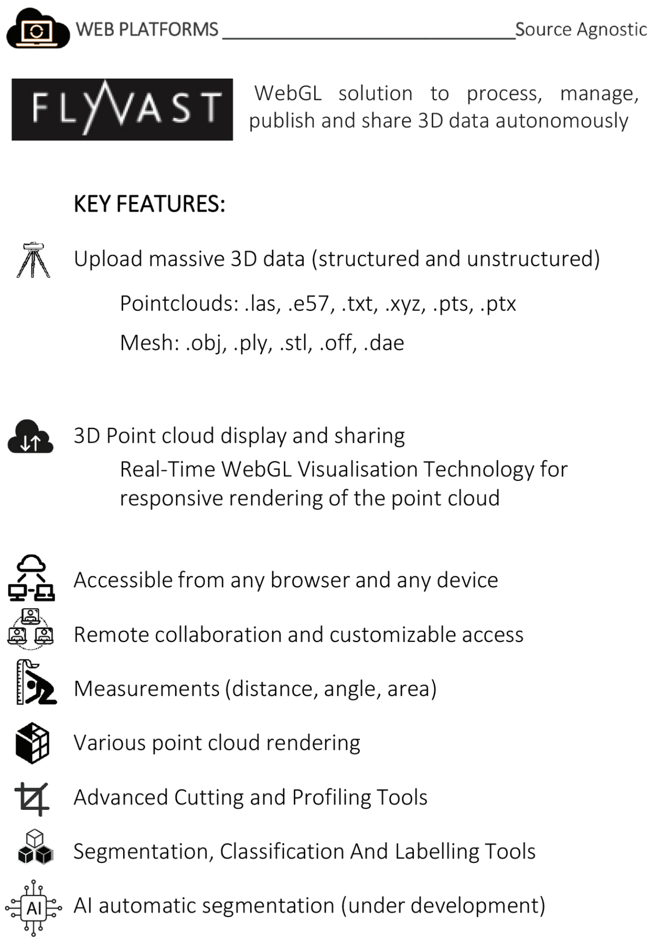

Fig. 13 – Features of the Flyvast web platform.

WEB PLATFORMS ________________________________ Source Agnostic

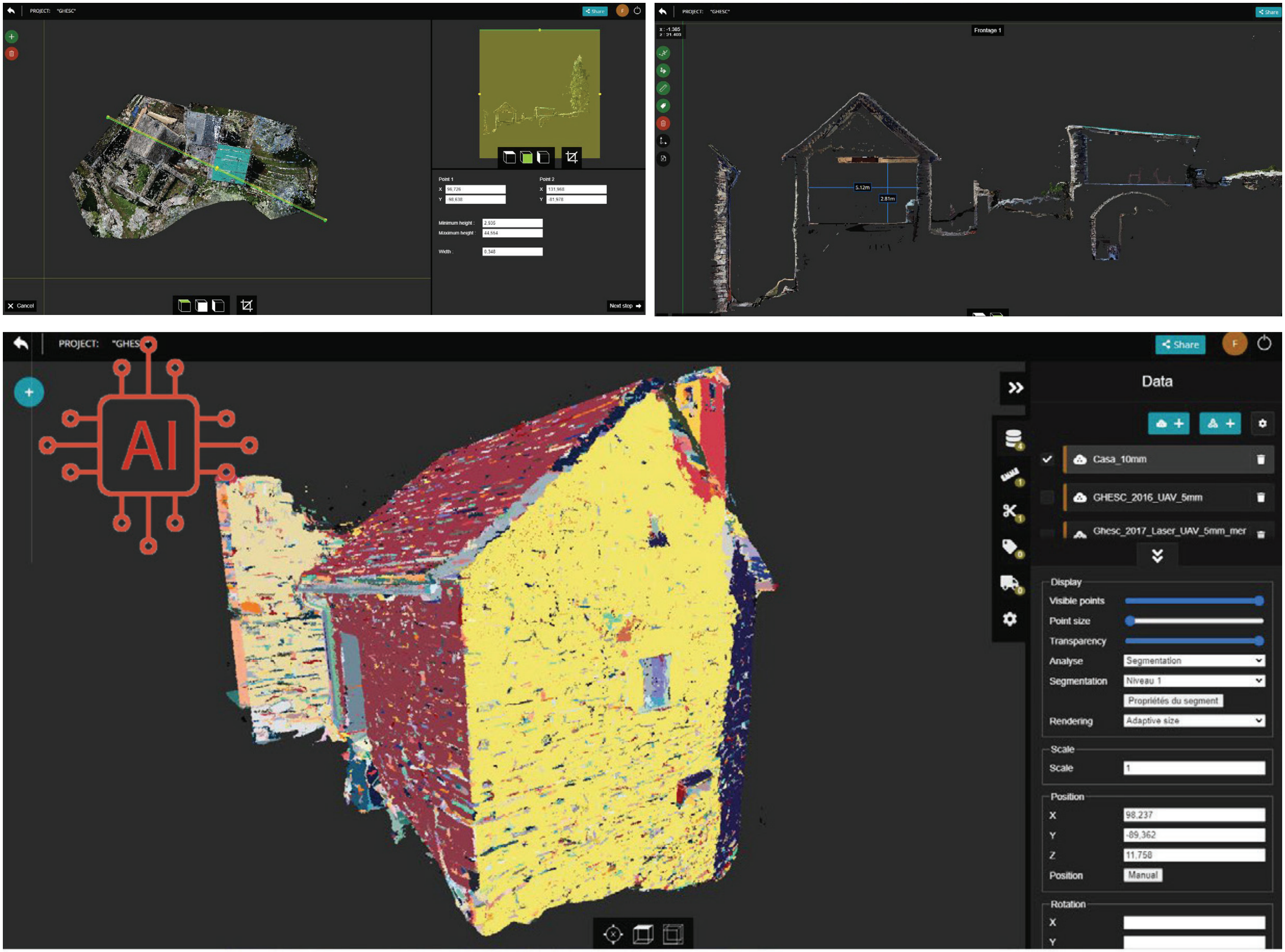

Fig. 14 – Flyvast point cloud sectioning tool and, below, flyvast automatic segmentation tool.

WEB PLATFORMS ________________________________ Source Agnostic

VERCATOR

Automatic Point Cloud Processing,
Powered by the Cloud https://vercator.com

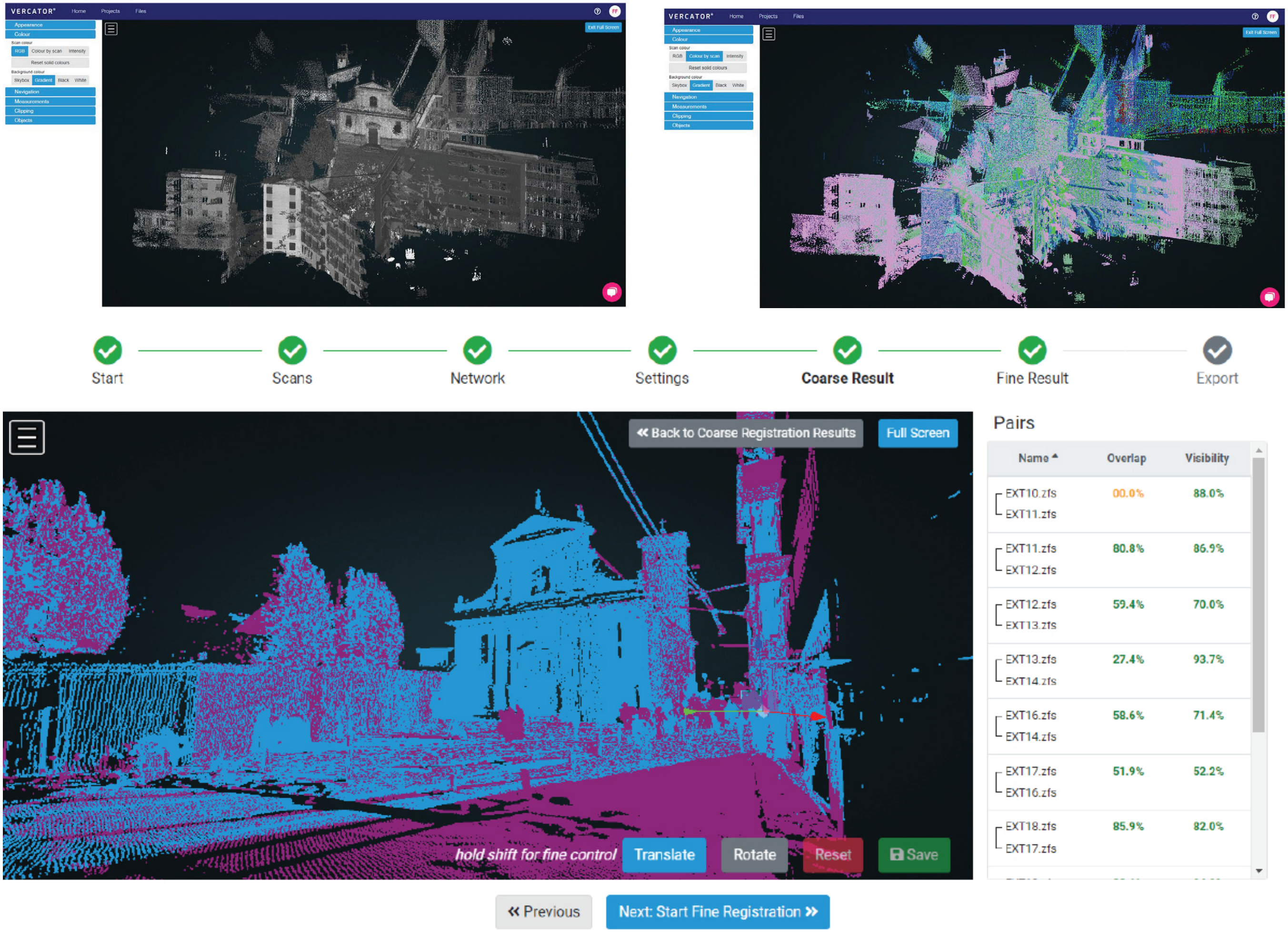

Fig. 15 – Features of the Vercator web platform.

CONCLUSION

- ✓ allow improving the workflow from the digital survey to the use of its outputs in a collaborative way, without specific software, anywhere-anytime-anydevice.
- ✓ allow using of annotation and labels to attach other types of information to the point cloud.

This approach can be advantageous in the Cultural Heritage field, especially when CAD or HBIM modelling is unnecessary because it is not the final aim. The solution can be to skip the complex and time-consuming modelling phase altogether and use the point cloud directly as a 3D geometric base and for the information repository.

- ✓ offer advanced tools for experiments aimed at automating specific processes, e.g. cloud registration, segmentation, classification, and change detections

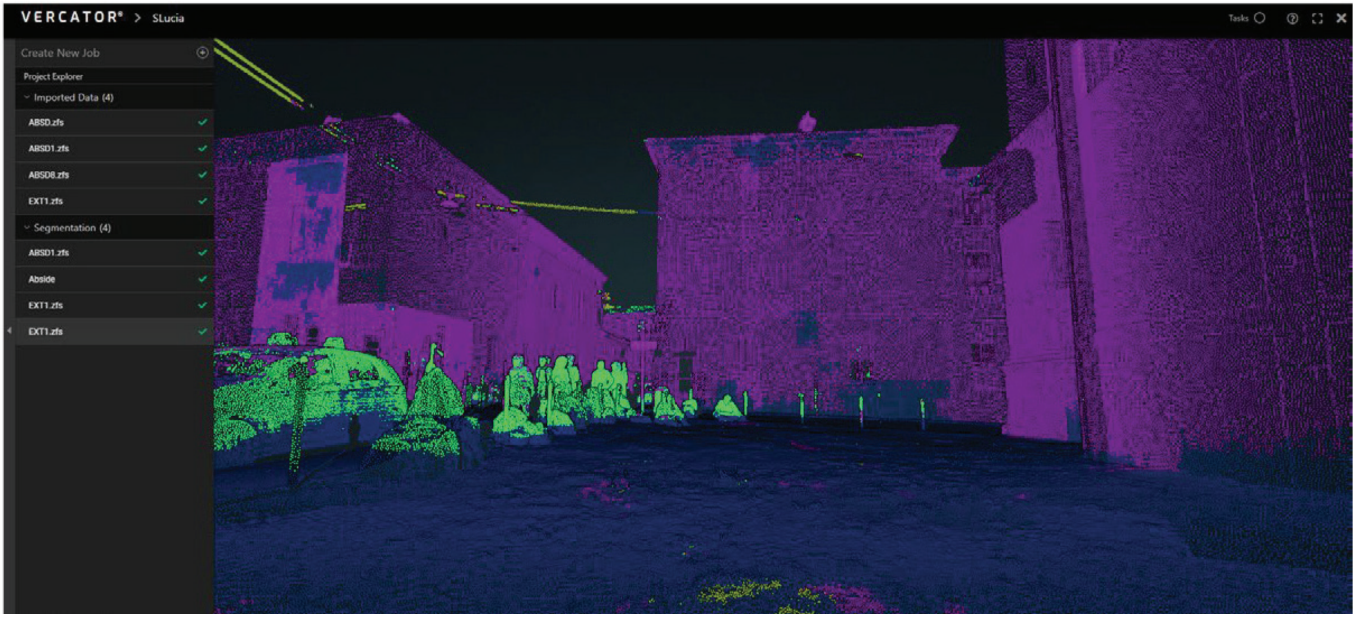

Fig. 16 – Summary and highlights of the paper.

Conclusions

The presented critical analysis is configured as a preliminary report regarding the cloud-based platform for reality data sharing and management, revealing the following benefits (Fig. 17). The web-based approach allows workflow improvement from the digital survey to the use of its outputs collaboratively, without specific software, anywhere, anytime, and on any device.
The point cloud can be employed as a geometrical reference for attaching different forms of technical data, information, and additional analyses about the under-studied object using hotspots, annotations, and labels. This approach can be advantageous in the cultural heritage field, especially when CAD or HBIM model is unnecessary because it is not the final aim. The solution can be to skip the complex and time-consuming modeling phase altogether and use the point cloud directly as a 3D geometric base for the information repository. This strategy cannot replace geometric analysis and architectural interpretation phases but can support them and other types of structural preservation and restoration investigations.
At last, this approach offers innovative advanced tools for experiments aimed at automating specific processes (e.g., cloud registration, point cloud segmentation, classification, and change detection) by exploiting machine learning algorithms and AI strategies.

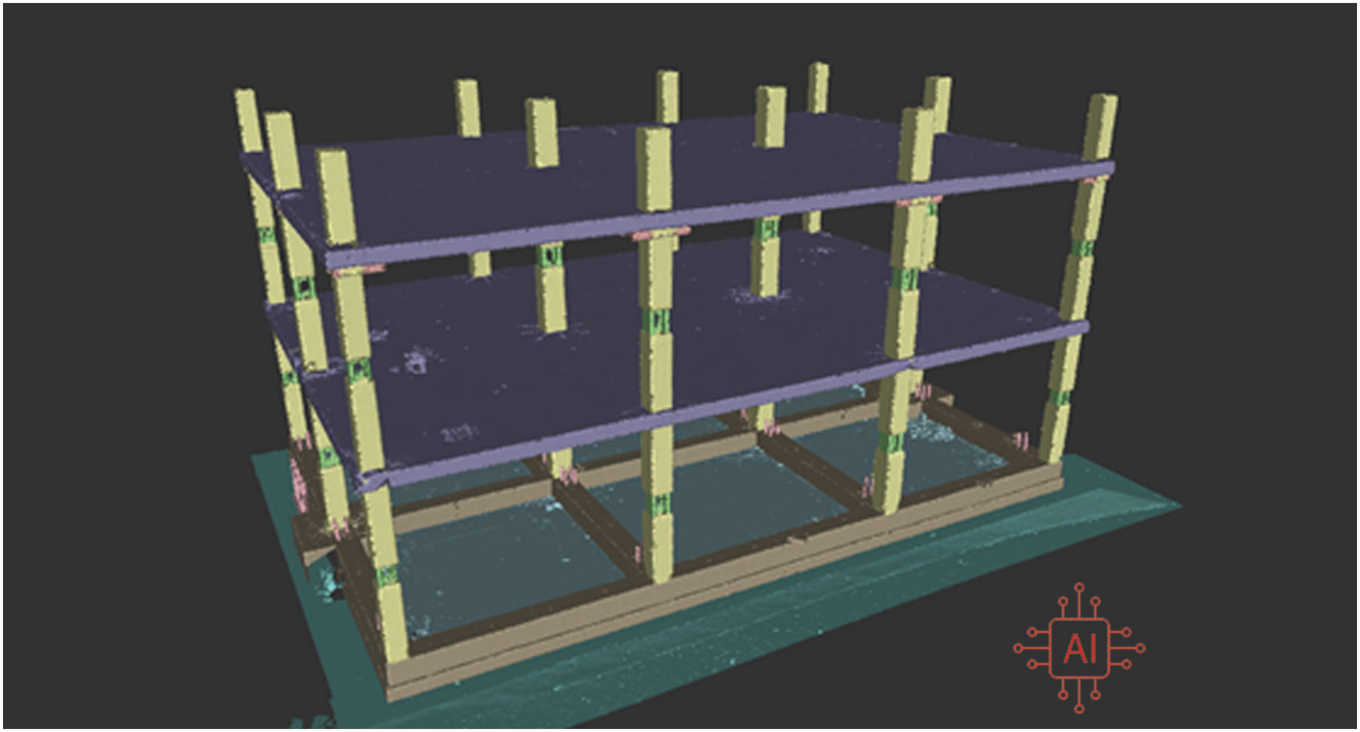

Fig. 17 – Point cloud classification.

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11 THE POTENTIAL OF BIM AND GIS MODELS FOR SUSTAINABLE WEALTH MANAGEMENT

Abstract

Public administrations, increasingly, promote the dissemination of heritage sites and environments in order to promote cultural tourism that contributes to economic and social dynamization of these destinations. The research of new capacities attached to technologies that involve the efficient management of information, as well as methods of work conducive to the planning of cultural tourism, becomes a scientific and also social necessity. The creation of a unitary management platform where all the actors involved in the management and planning of the public cultural visit to a heritage environment would be of great help. Geographic Information Systems (GIS) allow to relate any data available in a geographical environment, which makes this framework a tool with great potential from the perspective of planning and management of tourism and culture.

In this context, the Ministry of Science and Innovation of the Government of Spain, granted, in a public call, funding for the development of the R+D+I project entitled *Analysis and development of HBIM integration in GIS for the creation of a tourism planning protocol of the cultural heritage of a destination* (PID2020-119088RB-I00). This project proposes the creation of an online HBIM-SIG work platform, which meets the needs raised by public administrations.

History

Many geographic areas and population centers base a large part of their economy on their heritage values. Improving the planning and management of these assets becomes an obligation aimed at ensuring sustainability, especially in the framework of tourism development. For this reason, public administrations, increasingly, promote the dissemination of heritage sites and environments in order to promote cultural tourism that contributes to economic and social dynamization of these destinations. The research of new capacities attached to technologies that involve the efficient management of information, as well as methods of work conducive to the planning of cultural tourism, becomes a scientific and also social necessity. The creation of a unitary management platform where all the actors involved in the management and planning of the public cultural visit to a heritage environment would be of great help. Geographic Information Systems (GIS) allow to relate any data available in a geographical environment, which makes this framework a tool with great potential from the perspective of planning and management of tourism and culture.

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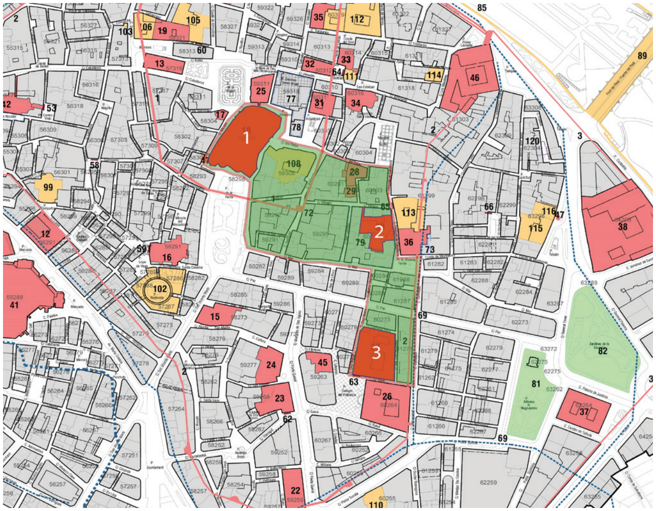

Fig. 1 – The case studies: 1.- Cathedral; 2.- San Juan del Hospital; 3.- The Patriarch (Source: the PEPCV 2018 Plan own reworking).

Fig. 2 – The case studies: 1.- Cathedral; 2.- San Juan del Hospital; 3.- The Patriarch (Source: Gooble Maps own reworking).

management of the public visit, as well as the interpretation of heritage sites and environments. In addition, it would help the preventive conservation and maintenance of heritage assets and the digitized registration of them.
This project is part of the international framework programmes such as Horizon Europe, successor to Horizon 2020, and Digital Europe 21-27, which support and promote research projects based on the use of New Information Technologies (ICT).
For the development of the project, an urban area of the historic center of Valencia (Spain) designated BIC in the category of "historic center" has been taken as a test laboratory and for which its Special Protection Plan (2020) has recently been approved. In this area there are three case studies: The metropolitan cathedral, the church and the medieval complex of San Juan del Hospital and the Royal Seminary College of Corpus Christi (the Patriarch). Both the historical urban areas of the Ciutat Vella, and the three complexes possess the highest range of protection in the artistic and cultural sphere of the city. (Fig. 1 and Fig. 2)
The metropolitan cathedral stands on the site of what was once the Great Mosque. Work began in 1262 on a scheme of three naves, transept, polygonal apse and girla. On the Gothic temple have accumulated interventions belonging to the different stylistic periods. These performances were carried out by the best teachers of the moment, treasuring the best of each period, which makes it a didactic example (Viñals and López, 2022). It has been of cultural interest since 1931.
In the old chapter house (1365-1369) built entirely in stone and covered with a splendid star vault. It preserves one of the most important relics of Christianity, the Holy Grail. Originally it was exempt from the temple. The free-standing bell tower popularly known as the Miguelete due to the name of its largest bell was built between the years (1381-1418). It is octagonal for centuries the tallest tower in the city. (Fig. 3 and Fig. 4)
The complex of San Juan del Hospital is documented

Fig. 3 – Interior of the cathedral (Source: Own).

Fig. 4 – Exterior of the cathedral (Source: Own).

Fig. 5 – Outside of San Juan del Hospital (Source: Own).

since 1244. At present it consists of the temple and two courtyards located north and south of the church. The south courtyard is one of the few examples of a medieval walled cemetery with arches and a central funeral chapel. The temple is an excellent example of Mediterranean Gothic. In the enclosure were vestiges belonging to the diverse cultures that have shaped the city. It has been an Asset of Cultural Interest since 1943. (Fig. 5 and Fig. 6)

The Royal Seminary College of Corpus Christi is one of the best examples of the episode of the Counter-Reformation in the Spanish scene and one of the few examples of Renaissance architecture that can be found in the city of Valencia. It was built in 1583 by Juan de Ribera (Bérchez and Gómez-Ferrer, 1995). It presents a clear influence of architectural treatises (López et al, 2020). It is of Cultural Interest since 1962. (Fig. 7 and 8)

The three buildings are located in the historic center, one of the largest in Europe. In its central part is the Seu-Xerea district where the Cathedral and San Juan del Hospital are located. Here are the remains of the Roman Valencia of republican and imperial times. It is the civic center of the city, enclave of traditional noble settlement;

Fig. 6 – Inside of San Juan del Hospital (Source: Own).

Fig. 7 – Inside of the Patriarch's College (Source: Own).

to the north is the neighborhood of the University Frances, where the old Jewish Quarter was located on which, after its demolition, the Patriarch was built; both neighborhoods are separated by the axis of Calle de la Paz, one of the most coherent and representative spaces of the city, characterized by the implantation of the aesthetic currents of Modernism and Eclecticism of the late nineteenth century.

Fig. 8 – Outside of the Patriarch's College (Source: Own).

Integrative Principles of BIM and GIS

One of the challenges facing the documentation and management of cultural heritage is the large amount of scattered information that is sometimes incomplete and messy. Lack of reliable sources of documentation can impair the preservation of the building and even create inefficiency issues throughout its life cycle. To overcome this difficulty, it is necessary to create a Common Data Environment (CDE) or a "Common Data Environment" as a solution to the problem. CDE involves a single source of information for collecting, managing, interpreting and disseminating project data. In 2013, English Heritage already advocated the need to create a CDE for the study of heritage and even began to consider BIM in its strategy for heritage conservation by creating a BIM SIG Special Interest Group. In 2017, Historic England, heiress to English Heritage, established the scaffolding on which a CDE intended to manage heritage assets should be based.

In 2009, Murphy et al. perceived the advantages that the BIM methodology could facilitate in the study of architectural heritage. Since then, the research and technical advances carried out, as well as the associated scientific literature, have revealed the potential of HBIM to document heritage buildings (Jordan-Palomar et al., 2018). However, most of them refer to studies on a specific case without establishing methodologies or working prototypes that can be extrapolated to other buildings.

In Spain, Francisco Pinto Puerto was a pioneer in the research of the BIM methodology applied to architectural heritage developed in the project "A Digital Model of Information for the Knowledge and Management of Real Estate of Cultural Heritage". Subsequently, studies have been carried out aimed at incorporating diverse information around the study and management of a heritage asset, confirming the great potential of HBIM to manage the maintenance work of buildings throughout their life cycle (Fassi et al., 2016). In this same sense, progress has been made in the registration of injuries through the monitoring and placement of sensors, which represents a great advance in the preventive conservation and planning of actions (Bruno et al., 2018). Advances in the documentation and management of HBIM heritage have not only been limited to buildings, but the creation of models in the field of archaeology is also being tested (Martín and Murillo, 2020).

However, there is no research related to the use of the HBIM methodology aimed at the management of the tourist visit, except that tested by Elena Salvador on a religious building in Valencia (Salvador-García et al., 2020). (Fig. 9)

For their part, GIS represent a powerful tool for working on issues related to urban planning and resource management. These characteristics have led to interoperability trials with BIM in different areas related to cultural heritage. The review of the scientific literature around HBIM and GIS capabilities by Pavel Tobiáš (2016) and Xiucheng Yang et al is very interesting. (2020). It should be noted that HBIM integration in GIS also begins to be used in works framed in a geographical area. Thus, Martín, et al. (2018) assess the potential risks to which the heritage assets of an archaeological area may be subjected. Mascort Albea et al. (2016) advance in the creation of interactive maps of heritage complexes for public consultation through the Geoportal of Spatial Data Infrastructure. For their part, Bruno et al. (2020) have developed a web information system capable of integrating BIM and GIS data, focusing on the analysis of the historic city and its main buildings over time. Along the same lines, Chenaux et al. (2019) address the integration of BIM with GIS as part of the workflow

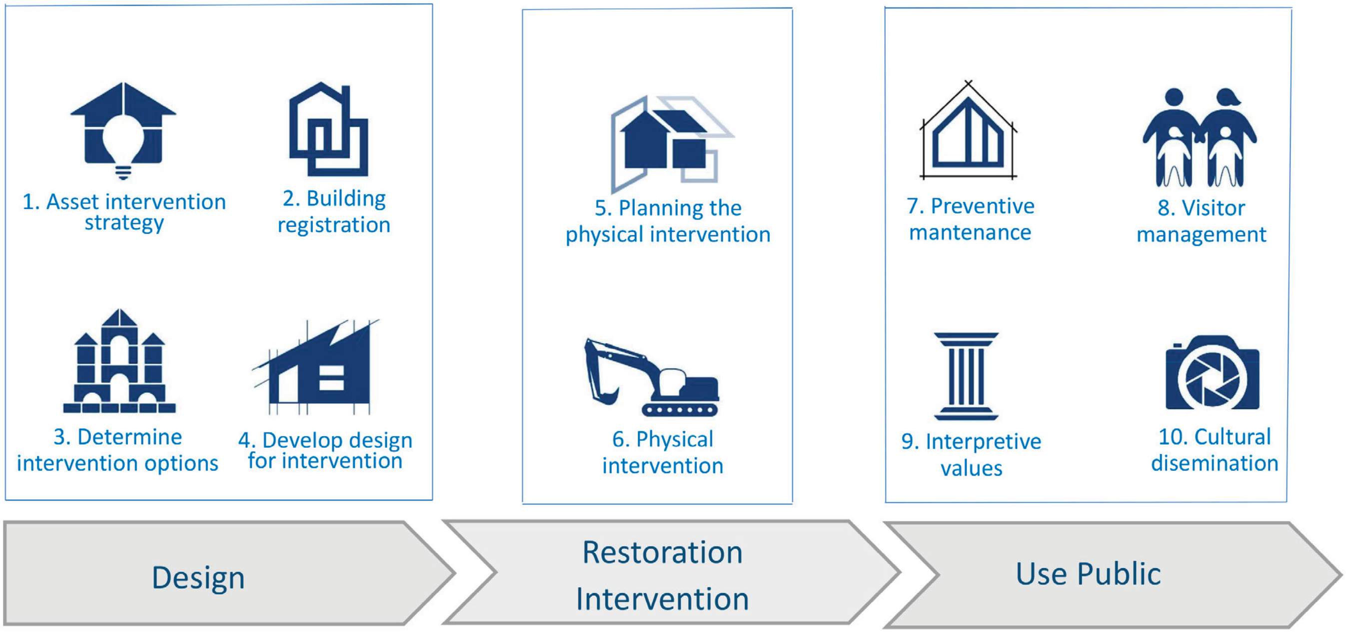

Fig. 9 – Diagram of the phases of the HBIM process (Source: Own).

in the creation of Virtual Historic Dublin, designing an interactive 3D model of Dublin's historic center.
This great management capacity that can be achieved with the interoperability between BIM and GIS aims to be tested for the management of public use and cultural tourism in the R+D+I Project that is being developed. (Fig. 10)

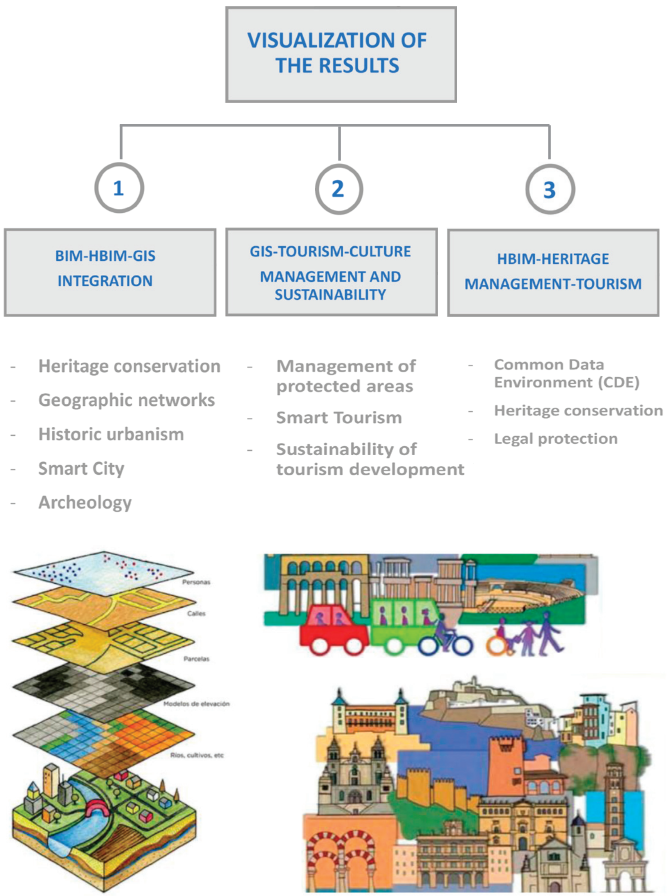

Fig. 10 – Outline of HBIM integration capabilities in GIS (Source: Own).

OBJECTIVES AND METHODOLOGY OF HBIM-SIG INTEGRATION

The overall objective of the R+D+I Project is to explore and determine the possibilities of interoperability between HBIM and GIS for the creation of a Protocol aimed at synchronizing and managing information on heritage architecture, sustainable conservation of goods, territorial planning and cultural tourism. This objective is developed through six specific objectives leading to establish the conceptual bases, optimize the management of heritage elements, develop the HBIM-SIG integration aimed at generating a first draft of the Tourism Planning Protocol, apply it to the case studies and, finally, analyze the results in order to improve the proposed Protocol that may be exportable to other case studies.
The achievement of these objectives is only possible through the design of a working methodology suitable for this purpose. The Design Science Research (DSR) method has been used as it aims to solve a problem related to heritage architecture and its public use. The five stages suggested by Vaishnavi et al. (2004) and Chaves et al. (2016) for Design Sciences have been proposed: 1. Identify the problem: through the analysis of the scientific literature; 2. Understand the problem: through the analysis of cultural tourism planning in the proposed case studies, all three cases being framed in the same management body; 3. Develop a solution: with the creation of a Protocol integrating the HBIM-SIG functions related to cultural tourism planning and conservation of property; 4. Implementing the Solution: Implementing the Protocol in Case Studies; and 5. Evaluate the solution: checking the functioning of the Protocol, detecting possible changes and improvements and analyzing the potential for exportability and transfer of results to other situations. (Fig. 11)

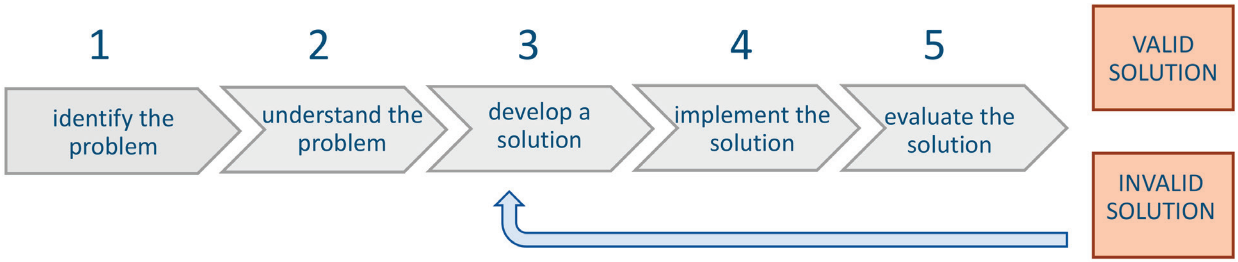

Fig. 11 – DSR Outline (Source: Own).

APPLICATION OF HBIM AND GIS INTEGRATION IN CASE STUDIES

For the integration of the HBIM and GIS models, the following question was formulated as a starting hypothesis: Is it possible to achieve a Common Data Environment (CDE) by integrating the BIM and GIS models, so that the CDE becomes a single source of updated information aimed at collecting, managing, interpreting and disseminating data from the integration of the two models?

First of all, the works of Elena Salvador García (2020) who managed for the first time to implement the tour of the tourist visit in an HBIM model was considered. Identified the agents involved and the needs, traditional work processes and potentialities of HBIM in the field of public use management. (Fig. 12 and Fig.13)

Secondly, Marta Quintilla Castán (2022) managed to define a digital graphic inventory model of architectural heritage in a geographical area. The solution was the design of an integrated geometric relational model of information. This tool allowed the diffusion and exploitation between the different users through a Web Portal in which a cartographic viewer is integrated with the access through a point cloud manager based on WebGL and in the repository of the HBIM-SIG information.

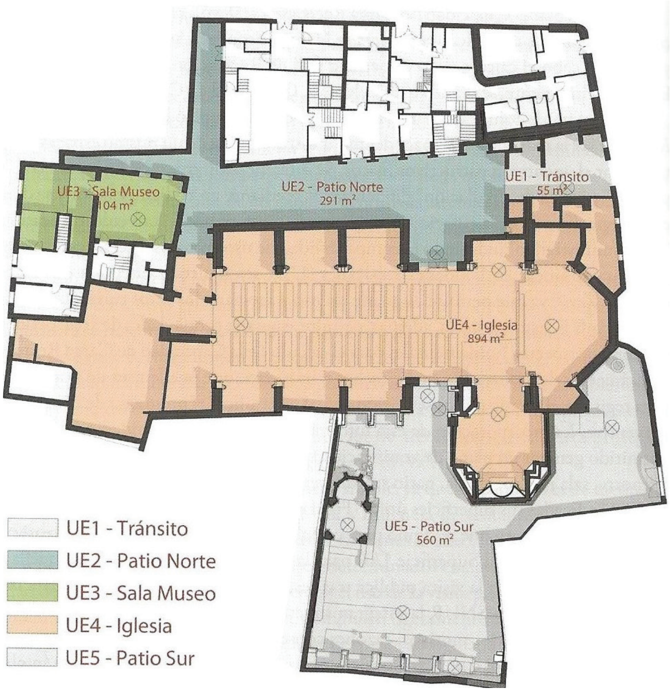

Fig. 12 – The implementation in HBIM of the Expository Space Units of the San Juan del Hospital complex (Source: Salvador García, E. 2020) .

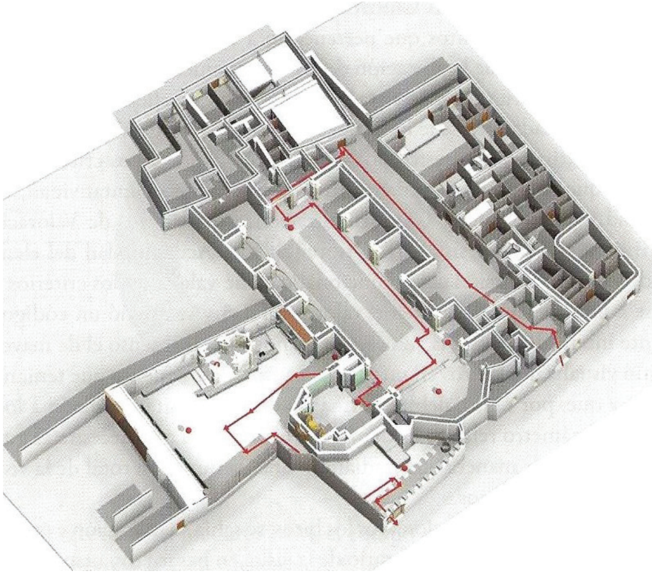

Fig. 13 – The implementation in HBIM of the tourist routes of the whole of San Juan del Hospital (Source: Salvador García, E. 2020) .

Taking these two studies as a precedent, the following information was generated and elaborated through the following tools:

1/ The data collection of the point clouds of the area comprising the three buildings in the neighborhoods of Seu-Xerea and Universitat carried out by means of a laser scanner equipment Leica RTC360 and the associated program Cyclone. (Fig. 14)
2/ The data collection of the Patriarch, cathedral and SanJuan del Hospital through the FARO Focus Premium, Focus 360, Focus 3D and Freestyle equipment, portable scanner equipment and processed with the scene program. (Fig. 15, 16 and 17)
3/ Point clouds have been implemented in Revit for digital modeling. (Fig. 18)
4/ These models have been incorporated into GIS through the ArcGIS online platform. This facilitates the integration of 2D and 3D cartographic models of different origins in an intuitive interface. At the same time, it allows the visualization, analysis, image processing, data management and integration of information generated by the participating agents. (Fig. 19)

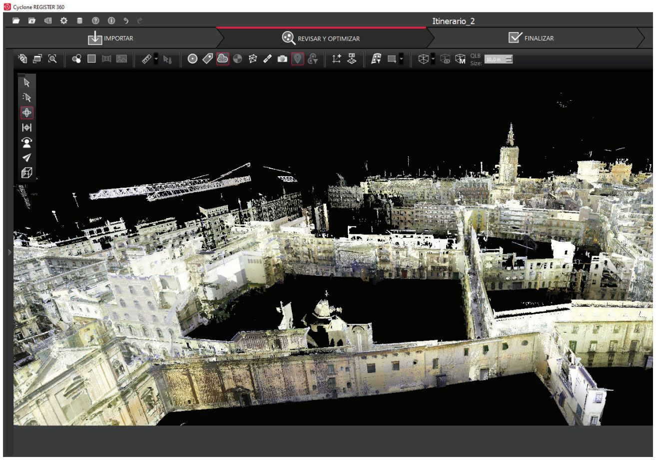

Fig. 14 – Point clouds of the way.

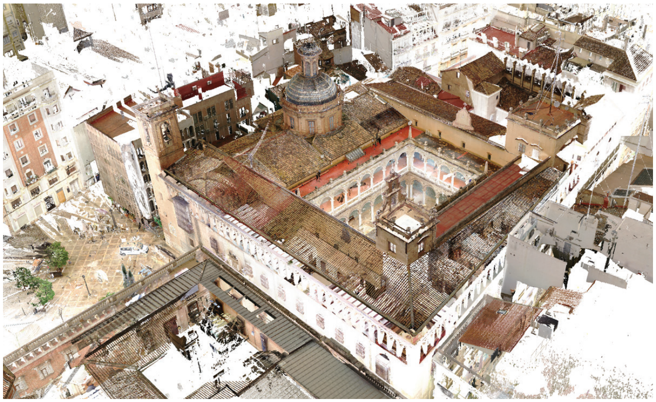

Fig. 15 – Top view of the point clouds of the College and Church of Corpus Christi (Source: Junshan, Li, 2022).

Fig. 16 – Point clouds of the Cathedral (Source: Own).

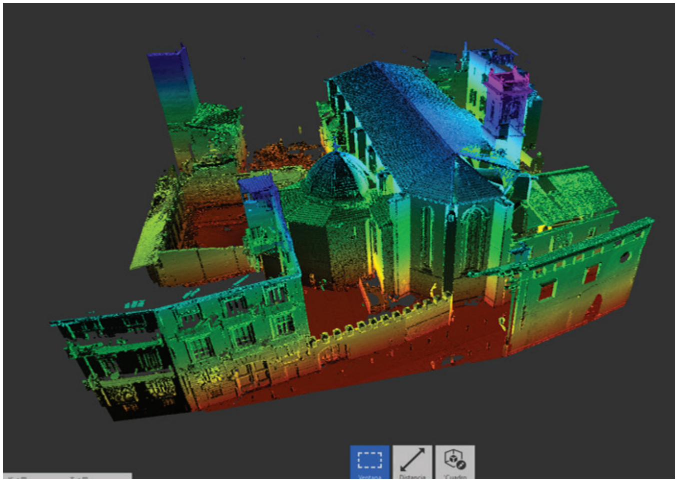

Fig. 17 – Point clouds of the set of San Juan of the Hospital Recap (Source: Own).

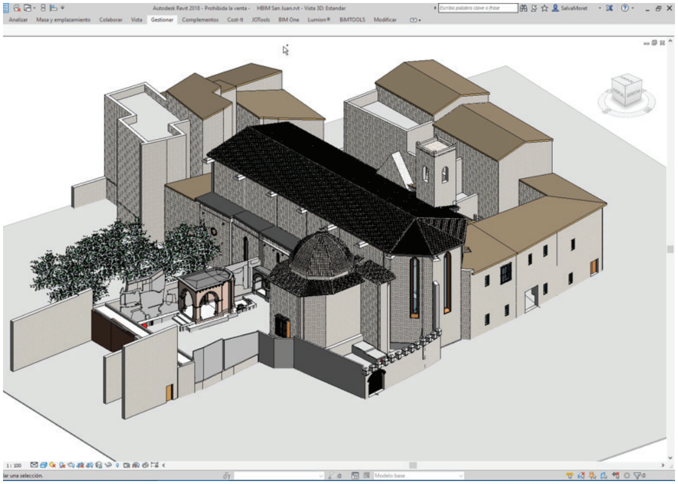

Fig. 18 – Model 3D-HBIM Revit of San Juan (Source: Own).

Conclusions

The potential of HBIM and GIS tools, as well as their interoperability, for the management of public use of heritage buildings are evident. In parallel, the integration of both methodologies to an Access database effectively collaborates in the management of preventive maintenance and conservation and in the documentation of heritage buildings located in a given geographical area. All this involving all the actors involved in the different thematic areas.

It should be noted that the integration of these databases is what allows the combination of information at different scales, both on a building scale and on a territorial scale.

It has been found that the capabilities of the integration of HBIM and GIS can be classified in the following fields related to the study of the cultural visit to the architectural heritage in an environment: 1/ assess and coordinate alternatives of simultaneous thematic itineraries; 2/ study the management for the efficient for the design strategies of devices that allow to compatibilize the tourist use with the residential taking into account aspects that concur; 3/Virtually identify the problems of visitor flows considering the profile of the visitor and their physical and psychological comfort, as well as visits destined to people with functional diversity.

Fig. 19 – HBIM integration in GIS of architectural ensemble of San Juan (Source: Own).

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12 3D MODELS FOR ARCHITECTURAL HERITAGE DOCUMENTATION: TRANSPARENCY AND RELIABILITY ISSUES

Abstract

Digital modelling has multiplied the opportunities offered by graphic representation for the study, analysis, documentation, and enhancement of the architectural heritage. In particular, 3D models, intended both as a visual computing tool -that is, data processing and deepening of the characteristics of buildings- and as "complex" models -as they are connected to a heterogeneous information system- favour the documentation of the historical and architectural values of the heritage. In this context, Building Information Modelling (BIM), in its dual meaning of graphic representation and database, has amplified such potential, offering itself as an interactive platform where to manage the heterogeneous and multidisciplinary information inherent to the architectural heritage. However, these models are not a complete and exhaustive transcription of the characteristics of the object of study, but rather a critical selection of these, made according to the purposes of the representation and the specificities of the architectural object. For this reason, in order for the representation to have a scientific basis, it is necessary that the sources used for the realization of the model are declared transparently and that the interpretative level of the virtual reconstruction is clear.

The contribution deals with the issues of transparency of models and their reliability, in relation to both geometric and non-geometric contents. In particular, based on an experiment conducted on several case studies, it proposes a possible specific procedure for modelling transparency and reliability evaluation, necessary for the documentation of the architectural heritage through 3D models.

Introduction

Digital modelling has multiplied the possibilities offered by graphic representation for the study, analysis, and enhancement of the architectural heritage. 3D models, in fact, can favour the documentation of the historical and architectural values of the heritage and, at the same time, can be tools for communication and valorisation.
In this respect, 3D models must be intended both as a visual computing tool -that is, data processing and deepening of the characteristics of buildings - and as "complex" models -as they are connected to a heterogeneous information system.
The modelling of the architectural heritage can concern different themes. It may involve for example reconstructive hypotheses of past phases of a building or an urban context (Brusaporci et al., 2020).
Since what can be known is only current reality, the reference of these reconstructions is the survey of the present state. In addition, there is the critical analysis of the various archival documents, such as historical photos, drawings, and so on. The scholar, then, on the basis of the critical analysis of survey data and archival documents, makes interpretative choices. Similar interpretative problems can be found in the digital visualizations of hypotheses of projects never completed. In this case, the 3D model becomes an instrument for understanding how the artefact could appear and the current architectural values. The modelling of incomplete architectures is carried out on the basis of a critical overlap of the project with the survey of the current state. The digital

Fig. 1 – The different themes of 3D modelling for the architectural heritage.

reconstruction of unfinished architectures, therefore, raises important matters of interpretation: on the basis of a critical analysis, interpretative choices must be made, aimed at overcoming any inconsistencies and hypothesizing what in the project is incomplete or unclear. However, even when the modelling concerns existing buildings, digital visualization is not exempt from interpretative choices: for example, the interpretation of survey data, the reconstruction of non-geometric aspects such as the constructive technology, and so on. So, the declaration of the sources and the "interpretative" level of the information obtained with respect to the available data are two essential themes in the context of the representation of the architectural heritage. The issue of the model "Transparency" becomes essential, understood as the declaration of the information sources and the possibility of philological reconstruction of the choices made for the realization of the model. As it is essential to declare the level of reliability of the model, with respect not only to the geometry but also to the other information contents, such as the construction technology. In this context, Building Information Modelling, in its dual meaning of graphic representation and database, has amplified the potential for documentation, offering itself as an interactive platform where to manage the heterogeneous and multidisciplinary information inherent to the architectural heritage. At the same time, it has made the issues of transparency and reliability even more relevant. The proposed contribution deals with models for the documentation of architectural heritage, focusing in particular on the issues of transparency and reliability of the model.

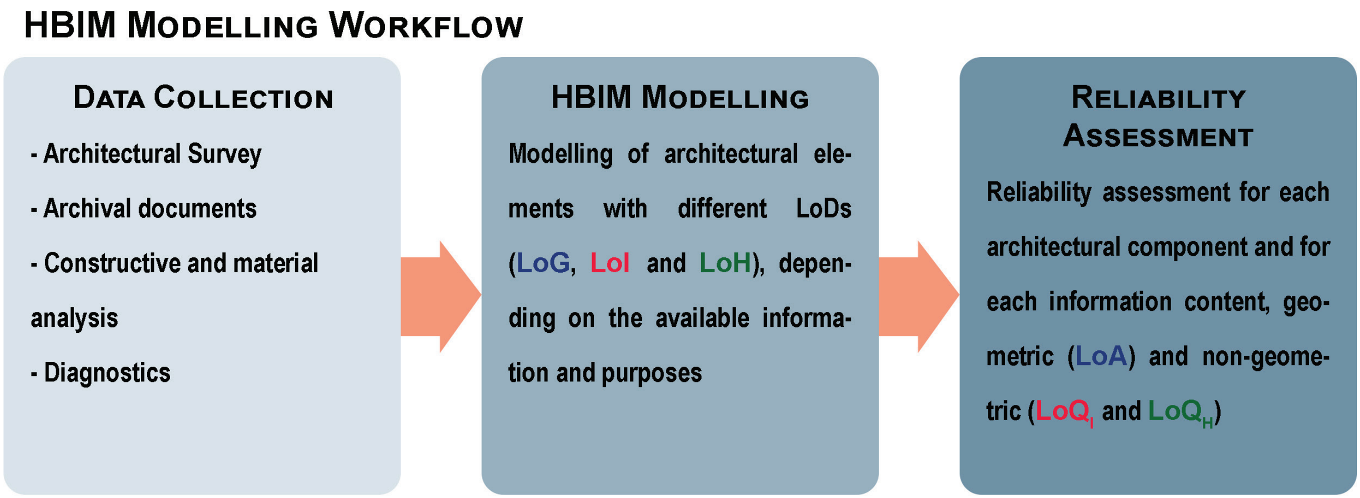

Fig. 2 – The HBIM modelling workflow: The model, created on the basis of the historical-critical analysis of the collected data, must be evaluated to declare its geometric and informational reliability.

3D models for architectural heritage: themes and issues

In accordance with Levi-Strauss's definition of models as "systems of symbols which safeguard the characteristic properties of experience, but which, unlike experience, we have the power to manipulate" (Lévi-Strauss, 2008), the digital interpretative model is configured as a simulation of reality (and not an uncritical mimesis), through which it is possible to investigate and get to know it, enriching our experience much more than it would be possible without the mediation of visualization (Maldonado, 2015).

This simulation does not only concern the geometric-dimensional characteristics of the building, but also includes the material, technical aspects and the historical-architectural values of the building.
The model consists of a simplification of the phenomenon, aimed at enhancing its most significant and representative aspects. In the necessary reduction of architectural complexity made during modelling, there is thus an increase in the level of knowledge of the object of study.
The constituent elements of the model are linked together by the same relationships that link the elements of the real object, building an analogy between the model and the

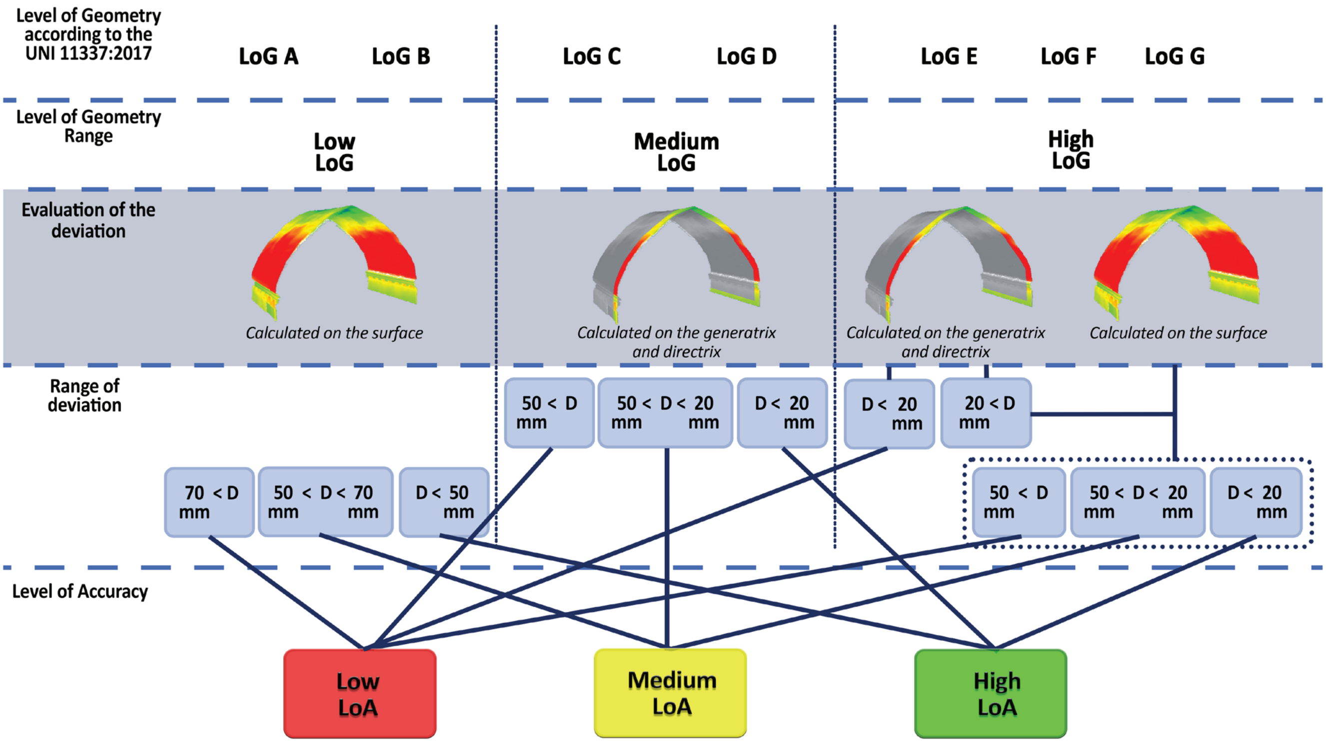

Fig. 3 – Evaluation of geometric reliability in terms of deviation between the point cloud and the model. Depending on the LoG of the element analysed, the deviation is evaluated on the entire surface, on the generatrixes and directrixes, or on both, according to different ranges.

modelled phenomenon (Docci and Chiavoni, 2017). Thus, "interpretive graphic models" facilitate the understanding of the building's distinctive features, providing the foundation for the study, reading and interpretation of architecture.
Due to its inherent characteristics, the study of architectural heritage constitutes an articulated process of building knowledge comprising a vast amount of heterogeneous data and information, the analysis and correlation of which is aided by the creation of digital models. For this reason, three-dimensional modeling can be traced back to Visual Computing, a technique for processing data based on their visual representation, through which to derive information and create new knowledge (Brusaporci, 2015).
During the modelling process, the architectural object is examined in its constituent aspects, which are then translated into three-dimensional digital elements. By modelling the building, the scholar analyses its architectural, spatial, technical, and material characteristics, as well as aspects related to architectural and constructional events and changes that have occurred over time, thus coming to understand its historical and artistic values.
Thus, the 3D model should be understood as a visual tool for studying and analysing architectural features and,

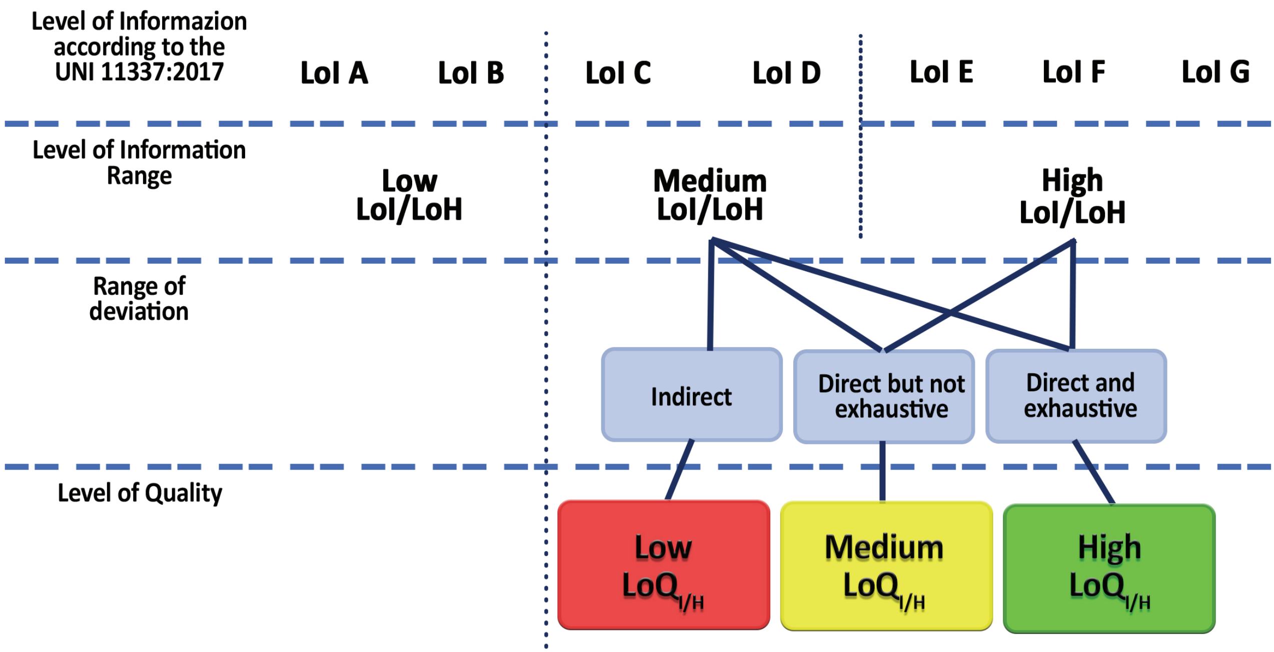

Fig. 4 – Evaluation of information reliability, depending on the LoD and the type of source (direct, indirect, exhaustive or otherwise).

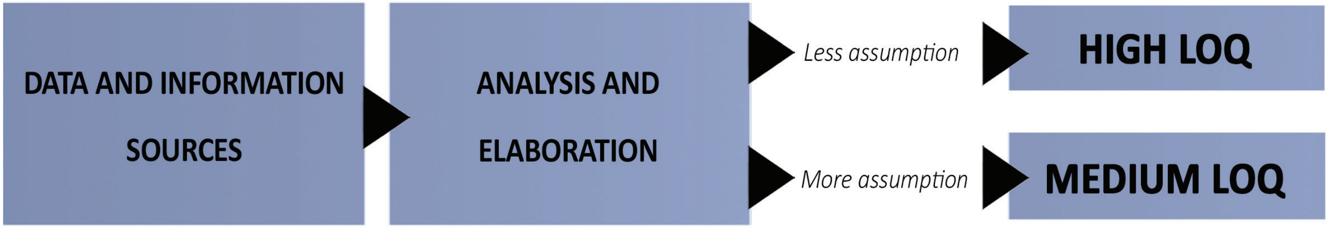

Fig. 5 – With the same information, the higher or lower information level will require more or fewer hypotheses, with a consequent reliability that may be higher (fewer hypotheses) or lower (more hypotheses).

at the same time, verifying the hypotheses and research conducted on the architectural heritage.
Digital modelling, as well as drawing in general, is characterized by its heuristic nature, in that what is represented, two- or three-dimensionally, is the scholar's idea of the building or urban space being examined, which must be continuously verified through comparison with phenomenal reality.
Representation, therefore, takes the form of an iterative process consisting of the succession of hypotheses and validations, that is, of drawing and comparing the visualization with the perception of the reality studied.
The interpretive nature of this process is evident: it is the modeler-scholar who, based on his or her expertise and sensitivity, makes critical choices regarding both geometric and nongeometric aspects. For a scientific foundation of modelling, it is therefore necessary to consider the requirements of transparency and reliability [Centofanti, 2010].
Transparency, which originated in the field of archaeology, refers to the declaration of the sources used in making the model and the possibility of philologically reconstructing the choices made in relation to these. In view of the "opacity" of digital visualization, The London Charter (2009, p. 2) hopes "[...] that research results that include digital visualization should convey to users the state of the art, such as the distinction between evidence and hypotheses and between different levels of probability" [Bentkowska-Kafel et al. 2012].
The Principles of Seville (2012), introducing "Scientific Transparency," state that.: «All computer-based visualization must be essentially transparent, i.e. testable by other researchers or professionals, since the validity, and therefore the scope, of the conclusions produced by such visualization will depend largely on the ability of others to confirm or refute the results obtained».
The need to enable the testability of visualization by other scholars through the transparent presentation of the entire elaborative process (methodology, techniques, reasoning, origin and characteristics of the sources of research, results and conclusions) and the organization of metadata and paradata is, therefore, emphasized. (p.8).
Digital modelling and visualization of architectural heritage, moreover, pose the problem of the reliability of virtual reconstruction, referring not only to the geometric-dimensional aspect, i.e., the relationship between the restitutive model and measurement, but also to all issues inherent in the knowledge of a historic building (concerning, for example, the construction equipment or the historical sources on which reconstructive hypotheses of buildings that no longer exist or have been heavily modified have been advanced). To the issue of deviation, understood as deviation of the model from the real object represented by the point cloud [Quattrini et al., 2016; Apollonio 2017; Brumana et al. 2019], therefore, reflections related to the other information contents of the model as well can be added

[Apollonio and Giovannini, 2015; Bruno and Roncella 2018]. These issues are amplified in Building Information Modelling (BIM). Alongside the important possibilities offered by BIM in the field of architectural heritage documentation, there is an even more urgent demand for transparency of modelling and declaration of its reliability. As is well-known, in the BIM environment the geometric representation and the information enrichment are defined inside the level of development of the digital objects, whose increase corresponds to a linear increase in the quantity and quality of the information contained within the BIM objects. In international and national regulatory references (such as the English system PAS 1192-2, the American BIMForum and the Italian UNI 11337), the Levels of Development consist of both the graphic attributes (according to UNI 11337, geometric attributes - LoG) and the non-graphical ones (according to UNI 11337, information attributes - LoI). These levels, both concerning aspects that can be quantified and computable (e.g. dimensions, materials, costs, etc.), are not sufficient to exhaust the information needed to describe an architectural asset. Therefore, it becomes necessary to consider an additional level related to all those heritage-specific information, not covered in current BIM environments, which we can call Level of History (LoH) [Brusaporci et al., 2021], The new international standard UNI EN ISO 19650:2019

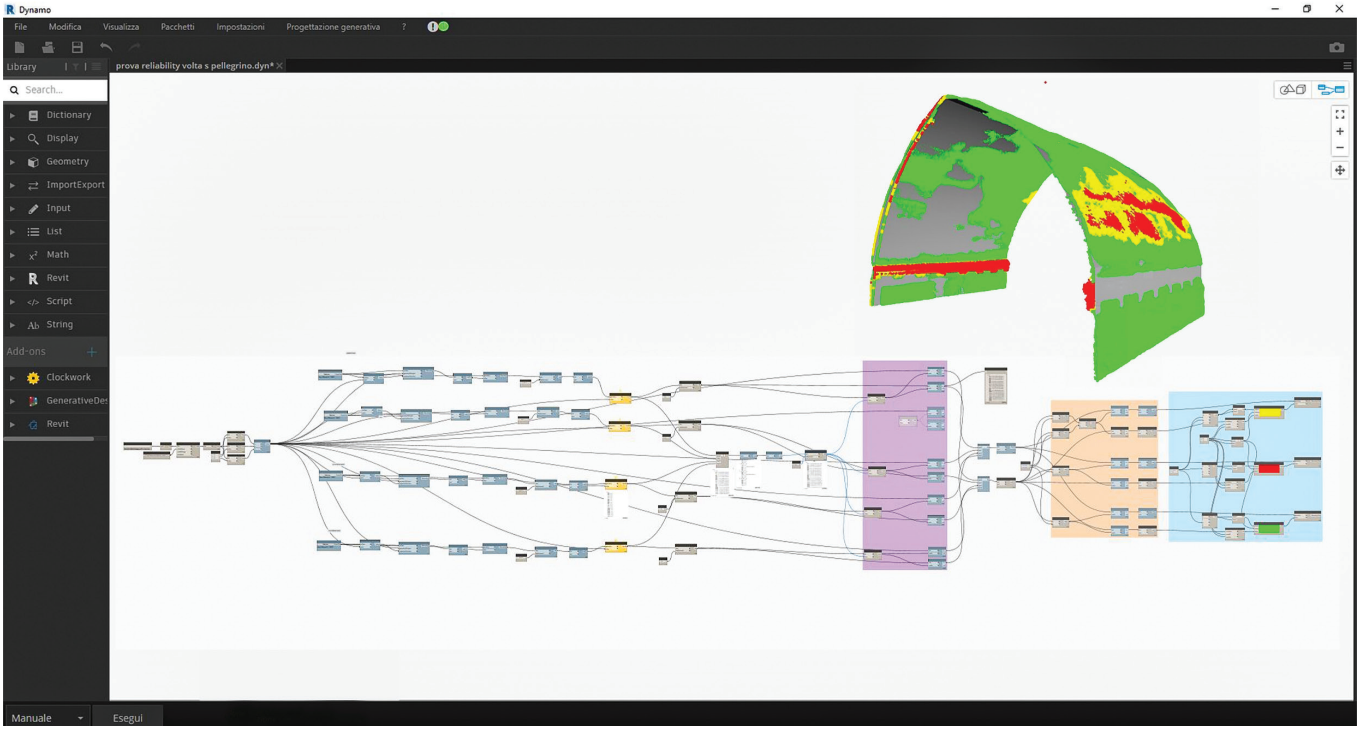

Fig. 6 –The Visual Programming Language (VPL) for calculating deviation and evaluating reliability.

proposed to replace the LODs with the Level of Information Need (LoIN), which, referring only to information necessary for the purposes of the model (thus, in the case of HBIM, also to information of a historical nature), can help overcome some of the limits deriving from the extension of the BIM procedure to historic buildings. However, to date, awaiting the transposition of the LoINs by national regulations (in Italy by UNI 11337-4), the LoDs are still in force, so the standard presented in the paper is referred to these.

Transparency and reliability: a standardization proposal for HBIM

Since the issues of "Transparency" and "Reliability" become even more important in the case of HBIM, where the geometric representation is enriched by heterogeneous information attributes, it is therefore necessary to define specific standards that can ensure the effectiveness of the HBIM process for the documentation and restoration project of historic buildings.
Regarding the transparent presentation of the entire modelling process, it is possible to exploit the potential of BIM for reconstructing the choices made, in relation to the sources used in the modelling. In fact, thanks to the BIM information base, it is possible to insert into the digital environment the

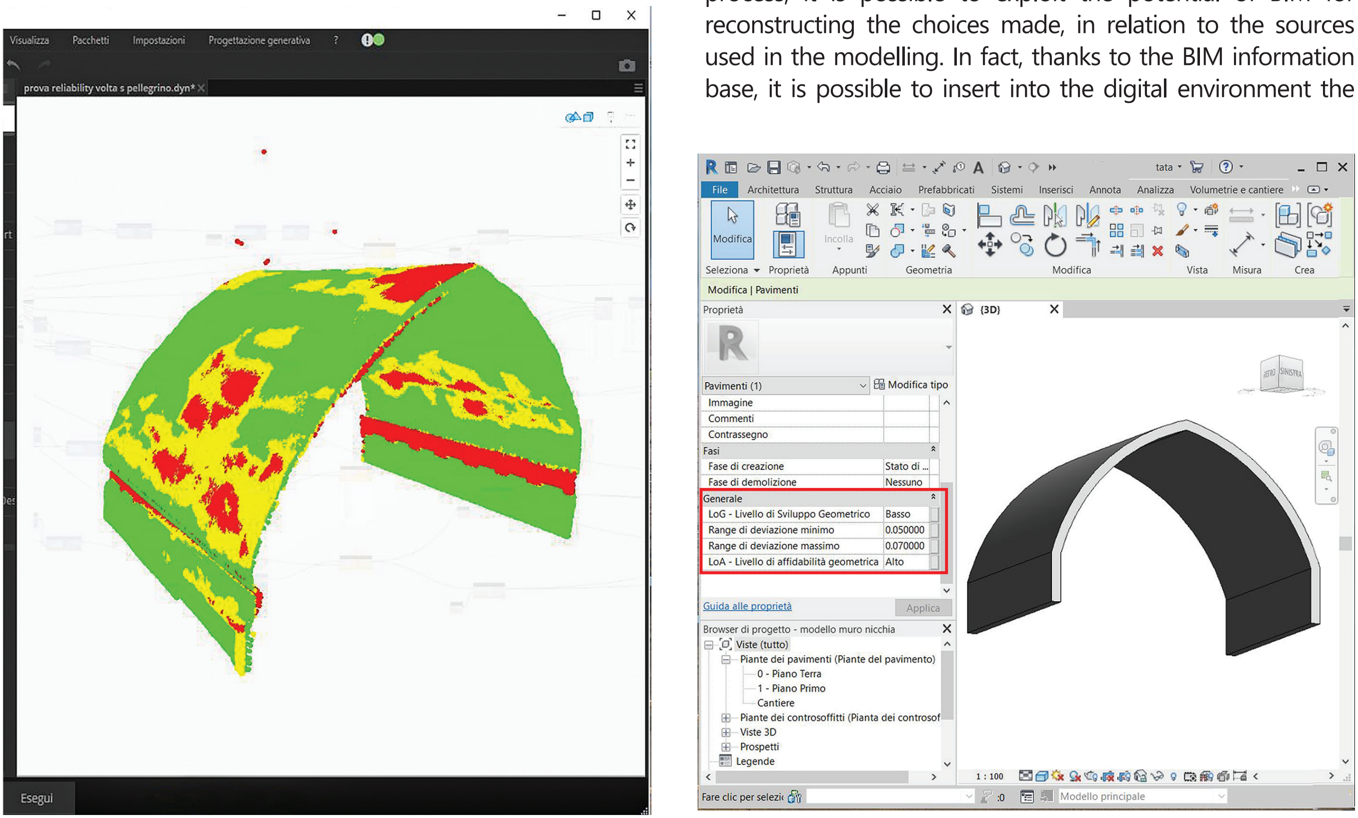

Fig. 7 – The Level of Accuracy, assessed through the VPL, is automatically displayed in the BIM environment.

documents based on which the BIM model was builted in all its aspects (architectural, structural, historical, etc.).

Considering that the reliability should cover all the heterogeneous information relating to the historic building and that a third level of development (the LoH) has been introduced, three levels of reliability have been considered:

1. Geometric reliability, called Level of Accuracy (LoA), evaluated through the measurement of deviation between the restitution model and the point cloud.
2. Informative reliability, called Level of Quality with subscript I (LoQI), relating to the non-geometric contents of the model. In turn, it is divided into several sub-levels, as many as the different types of information entered in the model: reliability of the construction equipment; reliability of the plant system etc.
3. Historic reliability, called Level of Quality with subscript H (LoQH), referring to the specific information content of the architectural heritage, that is, to all historical information concerning the process of formation and modification of the building.

In the proposed standard the reliability assessment, while remaining the same in methodological approach, differs according to the LoD of the specific architectural element.

The geometric reliability of the architectural element (LoA), in fact, is evaluated through the measure of the deviation (the range of deviation must be respected in the majority of the surface): on the entire surface of the architectural model element, for the low LoG; on the generatrix and directrix of the surface, for the medium LoG; on both of them for the high LoG. For each LoG, depending on the interval in which the value falls -average value over most of the surface- the Level of Accuracy can be low, medium or high, and, taking into consideration the greater geometric detail, the range of acceptable deviation becomes more restrictive as the LoD increases.

The LoQ concerns all information not related to the geometric shape which, therefore, cannot be evaluated in terms of deviation between the model and the point cloud. Considering this, also the stratigraphy of the architectural elements can be ascribed to the non-geometric contents since its knowledge is mainly linked to the diagnostic campaign and archival-document research. So, its reliability is of an informative type: the LoQ_I for the construction technologies.

The informative reliability depends on both the LoI and the sources used for modelling (direct, indirect, exhaustive or not). In the evaluation of the Level of Quality, only the medium and high LoI or LoH are considered, as in the low level there is no information, and specifically for medium LoI / LoH, the reliability (LoQ) can be low, medium, high, depending on whether the sources are, respectively, indirect, direct but not exhaustive, or direct and exhaustive.

In the case of high LoI / LoH, instead, the reliability can be: medium, if the sources are direct but not exhaustive, and high, if the sources are direct and exhaustive. Lastly, if there are only indirect sources, a high LoI or LoH is considered unreachable because of the excessive need to hypothesize.

From an operational point of view, the assessment of the geometric reliability is carried out through the visual programming language (VPL). The VPL allows for a semi-automatic procedure for evaluating the deviation between the point cloud and the model on the basis of the standards set out above, and declaring the Level of Accuracy, directly in the BIM environment.

The advantage of using VPL is that once the algorithm is set up, it can be reused many times for different components. In fact, by changing the inputs (e.g., model surface, range of deviation values, etc.), the calculation of the distance between the point cloud and the 3D model is automatically updated.

The informative reliability, on the other hand, is assessed through the use of view filters. For each informative reliability, 3 parameters were created and assigned to specific families: source, type of source (direct or indirect, exhaustive or non-exhaustive), reliability. Filters connected to the “reliability” parameter were then created for each type of reliability, which apply a graphical substitution showing the value of the reliability (low, medium or high).

Once created, these filters can be activated or deactivated in the views, depending on the type of reliability to display.

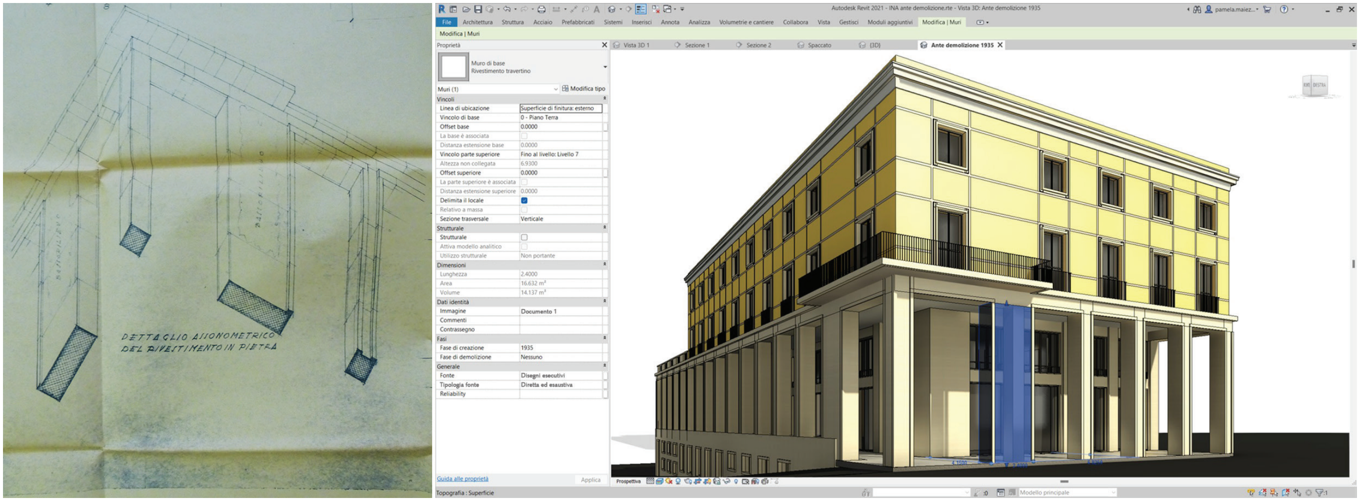

Fig. 8 – The informative foundation of BIM is exploited to declare the sources used for HBIM modelling.

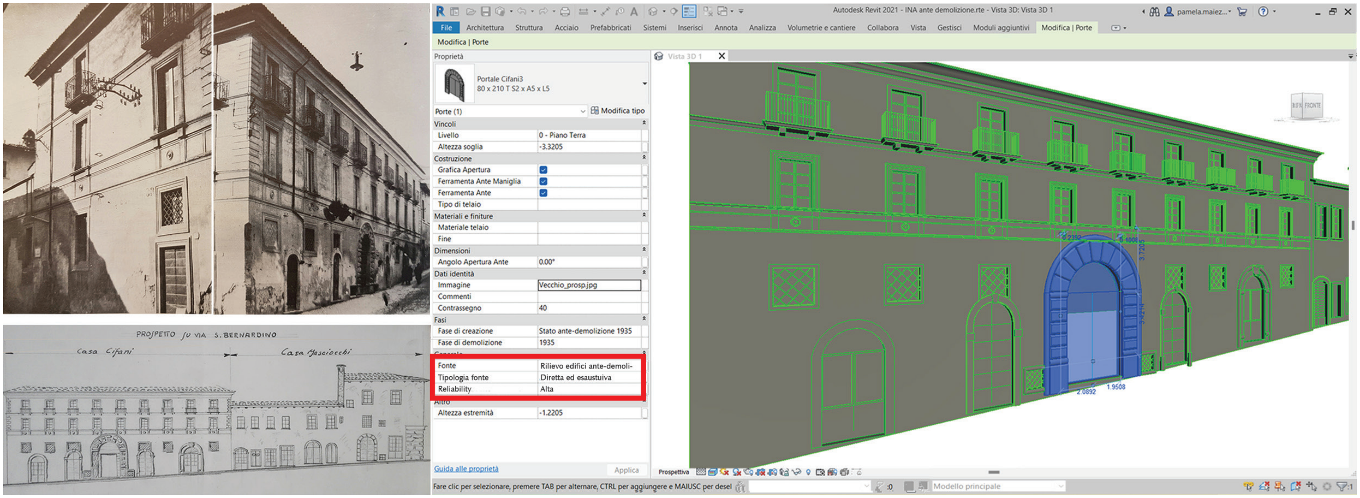

Fig. 9 – The assessment of the informative reliability (LoQH) relating to the specific non-geometric attributes of the architectural heritage (LoH).

Conclusion

The contribution is meant to be just a proposal that aims to exploit the BIM information foundation to insert the transparency and reliability requirements, fundamental for the documentation of the architectural heritage through 3D models. This procedure, developed today on the basis of the LoG and LoI defined by the the UNI 11337, can be adaptable also for the foreign regulations and for LoINs when their introduction will be effective.
In order to guarantee the model transparency, information and documents are linked to each digital object.
In addition, for each digital element the relative reliability level is declared, concerning the geometric (LoA), informative (LoQ_I) and historical (LoQ_H) aspects. Moreover, by inserting the level of reliability within the BIM environment as an attribute of the individual architectural components, transparency and interoperability between the various stakeholders is promoted.
The obtained result is a standard that can make the HBIM an effective procedure to be used for the documentation of the architectural heritage.

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13 DATABASES AND DRAWINGS TO SUPPORT THE DEVELOPMENT OF THE DOCUMENTATION PROJECT. THE CASE STYDY OF "LE TORRICELLE" IN VERONA

Abstract

The research concerns a process of documentation and analysis for the development of guidelines useful for the conservation, maintenance, and enhancement of a portion of the Magistral Walls of Verona. Within an agreement between the Municipality of Verona and the University of Pavia, numerous documentation campaigns were developed to define an overall knowledge of the diagnostic conditions of a 300 m portion from the 11 km boundary of the mediaeval Scaliger's wall. The goal is to define, through a dialogue with the Superintendency of Archaeology, Fine Arts and Landscape of Verona, Rovigo and Vicenza, standard identifications of documentation and conservation approaches. It involved the integration of multiple phases of digital documentation for morphometric drawing and 3D modelling, to support mineralogical, petrographic, archaeological, geo-seismic, endoscopic, structural and design evaluations for restoration and conservation. Data on construction and technological characteristics were cross-referenced with data on documented conditions of degradation. In this way, it was possible to generate synthesis frameworks useful for guiding conservation interventions on the typological and formal classifications of the fortified system. The issue of interest, however, is not only the quantitative richness of the data but the fact that this can be queried in the same database. All this is related to the idea of sustainability of the knowledge process and optimization of resources and costs. The work aims to define, together with the stakeholders of the city of Verona, an exportable protocol calculated to be sustainable over the entire extent of the walls of Verona, a UNESCO World Heritage site.

Introduction

The city of Verona has been a central and strategic crossroads from a historical and military point of view; located in the Po Valley it is a link between the east-west axis of the plain and the main historical artery leading to the Alps. On 30 November 2000, the XXIV Plenary Assembly of the World Heritage Committee (W.H.C.) inscribed Verona on the World Heritage List (W.H.L.) with the name "City of Verona" with two criteria, the II and IV. In particular, criterion IV "Verona represents exceptionally the concept of the fortified town at several seminal stages of European history", is what made it possible to activate an agreement between the Municipality of Verona and the University of Pavia (2020, ongoing), in collaboration with the Soprintendenza Archeologica, Belle Arti e Paesaggio, to conduct non-invasive documentations and a diagnostic

Fig. 1 – Plan of the city of Verona with the fortifications. The collaboration project between the UNESCO office of the Municipality of Verona and Pavia University is called "Verona città Murata".

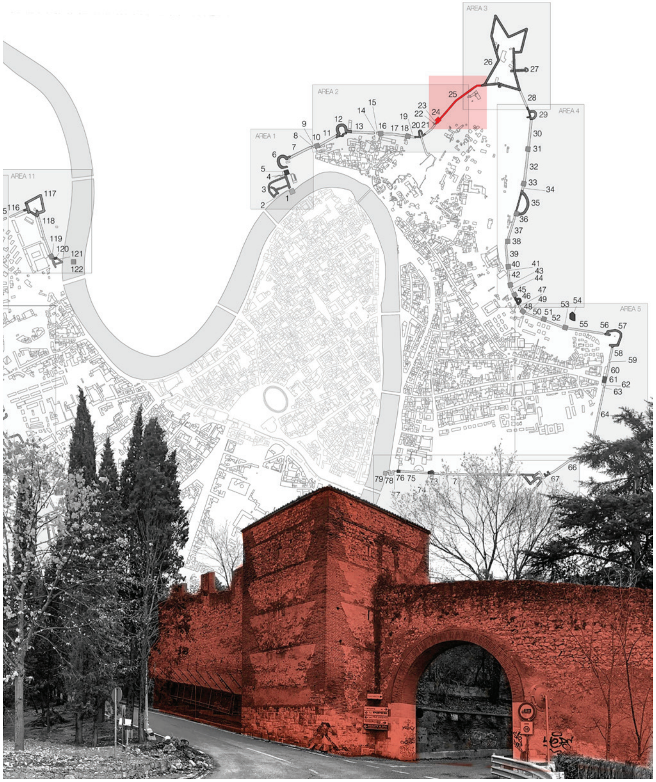


Fig. 2 – Area of interest of the "Torricelle" project, i.e., the area between Castel S. Pietro and Castel S. Felice. In the lower portion of the image: the breach today is used as a vehicular roadway.

study on a 300 m portion of the Scaliger's walls, in the area between Castel S. Pietro and Castel S. Felice[1]. The part under consideration is the section that runs along the side of the Torricelle along Via San Felice to Fort San Felice, located at the top of the hill. The research involved professors, researchers, and scholars, in collaboration with the University of Florence and the University of Siena, for an integrated multidisciplinary analysis protocol that could define the state of conservation and stability of the walls, useful for the restoration project and planned conservation strategy.

Historical Context

The city of Verona and its fortifications underwent numerous transformation processes linked to the succession of different dominions and powers. In particular, the phases that most concern the stretch of wall in which the project was carried out belong to the Della Scala and Austrian phases. During the Scaliger phase, the Della Scala family initiated a season of economic and artistic growth for the city and, as far as the system of fortifications is concerned, the first work began in 1287 until 1325 when Cangrande Della Scala completed the construction of the wall circuit now known as the 'Scaliger walls'. Nine kilometres in length made Verona one of the largest fortified systems in Europe. The perimeter of the Scaliger defences has been preserved over the centuries with the influence of the Venetian reinforcements of the 19th century. The Scaliger era was followed by the Visconti period[2] until 1405 when Verona was annexed to the Serenissima Stato da Terra[3].

In 1814 Verona came under Austrian control and underwent interventions that transformed it into a fortress. The interventions from the Austrian era are recognisable in that a particular construction technique of *opus* polygonal was used, using the local Avesa stone. Walls parts that could be useful even despite changing needs were retained and adapted, including portions of medieval and 16th-century curtains. In 1866, with the conquest of Veneto by the Savoia following the Third War of Independence, the history of Italian Verona began (Zorzi, 2019). Nowadays, the walls are in a state of material decay due to both a lack of maintenance and vandalism. Spontaneous vegetation has undermined the structures and many internal portions are inaccessible. The project area, which is about 300 meters long, is mainly characterized by walls from the Scaliger era, except the summit portion near Castel San Felice. This portion is characterized by clearly recognizable and identifiable Austrian walls, as they were built using the aforementioned opus polygonal construction technique.

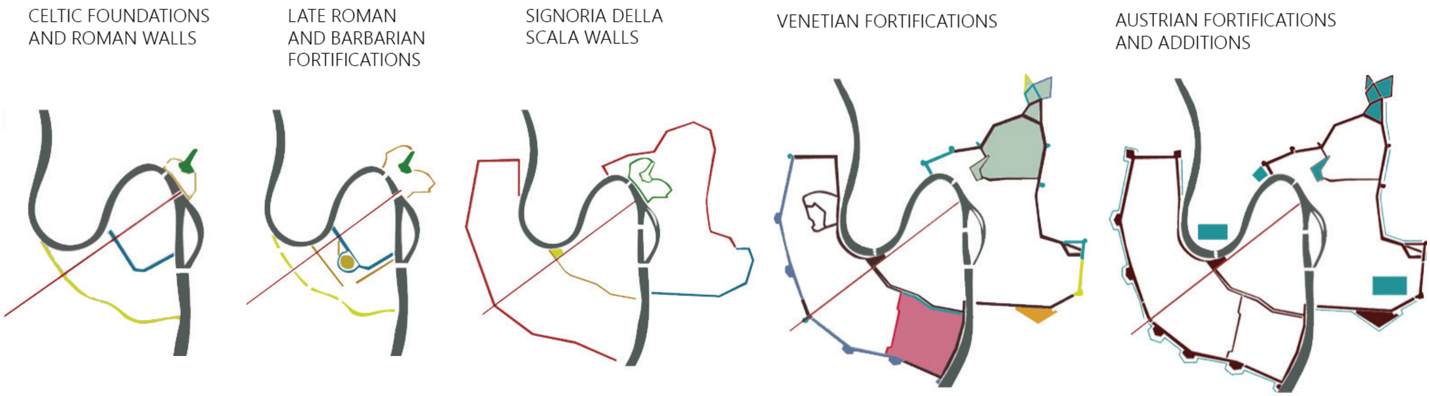


Fig. 3 – Graphical analysis of the historical phase of the Verona city walls. Elaboration By DAda-LAB, University of Pavia.

Database and information systems for Heritage Knowledge

The definition of Cultural Heritage (CH) has been widely discussed and defined in the cultural debate[4], changing along with the development and study of heritage conservation techniques (Vecco, 2010). According to the United Nations Educational Scientific and Cultural Organisation (UNESCO), CH is a particularly broad definition in which both Tangible (Tangible Cultural Heritage - TCH) and Intangible (Intangible Cultural Heritage - ICH) assets are included (Skublewska-Paszkowska, 2022; Besana, 2018). The willingness and act of conducting a defined CH item from the present to the future are referred to as asset preservation (Della Torre, 2021), a discipline that is nowadays largely conducted, in the initial phase of defining actions, with the support of Information and Communication Technologies (ICT), digital platforms, Information Systems and virtual environments.

This contribution deals with the use of these technologies in the context of CH and, in particular, with three-dimensional modelling and the management of thematic layers to document and analyse aspects related to the state of conservation and prevention. Digital models of CH assets are to be understood as sensing systems enhanced by the Internet of Things (IoT) and data analysis and represent virtual simulations. Digital replicas are generated using information technologies and models in which updating is an integral part of the planned documentation process. Models in information layering can include layers that

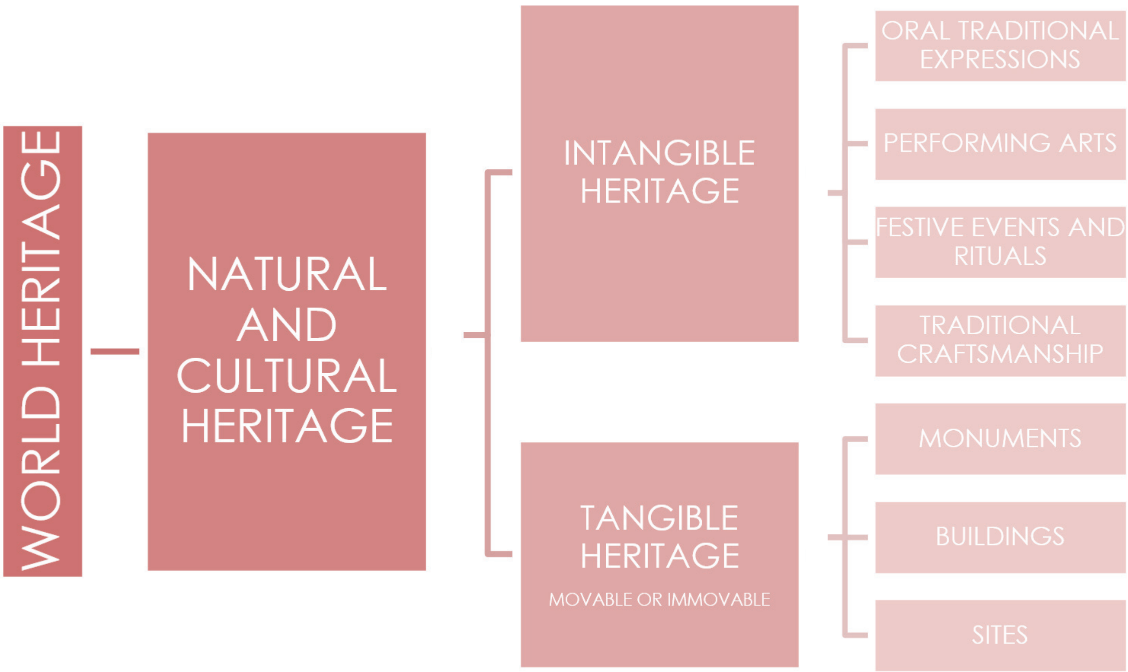


Fig. 4 – Explanatory diagram of some subdivisions of the C.H. The term Cultural Heritage according to UNESCO encompasses two main categories: tangible, and (ii) intangible Cultural Heritage.

provide a cohesive picture of the environment, along with developments in information modelling of buildings and infrastructure (Batty, 2018; Bocconcino, 2022). Actions and strategies for the protection of CHs must be based on an in-depth knowledge of the heritage and the technologies used at the national level, which together with coordinated management, documentation and knowledge of the assets contribute to reducing the risk of the number of lost heritage assets. Among the measures currently indicated for risk prevention are monitoring and planned maintenance of the historical heritage; spatial planning and management; awareness-raising campaigns and training of technical staff; cooperation of institutions and availability of economic resources; and legislative support (Chiabrando, 2018). Risk prevention is one of the steps in the strategic plan for the reduction of risks related to heritage buildings and works of art, and the heritage conservation sector attaches great importance to the use of principles to guide operators towards appropriate interventions for heritage properties[5].

The population of databases and their use of them within Information Systems (IS) are now essential and widespread support for heritage digitisation. A database makes it possible to structure and systematise the information assets of an organisation (or Cultural Heritage) to make the data more easily consultable by external or internal users. An information system is a set of tools and technologies that collect, process, store and distribute data and information to support activities, including decision-making, coordination, and control activities. The

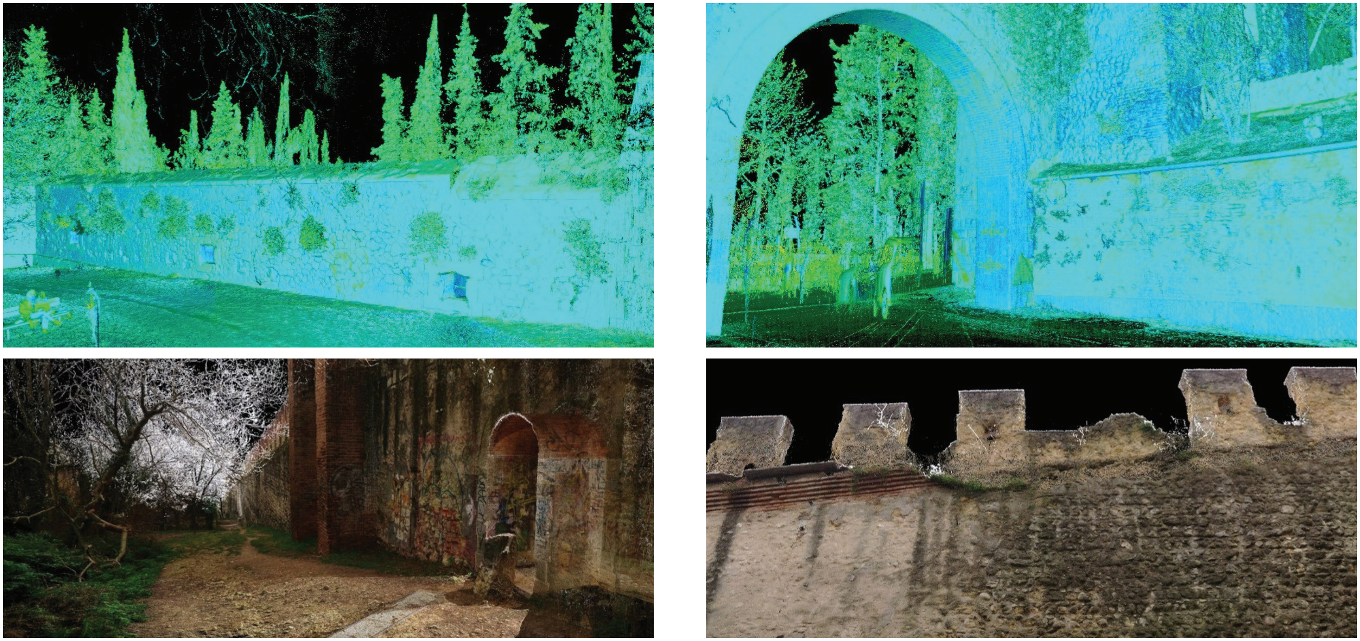
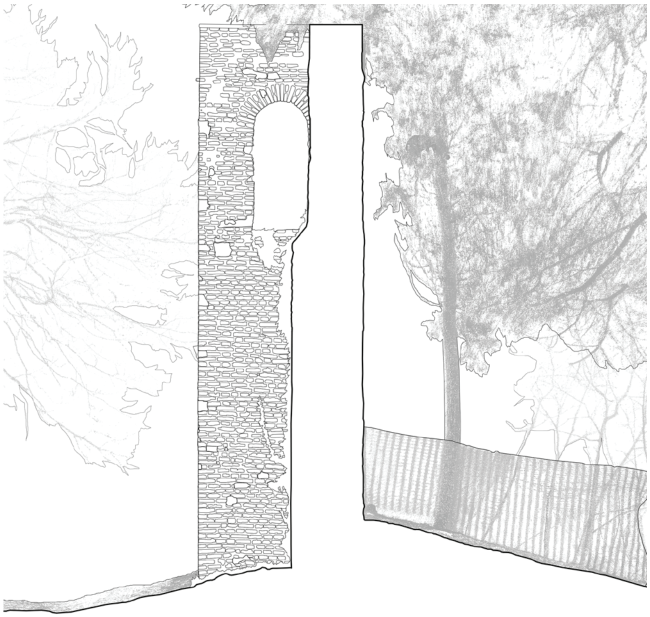


Fig. 5 – Images of the TLS and MLS point cloud of the surveyed walls. The global point cloud was created with the collaboration of researchers from the Universities of Pavia under the scientific coordination of Prof. S. Parrinello.

database associated with the information system can be used to store and access structured data and to resolve user queries; the system also supports all phases of the intervention process based on the associated data. The Georeferenced Information System (GIS) approach could be perceived as a limitation for some CH applications since it was created to represent 2D models but recent developments with the integration of GIS and 3D systems (Apollonio, 2018; Doria, 2022; Porcheddu, 2022) have led to numerous experiments in the built heritage field (Coluccia, 2018). In the case study under consideration, a georeferenced information system is optimal with a view to the development of the process for the entire fortified complex on an urban scale, interacting also optimally with the 2D vector products created for the morphological and material documentation phase.



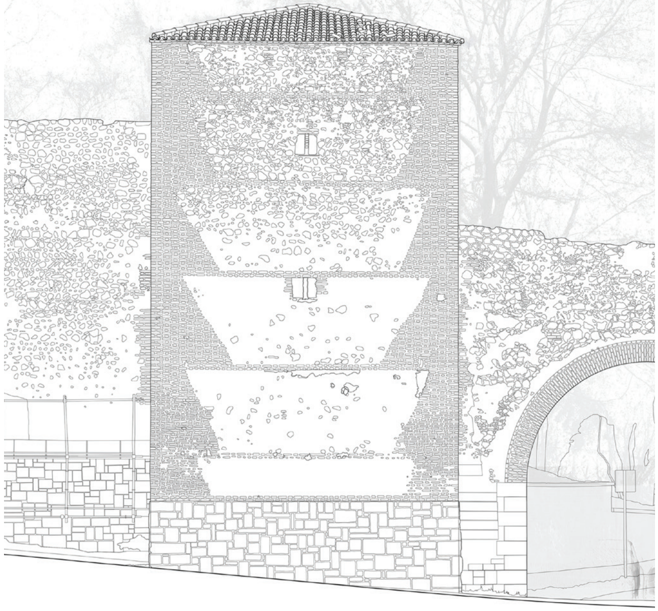


Fig. 6 – Two-dimensional vector drawings made from TLS point clouds. The drawings produced were used by the entire research team as support for the analysis and diagnostic phase.

Previous Interventions

The portion of the "Torricelle" wall, the object of the described analysis, constitutes a significant and representative portion of the Scaliger walls, with the heterogeneous presence of architectural elements characteristic of medieval walls, including towers, battlements, a partial but original upper walkway and the presence of various historical construction techniques visible. The site has, however, undergone significant transformations of the neighbouring urban infrastructure, such as the dual carriageway road that was built following a major overburdening of the wall structure between 1938 and the 1950s. Today, the site is in a critical state of preservation, especially with regard to the top portion of the walls consisting of battlements with an advanced state of erosion and numerous missing portions (74 battlements originally present, 16 missing – loss of 12%) and without a cultural appreciation of its historical and artistic importance. The documentation project resulting from the agreement between the parties aimed to develop an interdisciplinary state of preservation monitoring, analysing the elevated portions, foundations, wall compositions, stratigraphy, and geological and archaeological and structural considerations for a diagnostic overview. The morphological documentation was conducted starting in December 2020 from the integrated Terrestrial Laser Scanner (TLS) survey with high metric reliability of 3 mm error, Mobile Laser Scanner (MLS) point clouds from aerial photogrammetry (UAV) and terrestrial Structure-from-motion (SfM) that allowed the creation of highly reliable two-dimensional vector drawings that write the wall textures of each portion.

Fig. 7 – Example of high-reliability close-range and ground-based photogrammetric techniques. This type of processing was carried out for the entire length of the wall section (600m).

Dataset collection and database population: Pathologies and wall textures

The material and technological analysis phase had the goal of structuring a database to support the restoration and valorisation of the "Torricelle" wall. The highly reliable vector drawing of the walls was produced to represent a snapshot of the state of conservation of the portion under consideration and as a documentation tool. These drawings became the basis of different outputs for the conservation project, among them the one supporting the stratigraphic and typological reading of the masonry. The two-dimensional technical drawing is the tool on which to activate typological analyses of the masonry found, in collaboration with archaeologists, and their composition to create a map of masonry construction technology, in collaboration with petrographers. The understanding of the masonry apparatus was conducted with the support of the results of masonry endoscopies. The endoscopies made it possible to define circumscribed areas where building materials recur and to identify portions of evidence to be analysed and on which to intervene within the restoration and conservation project.

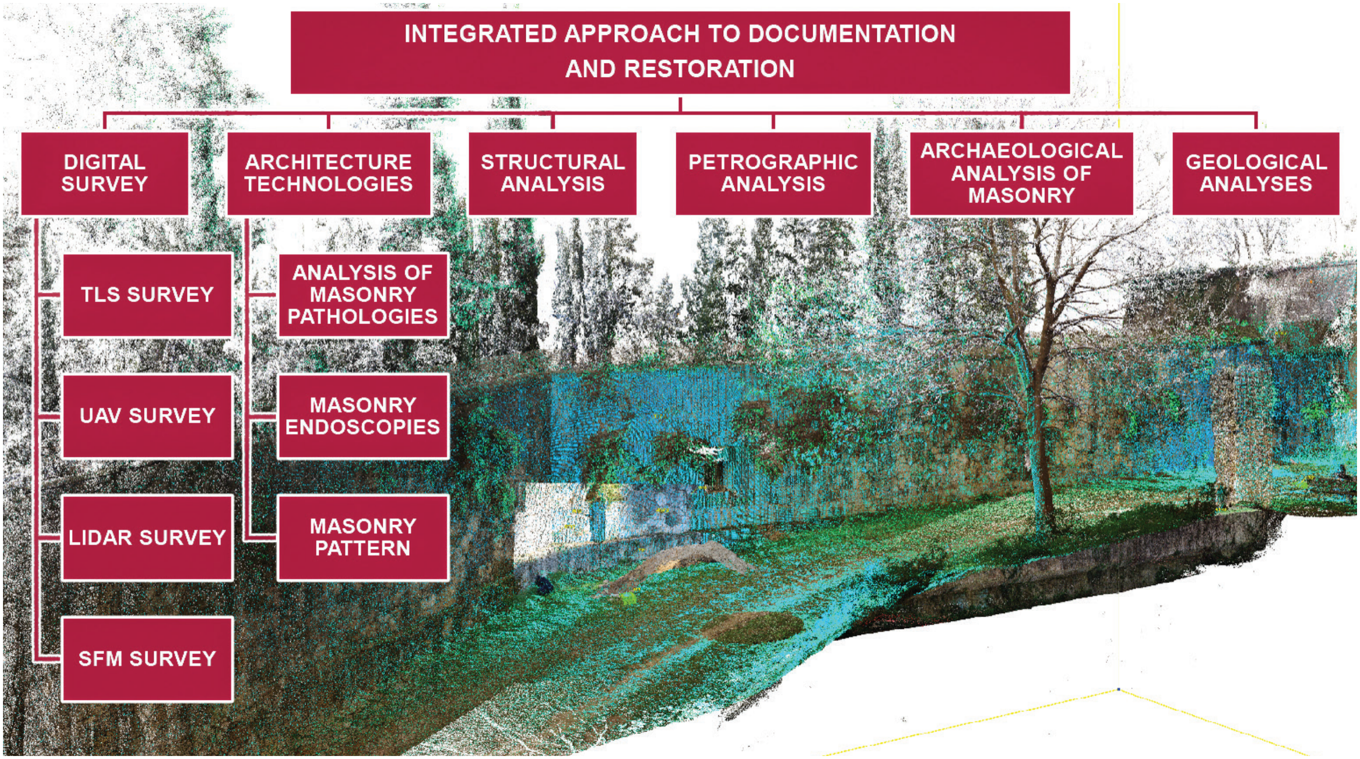


Fig. 8 – Methodology used for the project to define the conservation and restoration of the wall portion carried out in collaboration with the University of Florence and the University of Siena.

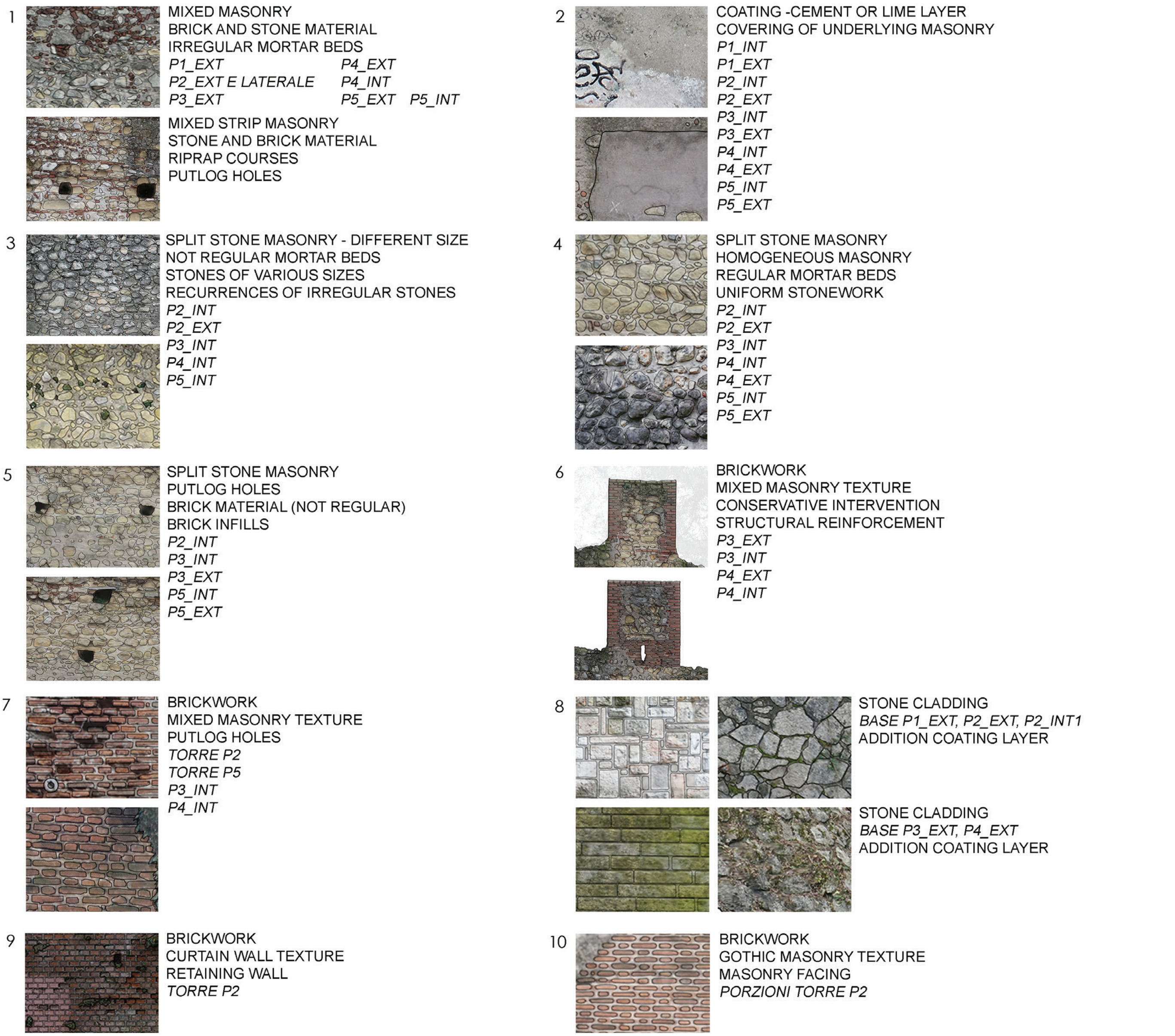


Fig. 9 – List of constructions types based on materials (stone, brick, mortar, and cladding) found on the defined masonry, taking archaeological stratification as a comparison.

The mapping allows for computation and thus calculation of the economic impact of the intervention and possible materials to be used. Eleven types of masonry were found, including: mixed brick and stone masonry; four different stone masonry apparatuses; three types of brick masonry differing in texture; one type of brick masonry used in a previous intervention as structural reinforcement; and two types of stone and plaster wall coverings. The documentation of the alterations was carried out using two different survey techniques starting from a field census: the two-dimensional vector representation on verified photomap and the compilation of census cards structured directly on a compliable and interrogable platform. The compilation of the census cards took place with the use of a relational database in which the data was collected directly in the field using a dispatched survey. The database was

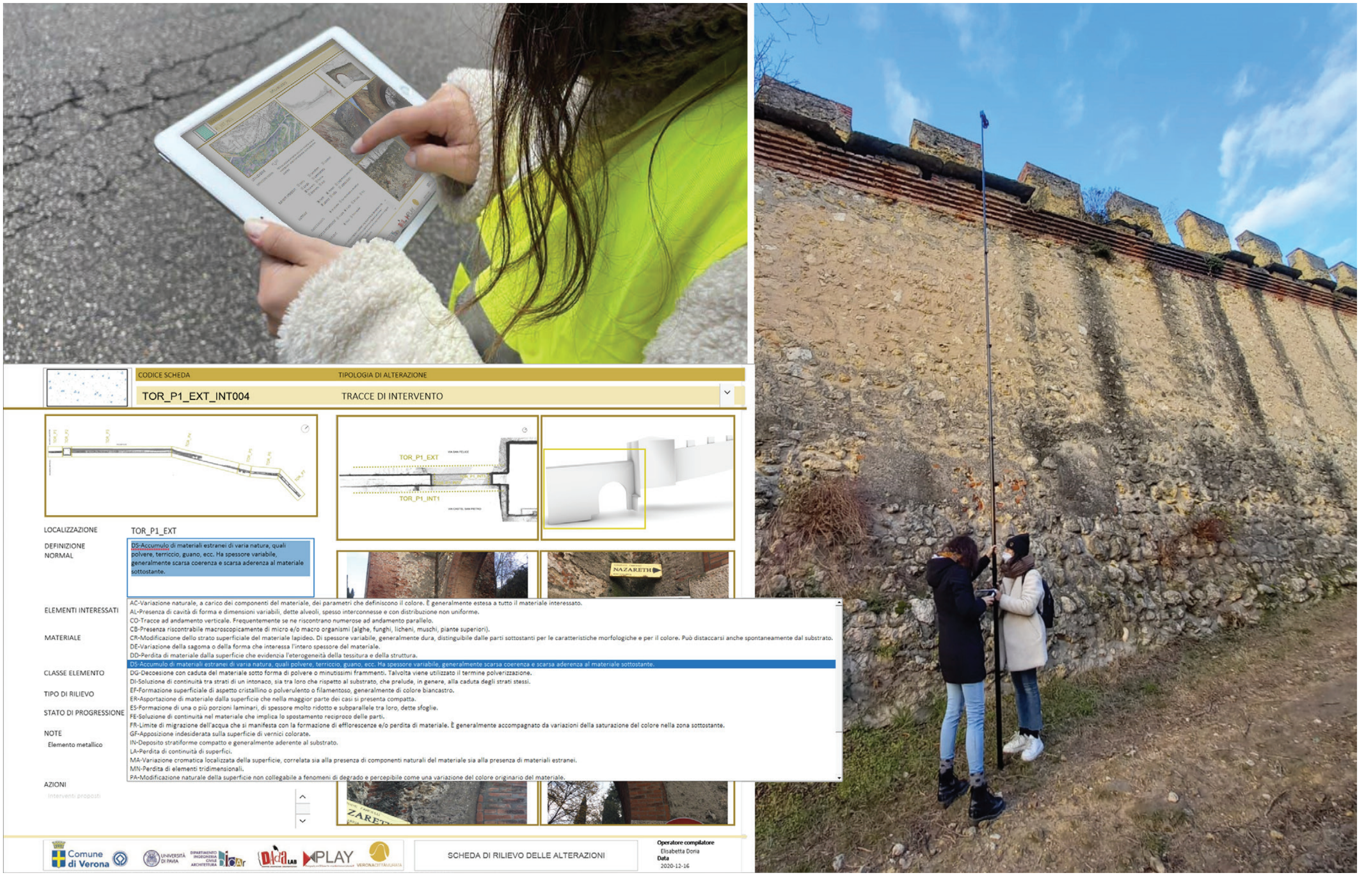


Fig. 10 – The census of pathologies was conducted on the field. This allows an optimisation of survey and data entry times based on direct observation during the survey phase.

populated according to a series of fields and values chosen based on the case study and the Italian and European reference standards. In particular, the UNI 11182/2006 standard (ex Nor.Ma.L. 1/88) and the Illustrated glossary on stone deterioration patterns ICOMOS 2008 were used. Thanks to the choice of using a multi-platform database as the data input method, values can be collected, queried, and organised according to chosen parameters[6]. In addition, it is possible to define levels of database depth according to the user, so that the compilation of the census is within the reach of different categories of users who may have access to the compilation (technicians) or consultation (institutions or private individuals). The census is compiled via interactive records/tables from the FileMaker and FileMaker Go platforms[7], which can be used from computers or mobile devices. This optimises survey time by combining the pathology observation phase with the photographic documentation phase, and the activity is possible both in situ and remotely. The structure of the cards consists of several sections and value fields. Fundamental is the management of the card's unique code, which indicates the location of the alteration or degradation and the type, followed by a progressive number; this code corresponds to the degradation maps present in the graphic drawings (Parrinello, 2019). The insertion of images and photographs describing the presence of degradation can take place directly in the field using a tablet or subsequently on a computer in post-production for points that are not accessible from the ground and for which photographic recordings using Remotely Piloted Aircraft Systems (SAPR) or other instruments (e.g. 3DEYE photogrammetric system) are required. The use of a census system with the use of a relational database and thus, with all the advantages of this technology over a static template, is part of a strand of research developed by the DAda-LAB, PLAY and STEP laboratories of the University of Pavia for the optimisation of fast surveys of pathologies and criticalities of Cultural Heritage.

Information system and valorization

The articulation of information datasets follows the FAIR principles (Wilkinson, 2016) of Findability, Accessibility, Interoperability and Reusability. In the process, there must be a proper connection between the record and the graphical medium, that is, between the information-gathering interface and the query and representation medium. Making queries of the digital archive is a strength for the preservation project as different combinations of values can be tested through keyword queries. This allows for multi-variable data extraction, which results in the linking of otherwise disconnected information elements that are difficult for a technician to observe as a global object, achieving greater cognitive value than from individual units of information.

Many Georeferenced Information Systems platforms nowadays allow the management of three-dimensional models, which can be managed and exchanged between platforms. The model can be organized according to different methods, among which the tested: 1. different surfaces and volumes of the model are separated as layers according to the classification criteria of the project (e.g., technology packages, surfaces, volumes, structural elements) to be linked to the census sheets and data obtained during the different stages of analysis. 2. The base model is a single volume to which layers and information buttons are applied and updated without replacing the model. The choice is closely related to the user and ends user of the information system; the first solution provides for a more advanced modelling capability because, in the case of updating the surfaces, it is appropriate to update the digital volumes falling within the scope of the Cultural Heritage Digital Twins[8]. The second case is greatly simplified from the point of view of the operator's modelling capabilities but there is a risk that the model may no longer represent the actual state in the case of changes in CH morphology.

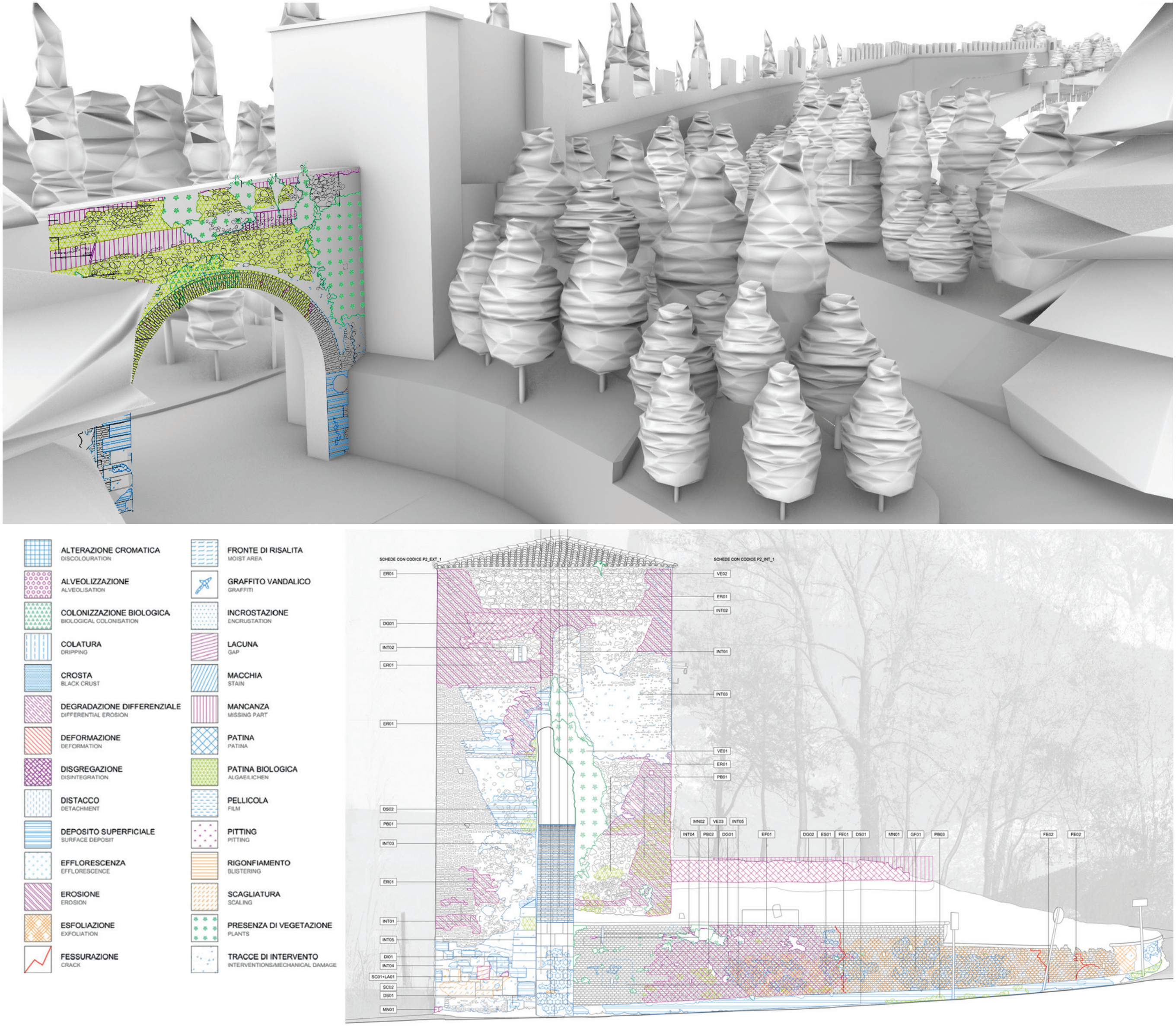


Fig. 11 – The interaction between model and pathology analysis takes place with the direct query of the model by the associated unique code. Georeferencing is possible through the use of the TLS cloud with GPS points as a basis for three-dimensional modelling.

In both cases, which can be evaluated according to the purpose of the information system and the end user, each information layer of the model owes the information that connects it to the surveyed dataset; a connection is then made between layers and the relational database by managing the information acquired through information hotspots, which represent the information related to the analyses conducted in the documentation phase.

Future developments

All the analysis conducted allows the team to develop an approach to the restoration base on the multidisciplinary investigation. The richness of data in an information system was designed to support a wide range of different application domains, where each operator could use a small fraction of the available functionality yet have the totality of the information collected at his or her disposal. Collecting the dataset and populating the documentation database are prerequisites for the remaining work of defining possible intervention techniques. The process draws up an integrated framework of heritage knowledge, characterized by the layering of information. The project follows the perspective of the sustainability of interventions, resources, and costs through integrated planning. The team has given the Municipality of Verona an approach to the conservation process based on the criticalities found and schemes with indicated the kind of intervention that could be done on a planned conservation project to be agreed upon with the asset management bodies. The project conducted so far represents the initial phase and aims, over the next year, to define together with the stakeholders of the city of Verona the exportable protocol calculated to be sustainable over the entire fortified system of the city.

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14 TRACEABILITY OF ATTRIBUTES IN BIM MODELS FOR THE HERITAGE DOCUMENTATION

Abstract

The BIM methodology, together with its associated tools, is still perceived, especially in our country, as an exception to established practice, an eternal novelty with clearly something unfinished. In Europe and worldwide, the branch of BIM, aimed at buildings without cultural connotations, has long remained in the shadows due to a lack of market interest. Only recently has this trend been reversed, particularly in Italy, thanks to tax breaks.

However rigorous the process of constructing a BIM may be, it loses its value if the information on the operational steps and reliability of the collected data is not implemented in the virtualisation itself. The functional aspects of the methodology also include quality assessment, on which the possibility of reusing the model depends.

In any BIM process applied to existing buildings, content validation is crucial: the geometric and semantic data must be sufficiently reliable to meet customer-specific requirements and these aspects must be adequately documented. Valid solutions emerge from the literature, but they struggle to establish themselves because they are not well integrated into the tools outlined in the technical standards.

This contribution proposes a possible approach, identifying in the vast panoply of technical sector standards all those tools that can be used to quantify the reliability of information content, possibly updating them and making them compatible with current BIM regulations.

The needs of an evolving digital environment

Digitisation has changed representation techniques and tools over the past ten years, resulting in a massive increase in the quantity, quality, and variety of data and products. The employment of Building Information Modelling (BIM) platforms in new construction has allowed the identification of shared approaches and the consolidation of procedures [1-3].
However, it is still up for debate whether BIM is effective in the field of built heritage. Since the latter is one-of-a-kind, it is hard to imagine how a methodology developed for standardising representation processes could be used in a context where saving time means saving money [4]. As a result, BIM is criticised and questioned regarding its usefulness. An in-depth examination of the purposes and modelling techniques is required because the description of an existing asset can have relevant limitations [5].
It is the responsibility of academic research in the field to investigate the possibilities and viable implementation approaches for the building digitisation [6-8]. The ability to exchange information within a system that is naturally fragmented due to its heterogeneous composition is another restriction of this methodology applied to the built environment. The process of computerisation in the management of the architectural heritage is still poorly integrated in the public authorities in charge of control despite the consistent technological evolution. Most of the data exchange takes place through files in market-standard formats that are used too casually although their unique characteristics, ignoring the possibility of qualitative information loss.

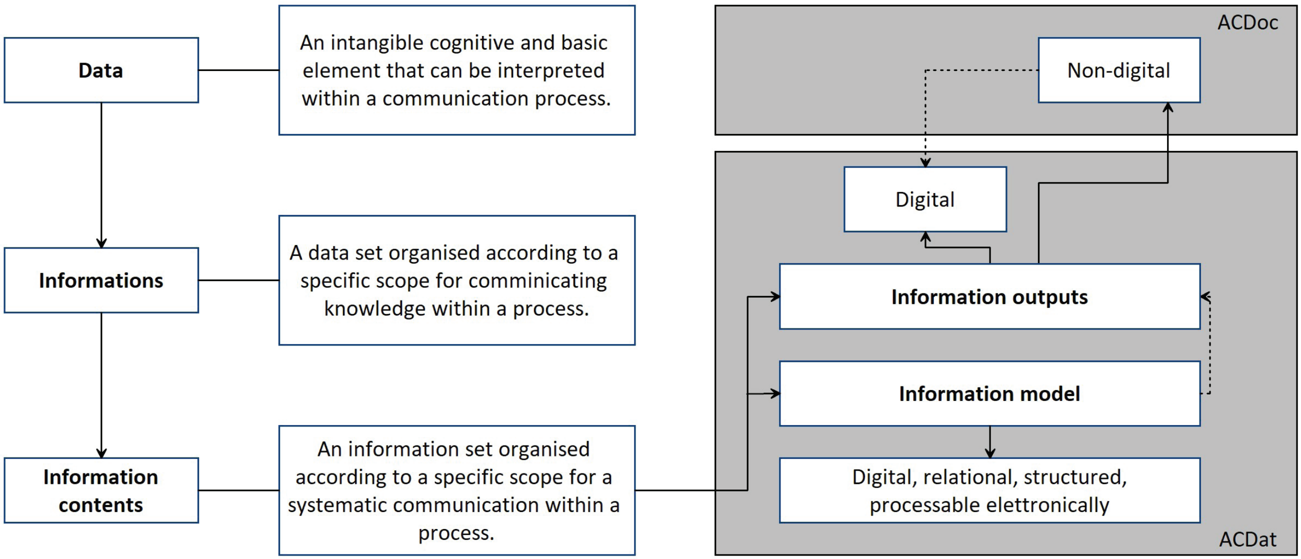

Fig. 1 – Content management in ACDat (based on UNI 11337-1:2017).

The international state-of-the-art demonstrates a renewed interest in the innovation of asset management protocols and the unification of technical regulations on BIM, paving the way for the definition of IT procedures related to restoration or renovation [9]. Even though cataloguing methods for conservation and reuse are consolidated and tested in the case of existing structures, the geometric, documentary and iconographic components are not properly linked together. As a result, there is a lack of the necessary osmosis, which is essential for the effective transmission of knowledge between the actors involved in the protection and management of heritage and the fields of work design and execution.
The development of electronic protocols, which are becoming a regulatory tool because of the spread of international frameworks, is in line with the application of a methodology that can respond to the need for continuous data updating through the structuring of BIM virtualisations [10]. Our research focuses on the topic of information reliability. The possibility of reusing a model depends on this factor but there is a lack of a unified framework to solve the critical issue. Valid solutions emerge from the literature [11-13], but they struggle to establish themselves because they are not well integrated within the tools outlined by the technical standards.
For this reason, our proposal for assessing reliability does not introduce any further novelties but aims to seek out solutions already used in parametric modelling or related fields, reforming them if necessary and lightening the notional load on technicians, who could make use of tools they know and master.

Information content management in the Italian technical standards

Before defining any possible approach to the documentation of the building fabric, it is necessary to have a clear understanding of the technical guidelines regarding the management of learning flows in the construction sector. Data, information, and information content are the three cognitive elements that should be used to transfer knowledge and negotiate between parties involved in any process (design, production, execution, and decommissioning) of the construction industry, according to UNI 11337-1:2017 standards (Fig. 1).
Data must be structured, related, worked with electronically, stored on media, and written in an open format for operations to be fully digitised. It can be expressed in multimedia (images and sounds), graphically (signs), or alphanumerically (symbols). This helps us organise and link the knowledge we have through appropriate vehicles (models and outputs) and understand the minimum requirements for communication between the involved parties, but it does not specify which geometric or non-geometric attributes to use when virtualising or representing physical entities and processes.
An information structure must be implemented before a more effective approach can be defined. The UK standards PAS 1192-2:2013 and PAS 1192-3:2014 identify the Development stage (CAPEX) and the Execution stage (OPEX), reiterating their close ties to one another. As a result, virtualisations have both a regulatory function for production (the Project Information Model or PIM) and an identification purpose (the Asset Information Model or AIM) for the actual situation and the time flow around existing structures.
By UNI 11337-1:2017, this duality has been fully supplied, with an emphasis on the beginning-to-end relationship between the two stages, which can be divided into multiple phases. It is important to note that there is no direct correlation among these aspects and design levels, at least in the Italian public works system. Instead, they are linked to the process goals, from which descend the targets of model and objects (Level of Development - LOD).
Systematising knowledge necessitates identifying an interchange stream. We could envision two complementary flows in a broader vision of BIM, devoid of case-study features or processing software: one of information, which comes from the model and lets it do its job, and one of

definition, which makes it clear and keeps it current (Fig. 2). UNI 11337-5:2017 covers the elements that constitute the latter flow. In accordance with British standards and UNI EN ISO 19650, the following documents are created to handle data requirements within Italian regulations:

- Information Specification (CI);
- Information management bid (oGI);
- Information management plan (pGI).

Exigencies are defined in the client CI prior to the awarding process. The parties interested in the contract prepare an oGI, which outlines their offer to meet the customer needs. The selected operator must draft a pGI detailing the initial proposal. The standards list the subjects that should be covered for the CI to have a minimum of content and divide them into two categories: the technical one (model features, information sheets and outputs, data exchange formats, etc.) and the management one (interchange flow, coordination, verification, and "dimensions" among other things). The regulation does not provide a template for the oGI and pGI. This is also evident because it essentially consists of the CI-formulated requirements. Operators have always been interested in automating the association of models in virtualisation management (Model Checking). The standards define three distinct coordination levels:

- LC1, data interaction within a single model;
- LC2, collaboration among various digital products;
- LC3, connection between non-graphical model-derived information, such as technical or calculation reports, CAD charts, etc.

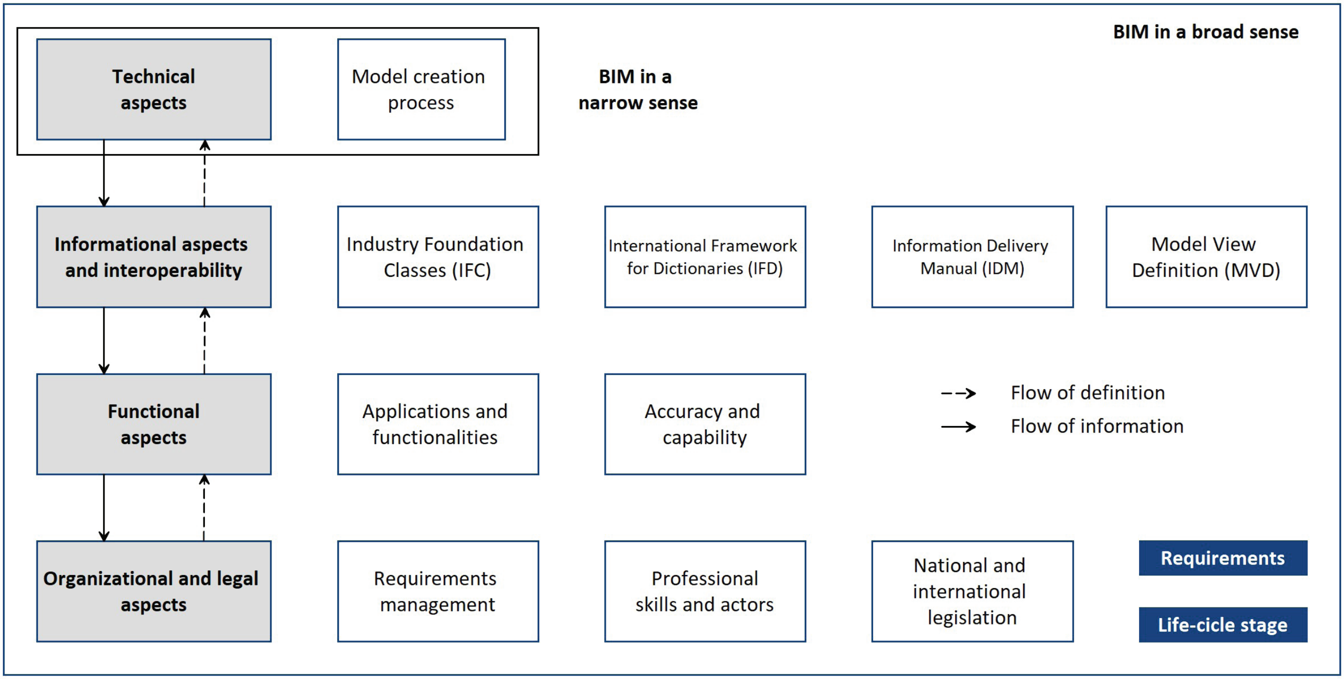

Fig. 2 – Relation between the different aspects of BIM (author's elaboration).

The responsibility for these activities lies with the person in charge of the specific contribution in the case of LC1, while in the remaining two levels the operator shall be identified in the CI. Verification moments exist for each phase and stage of the process, as defined by UNI 11337-1:2017. There are three steps:

- LV1, a formal internal audit that examines the correct production, distribution, and management of content in accordance with the CI and pGI indications;
- LV2, a substantial inner validation intended to verify the readability, traceability, and consistency of the various model information. It is carried out by ensuring that the requirements for the LOD of related objects and the content evolution of virtualisations have been achieved;
- LV3, a client-performed formal and substantial verification of the Common Data Environment.

The standards also introduce the progress and approval statuses for models and outputs to facilitate a conscious use of information by the process actors (UNI 11337-4:2017). The degree of operational advancement and the formal reliability of the content are the two things that they respectively specify. The interchange flow, in its elements concerning the definition, is described in detail, highlighting the evolution of the progress and approval statuses as well as the moments pertaining to verification and coordination, which are outlined in Part 5 of the standards.

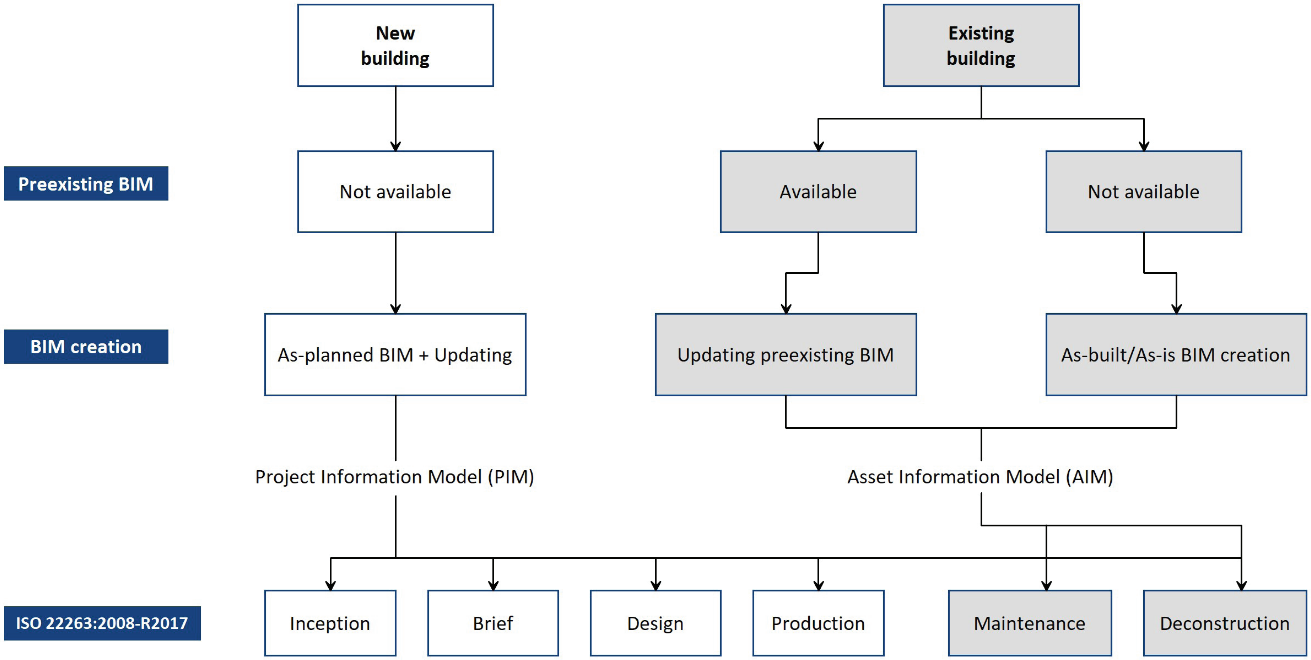

Fig. 3 – BIM process for new and existing buildings (author's elaboration).

A mismatch between technical standards and the real framework of requirements

Despite the fact that the Italian standards represent an indispensable starting point for the correct use of the methodology and are almost perfectly aligned with international regulations (UNI EN ISO 19650), there are still some issues that are not properly addressed. Since the advent of BIM in the architecture, engineering, and construction (AEC) industries, the characterisation of existing assets has become a significant problem. More than 60% of all structures in Italy date from the 1970s, and most of them lack digital documentation. As a result, the required information is almost always obtained using pricey reverse engineering processes (Fig. 3) [14-16].
To develop a framework concerning end-user-directed BIM for built assets, it may be useful to take a closer look at the subject by dividing it into two areas. Existing Building Information Modelling (eBIM) contains the basics needed to maintain and operate a construction, including data on the fabric and services, and an Historic BIM (HBIM) is an additional layer [17, 18]. The latter would also address historical and heritage information, significance values and conservation policies [19].
The development of a BIM model, especially related to the advanced phases of a building lifecycle, is an operation that requires a certain investment, both in terms of time and financial resources. This raises whether it is worth it, and the first thing to explore is why we need it. When it comes to projects involving major improvements and renovations, we might be able to justify the additional costs, which depend, for example, on surveying and the production of a 3D model [20]. However, most buildings will not go through such refurbishments, and you must ask if there is any value in developing an eBIM for them. The *D.M. 560/2017* introduces the compulsory use of digital tools only for public works while a large portion of the existing fabric, devoid of historical and cultural relevance, belongs to private individuals.

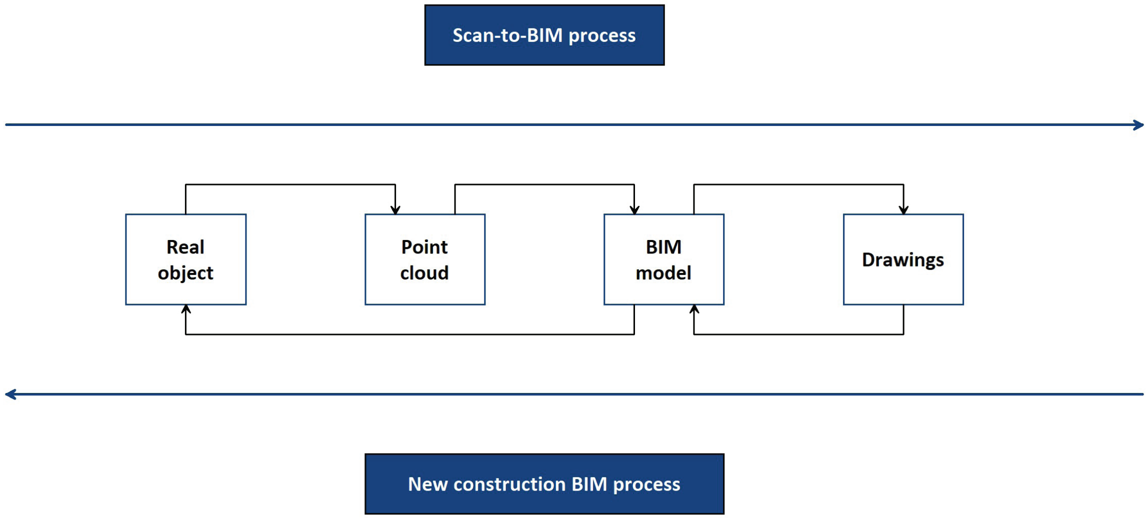

Fig. 4 – Direct (down) and reverse (up) engineering process (author's elaboration).

Most of the buildings do not have CAD drawings or perhaps even paper documents. If a BIM model is to be produced, its quality and characteristics must be calibrated to specific purposes. For example, its application in the execution stage might justify the use of expensive digital survey tools. Otherwise, 2D drawings accompanied by good photographic documentation may suffice. Alternatively, there are fewer resources and time-intensive solutions to produce a non-BIM-oriented 3D model [21].

As repeatedly stated, BIM is not necessarily the panacea to the coordination problems of the building industry information process, but it can become a valuable tool, especially for the execution stage of existing structures. Its implementation has a cost and it requires training of those involved to guarantee the desired results. It is, therefore, necessary to ask whether the benefits produced by the methodology are such that they justify the investment, especially in the private sector.

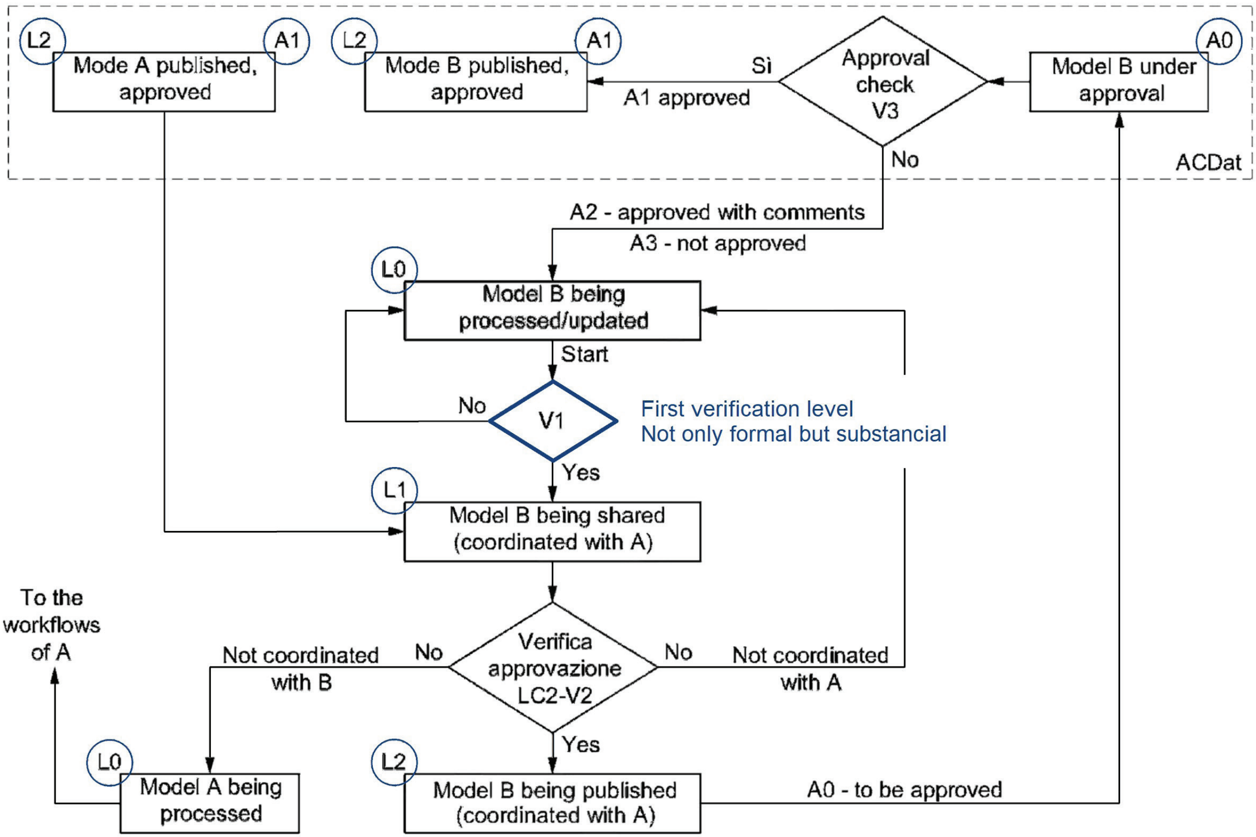

Fig. 5 – Our proposal for the coordination, progress and approval flow (based on UNI 11337-4:2017).

Levels of Development in the eBIM

A central issue in heritage documentation is the specification of the Levels of Development. Considering the Italian UNI 11337-4:2017 regulation, the client should detail the levels for the individual objects per phase of the implementation process. In this regard, a table proposed in the directive, which suggests specific ranks differentiated by discipline, comes to our aid. This is where the problem arises. The standard levels are conceived owing to a forward engineering methodology, with content increasing as one moves from the idea to the concrete element (Fig. 4).
Based on these observations, referring to an existing building surveyed and then modelled, one might be led to attribute the product to a LOD G, where the digital objects express the updated virtualisation of the state of an entity at a defined time, containing the trace of management, maintenance, repairs and replacements carried out throughout the lifecycle of the work [22].
Given the above considerations, it is not possible to acquire deep knowledge of all information and geometric aspects on an existing building without investing large amounts of resources. The same architectural survey, carried out with photogrammetric and laser scanning techniques, is limited to an exhaustive documentation of the structure 'skin', without providing information regarding the 'non-visible' elements, such as the stratigraphy of the walls. It is therefore evident that the LOD system needs to be rethought according to the type of building, as it is extremely difficult and above all costly for a private individual to implement the techniques and technologies necessary to collect the missing data [23].
Wanting to propose an economically viable solution, models and outputs deriving from the survey can be integrated

Level of reliability (LR)	Geometry (G)	Structural details (S)	Material properties (M)
LR0 Absent	Unknown geometry, derived from assumptions by analogy or historical images and documents.	Unknown construction techniques, derived by analogy with other elements or from images and documents.	Unknown materials, deducible from historical images or documents.
LR1 Limited	Geometry assessed from the original plans or from quick surveys using traditional techniques.	Simulated design according to the standards of the time and limited site investigations.	Values usual for construction practice at the time and limited in situ testing.
LR2 Extended	The geometry is known thanks to surveys with digital technology, but not certified.	Incomplete design drawings with limited in-situ investigations; alternatively extensive in-situ investigations.	From original design specifications or original test certificates, with limited in-situ testing; alternatively, from extensive in-situ testing.
LR3 Exhaustive	The geometry is known thanks to digitally controlled surveys that are certified for accuracy.	Comprehensive design drawings with limited in situ investigations; alternatively comprehensive in situ investigations.	From the original test certificates or original design specifications, with extensive on-site testing; alternatively, from extensive on-site testing.

Fig. 6 – Scheme for identifying reliability levels of information content.

with documents of various kinds (projects, deeds, etc.) in paper format and historical images, to outline a cognitive framework compatible with the objectives and uses of the virtualisation. It is therefore possible to achieve a LOD G for all architectural elements, although it is not practicable to validate all attributes in the field. This is a major problem, but one that could not be solved by solutions economically compatible with the general client's availability.

Fortunately, UNI EN ISO 19650 and UNI EN 17412, with the introduction of the Level of Information Need (LOIN) concept, allow us to go beyond the static approach of LODs and to calibrate the content according to a conscious and mature demand, providing mixed LODs for virtualised elements. Despite the increased flexibility, there is still a lack of clear reference to the existing building, having to define not only what information depth is to be achieved but also how it can be obtained.

A possible framework for tracking information content

Technical regulations barely address the issue of the traceability and reliability for the information that goes into a BIM model. There are some attempts to define a reference framework in the literature. These are almost always limited to specific types of content and completely detached from national and international norms for the proper management of product creation.

The coordination, progress, verification and approval of information in accordance with the Common Data Environment are all covered by the UNI 11337 standards in parts 4 and 5. The verification levels, which, along with the other three points mentioned earlier, outline the interchange flow, are the most valuable aspect for an in-depth examination of reliability.

We are interested in the first step (*LV1*) of formal internal validation that follows the elaboration and the second level (*LV2*) of substantial verification that follows the sharing and concerns the link with other models. We intend to incorporate our proposal into this framework by modifying the *LV1*, which is not only formal but also significant for individual virtualisation and aims to ensure the information readability, traceability and consistency (Fig. 5).

Once we know when the verification should be done, we can figure out how to check the object reliability. We make use of a system that is already in the Italian regulations: the levels of knowledge achieved in relation to structural analysis methods, financial resources and available time, which measure the degree of learning about a facility. The Technical Standards for Construction (*NTC 2018*) and the relevant circular provide a description, but state legislation has included them for many years. In comparison to what is currently stipulated in the regulation, our proposal introduces three main innovations: the existence of a level 0 that indicates there is no information (I), the availability of a single classification system devoid of construction methods (II) and the division of the investigated properties and features into distinct parameters (III) (Fig. 6).

In addition, to avoid confusion with Italian acronyms that correspond to the coordination levels in the interchange flow, we have replaced the term "knowledge" with "reliability." This indicates that national regulations governing the AEC sector still lack uniformity. For individual objects, three information contents are discussed: geometric, structural and material. As anticipated, an in-depth investigation is required for the first ones because it is not sufficient to clarify how the building is detected; additionally, uncertainties in the measurements must be considered.

Conclusions

Digitisation has emerged as an essential tool for the methodical documentation of existing heritage. Although it lacks a general codification, it is a routine procedure. There is a growing demand for models that can be used not only to describe the geometries of the building but also to manage it throughout its lifecycle, despite the progressive decrease in costs, both instrumental and operational, associated with producing reality-based virtualisation.
BIM philosophy is a response to this requirement, providing a useful tool for decision-making and an alternative to conventional approaches to documentation based on CAD drawings that only focus on geometric attributes.
The creation of as-built/as-is models needs a significant outflow of resources, although BIM widespread acceptance in the design and construction of new buildings and growing interest in advanced lifecycle phases in heritage documentation. This is typically accomplished through a highly interactive process of fitting parametric objects to the survey-derived point cloud. If the structure is full of unique elements that are difficult to standardise, this task becomes especially challenging.
Even though the literature focuses a lot on the development of modelling strategies, we can see that there aren't many ways to evaluate the traceability of information sources and their reliability, all main aspects that ensure the virtualisation can be used over time.
In any BIM process applied to existing buildings, content validation is crucial: the geometric and semantic data should be sufficiently reliable to meet customer-specific requirements and these aspects must be adequately documented. Effective solutions emerge from the literature, but they struggle to establish themselves because they are not well integrated into the tools outlined in the technical standards. For this reason, our proposal for reliability assessment does not introduce any further novelties but looks for solutions already used in parametric modelling or related fields, reformulating them where necessary and lightening the notional load on engineers and experts, who could make use of tools they know and control.
It is hoped that the understanding and mastery of information instruments will be a stimulus for the complete and correct implementation of BIM methodology in the field of heritage documentation.

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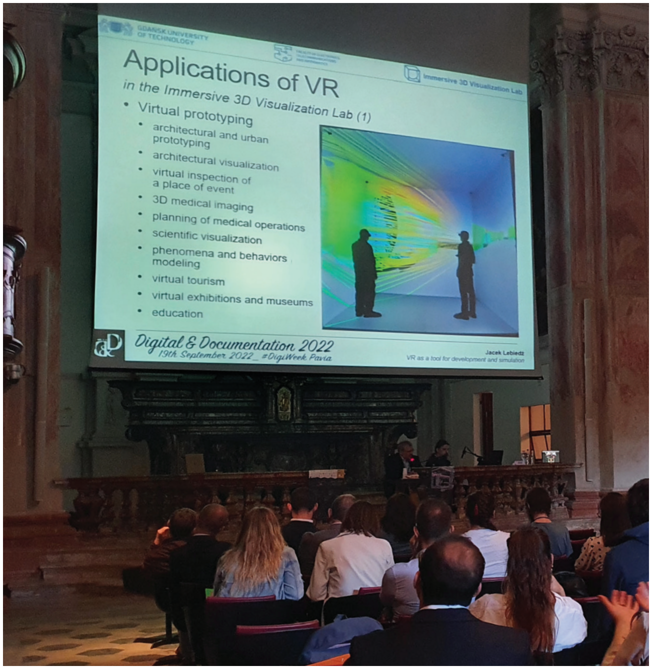
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The evolution of theories and methods for creating informative or educational digital images of cultural heritage is an ongoing process, anticipating and following technological and instrumental advances. The fifth edition of the conference 'Digital and Documentation' and the present volume, which collects the results of a study day, is part of this debate by showing the use of digital tools for understanding and preserving cultural heritage. Young researchers presented case studies focusing on two current topics: the perception of heritage through virtual design and its renewed management through three-dimensional information systems. Despite their separation, the two parts of the volume intersect through the interaction between virtual and informational systems, prompting new reflections on potential evolutions of representation and opening new avenues for simplified and efficient management of cultural heritage through untapped digital strategies.

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