Digital Innovations in Architecture, Engineering and Construction

Andrea Giordano
Michele Russo
Roberta Spallone *Editors*

Beyond Digital Representation

Advanced Experiences in AR and AI for Cultural Heritage and Innovative Design

Springer

Digital Innovations in Architecture, Engineering and Construction

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

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Editors

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Foreword

This book testifies to the joint effort of a group of professors in the Disciplinary Sector of "Drawing" who were able to make clear already three years ago a channel of research particularly interesting for the topics covered. The Digital first, the Virtual then and again Artificial Intelligence and the complex intermingling of computer science and visual communication show a liveliness of speculation and research all directed to new ways of fruition, understanding and enjoyment of our Cultural Heritage, often suspended between material and immaterial.

While information technology and technological innovation might at first have created inhibitions for those trained in the social sciences, between documentary analysis, surveying and the design of architectural spaces, the REAACH-ID Symposia have been able to demonstrate how much the themes of Drawing, Representation, geometry and visual communication can be research opportunities that are always current and innovative.

It can be inferred from the pages of this volume how much the purpose of REAACH-ID meetings is to solicit and expand human intelligence through new inputs from new technologies; these are occasions that tend to bring together contiguous cognitive universes, not only between different disciplinary fields but also within the same discipline.

From the editors' introductory essay and the authors' contributions, an epistemological framework has significantly changed since the 20th century. The scheme of the two cultures seems outdated because of the complexity and cultural hybridity that marks today's knowledge society. We are far from the pattern of fifty years ago when the scientific and humanistic cultures were separated by "an abyss of mutual incomprehension" (Charles P. Snow 2005. Le due culture, Marsilio, Venice, p. 20).

However, the confrontation between the two cultures is far from exhausted since the field of Cultural Heritage, until yesterday the prerogative of the humanities and social sciences, today has also become one of the main targets of technological research; it is a common pivotal theme that protects collective memory and contributes overwhelmingly to the definition of community identity and awareness (see Horizon 2020, 8th Framework Program).

Given the above, the symposium chairs thought it appropriate to promote a national and international network of researchers (REAACH Association) interested in Heritage Science to propose an increasingly organic and conscious way line of research in the field of Cultural Heritage by exploiting IT skills and applying them to Cultural Heritage. All of this was with a view to multidisciplinary exchanges of knowledge and the enhancement of advanced transversal skills.

It is a volume that brings together valuable evidence ranging from different ways of accessibility to Cultural Heritage to the use of Artificial Intelligence and Augmented Reality to applications of Extended Reality and Gamification to enjoy the fantastic universe of Cultural Heritage in a diversified way.

May 2023

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

We are witnessing a rapid technological innovation, which in the space of two decades has completely subverted the panorama of the discipline of Representation: a panorama that now sees the involvement of interdisciplinary issues with findings, repercussions, and feedback in both theoretical and applicative fields. Furthermore, if the concept of Virtual Reality was already inherent in Representation also for artistic purposes—see in this regard the Renaissance pictorial works, precisely *ante litteram* attempts at Virtual Reality—today Artificial Intelligence (AI), fueled by Deep Learning, has made it possible to arrive at an Extended Reality (XR), which incorporates the adjectives of Virtual, Augmented and Mixed.

For this reason, Artificial Intelligence has proved to be a truly transformative technology, exploited daily in more and more areas, continuing to surprise us with its evolutions. Evolutions, however, must consider awareness. Awareness in both theoretical and practical terms is where training plays a significant role in engaging with a critical and constructive attitude. For this reason, it is unquestionably that an aware conceptual apparatus is at the basis of Artificial Intelligence and its relationship with Extended Reality, being able to relate to and describe entities directly suggested by the real and ideal world through more advanced conceptualizations. The definition of these concepts, with the awareness that interesting and ingenious considerations could be applied to them, is the first demonstration of the acute use of Artificial Intelligence for Extended Reality. Moreover, for this, we must consider the depth of thought that goes into the formulation of XR through the concepts of Representation and, subsequently, the skill with which these concepts are used.

Thus, the domain of reasoning becomes lawful and indispensable. It remains fundamental, for example, to be able to recognize an architectural surface in geometric and configurational terms to then have important effects in structural and constructive terms. Once these concepts have been acquired, implementing them through AI-XR increases the evolutionary scenarios, with enormous repercussions on the heritage (architectural/engineering/urban/landscape), whether existing or in progress.

This process, therefore, takes on a prodigious characterization, adapting the Representation to extensive/plural/multiple areas from a disciplinary point of view, with repercussions on the scientific aspect of the adequacy of the codes and expressions of knowledge to broad branches of culture. In this way, the "frontiers" of Representation are widened. Thus, the relationship between Representation Space and the Representation of Space further expands and explains the relationship between Science and Art, between concept and creativity and between elaboration and realization.

The digital world and the Representation domain are strongly interconnected. Their long-established relationship has seen a major step forward in the past two decades. The ability to survey in space any kind of artifact, draw and visualize it with digital models at different levels of detail and reliability is now considered an established practice. At the same time, the sudden growth in the last five years of Artificial Intelligence (AI) and Augmented Reality (AR) research, especially, but not exclusively, applied in the field of Cultural Heritage, has required a deep analysis of the role of these technologies in the Representation domain. Specifically, "if and how" these tools, strongly leaning by expertise to the world of computer science, can find a declination in the research of Drawing.

The answer to such a complex question requires extensive and in-depth discussion among those who have had the opportunity to critically experiment with AI and AR in different scientific domains. This is the main motivation that led us to promote in 2020 (REAACH-ID 2020), and for the first time, a symposium dedicated to these issues. The articulated framework of research that such an event brought to light allowed us to begin a journey of maturation from which two different needs emerged: on the one hand, the repetition of the event, promoting annually and consolidating a place for discussion and updating on emerging technologies. From this point descended, the organization of the symposiums in 2021 (REAACH-ID 2021) and 2022 (REAACH-ID 2022). On the other, the definition of a new entity that could support from a scientific and organizational point of view the promotion of these issues on a national and international scale, encouraging the increase of networks among different scholars. From this choice came the founding in 2022 of the REAACH Association (www.reaach.eu), which stands as a "bridge" between experts in different disciplines and some European research streams such as Heritage Science. The association promotes the symposium annually, nurturing interest in the issues and, at the same time, fostering that path of maturation toward an increasingly conscious use of emerging technologies.

The annual event presents an online format to maximize participation by both speakers and attendees. To encourage useful discussion, the authors present in-progress experimentation highlighting the pros and cons of the specific application. The definition of the paper occurs later, downstream of the meeting, reaching a more critical development of the contents. The articles, therefore, follow an autonomous path in which the symposium represents only a moment of critical feedback and comparison with similar research to understand the topic's relevance, arriving at a more informed synthesis in the research domain. The book presented here promotes the results of research that were presented as a first idea during the 2022 symposium and then developed independently following the event.

The book is divided into parts that collect contributions that weave together the two main topics, i.e., the discipline of Artificial Intelligence and the technology of

Augmented Reality, with specific objects of interest from the discipline of Representation. The definition of these parts is partly driven by the topics proposed in the call for papers and partly guided by the authors' responses, who have brought to attention new and interesting theoretical developments and application possibilities. According to this logic, the book is divided into six main parts.

The part "AR&AI and Historical Sources" deals with the accessibility and communication of archival historical heritage mediated by virtual reconstruction using 3D models and the experimentation of the heuristic potential of digital modeling for the 3D visualization of consistencies represented in archival drawings. The opportunities offered by the digital revolution and specific technologies and simulations are explored in the part dedicated to "AR&AI and Museum", with the aim of increasing the community's knowledge and awareness of heritage, also in terms of inclusion. In the "AR&AI and Heritage Routes" part, experiences in archeological sites are presented through virtual reconstructions and "augmented" tours of existing architecture and landscapes acquired through digitally surveyed. The part "AR&AI and Classification/3D Analysis" is largely devoted to papers presenting general considerations with extensive references to the most interesting and richly developed Artificial Intelligence methodologies. "AR&AI and Education/Shape Representation" is the part that contains Artificial Intelligence and Augmented Reality methodologies and technologies for shape representation and innovative teaching, as well as Extended Reality and Gamification applications for the presentation of curriculum work. The monitoring of the built environment, both historical and contemporary, characterizes the "AR&AI and Building Monitoring" part. The state-of-the-art digital methodologies and technologies enable the development of effective and efficient monitoring systems.

Each part is organized starting with the papers that set out general theoretical considerations or that refer to broad application areas and is followed by the papers that develop specific case studies. The parts are preceded by a keynote lecture dealing with a recent digital initiative at the Montreal Museum of Fine Arts that strives to mimic the lost pleasure of tactility, as well as to address the physical limitations surrounding the display of miniature objects in a museum, in an attempt to subvert canonical museum hierarchies by rendering visible the often-invisible, including the artworks' tactility, materiality and craftsmanship, which would otherwise be left obscured by a traditional museum display.

More than 150 scholars have participated in the realization of this volume, consisting of 53 chapters, contributing to the establishment of the scientifically up-to-date state-of-the-art of international studies linking the discipline of Representation with Artificial Intelligence and Augmented Reality.

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根付 *Netsuke* Hands on Subverting Untouchability Through the Digital

Laura Vigo and Lindsay Corbett

1 Points of Depart

1.1 Introducing the Museum

The Montreal Museum of Fine Arts (hereby MMFA) holds more than 44,000 works of art, including over 10,000 objects from different material cultures dating from the Neolithic times to today, which were predominantly collected in the first half of the twentieth century. One quarter of the museum's collection consists of an eclectic and fragmentary group of Asian, Latin American, and African objects, privately collected by the Montreal elite during the early twentieth century. The museum should therefore be understood as a collection of collections (Fig. 1).

As one of the oldest (once-called) "encyclopedic" museums in Canada, the MMFA was originally built to reflect the power and tastes of a small number of anglophone industrialists in Montreal, who saw themselves as "civilized and civilizing". To assert notions of their worldly erudition, in 1860 they built a "public" art gallery, which they initially named the Art Association of Montreal. Following an acclaimed exhibition of Oriental rugs and ceramics in 1916, the Art Association was prompted to develop a museum section that would provide the public with a window through which they could encounter a new, exotic world. The museum's ambition to foster a wider public appreciation for foreign aesthetics followed the pedagogic mission originally promoted by Henry Cole at the South Kensington (now Victoria and Albert) Museum in London. Using the South Kensington Museum as model, the MMFA was

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Fig. 1 The Michal and Renata Hornstein Pavilion, exterior view. The Montreal Museum of Fine Arts. (*Photo* Annie Fafard)

forever transformed from an art gallery into a fully-fledged “encyclopedic” museum. It was between these early years and up until 1962, that F. Cleveland Morgan, the MMFA’s first curator, would acquire thousands of Asian objects, through purchases and donations, actively taking part in the wider “intercultural articulation” of Asian art occurring in North America at the time [1].

1.2 Collecting Exotica

The museum’s Asian collection was predominantly amassed in the twentieth century through the donations of private collectors. As such, it reflects their tastes and prerogatives, characterized by gazing at Asia from afar. Many of the “exotic” objects these collectors purchased and consumed were small scale, which facilitated their easy circulation, rapid consumption, and affordability, propelled by a consolidated network of self-taught dealers and connoisseurs. Japanese objects like netsuke (cord stoppers), *kogo* (incense boxes), and *chaire* (tea caddies) were immensely popular on the art market in the nineteenth century, not only because they were interesting as individual objects, but also because their minute scale facilitated their circulation as large ready-made collections. These types of “ready-made collections” now form the backbone of the Asian collection at the MMFA, which consists of over 6,000 works.

1.3 Re-Orienting the Aesthetic Paradigm

ICOM defines a museum as a not-for-profit, permanent institution in the service of society that researches, collects, conserves, interprets and exhibits tangible and intangible heritage [2]. But beyond these responsibilities, it is perhaps even more important that museums spark curiosity and critical reflections surrounding the works that they preserve. To achieve this, museums are continually challenged to think outside the box, both physically and metaphorically, to encourage multiple readings and varied experiences from people visiting the museum, belonging to different communities and offering diverse perspectives.

All actions and dialogues must therefore be based on the *a-priori* recognition of the equality of all participants. Museums have been and still are expressions of the modern/colonial power, holding epistemic and aesthetic monopoly. The visitor's experience of the museum space and its implicit narrative reiterate a prearranged idea of a universal artistic canon. Object collection, exhibition, and didactics all contribute to configuring a history of aesthetics that primarily champions the history of the West. To this end, the museum has been instrumentalized as a tool of exclusion, erasing other worlds, forms of meaning, and ways of sensing.

Given this ongoing institutional history, it is imperative that curators ask how they can begin to counter systemized ways of looking and deconstruct the normative art historical canon. One solution has been to turn towards the object, focusing on its biography, social life, and at times, colonial footprint. Provenance and the history of collecting can offer a starting point for critical reflection, not only in the physical, but also in the digital space. Indeed, the opening of new galleries at the MMFA in 2019 began to address such entanglements (Fig. 2).

As one of the largest and most eclectic ensembles of non-western art in Canada, the reinstallation in 2019 was based on the recognition of the importance of showcasing processes of circulation, consumption, and commoditization of cultural artifacts that lay beyond our familiar sphere. The new permanent galleries feature objects from across time and space that share only one common denominator: they were all amassed by Canadian collectors during the first half of the twentieth century, according to arbitrary aesthetic preferences mostly informed by the euro-centric canon of art, indirect colonial violence, and the market opportunities that ensued.

In adopting a transhistorical and transcultural approach in designing the galleries, we sought to present alternative and over-arching narratives around the subjects of market circulation and collecting, the idea of the body, the relationship between human and nature, societal constructs and markers, death and memory, as well as intangible beliefs. All these themes relate and connect works from different cultural horizons in unexpected ways. This paper does not focus on such thematic organization, yet provenance and history of collecting did inform our digital initiative.

Such decolonial ambitions were limited given the constraints of a physical space that was originally designed to house an "encyclopedic art collection", entrenched in the western art historical canon that privileged certain artistic traditions, styles, and mediums as more "beautiful" or important than others. Curatorial frustration led to a

Fig. 2 The Japanese art collection. View of the Stephan Crétier and Stéphany Maillery Wing for the Arts of One World. (*Photo* MMFA, Denis Farley)

deep dive into the digital realm, a fourth dimension that would allow us (1) to explore another type of interaction with the public (2) to convey an alternative narrative (3) engage with the concept of tactility. 根付 *Netsuke Hands On* is the result.

2 Let's Go Digital

2.1 Rendering the Invisible Visible

根付 *Netsuke Hands On* is a digital application designed for in-gallery use that combines three-dimensional photogrammetry with didactic texts (Fig. 3). The objective for developing this application is to address the asymmetrical organization of power in "encyclopedic" museums by enhancing visitor engagement with miniature objects. Small scale objects are often poorly exhibited in spaces that originally catered to the display of larger "fine arts" works—like paintings and sculptures. This spatial imbalance is not conducive to a satisfactory visitor experience, as inaccessibility and poor visibility may prevent relaying the vital role that miniature objects played in the lives of their users, collectors, and viewers.

The first iteration of the MMFA digital initiative focuses on Japanese ivory carvings called netsuke (Fig. 4). Literally meaning "root-hangings", *netsuke* were widespread in Japan during the Edo period (1615–1868). Originally worn by men to fasten bags to the belts of their pocketless kimonos, these accessories became widely coveted items of fashion and markers of erudition in their own time. Only

Fig. 3 Using the App. (*Photo* MMFA, Jean-François Brière)

later did they stoke the interest of foreign western collectors, who, enthralled by the burgeoning of the *Japonisme* aesthetic movement in Europe in the mid nineteenth century, amassed them in large numbers.

Netsuke were ideal for global circulation and consumption because of their minute scale, often only measuring a one or two inches in height. At the same time, their miniature scale presents challenges for the curator when trying to convey their permutations of use across time and place. Indeed, even if tiny, these sculptural works

Fig. 4 根付 *Netsuke Hands On*. (*Photo* MMFA, Jean-François Brière)

are complex objects that elicit intricate narratives surrounding their production, circulation, use, materiality, and iconography.

2.2 Touch & Go

根付 *Netsuke Hands On* attempts to make visible the otherwise invisible cultural complexities of the netsuke by allowing visitors to engage with them beyond the physical parameters of the museum. A key feature of the web-app is the integration of three-dimensional photogrammetry that enables the viewer to rotate and view the object entirely in the round, exceeding the limited experience of a museum vitrine. Users can further zoom-in to observe intricate details that would be otherwise indiscernible to the naked eye (Fig. 5). Such close-ups allow for better scrutiny on material composition, surface texturing and various distinctive techniques of carving that may even help authenticate and attribute with more precision each individual netsuke.

Three-dimensional photogrammetry also enhances the visitor's experience by allowing them to mimic the "handling" of these tiny sculptures. Tactility always played a vital role in the desirability of netsuke, from the Japanese consumers who manipulated them as clothing fasteners, to their later western collectors, who sought to contain Japanese culture in the palm of their hands. Despite the historical role of tactility in collecting small "exotica", it is a sensorial experience that is difficult to replicate in museums, where the untouchability of objects remains an undeniable paradigm. 根付 *Netsuke Hands On* seeks to mimic the lost pleasure of touching, by prompting participants to virtually manipulate and eventually "collect" their favorite netsuke by storing images in a digital repository.

Fig. 5 Zoom-in. Yoshitomo (active in Kyoto in the 18th c.), netsuke: hare eating loquat leaves, about 1790. MMFA, purchase, Dr. Stephen Fichman Fund. (*Photo* MMFA, Jean-François Brière)

By doing so, the digital initiative subverts the museum "do-not-touch" diktat, challenging the institutional hierarchies of museums. While private collectors and "white-gloved" museum professionals maintain privileged access to handling artifacts, most people are never able to experience objects this way. Instead, they must encounter such objects from behind the glass boundaries of the vitrine. While we are still far from replicating the magic of physically touching netsuke, it is our hope that three-dimensional photogrammetry can highlight and somewhat obviate the access imbalances by giving more agency to the viewer to "manipulate" according to their own inclinations and curiosity.

2.3 *Storytelling Away*

The mobile web application offers two options to users: they can either simply "play" with the three-dimensional photographic renderings of the netsuke or follow along a more structured mixed media storytelling experience incorporating the three-dimensional interface (Fig. 6).

The digital essay traces the circulation of netsuke from their production in Edo Japan to their arrival in western museums. The essay goes beyond a linear story that follows cultural production from point A to point B, but provides important information on the netsuke surrounding their materiality, wider cultural influences, modes of production, iconographies, mythologies, and social significance. Users are also given the option to read the essay from beginning to end or jump in at a certain chapter that piques their interest.

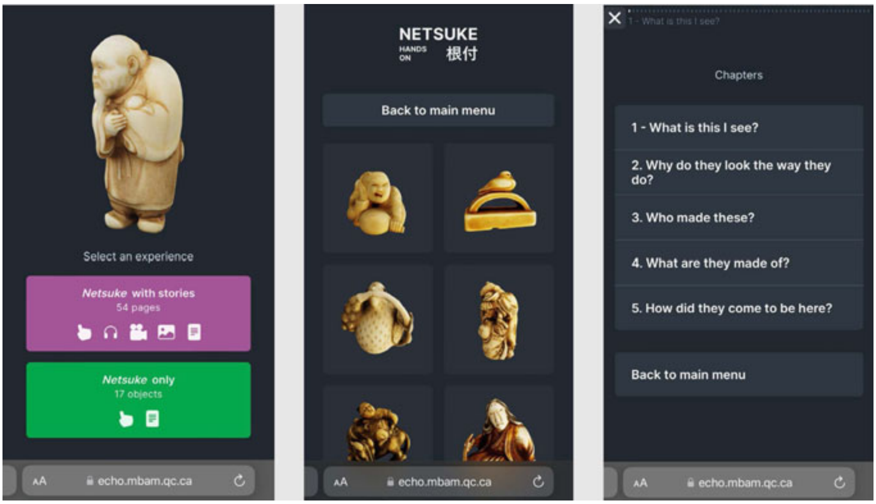

Fig. 6 根付 *Netsuke Hands On*. Choosing the experience. (*Photo* Laura Vigo)

Visitors then navigate through the essay using the familiar breadcrumb storytelling structure as familiarly seen on Instagram. They can either click between pages or linger on specific ones according to their own preference.

A final point about the organization of this digital essay is that it is a part of a progressive web application, which means it is a living essay that can be updated and tweaked in-house without having to rely on an external provider. We will therefore be able to update the application as we continue to learn more about the objects. For instance, the netsuke were recently analyzed by XRF scan by the Canadian Conservation Institute in Ottawa. Their new data will provide more insights into the materiality of the netsuke, their production and authenticity. The conservators' conclusions will eventually be added to the digital essay and will be available online.

3 Further Reflections

3.1 An Example

Our ambition to create an experience that was at once accessible to a wide audience, yet question expectations about miniature objects in museums was a challenge, given the complex cultural and artistic paradigms that netsuke index. Take for example the netsuke featuring a map of Japan across its two faces (Fig. 7). It was made by Ichimuken Nanka, a master carver in *kabori* (hair-carving)—a particularly fine style of engraving [3]. Nanka specialized in the production of manjū netsuke, characterized by their round smooth shape that did not snag and catch on the kimono of their owners. Nanka produced many manju netsuke depicting maps of Japan, indicating it was once a coveted subject matter, likely reflecting the increased interest in travel by the Japanese during the Edo period [4]. Indeed, the Edo period is frequently characterized by the increased movement of people, especially along the famous Tokaido Road, frequently depicted on woodblock prints (*ukiyo-e*) produced during this time [5]. Nanka's map features an inscription that reads: *Authentic Map of Great Japan in the Realm of the Buddha*, signaling that this newfound interest in travel was not only a social phenomenon, but one that was deeply intertwined with spirituality. The netsuke therefore also relates to entrenched Japanese traditions surrounding Buddhist mapmaking and pilgrimage [6].

But the story does not stop there. When Japan opened its ports to the western world in 1853, it stirred interest in all things Japanese, eventually burgeoning the development of *Japonisme* in Europe and North America. *Netsuke* were implicated in the European desire to claim and contain a little piece of Japan [7].

Their materials, scale, dimensionality, individuality, and relative affordability appealed to western art collectors. Through its illustration of a map, Nanka's *netsuke* would have conflated these desires by allowing collectors to theoretically "contain" all of Japan in the palm of their hands. Taking on a new life, this netsuke would offer a snapshot of Japan, easily consumable from the confines of the collector's home.

Fig. 7 Nanka (active in Japan, mid-19th c.), netsuke: two-part manjū with engraving of a map of Japan, 1820–1830. MMFA, purchase, Dr. Stephen Fichman Fund. (*Photo* MMFA, Jean-François Brière)

By observing Nanka's work, we can quickly get a sense of how deeply multifaceted one tiny object might be. Indeed, one single netsuke can inspire questions surrounding style, technique, iconography, artist, workshop, travel, portability, pilgrimage, trade, cross-cultural exchange, aesthetic transfers (*Japonisme*), provenance and collecting, to name a few. This is just one example in our collection that illustrates the culturally entangled lives of netsuke.

3.2 Engaging Viewers

As curators have increasingly started to think about objects differently and embrace their in-betweenness, netsuke offers an excellent opportunity to reflect on how this way of thinking can help to enliven and animate objects, as well as how objects were adapted and shaped across time and space. The challenge arises when curators are confronted with the ambition of not only encompassing the complex entanglements that objects index, but also presenting these in a way that is engaging and accessible to museum-goers.

In order to achieve this, when developing the texts for the digital essay, the object itself was placed at the center of the narrative and became the linchpin through which the text was generated [8]. Inspired by the critical importance of conveying the life en route of objects, one of the visions for this project has been to highlight how the portability of the tiny netsuke contributed to their circulation and spasmodic collecting in the west, conveying their journey from their origins as fashion accessory to their arrival in western art collections and museums as commodities. Each individual piece provided the opportunity to discuss certain aspects that related to the more collective themes and issues we wished to introduce, and this determined how we ultimately designed and organized the digital application.

One example is the netsuke of Tōbōsaku Sennin—a legendary Buddhist hermit (Fig. 8, left). He is depicted in a humble dress and clutching a peach, his characteristic attribute symbolizing longevity. When the visitors embark on the digital essay, Tōbōsaku is the first netsuke they meet. They are greeted with a three-dimensional rendering, layered with a text that directs them to not only observe the front of the object, but to also rotate it to inspect the reverse. Zooming in, they are made aware of a significant detail: a small tobacco pouch (*dōran*) hanging from a cord on his belt (*obi*) (Fig. 8, right).

Dōran were traditionally anchored to a kimono using a netsuke. In this respect, the netsuke of Tōbōsaku is self-referential: while constituting a netsuke itself, it also alludes to the presence of a netsuke in its representation of contemporary fashions. Drawing on this moment of self-referentiality, the essay allows for the viewers to learn about how these accessories originally functioned. Viewers are thus able to learn about netsuke's function in close detail. At the same time, they can experience the charming delight of discovery that netsuke were designed to convey.

In a similar vein, other netsuke contribute to other parts of the story. A netsuke of a pigeon on a knop used as a seal illustrates its many purposes as a personally charged object: as a seal, a status marker and a sign of erudition (Fig. 9). A netsuke of a monkey

Fig. 8 Left: Yoshida Sosai (Active in Tokyo, 1865–1944), netsuke: Tōbōsaku Sennin, about 1900. Right: Detail: dōran. Yoshida Sosai (Active in Tokyo, 1865–1944), netsuke: Tōbōsaku Sennin, about 1900. MMFA, purchase, Dr. Stephen Fichman Fund. (*Photos* MMFA, Jean-François Brière)

made of walrus tusk signals the diverse materials used in netsuke production, as well as the ecologies and trade networks of the raw luxury goods that were sourced to produce luxury arts (Fig. 10, left). On another netsuke of a monkey (Fig. 10, right), viewers can zoom in to observe in detail how the surface was originally worked, how patina was rubbed away in certain areas, constituting a memory of the hands that would have held and manipulated the tiny object.

Fig. 9 Left: Ohara Mitsuhiro (Onomichi, Japan 1810–1875), netsuke: seal with pigeon knob, about 1850. Right: Seal Inscription. Ohara Mitsuhiro (Onomichi, Japan 1810–1875), netsuke: seal with pigeon knob, about 1850. MMFA, purchase, Dr. Stephen Fichman Fund. (*Photos* MMFA, Jean-François Brière)

Fig. 10 Left: Attributed to Sadayoshi, netsuke: monkey with bamboo, about 1870. MMFA, purchase, Dr. Stephen Fichman Fund. (*Photo* MMFA, Jean-François Brière). Right: Yamaguchi Okatomo (active in Japan, 1780–1830), netsuke: monkey holding a gourd, about 1880. MMFA, purchase, Dr. Stephen Fichman Fund. (*Photo* MMFA, Jean-François Brière)

4 Conclusion

根付 *Netsuke Hands On* encourages the viewer to engage differently in the gallery space with minute objects that are often neglected or poorly displayed. Mixed media digital storytelling is particularly conducive as it allows us to directly integrate the object into the discussion by layering text with images, videos, and three-dimensional photogrammetry. Each individual *netsuke* invites the viewer to wonder about a certain aspect of their composition, while simultaneously conveying information that relates to the larger narrative of the digital essay. Furthermore, the invitation to digitally manipulate (*hands-on*) the objects in focus tacitly evokes the very reason they were originally coveted and collected, their tactility.

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AR&AI and Historical Sources

LabInVirtuo, a Method for Designing, Restoring and Updating Virtual Environments for Science and Technology from Heterogeneous Digital Corpus

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1 Introduction

The LabInVirtuo project aims to develop and validate, Realistic Sensory Intelligent Virtual Environments (RSIVE). These environments are envisioned as cross-disciplinary virtual laboratories, in which various players may work cooperatively on projects related to culture and heritage.

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The first hypothesis of this project is that the immersion of users in a Realistic Intelligent Sensory Virtual Environment, where bodies are kinematically, gesturally, and sensorially involved, allows for the following:

(1) An increased retrieval of procedural, episodic and autobiographical memories that are usually interrogated or worked on when producing oral accounts traditionally.
(2) Capturing gestures and embodied knowledge in context.
(3) Memorization of knowledge.

Our second hypothesis is that collaborative mixed reality allows for new methods of cross-disciplinary research and cultural facilitation, with a qualitative and quantitative leap with regard to eliciting and restituting knowledge and know how.

2 Context

LabInVirtuo strives to preserve industrial occupations and know how. It is cross-disciplinary, bringing together people with backgrounds in humanities and social sciences, and computer and mixed reality research scientists.

2.1 Positioning

Today, digital technology to capture our heritage is in established usage for all professionals in the field. Projects carried out within institutions display heritage items in their historical context [1] and allow for their virtual manipulation [2]. To our knowledge, none of them lets them be operated so that their usage may be archived. Yet VR seems to have a significant effect on the acquisition of knowledge about these historical objects [3]. According to Barreau [4] "In the more distant future, the stakes will lie in the simulation of, and interaction with, virtual humans from the past".

LabInVirtuo focuses on human activity, and the elicitation and restitution of expert knowledge in an RSIVE. It complements current approaches focused on the technical object, as in the issues raised with regard to the Digital Heritage Reference Model (DHRM) [5]. Being interdisciplinary, the project is at a crossroads of various fields: history, anthropology, industrial heritage, virtual and augmented reality, coupled with a sensory aspect, which, while a little explored field [6–8], is essential to achieve a better virtual restitution of usage and embodied knowledge, given all the data this aspect carries.

Clarifying knowledge in virtual environments is the purpose of Intelligent Virtual Environments (IVEs) [9]. Some works in the VR field [10, 11] come close to the objective of designing IVEs using metamodels. These models only allow the end user to access knowledge, not to create new knowledge in real time. Embodied Conversational Agents (ECAs) are increasingly frequent in IVEs, taking on the roles of helpers, tutors, or attentive psychologists [12] and producing clear benefits [13, 14]. For interaction to be effective and satisfying, an ECA must be able to speak but also listen, modify, and adapt its behavior in accordance with that of the user [15]. However, the agent behaviors developed in this domain focus on the feedback exchanged between participants while speaking, but rarely on the semantic content of the messages or in the agent's knowledge base. Recent works [16] describe a conversation system, involving social robots or conversational agents, based on the semantic content of speech. This system aims to generate rewarding interactions through the restitution of subject-appropriate knowledge, but does not provide a way to update this knowledge. For our project, we want ECAs to serve as interfaces for expert users to update knowledge or enter new data.

From a methodological point of view, developing an RSIVE raises the question of how to convey realistic, sensory information from the historical data that was collected:

(1) How to restore a past industrial setting in all its dimensions: tangible and intangible; from material traces, which include old preserved workshops, usually with their machines removed; from archival sources; from oral memory…? This question implies enriching the existing reference works [17, 18] with notions of authenticity and integrity, and tackling the challenges identified twenty years after the Nara document [19] with the acknowledgment of "the emergence of new forms of heritage that have not previously been given much attention". […] as "emerging modes and technologies for accessing and experiencing heritage, which may include new ways of enhancing or providing perceptions of heritage through increasingly widespread practices such as historical role play, living history, historical reenactments, computer games set in the past, and the creation of virtual realities augmenting visitor perceptions".

(2) By extension, and given the prospect of immersion in an RSIVE, sensory studies are necessarily central to our reflection. Corbin [20] suggests that there is perpetual tension between the senses known as "social" (sight and hearing) and the rest (touch, taste, and smell) which "provide the feeling of objects" and "give information on things' true natures". Additionally, "Means of doing and means of feeling cannot be dissociated if we want to apprehend, in their entireties, the bodily tactics which intervene in certain situations of shared cognition aiming at the elaboration and the collective exploitation of knowledge" [21]. Let us also quote Gélard [22]: "the senses have been slowly but securely permeating research settings and they are opening up many new prospects. Through their ability to express specific information, the senses inform us about the societies within which the anthropologist examines them. The senses are identified by and in singular manifestations (visual, auditory, olfactory, etc.) that we must describe and decode." […] "It is under this methodological angle of a decryption of the senses and their diversity that the most fertile anthropological approaches are situated".

Although the question of sensory landscapes has been studied from the perspective of Humanities and Social Sciences (HSS) [23], a cross-disciplinary approach to the restitution of multi-sensory landscapes from the perspective of Digital Humanities remains to be conducted. These aspects will therefore be analyzed through the various senses that humans develop in a technical context, from hearing (soundscape archaeology) to touch (tactile and haptic), from smell to thermoception and, of course, sight. While graphical representations are a staple of 3D modeling projects, the remaining senses are more rarely called upon, even though they fully contribute to understanding a complex technical system, through the interpretable information they provide.

The originality of our interdisciplinary approach lies in:

- The interdisciplinary coupling of previous and ongoing work in the present consortium including the alignment of the HSS activity metamodel ANY-ARTEFACT [24, 25] (and its associated history methodology) with the DHRM metamodel [26, 27] and the MASCARET metamodel in IVEs [28] (and its IVE design methodology used in research and industry).
- The hypothesis that situating users in a collaborative IVE where the body is engaged from a sensory, kinematic, and gestural perspective results in:
    (a) An increased retrieval of the different procedural, episodic and autobiographical memories that are usually interrogated in the classical setting.
    (b) More efficient elicitation of expert knowledge. LabInVirtuo constitutes a mode of implementation and evaluation of this hypothesis.
- New modes of cultural facilitation:
    (a) Reaching a sensory informed environment, which kinematically and physically involves its users.
    (b) Zooming in and out according to multi-scale space–time modalities.
- The ambition to validate methodologies of preventive preservation of cultural heritage and industrial skills, considered as factors of innovation to build the society of tomorrow.

2.2 Use Cases

Our model needs to be generic enough to be applied to various use cases in four French cities:

(1) In Brest, the Pont National, inaugurated in 1861 and destroyed in 1944, and the Pontaniou forges in the arsenal, which house a Schneider & Compagnie power hammer from 1867.
(2) In Nantes, Cap 44, a former flour mill built in 1895 and transformed into a storage warehouse and then into an office building in the 1970s. Its interest lies in being one of the first large buildings made of reinforced concrete in accordance with the system designed by François Hennebique.

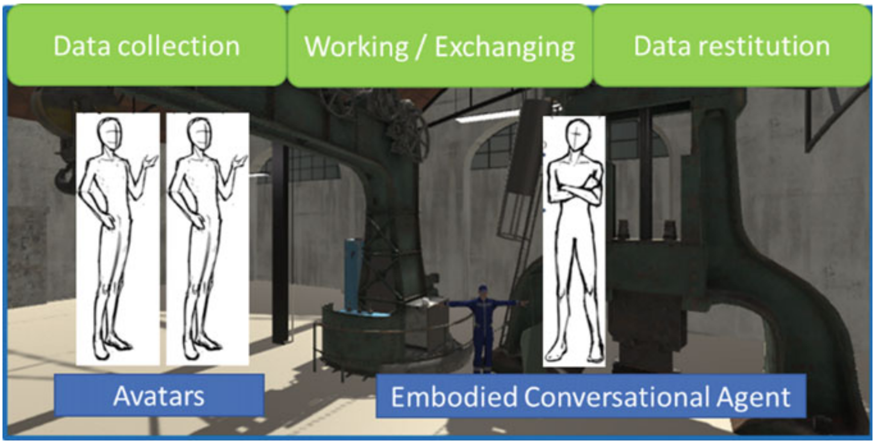

Fig. 1 Three ways of interacting with the digital corpus in LabInVirtuo (*Modeling* Virtualys, diagram: R. Querrec)

(3) In Paris, the Numasurf, a numerically controlled milling machine, the only remnant of the UNISURF system, and the first system allowing end-to-end digital design, which was designed by Pierre Bézier for Régie Renault in the late 1960s.
(4) In Belfort, Techn'Hom, formerly made up of several industrial sites in the textile and mechanical construction sectors such as DMC or Alstom and which, at the beginning of the twenty-first century, became an economic business park spanning more than 100 acres.

Each use case needs to be formally described through an ontology (the digital corpus) and reconstituted as a virtual environment. To this end, various kinds of sources are gathered: three-dimensional scans, floor plans and texts, among others.

While users are involved in the virtual environment, the digital corpus can be interacted with in three manners (Fig. 1):

(1) Collecting data in the virtual environment by interacting with the reconstituted industrial system.
(2) Working and exchanging: we could compare corpus built by experts in different fields, e.g. historians and archaeologists. With the same collaboration mindset, we can present reconstitution ideas within LabInVirtuo to have them validated.
(3) Restituting knowledge in facilitation and teaching contexts.

3 Proposed Models

The goal of the project is to design the tools and interactions that will enable a bidirectional link between the digital corpus and the virtual environment (Fig. 2).

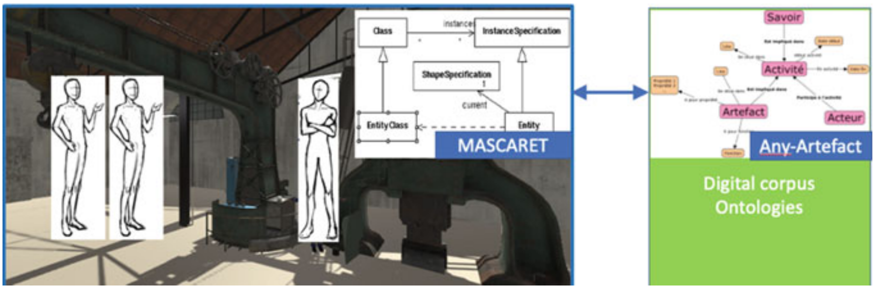

Fig. 2 The global architecture of LabInVirtuo, exemplifying the bidirectional relationship between the virtual environment and the digital corpus (*Modelling* Virtualys, *Diagram* R. Querrec)

3.1 The Digital Corpus

The digital corpus comprises not only the historical data and sources as ontologies, but also the technical provisions to preserve and access them. The ontologies are stored in Omeka S with ANY-ARTEFACT. ANY-ARTEFACT is a generic ontology which adapts CIDOC-CRM for defining specific ontologies in science and technology. ANY-ARTEFACT is designed around the following concepts (Fig. 3):

(1) The concept of Actor, which can be:

  (a) A human being as a person.
  (b) A group, i.e. two individuals or more arranged in a social structure.
  (c) A character, representing a status or an appointed position (for instance a blacksmith).

(2) The concept of Artefact, namely a human-made production with a function, that is, the ability to perform an action, as well as a use.
(3) The concept of Knowledge: specifically theoretical and procedural knowledge.
(4) The concept of Activity: an activity is envisioned as a series of (unique or repeated) events involving actors, artefacts and a knowledge system. An activity

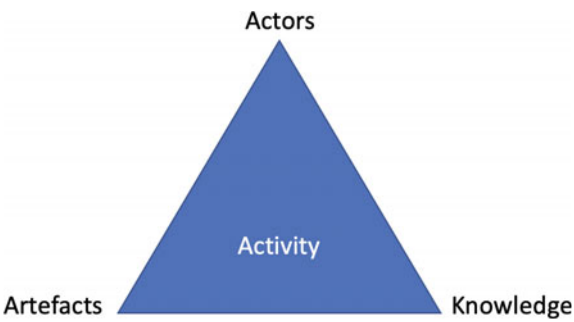

Fig. 3 The main concepts of ANY-ARTEFACT (*Diagram* M. M. Abiven)

unfolds as time passes and is spatially situated [23]. In the context of ANY-ARTEFACT, we call industrial cultural practices any kind of industrial activity:

(a) Periodic industrial activities (spatially and temporally situated, with a set duration), which we call technological or scientific procedures, involving actors, artefacts, and knowledge (for example forging a metal part).
(b) Unique events (the creation of a factory, a technical failure, an accident, etc.).

Therefore, an industrial cultural practice is fixed at a set time and place (e.g. all the activities carried out at the Pontaniou forges in the nineteenth century within the Brest Arsenal). A procedure is an operational sequence that will be regarded as identical over the related period (e.g. the anchor forging procedure in Brest between 1710 and 1760). Hence, it happens repeatedly. Unique events are samples of such procedures (the forging of an anchor on 16 January 1730, on 6 February 1755, etc.). These specific ontologies match the four use cases we previously described.

On a technical level, we created a library to interact with Omeka S from the virtual environment. This allows us not only to look up concepts and sources, but also create new ones in real time. Storing historical data in a tool like Omeka S is useful in that it allows historians to keep their usual data collection and facilitation workflows. However, we posit that the VE constitutes a more natural interface for browsing, simulating and extending this digital corpus. Designing these virtual environments requires resolving two scientific obstacles.

The first obstacle is implementing the methods to establish the bidirectional link between the digital corpus and the virtual environment by offering multi-sensory interactions.

3.2 The Virtual Environment

The informed virtual environment must be generated from the digital corpus data, and we need to propose interaction metaphors for the VE. To this end, we rely on an informed virtual environment metamodel: MASCARET. MASCARET [28] is based on the UML metamodel and is used to describe technical systems and the human activities related to them. The operational semantics is specified, which allows for interpreting MASCARET-described models in virtual environments.

The main added value of MASCARET in this context, compared with ontologies, is that it has a precise operational semantics for activities (Fig. 4).

An activity is declared within the framework of an Organizational Strucure, which also references roles and resources. The activity is actually performed by an organizational entity that assigns resources to entities and roles to agents. Thus, Entities correspond to the notion of Artefact in ANY-ARTEFACT-O. In a similar way to

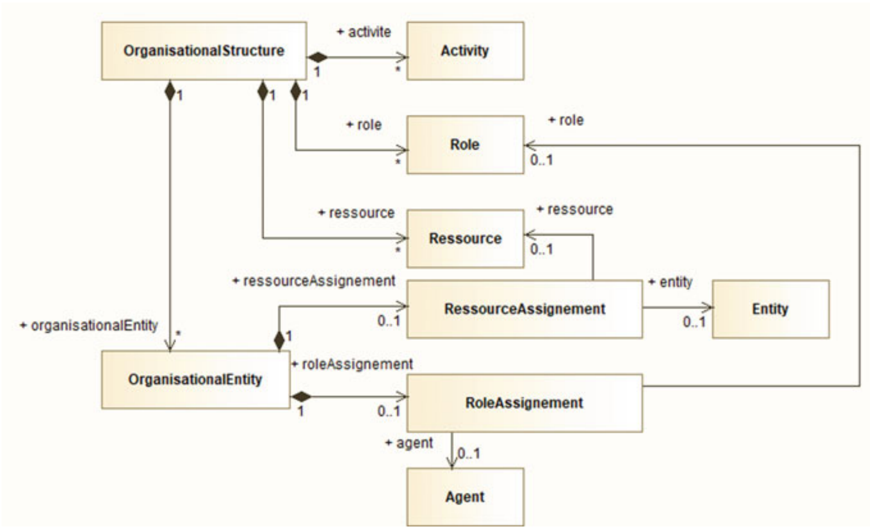

Fig. 4 The concept of Activity in MASCARET (*Diagram* R. Querrec)

ANY-ARTEFACT-O, Entities have Properties, which can be behavioral or structural. As MASCARET is based on UML, it also includes the notion of class (Entity Class).

When reading the ontology, if an artefact matches an instance, MASCARET will then create an Entity. If it represents a concept in the ontology, then an Entity Class will be created in MASCARET. An Embodied Agent in MASCARET is an agent, which means it has its own autonomous behaviors and its own properties. It also possesses a body by way of an Entity.

Algorithms relying on the alignment between ANY-ARTEFACT and MASCARET have also been produced. On a first level, we consider 3D, sound, gestural, haptic and tangible data, and if possible smells and tastes. On a second level, we look at how to manage human activity within the virtual environment. An activity may be, for instance, a series of actions undertaken by machine operators with the goal of manipulating a technical system. This level relies heavily on the first one, because operations may alter the geometry (position, orientation) of part of the system, generate sounds, or necessitate operators (either autonomous agents or LabInVirtuo users) to perform gestures. The main originality of this task will lie in the ability to enrich and modify the digital corpus from the virtual environment. For the first level (3D objects, sounds…) altering raw data from the VE is not necessarily relevant; however, this becomes relevant in the case of semantic data. Conversely, describing activities, operations and gestures in the virtual environment through demonstration is more pertinent.

3.3 Embodied Conversational Agents

The second obstacle lies in designing interactions with Embodied Conversational Agents (ECAs) and VEs. ECAs are meant to act as interfaces between users and the knowledge in the informed virtual environment, extracted from or bound for the digital corpus. The first goal is to provide ECAs with the ability to understand questions and information expressed by the user and to verbalize answers and information. The ECA's verbalizations will be based on classical text-to-speech techniques, but their content will arise from the ECA's reasoning about the knowledge base of the informed virtual environment. Our objective is not to work on automatic natural language processing. Here, the originality is we can devise a grammar based on the metamodel used to design the informed virtual environment. The second goal is to design the algorithm ECAs will use to reason about the knowledge base and user interactions within the VE. The aim is to offer new modes of interaction (haptic, gestural, tangible…) to query or inform the knowledge base through agents. Agents must also be able to reason to generate new interactions with the users. For instance, An ECA must be able to answer users' questions, pinpoint deficiencies in the knowledge base (such as a 3D object with no semantic data) or inconsistencies (an item with different names given by different users). From these interactions, new knowledge will emerge, and this knowledge will be relayed to the digital corpus.

4 Data Restitution

Designing facilitation situations in virtual environments designed according to the proposed method involves three roles whose relationship is presented on Fig. 5.

(1) The history expert is a specialist in the research field and has experience with the notion of industrial cultural landscapes. From the knowledge in the field about a given cultural landscape and ANY-ARTEFACT meta-ontology, they create a specific ontology for their field which will be automatically aligned with MASCARET.
(2) The facilitation expert has high levels of expertise in history and digital humanities. They define generic facilitation actions that will serve to guide or correct the user within the environment.
(3) The facilitator: from the data provided by the history and facilitation experts, they design facilitation scenarios, that is, situations in which the user will perform actions and interact with items in the environment. These scenarios involve the acquisition of knowledge or procedures and are adapted to fit different audiences.

Fig. 5 The organization of roles to develop facilitation scenarios with the LabInVirtuo method (*Diagram* R. Querrec, M. M. Abiven)

5 Conclusion and Perspectives

We consider the industrial landscapes represented by the use cases as sensory landscapes that solicit different senses. By sensory landscape, we mean an environment where the senses are solicited either in terms of bodily context or by participating in the industrial activity through the information they provide.

In this project, we would like to continue the work within this framework by trying to represent in the environments the sensations felt by former users of the systems. Currently, the immersion of the user in a virtual environment and the possibility of carrying out actions solicit a certain number of senses (sight, hearing). To make this immersion as complete as possible, reflections are engaged in order to solicit other senses such as touch and smell. A more advanced study of sensoriality would allow us to get as close as possible to these industrial landscapes and thus, to express specific information that informs us about society [22].

When it comes to cultural heritage, two notions are essential: those of authenticity and integrity. Authenticity corresponds to the knowledge and understanding of cultural heritage, but also to its meaning [29]. This authenticity is ensured by verifying the sources of information about its relevant values as specified in the Nara Document on Authenticity (1994) which represents a key reference for the recognition, conservation and restoration of cultural heritage. The conditions of integrity, on the other hand, require judging the extent to which the property possesses all the elements necessary for the expression of its value and that it offers a complete representation of the characteristics that convey the property's meaning. In this project, we would like to be able to express information related to these two notions. Indeed, authenticity and integrity data must be represented in ontologies by historians. These expressed data aim at guaranteeing the scientific reliability of this cultural heritage, from the collection of the historical data to the presentation of the RSIVE to the final public.

We plan to undertake two distinct experiments to test our initial hypotheses. One is a laboratory experiment, during which we will compare ontologies created while immersed in LabInVirtuo with ones built using traditional methods (i.e. by describing them in Protege or OntoMe). The other experiment will be conducted in a museum setting, as a temporary exhibition. Visitors will be presented with a facilitation scenario using LabInVirtuo. We will collect qualitative data about their memorizing level and understanding of the subject, to compare LabInVirtuo with more traditional facilitation methods.

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Augmented Reality for the Accessibility of Architectural Archive Drawings

Laura Farroni, Marta Faienza, and Matteo Flavio Mancini

1 Introduction

The cultural heritage represented by architectural drawings preserved in Italian public and private archives has been the object of attention by the contexts institutionally responsible for their management in terms of preservation, description, and fruition. As digitization processes in the archival sector have become established and platforms dedicated explicitly to architects' archives have been created, ways of managing the accessibility of information and strategies for valorization have been experimented.

In particular, two needs emerged: to place the interpretation of drawings alongside their archival description, thus showing their role as a witness of the thought and poetics of the authors and their cultural context; to pursue the creation of digital products with differentiated accessibility goals and use possibilities by a diverse audience that, increasingly, is accustomed to interaction with digital interfaces in the exhibition field. The essay presents some experiments by the authors dedicated to Augmented Reality for architectural design, the analysis of some processes for elaborating models and their optimization related to the specific output chosen.

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2 Augmented Reality for Archives and Architectural Design

Augmented Reality technology allows digital content to be superimposed on the real environment, enriching the user's perception and interaction with the environment and providing visual information that the senses could not directly detect [1]. The use of this technology has increased rapidly in recent years as a reaction to the intense and rapid stresses arising from the digitization of content and the massive public use of technologies for research and outreach.

A survey of the current research was necessary to better understand this technology's potential and its applications for the enhancement and communication of architectural drawing. Initial analysis shows that, although AR can undoubtedly be adapted to many uses—in design and planning, in advertising contexts, in the education sector, in the military or the videogame sphere—its use in the cultural heritage sector, as a tool for communication and valorization, has been rapidly increasing in recent years, also due to the pandemic. Indeed, Augmented Reality makes cultural heritage more accessible and usable, both as a source of study and research for specialized users and as cultural content for a broad and diverse audience.

It also emerges that the applications of Augmented Reality can be of different types in the field of Cultural Heritage. The experiments offer different application fields: in the museum sector, for exhibitions and as a tool for fruition, for knowledge and communication of urban development and architectural design, in experiments on architectural forms and as a tool for archives. The relationship between Augmented Reality and the museum sector represents the natural outcome of a long digital evolution process sweeping this field. Using this technology transforms the visit to the museum into a new experience, fostering in-depth knowledge and enriching the enjoyment of the artefacts on display with multimedia content and allowing the visualization of three-dimensional digital reconstructions, specially elaborated for the exhibited materials. Experiments in this area are numerous, and although they pursue the same goal, they use different technologies and application solutions.

Much research is aimed at developing museum displays made using only the Augmented Reality technique. For this, they must ensure the full integration of objects with the real environment. In these cases, it is necessary to use markerless (featured-based) systems, in which the position and orientation of the device are calculated in real-time without relying on the reading of individual markers but based on the interpretation of the geometric and morphological characteristics of the surrounding environment [2, 3]. However, these solutions are not always adequate, such as in the case of an archaeological area, where environmental conditions, which change and differ from time to time, influence the construction of an unambiguous reference system between virtual space and real scene [4]. To overcome this issue, it is possible to insert markers that establish a reference system for the AR application, which can place digital content in the same framing as the elements of the real environment. Hypothetical three-dimensional reconstructions from archaeological remains can thus be placed in direct relation to the ruins themselves, so that users can experience the original proportions of the architecture more immediately [5]. Similarly, it is possible to develop digital content linked to descriptive panels, accessible through framing a marker placed on the panel itself, to enrich the enjoyment of and interaction with the archaeological remains [6]. Through this technology, it is, therefore, possible to make cultural features more accessible, facilitating access to knowledge and understanding of archaeological remains, which are often intended only for specialized audiences.

There are numerous experiments developed by museums, which are creating Augmented Reality apps to expand the museum space and offer innovative experiences to visitors of the museum, and in some cases, to parts of the city. Among the most recent of these are the *La visione di Leonardo* project of the *Museo Nazionale della Scienza e della Tecnologia Leonardo da Vinci* in 2022 [7], and the *MRT Virtual App* of the *Musei Reali Torino* in 2022 [8]. In addition, it is essential to point out, among those carried out by public institutions, the publishing in 2019 of the project *Italiani—La nostra storia* by the *Archivio Luce* [9], which offered extra content in AR accessible through smartphones linked to the paper files.

AR can also be an auxiliary tool for in-depth historical and urban knowledge of cities. For this reason, it configures itself as a guide and useful framework for interventions in the restoration, conservation, functional integration and innovation of the built heritage [10]. In the same way, therefore, it can become a tool for communication and knowledge of architectural design. From reading and interpreting graphic materials of ephemeral architecture [11] or unbuilt projects [12], it is possible to investigate and restore the style, poetics, and thinking underlying these projects and, through three-dimensional and digital renderings, to understand the true character of these architectures. AR can also be used as a tool for geometric experimentation on architectural forms [13], where learning can result through direct experimentation on models, understanding of existing forms, and room for imagination and design of new ones.

From this picture, it emerges that although experiments and applications of Augmented Reality are numerous and increasingly involve the field of architecture, built or only drawn, AR experiments on archival drawings, on the other hand, are relatively small. Their analysis can facilitate the understanding of the designs and creative principles followed by the designers, who often entrust part of their design methodology to graphic expression in the transition from architectural idea to its realization. Augmented Reality applied to the interpretation of archival drawings and the consequent realization of three-dimensional models can be a tool for communication and knowledge of the architectural project, even unbuilt, as is the case of the AR application to the case of Pier Luigi Nervi's Casa girevole [14].

Starting from these considerations, the research presented here follows some experiments performed by the authors in the educational field on a selection of unbuilt projects by architect Francesco Cellini (1944), the analysis of which began with three-dimensional reconstruction based on the design drawings and arrived at the realization of specific Augmented Reality Applications addressed to the explication of the relationships between the original drawings and the reconstructive digital models.

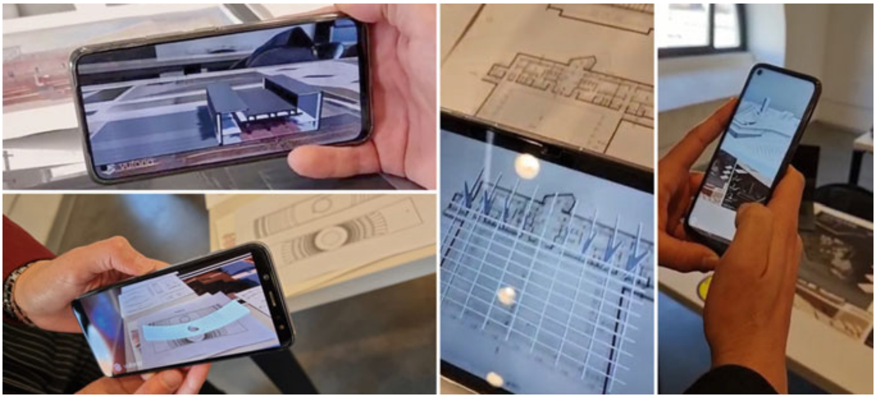

Fig. 1 AR examples of unbuilt projects by architect Francesco Cellini (Modeling and AR Apps by students: C. Attolini, M. Gaggio, F. Lo Re, D. Marcotulli, L. Pellegrini, D. Piccolo, F. Ranalli, R. Scisciola. Photo by L. Farroni)

The methodological approach chosen for the experiments starts from the assumption of not using AR as a digital surrogate for a final model but as an opportunity to show elaborations linked to the characteristics of each project. Therefore, the choice was not to link a whole 3D model to the original drawings but specially elaborated models to show the spatial qualities of the projects (cutaway models), or their constituent elements (exploded models) or specific families of significant elements (thematic models) such as structural ones (Fig. 1).

3 Experiments on Studio ABDR and the Redevelopment of the Crypta Balbi

The experimentation subject of this contribution is built on these previous experiences. It is part of ongoing research concerning architectural drawings funds by Italian designers on which different data interpretation and content visualization strategies have been applied through digital technologies. Specifically, it aims to show the cultural and technological process of using Augmented Reality (AR) to the drawings for the unbuilt project for the redevelopment of the Crypta Balbi in Rome (1984–1986) by Studio ABDR, which has been active since 1982 on a national and international level [15]. This project is of particular interest for several reasons: it is representative of the ABDR's thought and design language, which contributed to the history of Italian architecture in those years and shows the cultural references that conditioned its poetics (O. M. Ungers, P. L. Nervi, Five Architects); it requires the management and visualization of complex spatial configurations; it insists on a central archaeological area of the city of Rome and therefore confronts its stratifications.

The area occupied by the Crypta Balbi block is located in the historic center of Rome—between the areas of Piazza Venezia, Largo di Torre Argentina, and Piazza di Campitelli—and is surrounded to the north by Via delle Botteghe Oscure, to the south by Via dei Delfini, to the east by Via Michelangelo Caetani, and to the west by Via dei Polacchi. This area, which currently houses one of the four main branches of the *Museo Nazionale Romano*, is characterized by the exceptional legibility of urban stratification, ranging from the Theater of Lucio Cornelio Balbo (first century B.C.) to the nineteenth century gutting and the settlement of the museum opened in 2000.

The corpus of archival drawings used for the analysis and three-dimensional reconstruction of the Crypta Balbi redevelopment project is composed of different typologies: some study sketches, a general plan, a vertical section, an elevation, an axonometry, and a summary table that contains, superimposed and interwoven, two more elevations and an additional section. Moreover, a brief report supplements these graphic representations with conceptual and functional aspects. The design sketches describe a series of ABDR projects, which originated in different contexts (competitions and dissertations), for the central area of Rome, included between Piazza della Rovere to the northeast and the Crypta Balbi to the southwest. Four planned interventions concern areas of the historic centre characterized by urban voids and historical stratifications*:* Piazza della Rovere, Vicolo della Moretta, Piazza del Parlamento, and the Crypta Balbi block. These are quick sketches, executed with mixed technique, that locate the interventions in the plan of the central area of Rome, defined by the presence of the river Tiber, some notable elements such as Piazza Navona and the Trident, and by grids representing the course of some urban blocks (Figs. 2, 3).

From these drawings, even in their extreme conciseness, specific architectural values emerge, linking the four projects and characterizing this phase of ABDR's production: the stereometry of volumes interrupted by single diagonal cuts, the themes of the bridge and the tower, and the adoption of grids that define both planimetric scans and the elevations surfaces as well as three-dimensional grids. A more refined sketch concerns the head of the intervention on Via dei Delfini. It provides suggestions regarding the use of at least two different materials alternating between the bands of the basement, elevation, and crowning.

The same elements emerge from the translation of the sketches into the available technical drawings. In particular, the general plan and the axonometry highlight the theme of diagonal cutting, thanks to the choice of a special oblique axonometry in which two axes of reference are mixed (the vertical one and the horizontal one), a graphic choice that recalls the typical axonometries by John Hejduk (1929–2000) of Five Architects. The themes of modular grids, bridge elements and towers also emerge from the sections and elevations. The last elaboration, a panel with the superimposition of several drawings and colored screens, fully represents the project and its main features. There, it can be recognized: the general plan, sampled with a red hatch, in which the project features are red and those belonging to the context are black; the axonometry of the intervention purged of the context volumes drawn in black; above, colored in yellow the elevation on Via dei Delfini, again isolated from the context; below, one more elevation on Via dei Delfini, this time partially inserted

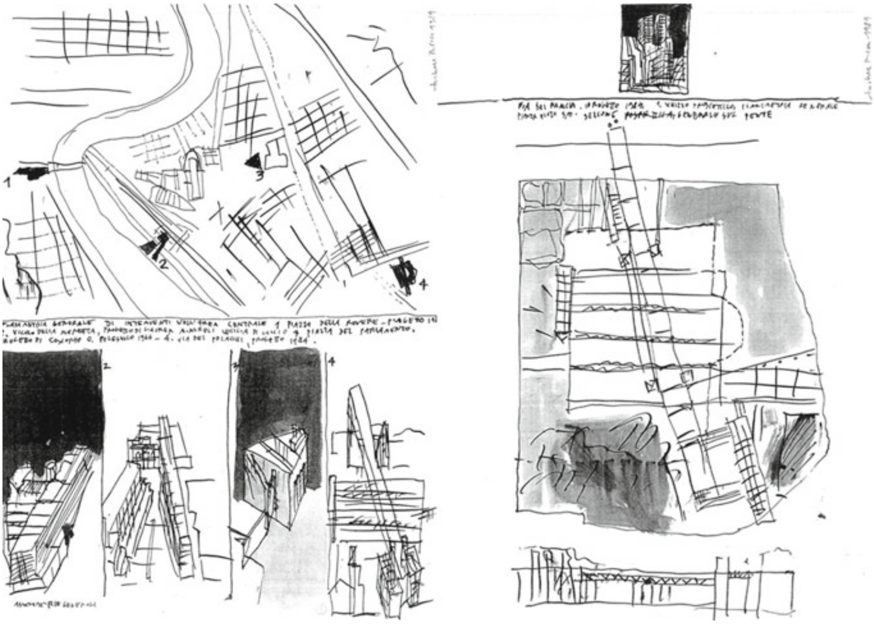

Fig. 2 Sketches for the designs of the central area of Rome (left) and for the Crypta Balbi (right) (Drawings by M. Beccu, FFMAAM, Fondo Francesco Moschini Architettura Arte Moderna)

into the context and colored in yellow and light blue; and still further down, a cross-section roughly parallel to Via delle Botteghe Oscure colored in light blue. The complexity of this representation is suggestive because the layering of the drawings seems to allude to the corresponding layering of the intervention, of the ancient on the ancient and the new on the ancient (Fig. 4).

4 Three-Dimensional Reconstruction and Analysis

The reconstruction of significantly altered, lost [16] or never built architectural contexts and artefacts and their analysis is a well-established practice in several fields, has received a strong impetus from the advent of digital techniques [17] and has had to adapt to the claims of the London Charter and the Seville Principles for transparency of the sources and procedures adopted, directing scholars toward the search for reliability assessing methods of proposed reconstructions and its visualization. This has led to the development of research concerning both the connection between three-dimensional reconstructions and sources and the definition of their level of reliability [18–21]. The process of three-dimensional analysis and reconstruction of unbuilt architectural projects adopted in this research can be summarized in four main stages: collection and reading of sources, both graphic and textual, referring to

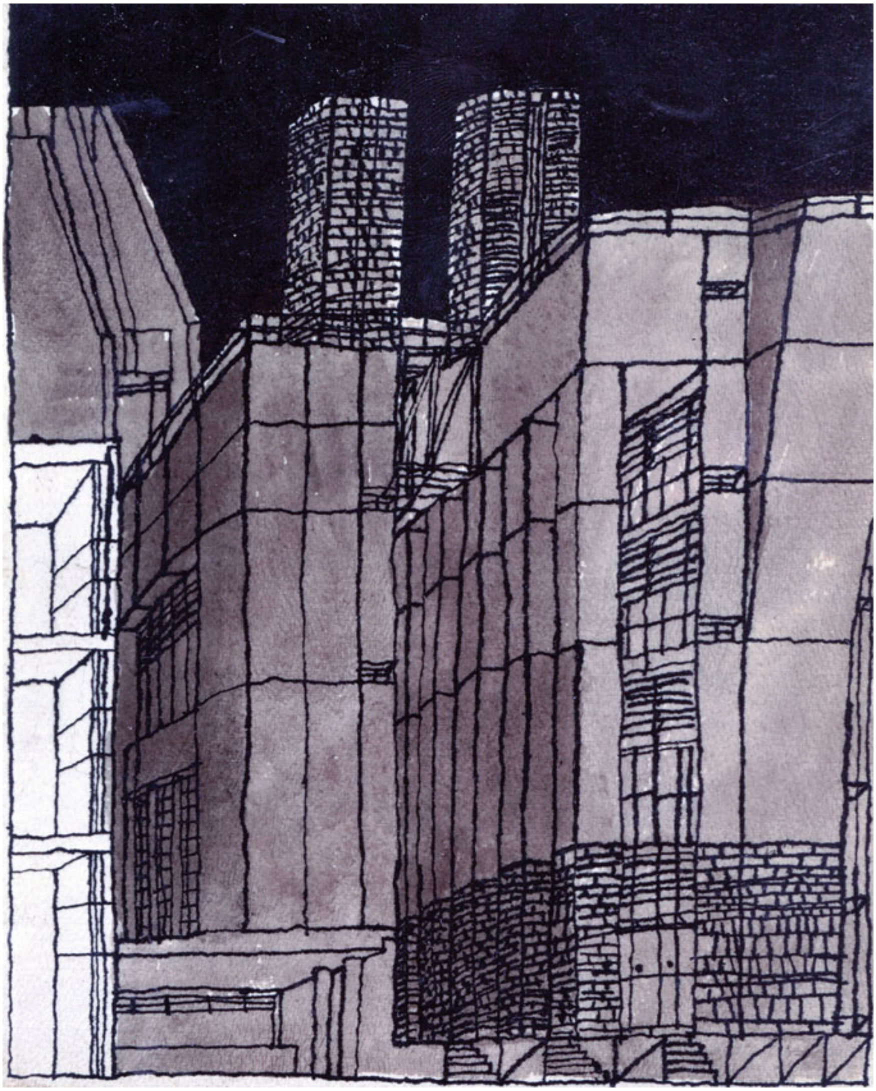

Fig. 3 Sketch for the Crypta Balbi redevelopment project, access on Via dei Delfini (Drawing by M. Beccu, author private archive)

the project; systematization of the information and its two-dimensional processing; three-dimensional interpretation of the project; and management of different types of outputs depending on the purpose, the final recipient, and the available technologies (Fig. 5).

The reconstruction of the project for the Crypta Balbi considered the available sources by distinguishing their use: the sketches and technical report were considered

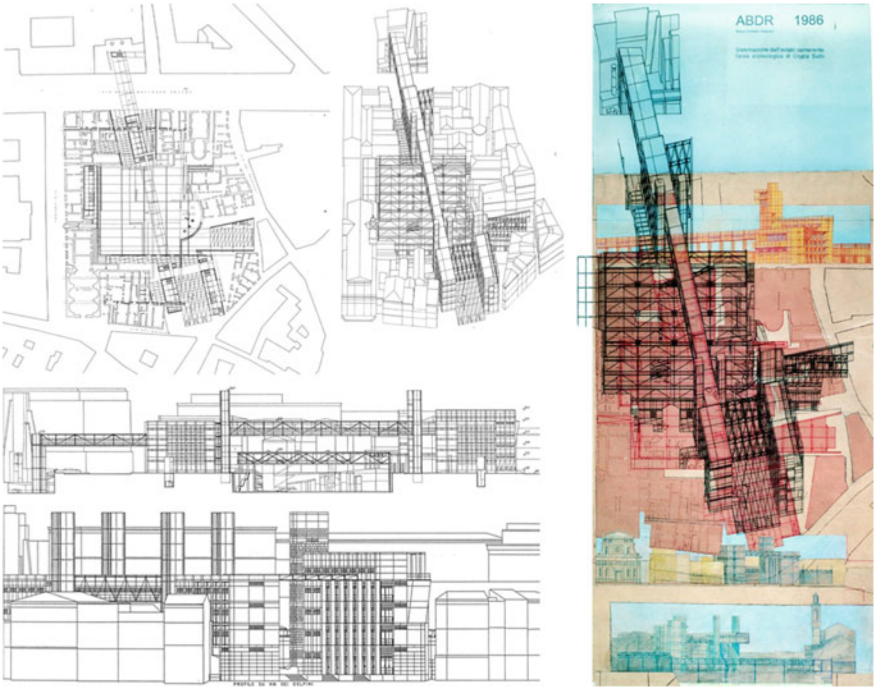

Fig. 4 Technical drawings for the Crypta Balbi redevelopment project (Drawings by ABDR Studio, ABDR Archive)

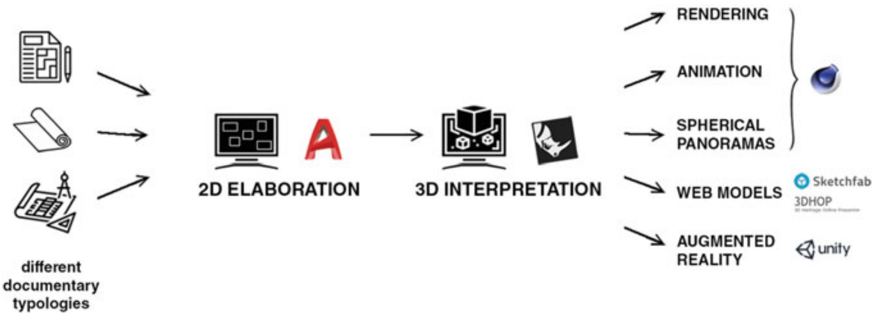

Fig. 5 Diagram of the methodology followed for three-dimensional reconstructions (Image by M. Faienza)

at the beginning of the process because of their value as a summary, a presentation of the general concept and the essential elements of the project, while the technical drawings were instead used as a database for the redrawing and modelling process. The redrawing of the available technical drawings allowed us to define both the morphological and dimensional aspects of the project and enabled the normalization of inconsistencies, while highlighting the parts that are not fully described by the drawings. Several project choices stand out from this first phase: the inclusion in the block of two systems of orthogonal elements rotated between them by thirteen degrees, the first referring to the excavation cover that takes up and regularizes the existing fabric matrix, and the second composed by the axes of the pedestrian bridge and the east entrance to the block; the existence of two types of lattice meshes in modular relation, in which the modules of the canopies covering the three accesses to the block are submultiples of the archaeological excavation cover, whose modules measure 12.00 × 5.00 m; the insertion of new volumes at the accesses along the perimeter of the block.

These two-dimensional drawings were then used for the creation of the three-dimensional reconstruction of the project and the volumetric reconstruction of the context. The transition to the three-dimensional analysis of the project, implemented through the elaboration of axonometric exploded views and the extraction of new sections, which were not present in the original documentation, highlights other features: the elevation sequence of the ancient and project elevations, which oscillates between the − 6.00 m of the archaeological excavations, the reference elevation of the current street level, the + 3.00 m of the practicable cover of the excavations, the + 8.50 m of the walkway over Via delle Botteghe Oscure, the + 12.00 m of the bridge crossing the archaeological area, and the + 25.70 m reached by the towers; the contrast between horizontal elements, both areal and linear, and the vertical ones; and the ability to essentially maintain the identity of the area, empty in the center and built at the edges (Fig. 6).

Three-dimensional reconstruction has also allowed for various digital outputs directed at communicating the spatial and perceptual qualities of the project and, where technically possible, the level of reliability of the reconstructions through the adoption of specific graphic codes characterized by the adoption of variable iconicity levels depending on the accuracy of the reconstruction [22]. In particular,

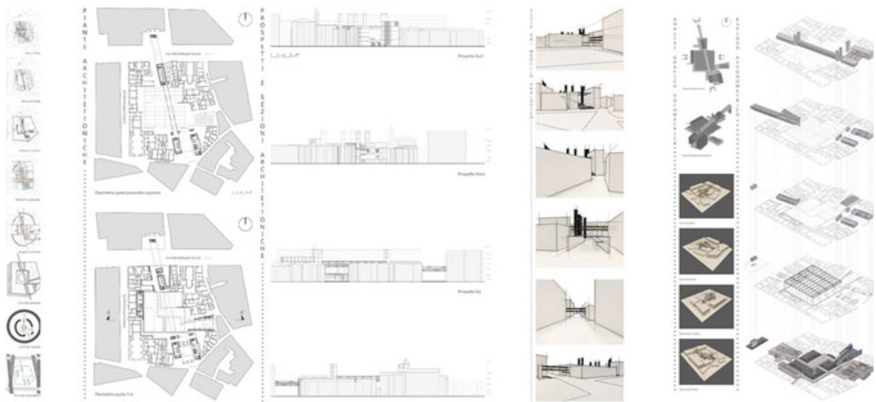

Fig. 6 Analysis panels of the Crypta Balbi redevelopment project (Image by students: C. Fuduli, B. Gaveglia)

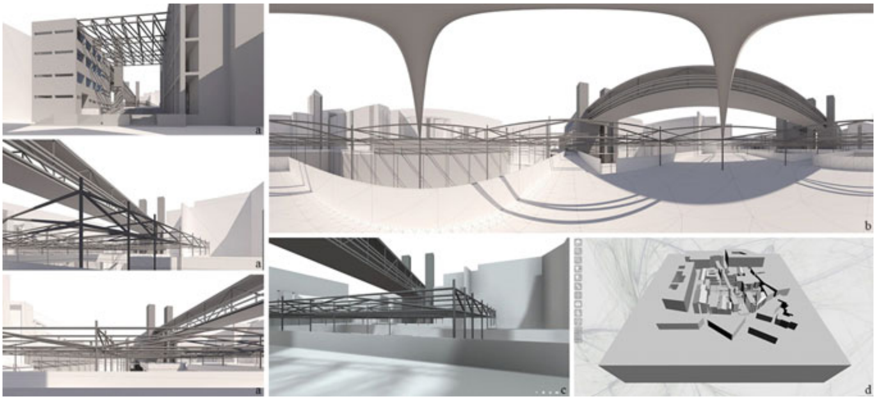

Fig. 7 Outputs produced for the three-dimensional reconstruction of the project for the Crypta Balbi: **a** series of renderings; **b** 360° renderings; **c** 3D model on Sketchfab platform; **d** 3D model on 3DHOP platform (Modeling and rendering by M. F. Mancini)

outputs have been produced through different techniques, ranging from traditional computer-generated imagery (CGI) applications, such as flat and spherical renderings and animations, to the adoption of web-based solutions, such as virtual tours and interactive 3D models. These products cover a broad spectrum of levels of interaction, visualization, and accessibility, thus enabling them to reach different audiences with their respective needs for autonomy and insight [23] (Fig. 7).

5 The Process for Augmented Reality

As part of this research, the aforementioned types of digital products were complemented by the experimentation of AR, developed in Unity through the Vuforia plug-in, with the creation of a specific App. The relationship between sources and reconstruction triggered a reflection on the scientific foundations to be put behind critical and methodological choices. In fact, the technical process of AR production is accompanied by a critical process of choosing the drawing to be entrusted with the beginning of the 3D visualization (target) and matching it with models elaborated to highlight the main qualities of the analyzed project. In particular, the three-dimensional reconstruction of the project allowed us to understand the spatiality generated by the themes emerging from the drawings and to specify the relationship with the urban context.

As a result of these considerations, it was chosen to include as digital content of Augmented Reality not only the three-dimensional model but also a series of materials that could add information and clarify some design choices, such as the survey of the context in its current state, one of the main project elevation, the one on Via dei Delfini, and finally the three-dimensional model of the project reconstruction.

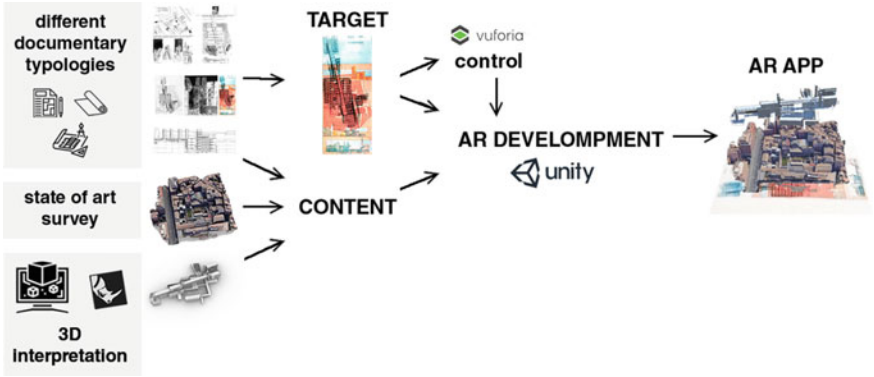

Fig. 8 Diagram of the methodology followed for Augmented Reality experimentation (Image by M. Faienza)

The most emblematic project design for the competition was chosen as the target. This consists of a palimpsest of drawings in which the plan, elevations, a section, and an axonometric view are interwoven and correspond, presenting the complexity of the intervention and its supporting themes: the paths and the structural latticework. The very structure of the chosen drawing is, on the one hand, particularly evocative and representative of both Studio ABDR's architecture and graphic representation. On the other hand, it presents a high complexity level that may appear as a tangle to be unraveled, especially to a non-specialist audience (Fig. 8).

Therefore, two applications were developed, experimenting with different solutions for the relationship between the elements, specifically using a static and a dynamic configuration.

In the first application, a static configuration was used, where it is possible to observe a three-dimensional exploded view that allows exploring the two levels that constitute the project: the urban-archaeological space and the context, the reconstruction of the ABDR project. The elements appear distinct but the relationships that bind them are transparent, allowing them to overcome the interpretative difficulties typical of a highly codified language such as technical architectural drawing (Fig. 9).

In contrast, the second application presents a dynamic configuration of the same elements. Initially, the three-dimensional model of the ABDR project reconstruction results directly embedded into the context, facilitating the understanding of the relationships that bind the different elements; at a second moment, the three-dimensional model, after a vertical translation, results separated from the urban context in such a way that the elements are recognizable and can be analyzed separately. Thus, this dynamic configuration allows us to visualize the elements in their singularity and relationship to each other, allowing for a clearer understanding of the project as a whole and facilitating the process of increasing accessibility (Figs. 10, 11).

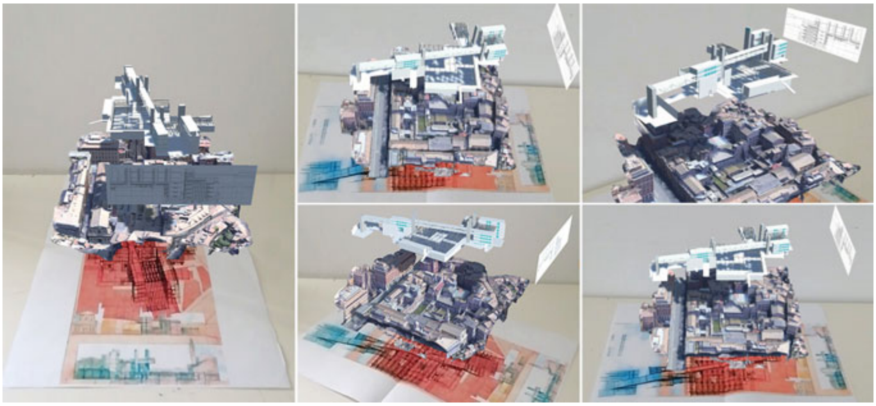

Fig. 9 AR experiment, static configuration (*Modeling* M. F. Mancini; AR App: M. Faienza)

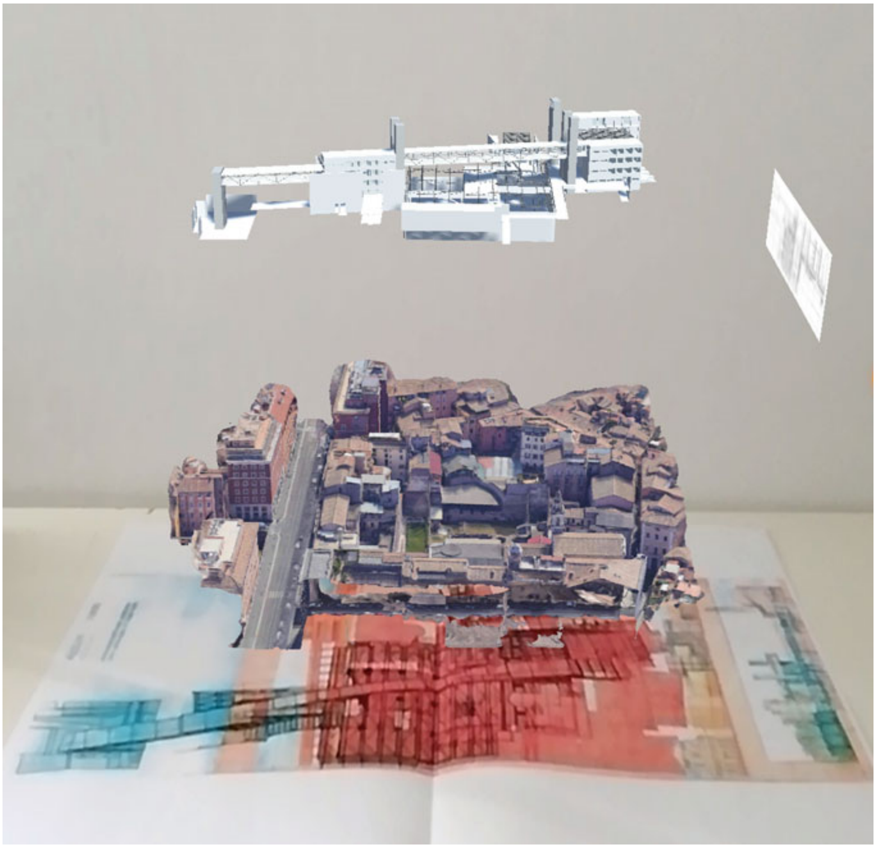

Fig. 10 AR experiment, dynamic configuration (*Modeling* M. F. Mancini; AR App: M. Faienza)

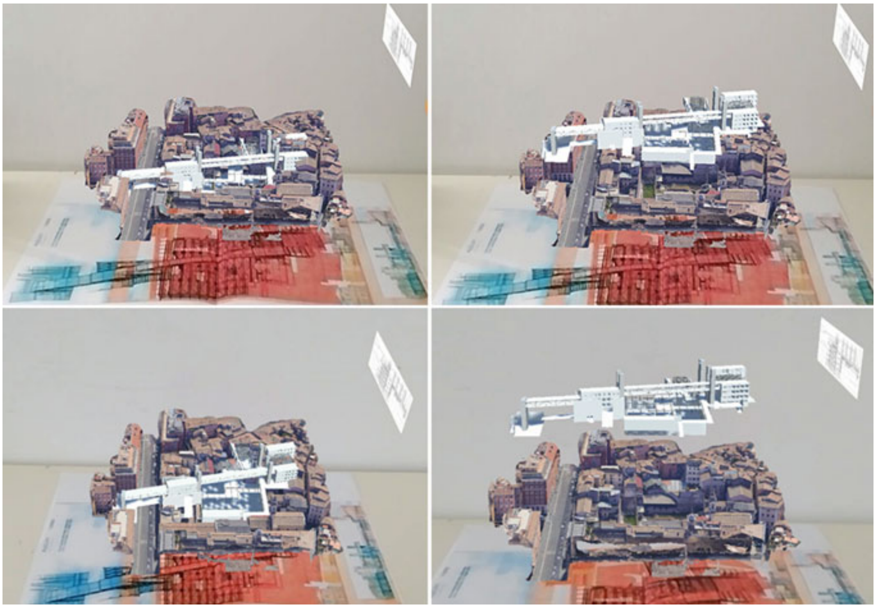

Fig. 11 AR experiment, a set of frame from the dynamic configuration (*Modeling* M. F. Mancini; AR App: M. Faienza)

6 Conclusions

The AR experiments presented here are intended as communication tools for the architectural project and its study, adding to the path that begins with traditional drawings, goes through digitization, three-dimensional analysis and restitution, and reaches the realization of the multifaceted digital outputs.

Some critical technical issues have emerged, such as the distance between the target and other content, which have been addressed several times. This, in fact, must be designed to ensure that all the elements can be clearly distinguished in the visualization of the application. In addition, the need to optimize the three-dimensional models emerged to ensure their rapid recall, and thus effective use, during regular use of the application.

It seems clear that the second application dynamic configuration can be a further step forward since the animated model allows the project to be understood both by referring to its context and as an individual element.

Thus, it remains open to increasing the animated elements of the model to show better the relationships between the model, the drawings, and any other elements deemed necessary.

In conclusion, the experiments of AR applications to the ABDR Studio drawings for the Crypta Balbi area redevelopment project demonstrate the potential of this technique on these specific cultural assets as well. Indeed, project drawings, in addition to their explicit value as artefacts, carry the implicit value of the strategies and characteristics—spatial, configurational, structural, and technological—of the projects to which they refer. Understanding the implicit value requires the specialized ability to decode the language of architectural drawing, and the application of AR techniques, as we have attempted to illustrate, makes explicit the relationship between drawing and project through the simultaneous viewing of one and the three-dimensional reconstruction of the other, allowing increased accessibility to the individual architectural work and the design culture that generated it. This latter aspect is perhaps the most significant as it represents an essential evolution from static and dynamic visualizations of three-dimensional reconstructions that leave the user in a position of mere observation. The visualization and interaction that AR allows, the presence of animations appropriately designed to highlight the qualities of the architectural design, put the user in a position to interact playfully and prompt him or her to an exercise in interpretation.

The same reasons make it conceivable to include AR applications not only in the analysis phase of architectural projects but also as a verification tool during the design process, internal communication among the technicians involved and external to other audiences involved in the building process.

Thus, it seems evident how the multifaceted potential of AR applications can foster the process of valorization and dissemination of cultural heritage, not least archival heritage, traditionally used only by academic users, for which possible installations to support musealization processes can be foreshadowed.

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Invoking Filarete's Works Through Interactive Representation: The WebVR Project of the Baths Courtyard (Ex Ospedale Maggiore in Milan)

Fabrizio Banfi and Daniela Oreni

1 Introduction

Augmented Reality and Virtual Reality (AR-VR) have emerged as powerful and effective tools for supporting the dissemination, enhancement, and management of built heritage. These technologies provide a means of visualising interactive digital environments, historical reconstructions, and innovative information-sharing methods. On the one hand, AR-VR offers enormous potential for constructing engaging narratives around the evolution of buildings over the centuries. On the other hand, it can also be a valuable aid in the maintenance and conservation of the asset through the data registration and querying phases. A geometrically accurate 3D model, which captures the building's features and characteristics, must be constructed, considering the information available in various forms, such as archival drawings, historical documents, images, texts, and videos. The research aims to create a tool that facilitates virtual-visual storytelling (VVS) of the research case study's history to support the knowledge dissemination process. In this context, understanding the differences between AR and VR, and their future developments and applications is crucial.

Various WebVR frameworks and APIs have been developed, enabling web developers to create VR-AR applications without dealing directly with the hardware. One of the primary challenges in creating compelling VR experiences is achieving low latency, high accuracy, and a high capacity to process data quickly. This poses significant hardware and web platform development challenges. Consequently, efforts

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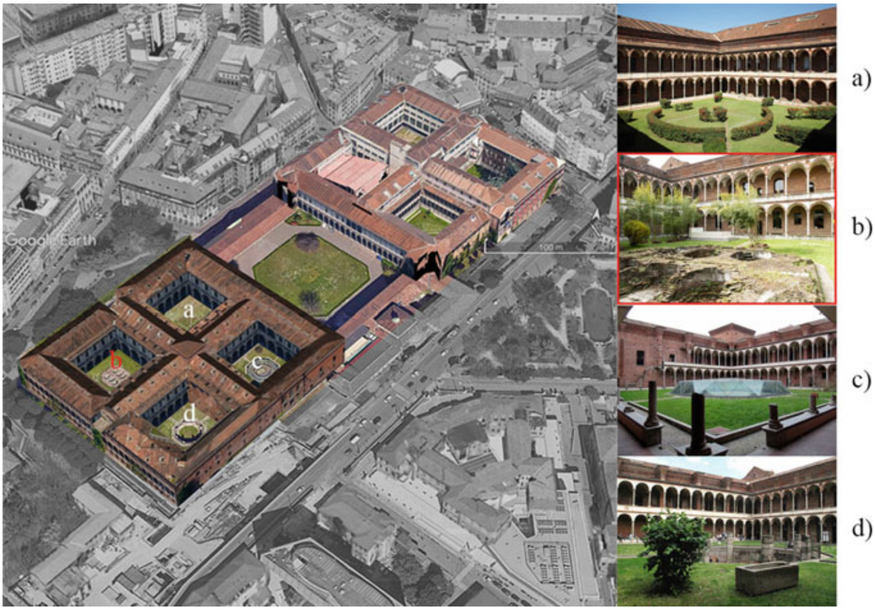

Fig. 1 The courtyards of the Ex Ospedale Maggiore in Milan: **a** Pharmacy, **b** Baths, **c** Icehouse and **d** Woodshed (*Source* Google Earth)

are being directed towards investigating how these two forms of representation can merge and create osmosis to expand heterogeneous contents via the web, thereby creating a customisable platform for knowledge creation and dissemination that can be accessed from home, school, or work. The research aims to explore the creation of a WebVR experience (for VR desktop and mobile devices) of the Baths Courtyard of Ex Ospedale Maggiore in Milan, designed by Filarete (Fig. 1).

2 The Research Case Study

The selected case study, namely the ex-Ospedale Maggiore in Milan, a fifteenth-century building, is distinguished by its extended construction history, comprising of modifications, alterations during construction, and augmentations necessitated by the evolving functional requirements of hospital spaces over the centuries. Additionally, the structure was subjected to a catastrophic event—the World War II bombing—which inflicted considerable damage upon various segments of the edifice. Consequently, the conservation and reconstruction project leaders were faced with the daunting task of deliberating what and how to rebuild [1]. Presently, the building represents the outcome of a complex and multifaceted historical stratification, encompassing an array of actions of diverse natures, including re-interpretations of various sections that were undertaken during restorations in the twentieth century. The chronological reconstruction of these events, spanning from Filarete's design to the present day, is not always immediately discernible on the current structure, despite being known to scholars and experts. The building has been the subject of numerous research and in-depth studies of a historical, architectural, and archaeological nature in the past; vast and varied is the literature available on the ex Ospedale Maggiore complex. Nevertheless, despite serving as the current headquarters of the Università Statale of Milan and attracting many students, researchers, and professors, the historical significance of this location remains relatively unexplored and underappreciated by visitors. While guided group tours and descriptive totems provide some limited insight into the complex's rich history, there is considerable untapped potential for cultural enrichment through VR technology. Such an approach would allow for the development of virtual narratives highlighting the building's multifaceted history, leveraging the vast array of available graphic, iconographic, and textual sources. Through this avenue, research and initiatives can unlock the material and intellectual values accumulated within the building over the centuries, often accessible only to select experts.

2.1 Historical Notes

The Ca' Granda is the hospital structure established at the behest of Francesco I Sforza as a hospital for poor people to provide free medical care to all Milanese citizens, improving the city's health service efficiency. The building was designed by Antonio Averlino, known as Filarete (1400–1469), and was to be built on land that was partially vacant or occupied by buildings to be demolished, including Palazzo Torelli, in an area southeast of the city of Milan, within the medieval walls and overlooking the inner circle of the Naviglio (General plan of the Hospital, 1451 ca. [2].

It was the Duke himself who was the first benefactor of the new *Spedale* (hospital), donating, in the area of Porta Romana, this large piece of land (400 × 160 Milanese *braccia*) that was located at the back of the church of San Nazaro in Brolo, included between the current Via Francesco Sforza, Via Laghetto and Via Festa del Perdono, also financing the start of the work. The proximity of the Naviglio, consumed to derive water from it in order to channel it inside the hospital and use it for hygienic purposes, according to an engineering model at the forefront of European states in the second half of the fifteenth century.

Filarete's 1451 drawings for the new hospital (Firenze, Biblioteca Nazionale, Magliabechiano, foglio 82v), reported in his *Trattato di architettura*, (Presumably written between 1461 and 1464, it was never published by Filarete [3]) show an ambitious, large-scale project, pandering to what was the Duke's desire to create a large centralised hospital structure that would be able to replace all those small facilities located in the city, a sort of infirmaries that until then had provided precarious and ap-proximate care. The novelty of the idea of the *Spedale* consisted not only in the centralisation of expertise in the medical field, but also a rationalisation in the management of care. Using the square module, the Florentine architect proportioned the new structures in plan and elevation [4]. Thus, starting in 1459, the building of the first cruise or men's infirmary took place, corresponding to the western part of the present building, along today's Via Festa del Perdono; Filarete worked on it from 1456 to 1465, the year he abandoned the construction site to return to Florence. Historical and archival research reports how the porticoes' foundations and impost masonry were already finished in 1461, up to the height of the string course of the first order. Following this, the construction work was carried on by Lombard architects: there were the interventions of the Solari brothers and, at the end of the sixteenth century, the building of the porticoed side towards the current central courtyard of the Cà Granda, in the courtyard known as the *farmacia* attributed to Giovanni Antonio Amadeo, who concluded the so-called Crociera filaretiana (Filarete's Cross), consisting of the four oldest courtyards of the complex. The execution of construction work on the so-called Baths courtyard, the westernmost of the four (Fig. 2), was personally directed by Filarete from 1460 until 1465. The buildings were then completed by Boniforte Solari (c. 1429—c. 1481), who decided to finish the structures by modifying some of the dimensions and proportions of Filarete's design, perhaps going more in favour of an architectonic language and manner of the building still linked to the late Gothic Lombard yard.

Originally, the Baths courtyard served as a facility for accommodating nobles willing to pay for lodging and was referred to as the Gentlemen's courtyard. Subsequently, it was renamed as the Separate courtyard of the women, due to its predominant use for women in labour, particularly in the vicinity of the church of San

Fig. 2 The Baths courtyard of the Ex Ospedale Maggiore in Milan (*Photo* F. Banfi, D. Oreni, July 2022)

Nazaro. However, it also catered to both male and female patients afflicted with conditions such as scabies and mental illness, providing a measure of seclusion from the congested thoroughfares of the central Cross. In the early seventeenth century, this room became the Servants' courtyard, used for nurses and orderlies; here were the checkroom, toward the entrance porch, and the laundry, toward the church of San Nazaro. A well is attested in the hospital's plans in the northeast corner of the courtyard.

It was not until the eighteenth century that the Baths building was located in the centre of the courtyard (already present in a plan drawn in 1852), whose octagonal shape had similar plan dimensions to the existing structures in the center of the adjacent courtyards of the Woodshed and Icehouse [5, 6]. Initially, there were only separate baths for men and women; in 1802, semi-cupboards were added, short tubs for partial immersion of the inmates, intended for hydrotherapy [7].

Today the courtyard is characterised by a square layout, and it has two orders of arcades on all sides; in the centre of the courtyard, there are the ruins of what remains of the baths building after the August 1942 bombing and the restoration activities of architect Liliana Grassi.

The buildings facing the baths courtyard house the offices and some classrooms of Università Statale of Milan, but it turns out to be the least accessible of all the Filaretian courtyards, as the access doors to the inner porticos are often closed. It is, therefore, only open to visitors on guided tours or during events such as the Fuori Salone, an international, yearly exhibition that takes advantage of the Cà Granda's spaces for various events.

2.2 The Dissemination Project of Filarete's Works

Similar to the other three Filaretian courtyards, namely the Pharmacy, Icehouse, and Woodshed, the Baths courtyard has been the subject of significant research activities conducted by Politecnico di Milano in recent years. These activities include the use of advanced technologies such as laser scanner, photogrammetry, unmanned aerial vehicle (UAV) survey, and direct survey, as well as graphic restitution, analysis of geometries and proportions, and the study of materials, their state of conservation, and the stratigraphic relationships between the various identified units. The primary objective of these activities is to update and integrate the available surveys and support study and research activities on the state of conservation of different parts of the building.

Numerous drawings and three-dimensional models have been produced over the years, which can now serve as a fundamental starting point for building a virtual model. This model can become a container and tool for narrating various stories about the transformations of the buildings, their uses over time, and their geometric and material characteristics. The virtual model can potentially open up cultural content that was previously accessible only to insiders to a wider possible audience.

Realising that such a virtual tool is updatable and implementable on a continuous basis, a number of in-depth themes related to the construction history of the Baths courtyard have been selected as a model that could be replicated for the other courtyards. This model could serve as a driving force for disseminating and sharing the content of different natures, communicable to different audiences, ranging from students to tourists.

2.3 The Filarete's Module and the Baths Courtyard Porticoes Design

The survey campaigns conducted on Filarete's courtyard and subsequent graphic representations have revealed a building that only partially reflects the original design by the Florentine architect. As noted by Liliana Grassi during the restorations, the square module, which forms the basis of the regular Filaretian representations, is found only partially present. Recent work on geometric-formal analysis of the four Filaretian courtyards has exposed a far more complex and nuanced construction and site reality. This observation is particularly evident when analysing the measurements and proportions of the elements in both plan and elevation of the two orders of the portico and the Baths courtyard. Despite the expectations of a Renaissance plan layout, the number of spans is inconsistent on all sides, with fourteen and fifteen spans present, in addition to the four corner spans. The distance between the columns is also not uniform and raised arches characterise the vaults that cover each quadrangular span. On the contrary, the stratigraphic evidence of an earlier portico, potentially established by Filarete and subsequently modified by Solari in form and proportions, allows for reconstructing a regular course portico on all four sides of the courtyard. This portico would comprise fifteen bays on each side, plus the four corner bays, with square spans and round arches, employing multiples and submultiples of the square module, which Filarete himself mentions in his treatise (Fig. 3).

Fig. 3 The Filarete's module and the Baths courtyard porticoes design. On the left, the plan of the ground floor of the courtyard of the Bagni inserted within the Filaretian square grid of the entire *Cà Granda* complex; on the right, the comparison of the dimensions of the current rectangular bays and vaults on the right floor (on the right) with the square bays virtually built following the stratigraphic signs of a first portico presumably set up by Filarete (*Source* F. Banfi, D. Oreni)

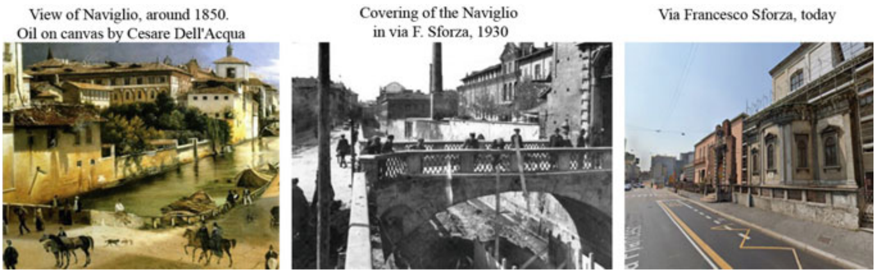

Fig. 4 The main historical phases of Naviglio (*Editing* F. Banfi, D. Oreni)

2.4 The Hospital Water System: The Disposal of Dirty Water in the Navigli Circle

The proximity to the Naviglio, whose waters flowed in a north–south direction, contained to have available, within the hospital, a continuous exchange of water for hygienic water purposes. From a hygienic-sanitary point of view, the hospital designed by Filarete represented an excellence in the European panorama at that time (Fig. 4). As well represented in the map of 1791, drawn by Eng. Pietro Castelli, the water of the Naviglio entered the hospital facilities from the Laghetto, through a complex system of underground circuits entered the building, and then re-entered the Naviglio in the vicinity of the Porta Romana [8]. The so-called *destri* system allowed the discharge of dirty water inside the hospital [9] into the sewers below, all of which could be inspected. Rainwater was also piped inside the structures to be used for hygienic purposes; terracotta conduits are visible and detectable in many parts of the building today (Fig. 5).

2.5 The August 1943 Bombing of the Bath and Subsequent Restoration by L. Grassi

The bombing of Milan on the night of August 7–8, 1943, also affected the building of the Cà Granda, demolishing entire bodies of the building and seriously damaging the structures of the surviving parts. The events related to the restoration activities conducted afterwards are retraced, also with the help of drawings and photographs, in great detail in Liliana Grassi's texts and those of later scholars. As for the courtyard of the Baths, as can be seen in the pictures taken immediately after the bombing, it was mainly the superstructures added later that were affected; the central structure of the baths also saw the collapse of the roof and the substantial destruction of the interior spaces (Fig. 6). Among the most obvious activities carried out during the restoration phase were the removal of both the superstructure and the infill of the two orders of porticoes on the four sides of the courtyard; then those accessory buildings

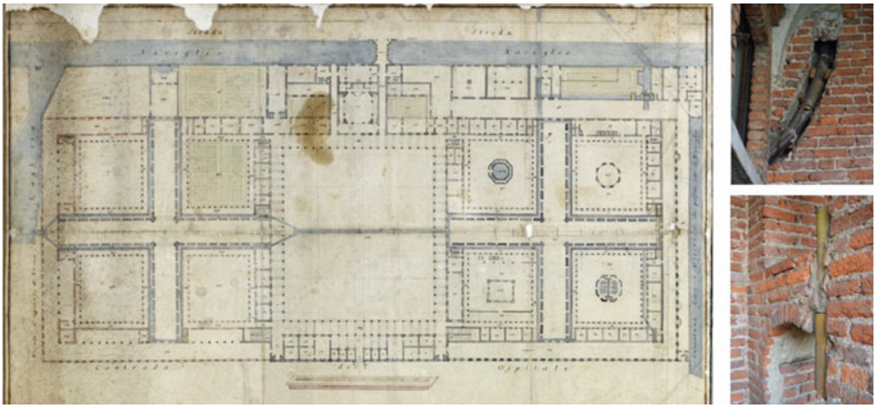

Fig. 5 Plan of the Maggiore Hospital of Milan by the engineer Pietro Castelli, 14 August 1791 (Archivio Ospedale Maggiore) and current images (2022) of the terracotta downspouts still visible today inside the thickness of the walls which collected rainwater for use them for hygienic purposes (*Source* [9])

built close to some parts of the portico, in the courtyard, were removed in order to make the courtyard designed by Filarete and modified by Solari visible again. Similarly, the perimeter walls of the bathhouse building, now totally compromised, were demolished, and of which only the basement structures remain today in ruins.

3 Architectural Representation and Immersive Web Experience

3.1 From Drawings, 3D Surveying to 3D Modelling and Interactive Architectural Representation in the Digital Era

In recent years, in the field of Digital Cultural Heritage, the link between representation, drawing and 3D digital surveying has become increasingly vital, both from a practical and theoretical point of view. As the etymology of the term suggests (from the Latin compound *re-ad presente*, to make past or distant things present), representation is a theoretical-applicative operation of restoring, through significant images, some aspects—formal, metric, structural or symbolic—of a real or just imagined object.

The advantages brought by recent technological developments in the field of surveying, VR and AR modelling have allowed professionals to improve their analyses through ever more accurate interpretations of heterogeneous digital outputs [1, 10–13].

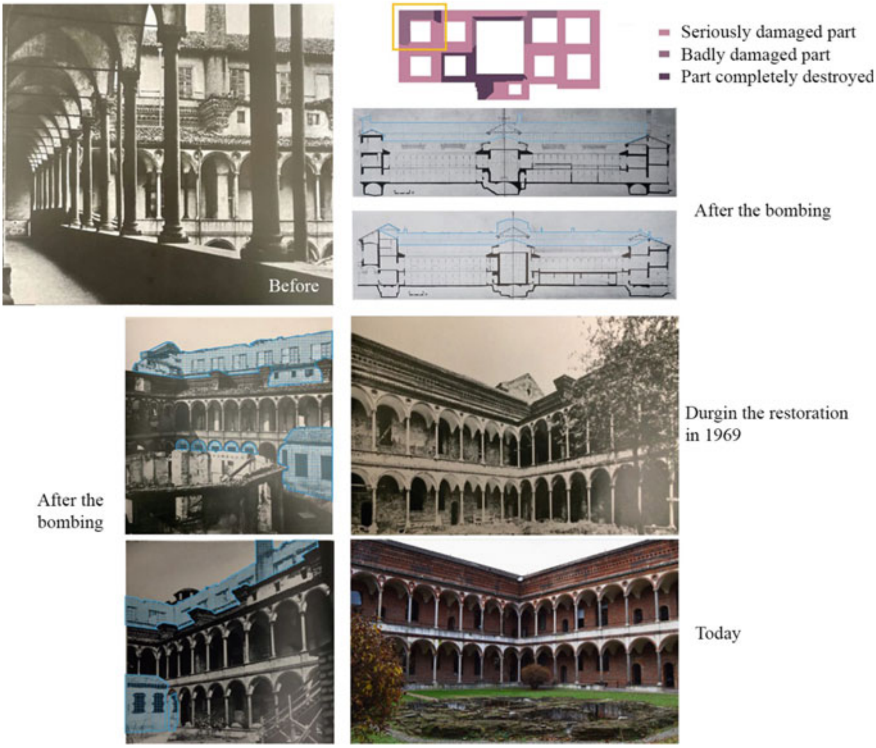

Fig. 6 The bombing of the Bath courtyard in August 1943 and subsequent restoration by Liliana Grassi (*Source* [9])

Various techniques, including laser scanning, aerial and terrestrial photogrammetry, and high-resolution textured mesh models, along with traditional drawings such as plans, elevations, sections, axonometric drawings, and perspectives, are essential tools for accurate interpretation and representation of a building in metric, geometric, and semantic terms. The process of representation involves measuring the distance between the rigorously formalised, precisely-drawn geometric description of the building and its ever-evolving reality, including the stochastic nature of human thought. The building must be understood as the main subject, an observed in continuous mutation over time and made up of innumerable architectural and structural elements which present different morphological and typological uniqueness and semantic values which must be represented and shared in the communication and sharing activities. Effective communication and dissemination of such values necessitate their accurate representation. Archival research constitutes a vital tool for comprehending the intangible values of the building, including its life cycle, forms of representation and description, and overall evolution. Consequently, the activities of representation and interpretation must be grounded in a comprehensive understanding of the historical and cultural heritage of the building and must address its inherent complexity and intricacy. Drawing and representation must adhere to the paradigm of the complexity of historic buildings and their multifaceted forms.

The concept of complex form must be a first requirement of digital models that address the heritage theme. On the other hand, the paradigm of time and how the latter has defined the form over the centuries must be considered a second requirement of all those forms of representation aimed at narrating historic buildings' tangible and intangible values. Thanks to the digital age and the most innovative forms of extended reality, such as VR-AR, fields of application and research have arisen in recent years that investigate new paradigms such as interactivity, interoperability and sharing of digital worlds. Consequently, drawing and 3D modelling are the key elements that lead to creating these new digital forms that transfer the attention from the building to the user/virtual visitor. The latter becomes the *observer* and, through the recreated immersive experience, opens the door to a series of opportunities not yet fully explored in heritage, museums, restoration and archaeology.

For these reasons, through the digital architectural representation, this study addresses the theme of heritage by trying to merge and tell in a single virtual-visual storytelling (VVS) the paradigms of complexity, interactivity, interoperability and sharing of digital infographic representations linked to the research case study.

The latest technologies in the field of VR-AR are addressed to an interactive representation capable of increasing the observed-observer dialogue by creating digital models capable of responding to user input on a sensory level [10–13]. Especially through archival research, surveying, drawing, the third dimension, the semantic decomposition of the elements, has come to define a mixed reality (MR) project able to relate the tangible and intangible values of the building with a human-centric approach. This study tries to put the observed and the observer on the same level, where information coexists with objects, unlike a traditional museum reality where the visitor needs audio support or paper to explore and understand the exhibits in the various rooms (Fig. 7).

The paradigm of complexity presents a challenge for 3D modelling aimed at achieving an appropriate and accurate metric and geometric representation of a building. The architectural and structural elements that constitute a building cannot be reduced to simplistic geometric forms. The understanding and interpretation of vaults' primary forms and typologies can be achieved through descriptive geometry and traditional forms of representation. However, the complexity paradigm necessitates understanding all aspects of a building that cannot be grasped through a 3D wireframe representation.

Recent developments in scan-to-BIM processes and Heritage BIM (HBIM) projects have enabled the representation of historical buildings with high levels of detail and information. The interpretation of 3D drawings and data is crucial for identifying significant geometric anomalies as detected by laser scans and photogrammetric point clouds. The case study of the court immediately posed the need to determine this geometric discontinuity. The building is characterised by numerous traces, which allow a diachronic reading of the building's life cycle if well identified. The representation of the main discontinuities of a vault can intercept their complex shape, identifying which points of the scan belong to a vault, wall, or capital.

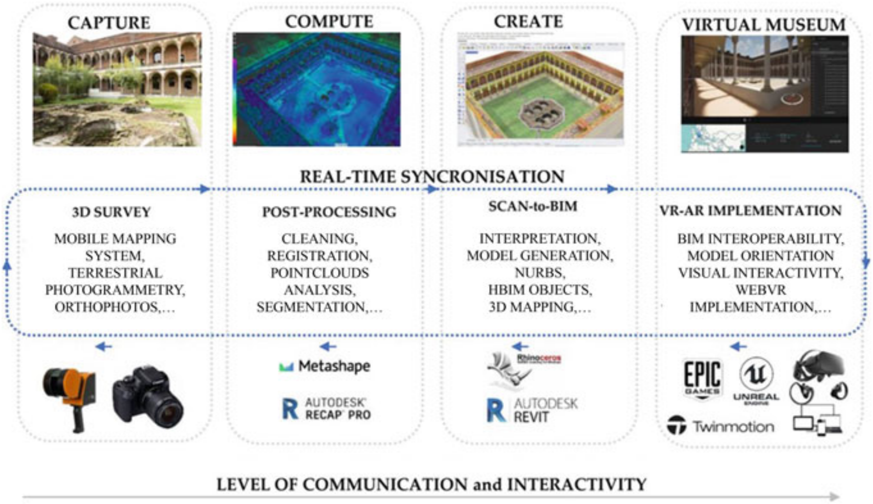

Fig. 7 The applied research method (*Source* F. Banfi, D. Oreni)

Semantic decomposition makes it possible to differentiate these elements and define a hierarchical flow of information from the parametric model to the drafting of schedules.

On the other hand, what happens between one edge and another, between one line and another that intercepts the shape of the vault remains a field of research that is still being fully defined. Starting from this premise, this study investigates and addresses geometric complexity by identifying which geometric elements can positively influence the accuracy and precision of the main outputs, trying to apply a process capable of drawing and then three-dimensionally representing each element. A laser scanner and photogrammetric survey were indispensable to acquiring the case study's geometric and material information. The measured survey operations have been planned using various instruments in response to the project needs.

The 3D survey, with Leica TPS1200, Faro Focus 3D × 130 HDR and the Geo SLAM Zeb (Fig. 8) performed from the ground level and loggia of the first floor. A geodetic network was established within the research case study to connect the different survey strategies (terrestrial photogrammetry and laser scanning) into a unique stable reference system. The geodetic network was measured with a Leica TPS1200 total station (TS), and a final least-squares adjustment provided an average precision of $\pm$ 1.5 mm. The result is an accurate point cloud, which proved essential to calibrate outputs from the other instruments. With photogrammetry, the authors also obtained the first accurate archaeological site survey in the middle of the court.

A photogrammetric survey, with Canon Eos 5D Mark IV and GO Pro, has been carried out to capture geometric and textured data for the MR project. Three main coordinated phases have been executed to document the geometric and material

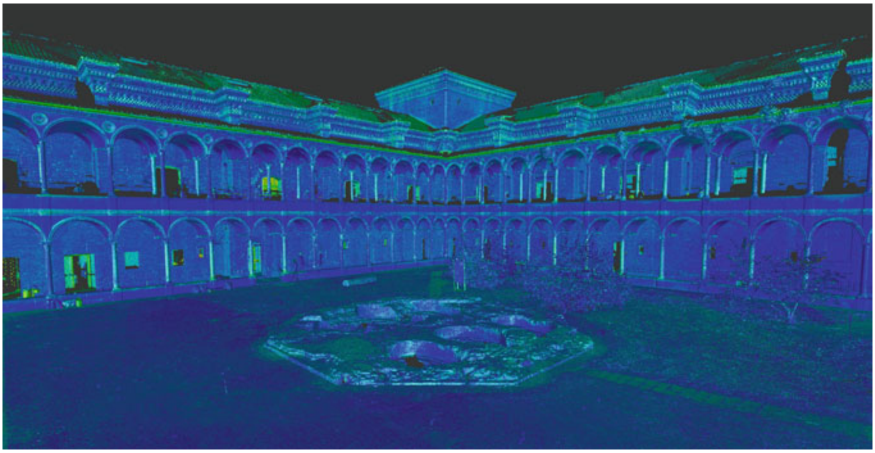

Fig. 8 The points cloud from Geo SLAM Zeb (*Source* F. Banfi, D. Oreni)

particularities of the site comprehensively. The initial phase involved ground acquisition, which enabled the operator to capture elements with exceptional detail and high resolution of the archaeological site. In the subsequent phase, the upper part of the court was acquired to capture all the ornamental elements of the four facades. All the intricate details along the first floor's loggia were documented in the final phase.

Digital photogrammetry enables the reconstruction of vaults, columns, capitals and the main front of the court. In particular, to obtain a complete and integrated repository in all its parts, the resulting outputs have been aligned using printed targets—located in strategically identified areas to obtain the best alignment results, but paying attention to the most well-defined edges and vertices.

The data deriving from the acquisition was georeferenced within the Metashape software, obtaining an average alignment error of 0.5 cm. The first result of the research is 2D–3D high-reliability drawings of the main four fronts, sections, and horizontal and vaulted ceilings. These outputs allow understanding and representation of the current state, focusing on the complex shapes of each element and the geometric and material discontinuities. In particular, thanks to the 3D drawing, the interpretation of many point clouds, and the consequent semantic decomposition and interpolation phase of the point clouds through NURBS algorithms of every single element, it was possible to model the main details not intercepted from photogrammetry.

At the basis of the generative process, NURBS modelling, based on mathematical algorithms, has made it possible to volumetrically represent the peculiarities and unique complexities of vaults, columns, capitals and the main fronts of the courtyard, passing from drawing to surfaces and then solids capable of achieve a grade of accuracy (between the point cloud and modelled element) of about 0.5 cm (Fig. 9).

Additional fields have been developed to communicate the reliability of each component. In addition to textual information and links to external resources, the

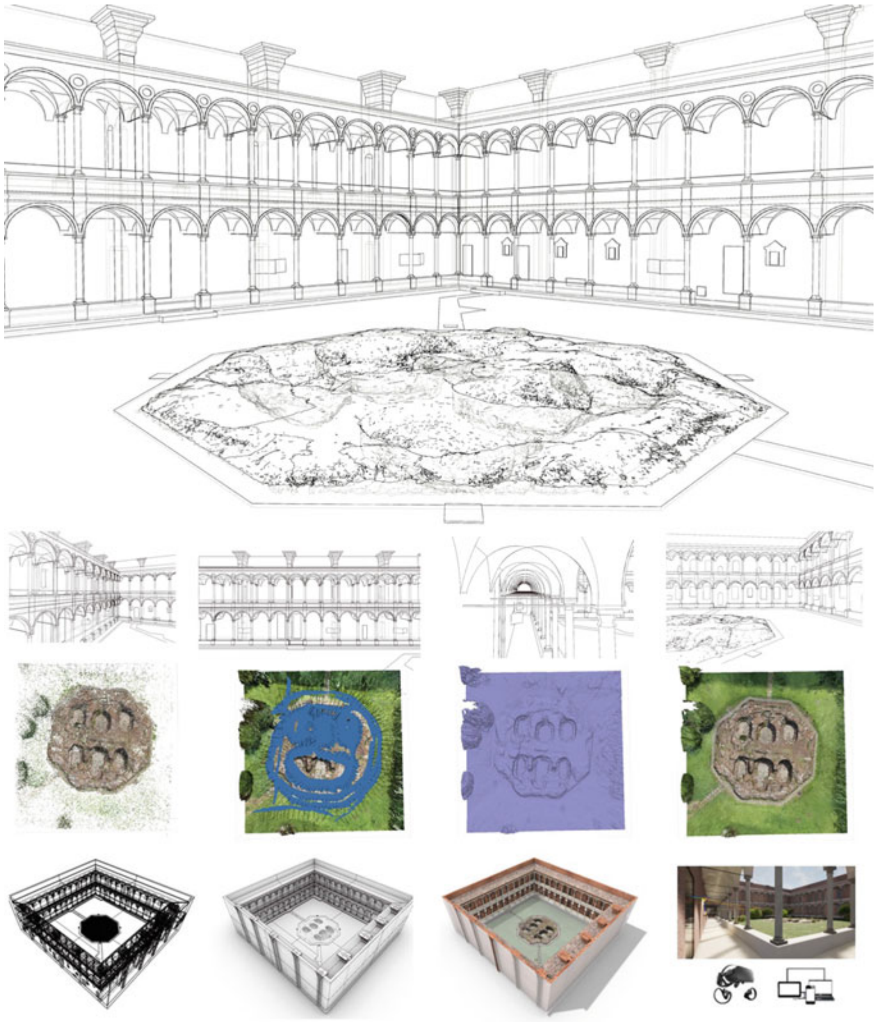

Fig. 9 From 3D drawings and mesh textured models to NURBS models and VR (*Modelling* F. Banfi, D. Oreni)

value corresponding to the grade of accuracy of the element has been entered for each component of the 3D model. The standard deviation value was reported directly in the properties window of the single object to declare the geometric and metric reliability achieved and which resource was used to model (TLS/photogrammetry point clouds, historical drawings). At the same time, the punctual analysis and understanding of the infographic materials analysed during the archival research and supporting the interpretation, semantic decomposition and 3D modelling phase favoured identifying a series of historical and infographic helpful information for the virtual story of the court.

3.2 From 3D Modelling to Immersive WebVR Experiences

VR and AR technologies have revolutionised the ways in which we approach the study and appreciation of archaeological sites, built heritage, and museum collections. In particular, museums recognise these technologies' potential to enhance the valorisation of their collections, which involves promoting knowledge of cultural heritage and ensuring optimal public use and enjoyment conditions, as per Article 6 of the Cultural Heritage and Landscape Code. By leveraging advanced three-dimensional reconstructions, digital technologies facilitate communication, accessibility, and transmission of information related to artefacts, from small sculptures to significant historical monuments. However, VR and AR projects related to heritage sites often lack easy accessibility or digital archives for various reasons.

These range from limited funding for heritage preservation and enhancement to dissemination and transmissibility methods that have yet to be fully oriented towards conveying the complexity of a site in terms of its cultural, historical, and geometric significance through easily accessible virtual stories. While VR requires a viewer capable of immersing users within a digital environment, AR relies on devices and applications capable of adding an interactive layer to the camera's frame on a mobile device. In the absence of or as an alternative to these methods, the web can offer a useful platform where VR and AR can be combined to create new forms of interaction and immersion (Fig. 10).

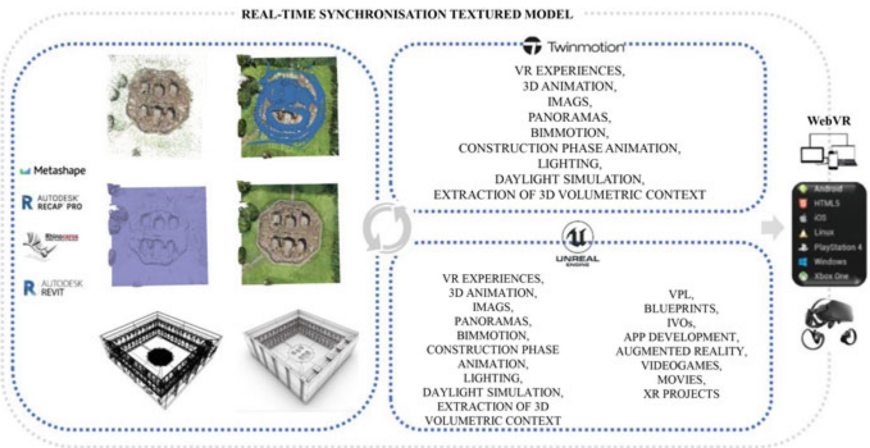

Fig. 10 Developing an immersive web experience: from digital models to WebVR (*Source* F. Banfi, D. Oreni)

This study, therefore, aims to enhance the interaction between the observed and the observer by developing an interactive environment that is navigable through a web browser. Specifically, it focuses on the court of the Baths and seeks to facilitate a more immersive and engaging experience for users by developing an interactive platform that allows users to explore the site and its various features more intuitive and user-friendly manner.

The case study of the state and its courts turned out to be an appropriate field of investigation to investigate the paradigms of interoperability, interactivity and immersion of digital models oriented towards VR and AR. Visiting the building, one realises how the alternation of the various courts represents a succession of historical and cultural events.

They also host modern installations and events such as the Fuori Salone which brings in a large number of visitors every year. In the absence of a virtual story of the court, this study lays the foundations for virtual visual storytelling (VVS) centred on diachronic storytelling. The definition of the virtual story was mainly structured on the way of using the court itself and the public spaces accessible during the various events open to the public. The visit can be taken along the ground floor in both directions. Clockwise, the story presents a diachronic evolution. Infographic drawings, AR objects and their QR code, 3D animation, audio and textual contents are incorporated through wall installations that allow the visitor to explore certain issues or interact directly with the courtyard's architecture and its spaces without particular visual occlusions or physical objects that obstruct navigation.

These information points' design has provided a double-sided screen to optimise the space dedicated to the story based on the spatial relationship between the architect and the visitor. The design of the screen envisaged a convex shape to immerse the visitor in understanding, viewing, listening and reading the various contents shown (Figs. 11, 12, 13).

The WebVR project offers advantages for users and developers alike. Firstly, its adherence to web standards means that anyone can access it with a compatible web browser and VR headset, promoting accessibility for all users without needing specialised hardware or software. Secondly, the cost-effective nature of WebVR eliminates the need for expensive VR equipment and software, removing a significant financial barrier to entry for many users. Moreover, the easy distribution of WebVR content through the web enables creators to reach a broader audience with minimal installation procedures. In addition, WebVR's cross-platform compatibility allows developers to create VR experiences that work seamlessly across various platforms and devices, promoting accessibility and reducing the risk of technical limitations.

The interactivity of project enables users to have immersive and interactive experiences, particularly in educational, gaming, and training applications. Furthermore, WebVR's flexibility allows developers to create diverse VR experiences, from simple 360-degree videos to complex interactive applications, catering to a broad spectrum of user preferences. Finally, project scalability enables it to support a large number of users simultaneously, making it ideal for creating large-scale VR experiences such as virtual events or conferences. WebVR, despite its numerous advantages, also presents limitations and challenges. Firstly, the limited hardware support of WebVR, which

Fig. 11 The Virtual-visual storytelling of the Baths courtyard: different sections and contents have been implemented to tell the court's history (*Source* F. Banfi, D. Oreni)

Fig. 12 The WebVR project of the Baths courtyard is navigable via the web and multiple devices such as VR headsets, mobile phones and tablets (*Source* F. Banfi, D. Oreni)

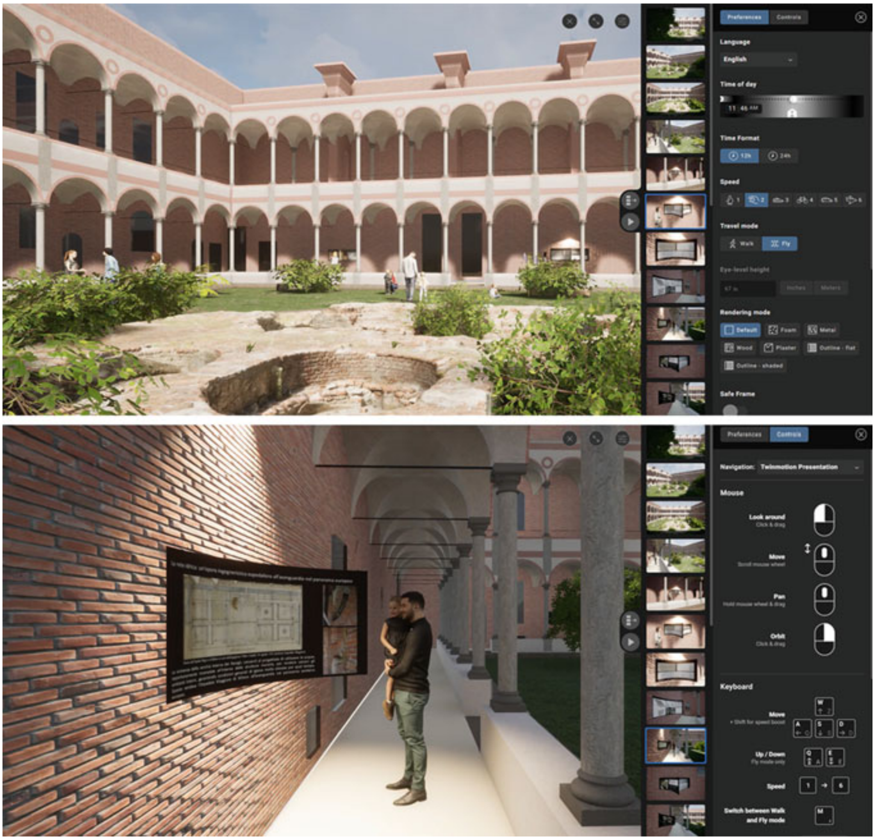

Fig. 13 The project allows users to personalize themselves via the web (time of the day, travel and rendering mode, controls, keyboard, speed) and implement content over time (*Source* F. Banfi, D. Oreni)

restricts the compatibility of VR content with certain VR headsets, can potentially limit the user base and accessibility of such content. Secondly, WebVR experiences may not perform as well as native VR experiences due to the overhead of running in a web browser, leading to reduced graphics quality, lower framerates, and other performance issues. Moreover, WebVR is still in its early stages of development, which means that it may not offer the full range of features and functionality that is available with native VR development tools. This can limit the types of experiences that can be created using WebVR. Furthermore, WebVR's accessibility poses security concerns related to transmitting and storing sensitive user data since it is accessed through a web browser, which can be a significant concern for applications requiring user input or involving sensitive information. Finally, WebVR presents accessibility challenges for users with disabilities, such as difficulty in using VR headsets or navigating VR experiences, which can limit their ability to participate in such content.

4 Conclusion

VR and AR have emerged as powerful tools in supporting the arts, tourism, and cultural sectors. Through archival research, representation, and 3D modelling, VR and AR provide highly relevant means for studying historical artefacts and buildings. In this regard, the authors propose a rigorous process for creating immersive and interactive virtual experiences for professionals and virtual tourists, which offer a stronger sense of presence and a closer connection to historical artefacts and buildings than traditional forms of data sharing. This approach leverages digital technologies to advance the study of cultural heritage and provide new and engaging virtual experiences. As digital acceleration continues to shape our interaction with the world, such approaches are expected to play an increasingly important role in preserving and disseminating cultural heritage. To achieve a more nuanced understanding of historical construction and design, this research aimed to develop an immersive web-based virtual reality (WebVR) experience that enhances the traces of the building's various phases of construction. WebVR is a promising platform that has the potential to democratize VR by providing an accessible, flexible, and scalable framework for immersive and interactive VR experiences. On the other hand, WebVR has several limitations and challenges that developers need to consider when creating VR experiences. Careful evaluation of the requirements of a project is necessary to determine if WebVR is the best platform to use, considering its limitations and potential challenges. In conclusion, to avoid turning the site into a static museum and thereby restricting its interpretive possibilities, the researchers aimed to perform a creative recovery that aligns with the design philosophy of architect Liliana Grassi: "The recovery of spatial and numerical values is not to be understood as a mechanical revival but as a creative recovery of historical memory, achieved through an impalpable relationship between the foundations that illuminate design research and the data of tradition".

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Exploring Lorenz Stöer's Imaginary Space Using Augmented Reality: *Geometria et Perspectiva*

Michela Ceracchi, Marco Fasolo, and Giovanna Spadafora

1 Lorenz Stöer and His Time

The research centers on the creative process that led Lorenz Stöer to the creation of the woodcuts published in his volume *Geometria et Perspectiva*, printed in 1567 in Augsburg. The objective of the research, which aims at understanding this heritage, as well as disseminating and valorizing it, finds in the applications of Augmented Reality the ideal means of a considerable communicative efficacy, in view of the idea of proposing a multi-medial exposition of his works, in which the visitor is led to explore not only the space that Stöer had represented, but also to discover the process by which this space was represented on the two-dimensional plane.

The cultural context in which Lorenz Stöer lived and worked was his native city, Nuremberg, which, together with Augsburg and Ulm, in the sixteenth century, saw the flourishing of intense publishing activity. Numerous manuals were published addressed to artists that contained above all practical information, with examples of geometric constructions necessary in perspective representations of architectures or compositions of solid figures, while omitting scientific explanations of the methods.

Even though these tomes did not represent any theoretical progress, some stood out in the effort to combine the aim of meeting the artists' needs with the opportunity to provide indications so that the images would be geometrically constructed following the shared and, in that era, consolidated procedures.

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Among those, Augustin Hirschvogel's work (Fig. 1a) [1], published in 1543 in Nuremberg, and Paul Pfinzing's (Fig. 1b) [2], published in 1598 also in Nuremberg, in which one finds tables with illustrations referring to the manner the images in perspective are constructed which, as we know, could be either drawn directly on the plane or by means of a perspective machine. Together with these, in great numbers, are also published books that gather a series of particularly suggestive images, perspectives of known geometric solids and images, products of the authors' imagination, without making the geometric construction that produced the images explicit. In these drawings the authors concentrated on the sculptural aspect of the geometric figures, competing with each other in ever more daring compositions. That is the case, for example, of the pages of Wenzel Jamnitzer's work which a series of polyhedra are represented in perspective, revealing the author's ability in imagining and realizing variations on the structures of known polyhedra (Fig. 2) [3].

The interest in the study of solid figures obtains a further impulse during the Renaissance: the understanding of the geometric characteristics allowed them to be easily representable subjects following perspective constructions known at the time, and, at the same time, their symbolic role exalted the peculiarity of perspective as a measure of space and sealed the strict connection between art and science. The harbinger of this bond can be traced to many treatises of the middle of the fifteenth century, a period in which the study of space and that of geometric figures were conducted jointly. As André Chastel reminds us, "The study of solids, no less than that of distances, is part of the painters' geometry: the abstract spatial cage is made to accommodate harmonious bodies, these are Plato's five bodies which boast a sort

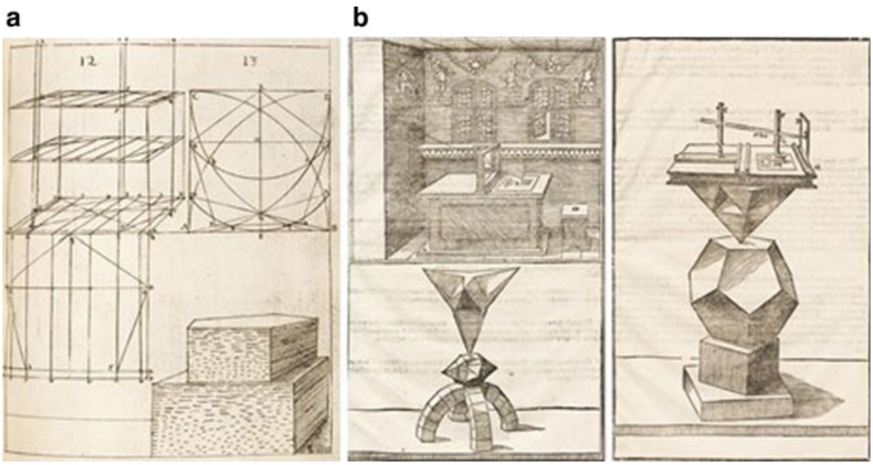

Fig. 1 On the left, a page from A. Hirschvogel's volume *Geometria*, showing the process of perspective construction of a group of solids **(a)** (*Source* Hirschvogel [1]); on the right two pages taken from P. Pfinzing's volume, *Geometriae und Perpectivae*, showing the use of a perspectograph **(b)** (*Source* Pfinzing [2])

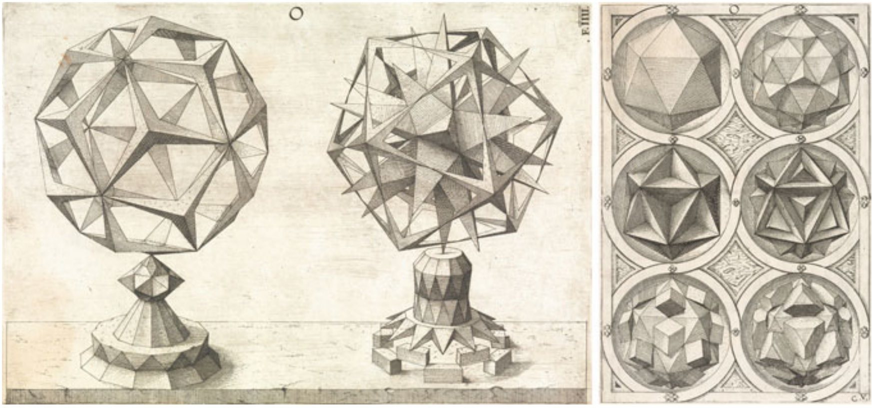

Fig. 2 Solids represented in the work of Wenzel Jamnitzer, *Perspectiva corporum regularium* (*Source* Jamnitzer [3])

of cosmological birthright according to contemporary science or of more complex polyhedra of crowns and scrollworks of a rich ornamental effect" [4].

2 Solid Figures and the Imaginary World

Lorenz Stöer, as recounted in some bibliographic references [5], was the son of an engraver, pupil of Hans Springinklee, himself Dürer's pupil. He therefore grows in a familiar and cultural context rich in stimuli, within which he identifies his main area of interest, the perspective representation of regular and irregular geometric figures, fitting through his work into that aforesaid brief period of creative experimentation that characterizes the graphical production in sixteenth century Germany.

Between 1562 and 1599, Stöer creates a large number of drawings gathered in the album *Geometria et Perspectiva: corpora regulata et irregulata* [6], representing solids articulated in various compositions (Fig. 3). In this period of time, more exactly in 1567, he publishes, in Augsburg, the volume *Geometria et Perspectiva*, eleven woodcuts in which the compositions of solids are inserted into imaginary landscapes, where among architectural ruins and natural elements, variously articulated geometric capriccios stand out. In both works the term perspective appears but in neither of them is reference made to the geometric constructions shown, and in particular, he states, in the front cover of the book *Geometria et Perspectiva*, that the objective is to illustrate images "useful for workers of marquetry".

Stöer creates other woodcuts and ink and watercolor drawings of solids in various compositions, always bearing the legend *Geometria et perspectiva.* The greater precision in drawing the solid figures is especially evident in some of the folios, showing that he well knew the rules of constructing perspective images, as in fact Stöer himself testifies in one of his woodcuts (Fig. 4a), where he writes "accurately drawn

Fig. 3 Lorenz Stöer, *Geometria et perspectiva: corpora regulata et irregulata*, 1562–1599. Album cover and one of the drawings (*Source* Müller [6])

in perspective; derived accurately from geometry" [5]. Among the various sheets, worthy of interest is the woodcut that represents a solid that dominates out of scale in the foreground, represented within an urban context, with ruins and human figures (Fig. 4b) [7]. Thinking of the images published in 1567, this sheet could be the project for a title page that announces the contents. Stöer, instead, publishes his work *Geometria et Perspectiva* containing a title page that emphasizes the polyhedra as the main subject of his representations (Fig. 4c) [8], with this also highlighting the symbolic value, without revealing the figurative complexity of the 11 woodcuts contained inside, in which the aim is to amaze the reader transporting them to an imaginary world. It was interesting to try to discover, by retracing the perspective procedures in use at the time, what the forms and their mutual relationships are—in this imaginary world—by reasoning on the space that he builds around the compositions of polyhedra in the foreground.

However, this objective cannot ignore some considerations that had constituted the premises of our work, summarized here and explored further later in the text. The first is that, at first glance, it is clear that not all the elements of the composition answer to a single geometric structure; but this is, after all, in line with the custom, which since the fifteenth century, was shared by artists, of not applying the perspective method rigidly, but of focusing on the overall effect of the representation. Furthermore, we are already in the middle of the sixteenth century and "the spatial harmony of the Renaissance has dissolved" [9].

It should also be considered that these drawings were destined to be subsequently reproduced in the inlays and Stöer was certainly aware that the marvel aroused by the mastery in the execution of the inlays would have further enhanced the perceptive impact of his works and guided the eye in recreating the mental image of a space, regardless of the presence of uncertainties in the geometric constructions.

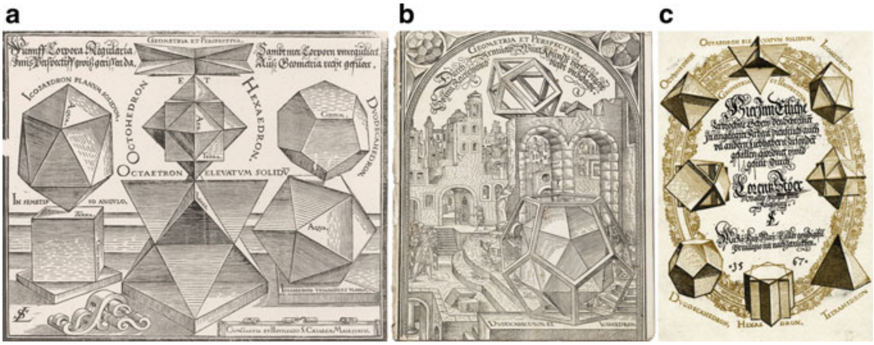

Fig. 4 On the left, the woodcut with a reference to the correctness of the geometric construction of the figures **(a)** (*Source* Wood [5]). In the center, the woodcut that may be the project for the title page of the work **(b)** (*Source* Stöer [7]), on the right, the cover of the work **(c)** (*Source* Stöer [8])

We have, however, worked to trace the conformation of the space depicted in these images and to deduce the geometric procedure by which they could have been created. The objective of this graphic analysis, however, is not to verify its correctness. This operation, moreover always susceptible to subjective interpretations, would presuppose, in fact, that we already have a preconceived idea of what the represented forms should be, or that we seek in the represented space the correspondence with the space that our mind has prefigured. As stated by Elio Franzini regarding the relationship between what is true, false, and probable in the image, "The falsity, for example, can arise on the mimetic level starting with the distance between the thing itself and its image. Even if, as has already been observed, the error does not belong to the world of the image, but to the level of memory and its specific imaginative representations […]" [10].

Therefore, what appears suggestive in this operation is to restore the forms and their relationships exactly as they were represented, thus giving substance to an imaginary space that we can explore through AR. In this sense, the process of reconstructing the space represented is configured as a creative tool and the AR applications allow us to explore another space, other than what Stöer had imagined and different from what he thought he was representing: the space of the drawing.

3 Lorenz Stöer's Curious Perspective Images

Lorenz Stöer's book, *Geometria et Perspectiva*, published in 1567 in various color and black and white editions, is composed of 11 plates fronted by a noteworthy title page. The volume referred to in this contribution is the version of Michael Manger's 1567 edition (Fig. 5) [11], and its dimensions are 202 mm (base) by 298 mm (height). Stöer composes the title page by inserting, following an elliptical line,

Fig. 5 The title page of *Geometria et Perspectiva*, in the version of Michael Manger's 1567 edition, and the 11 internal tables (*Source* Stöer [11])

eight geometric solids represented in perspective. This choice is perhaps the most effective testimony as to the explanation of the title of the Work.

In fact, these drawings make explicit the close union between *Geometria*, the presence of geometric figures, and *Perspectiva*: the central representation that permeates the entire book. And it is precisely the perspective that is also manifest in the arrangement of the solids, in fact assuming the imaginary line of horizontal symmetry as the horizon line, Stöer places two solids straddling this (on the left, a figure obtained from the intersection between a hexahedron and a cuboctahedron; on the right a polyhedron composed of a cube and an octahedron; these two solids are the only polyhedra on the cover that Stöer does not define). Above the horizon, three other solids are represented in a clockwise direction, following the view correctly from bottom to top: an octahedron, a solid elevated octahedron (stellated octahedron) and an icosahedron, while, below the horizon, there is room, always in a clockwise direction, for a tetrahedron, a composition of two hexahedrons, and a dodecahedron, all executed from top to bottom (Fig. 6a).

Along the elliptical frame, the Author inserts an emblematic inscription, a sort of pleasant admonition: "Who would do right by everyone? No one would even try" whose interpretation could perhaps indicate a conscious and declared modesty on the part of the Author in admitting that this work of his is far from being a pure treatise on geometry, and is aimed at a wide range of readers as we will see more clearly in the dedication placed in the center of the cover. In fact, inside the frame the title of the book appears accompanied by a long dedication to the readers: "*Geometria et Perspectiva*, containing various ruined buildings, useful to intarsia workers, as well as for special pleasure of many other amateurs; ordered and arranged by Lorenz Stöer, painter and citizen in Augsburg". In fact, the presence of ruins is found in all the engravings that make up the work, representing a constant which, combined with a landscape in the background, at times including an imaginative reticular structure and solids in the foreground, that characterizes the bizarre perspective images of

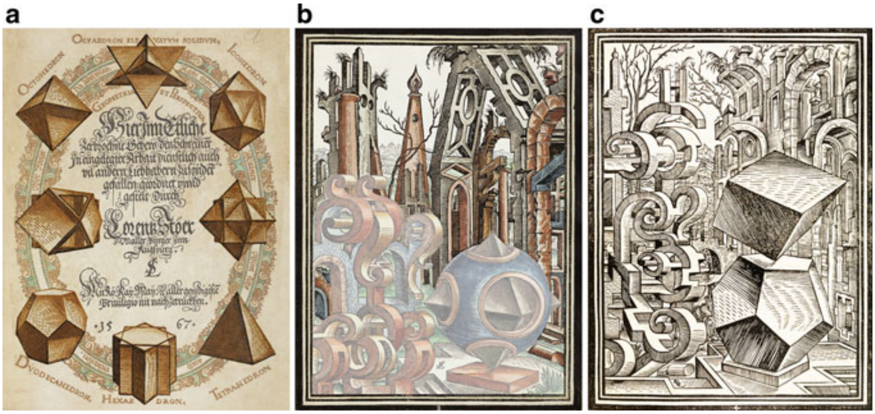

Fig. 6 Left to right: The title page showing the 8 polyhedra represented in perspective highlighted **(a)** (*Image processing* M. Ceracchi, M. Fasolo and G. Spadafora); Table 8 with ruins and reticular structures highlighted **(b)** (*Image processing* M. Ceracchi, M. Fasolo and G. Spadafora); Table 4, in Hans Rogel's 1567 edition, from which one can appreciate the quality of the Author's signs **(c)** (*Source* Stöer [8])

the volume (Fig. 6b). Still in the dedication, Stöer, assumes authorship of the work completed in 1567, expressly addressing his work to inlayers and generically to all those who delight in the world of art.

The German artist, therefore, in the few lines of the dedication, underlines how these woodcuts he created will be of particular interest to those wood carvers who dedicate their activity to creating wooden perspective images reproducing objects as well as visions of imaginary spaces. Undoubtedly the first reference that comes to mind when looking at Stöer's engravings are the famous representations of geometric solids present in many of the inlays made during the sixteenth century, works that attest to the high value reserved for these subjects in recognition for their geometric purity as well as for their symbolic meaning, as well as demonstration of the extreme skill in correctly translating the complexity of their forms in perspective. However, there are a series of Renaissance perspective wooden inlays that could have conditioned Stöer's dedication, we are referring to that wide repertoire of inlaid works that the artists of the time created with the intention of transmitting to the observer their particular and original vision of urban spaces and imaginative landscapes.

Let us now analyze the plane composition of the image. The setting found in the woodcuts is organized by placing at the bottom, a solid or a group of two solids generally joined by a bizarre capriccio of curved shapes; partially hidden by these geometric bodies there are ruins sometimes accompanied by curious reticular structures; lastly, a hilly landscape can be glimpsed. What strikes in the sight of these tables is the richness of signs, linear and curved, so dense as to leave very little space for emptiness (Fig. 6c). The dimensions of the engravings are mm. 162 for the base and mm. 218 for the height. These small sizes demonstrate the Author's great skill in the art of woodcut. Instead, in order to be able to read the spatial setting of the image, one can resort to its decomposition by planes of depth as if they were theatrical wings which, recomposed, restore in the observer a perceptive uniqueness of the three-dimensional space that the Author had seen with his vivid imaginative mind. Three main levels of depth can therefore be traced, understood therefore as theatrical wings of a scenography aimed at transmitting Stöer's, we could say dreamlike, vision.

Beginning with the deepest plane, the background plane, in which landscapes appear between the hills and the rocky formation with scattered houses; the choice of these subjects intends to provide the image that depth that leads the viewer towards unlimited spaces.

As mentioned, the relevance between these representations and those of the wooden inlays does not refer only to the dedication of Stöer and to the nature of the support itself (wood), but also to some elements that are present in both works of art. Thus, the presence of the landscape in the background can be found in many urban/landscape inlays (Fig. 7a). Closer to the observer, in what we could indicate as the second plane, the presence of reticular structures composed of geometric figures is sometimes revealed flanked, as stated in the dedication, by the remains of ancient buildings. On the other hand, the interest and passion for ruins were very much alive in Renaissance culture, therefore, it is not surprising to find them in these tables as well as in some wooden inlays (Fig. 7b). Lastly, the foreground: below it appears a bizarre capriccio in the shape of curved and curved curls devoid of an apparent logical meaning other than to demonstrate the virtuosity as engraver of its Author and his playful inclination that will find space in the tables of the album *Geometria et Perspectiva. Corpora Regulata et Irregulata* recently attributed to him (Fig. 3). On this plane, the absolute protagonist of the scene makes its appearance: the solid or a group of geometric solids (Fig. 8).

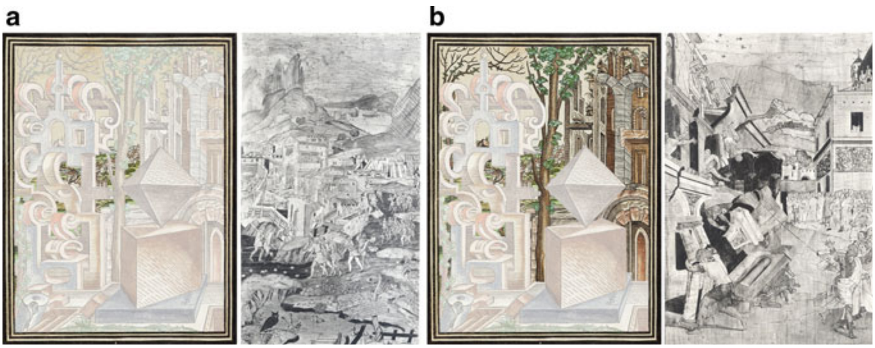

Fig. 7 On the left, comparison between Table 1 showing the rural landscape (*Image processing* M. Ceracchi, M. Fasolo and G. Spadafora) and one of the inlays of the church of San Domenico in Bologna, Fra Damiano da Bergamo, 1530–35 (*Source* Catalogo generale dei Beni Culturali, 0,800,026,757) **(a)**. On the right, a comparison between Table 1 with the architectural landscape highlighted (*Image processing* M. Ceracchi, M. Fasolo and G. Spadafora) and another of the inlays of the same church (*Source* Catalogo generale dei Beni Culturali, 0800640714) **(b)**

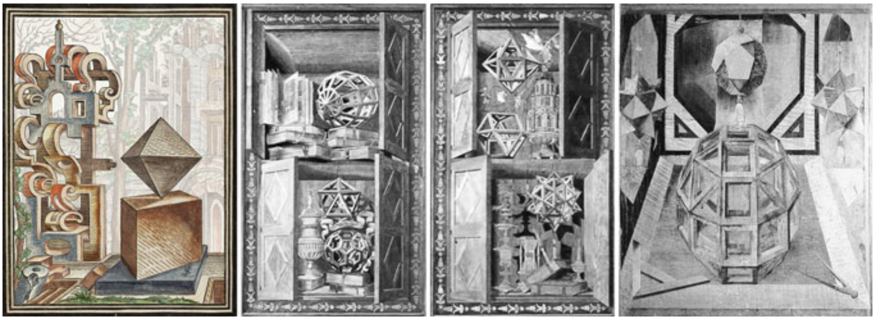

Fig. 8 A comparison between Table 1 with the foreground highlighted with the composition of solids and the capriccio (*Image processing* M. Ceracchi, M. Fasolo and G. Spadafora), two inlays of the choir of the Church of S. Maria in Organo in Verona, Fra Giovanni da Verona, 1518–1525, and an inlay in the Museum of Basilica of San Domenico in Bologna, Fra Damiano Zambelli (*Source* Catalogo generale dei Beni Culturali, 0500054733–33, 0500054733–27, 0800024970)

Geometric solids in their variants have always been a vast field of application for Renaissance artists, the attention these men reserved for polyhedrons was due, as we know, to various motivations ranging from scientific speculation to artistic fascination without excluding their profound philosophical meaning. Even Stöer could not escape this sentiment which is evidently manifested in his works. Each table of *Geometria et Perspectiva* presents the protagonist of the scene by placing it, as mentioned, in the foreground, thus we find in Table 1 a hexahedron surmounted by an octahedron; in 2 a tetrahedron whose upper vertex coincides with the lower vertex of an icosahedron, next to it a prism with a hexagonal base; in 3 a composition of two pyramids with a square base resting on an octahedron, next to it a hollow prism with a pentagonal base, in the background another pyramid with a square base surmounted by a sphere; in 4 a dodecahedron with a hexahedron above it; in 5 an icosahedron surmounted by a pyramid with a square base in turn surmounted by a sphere; in 6 a solid elevated octahedron; in 7 a polyhedron composed of a hexahedron and a cuboctahedron; in 8 an octahedron incorporated in a sphere; in 9 a sphere divided into four parts, inside a small sphere, in the background, hanging from the vault a sphere with spikes; in 10 a composition of geometric shapes and finally in 11 a hollow prism with an octagonal base.

Even the inlayers, as in the engravings of the German Master, portrayed polyhedrons in their works, the inlays made by Fra Giovanni da Verona for the choir of S. Maria in Organo in Verona are magnificent examples, those that decorate the study of Federico from Montefeltro in Urbino or the inlays of Fra Damiano Zambelli held in the Museum of the basilica of San Domenico in Bologna (Fig. 8).

Lorenz Stöer autographs all the plates by adding his initials LS, inscribed following the perspective line of the geometric layout. The entire composition is based on the setting of a central projection in which the many elements present in the scene respond visually to the geometric perspective, in fact by observing each of the individual tables we perceive a fantastic world governed by the laws of perspective.

The sequence of the three scenic floors gives us, in their unitary recomposition, a dreamlike vision of a world suspended between real and unreal.

4 Augmented Reality to Unveil Space Beyond the Drawing: The Possible Worlds Between Illustration and Representation

There exists a space beyond the material limit of the surface of the drawing that can be investigated and reconstructed using the digital model and explored in the real world using Augmented Reality.

The marker-based AR technology establish a strict relation between the physical consistency of the target and the virtual content. This allows the parts to be disposed so as to replicate the projective relations that bind the object to its representation.

The important intangible cultural heritage in the tables of *Geometria et Perspectiva* is worth studying and disseminating. From this conviction was the proposal for a multi-media exhibition born, which, using various Augmented Reality applications, would allow the visitor to explore the possible worlds concealed behind the drawing and at the same time understand the process in the construction of the perspective drawing (Fig. 9). The proposed applications, therefore, would not be limited to showing the digital content but intend to narrate the entire process of understanding that, from the interpretation of the images, has led to the reconstruction of the possible worlds represented in them, also advancing some hypotheses regarding the procedure that Stöer could have effectively used. The idea of diversifying the AR applications springs from the assumption that the Artist in order to represent the protagonist of the scene, that is the composition of the solids portrayed in the foreground, could have applied the graphical method of linear perspective, which he certainly knew, as described previously, or used a perspectograph to represent a physical model. For these reasons, the applications simulate the various methods of constructing the perspective image through the use of bi-dimensional targets that coincide with reproductions of the woodcuts, as well as three-dimensional targets which reproduce, in rapid prototyping, wooden models of the solid compositions that Stöer could have utilized when using a perspective machine.

The images created by Stöer, as we have seen, evoke an imaginary space that oscillates between the real and the unreal, in which objects can have a shape that corresponds to that being perceived (Fig. 10a), or, moving away from it, take on unpredictable forms, which, however, coincide perfectly with their image on the drawing's surface (Fig. 10b). The possibility of using reproductions of the woodcuts as the targets that activate the virtual contents, associating with each the various digital reconstructions, allows for the explorations of the different spatial conformations that could correspond to the same image, proposing a suggestive experience between the real and the imaginary, between what is represented and what is imagined, between what is alike and what is different, in which the observer can compare what they

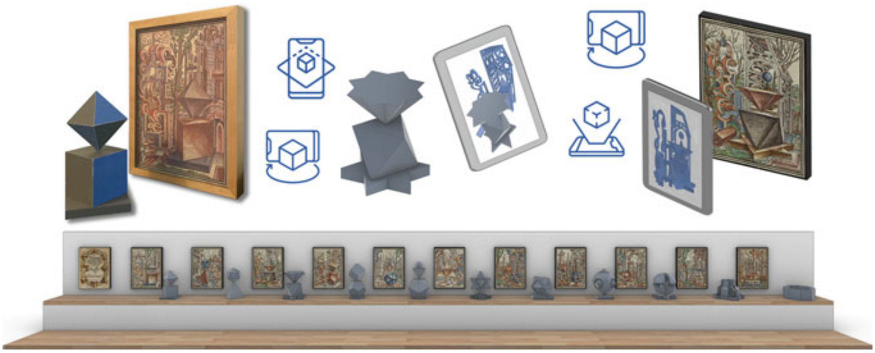

Fig. 9 The proposed multimedia exhibition: various applications in AR will explore the possible worlds that exist beyond the surface of the drawing (*Photo and modelling* M. Ceracchi, M. Fasolo and G. Spadafora)

perceive looking at the reproductions of Stöer's woodcuts and the virtual world that conveys what is represented in the space of the drawing. But what worlds can be animated by these images thanks to Augmented Reality?

Analyzing the composition of the drawings, it is possible to hypothesize that the Artist had juxtaposed the elements to saturate the surface contained within the frame, populating the world that exists behind the *velo* of the drawing with objects that evoke reality without, however, reflecting on the correspondence between their real and their represented forms. An imaginary world, therefore, from which infinite worlds may be generated; one corresponding to the space represented on the surface of the drawing, the others characterized by the perceived space in which objects have a form that differs for each individual that observes the scene.

Each, in fact "constructs his own mental model by recognizing in the representation the characters deduced from his perceptive experience" [12] and perhaps one of them corresponds to the worlds as imagined by Stöer himself.

The perspective structure that derives from the construction of the main composition of the image, regulates the representation of all the elements present on the scene which are integrated with a certain casual coherence (except for the capriccio in Table 2, which responds to another main vanishing point, and the pseudo-axonometry that appears in Table 11), without responding rigidly to its rules; they, in fact, prove to be illustrated rather than represented.

The illustration lacks that bijective relationship between the object and its image which, in the representation, makes it possible to trace back from one to the other and vice versa, which entails that the illustrated elements are perceived in such a way that does not necessarily correspond to the shape represented on the drawing. By considering these elements as belonging to the world of representation, however, it is possible to trace back their true form. Nevertheless, each perspective image can correspond to an infinite number of different objects in terms of shape and size, which seem indistinguishable when observed in a constrained view, because the same visual cone can intercept different objects. So, it is necessary to trace back the fundamental

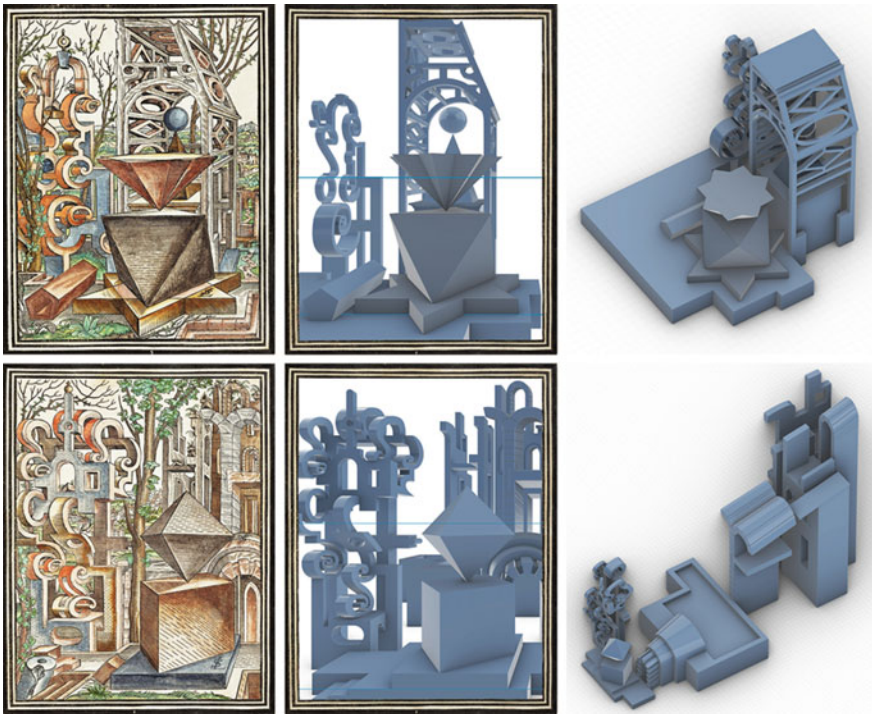

Fig. 10 A comparison between the original tables, the digital models in constrained view and unconstrained view. Above, the represented space rendered in Table 1a. Below, the perceived space reconstructed in Table 3b. It should be noted that the correspondence between the original image and the digital rendering of Table 1 does not exist between Table 3 and the digital model that reconstructed the perceived space according to one possible interpretation (*Modelling* M. Ceracchi, M. Fasolo and G. Spadafora)

elements needed to decode it. Only when it is possible in the image to identify or retrace the elements necessary for its decoding, is this configured as a representation and therefore allows the object to be reconstructed in its three-dimensionality.

The rendering of this imaginary world is not limited to an interesting operation from a cultural point of view, capable of augmenting the level understanding of Stöer's works, but may also provide a non-specialistic audience those instruments to comprehend and know the complexity of the world of drawing in general, and of these works in particular. This, furthermore, is the approach that extends applications of Augmented Reality from a mere recreational aspect, exploiting the suggestive power and capacity to relate the real and virtual worlds to each other, with distinctly cultural purposes. If we dwell on the definition of perspective restitution we read that "by restitution of a perspective means to restore in space the three-dimensional figures that it represents on the plane or surface, in any case bi-dimensional, that harbors them" [13]. Conceptually, therefore, it would make sense to restore only a represented space and not an illustrated one, but doing so permits highlighting the imaginative power of a drawing, which allows a non existent space to be perceived. In the drawings of the volume it is possible to identify some signs which do not follow perfectly the rules of perspective—such as the edges of a polyhedron which obviously should converge to the same vanishing point.

To evaluate these inconsistencies correctly we should take into account the different nature of the analogical drawing, from its physicality, with respect to the digital environment, composed of adimensional and a-scalar entities. Analogic drawing is characterized by the scale ratio between the object and its representation and by the dimensions of the signs traced on the support with an instrument that also has a certain thickness. When virtual signs are traced—with no thickness—over an analogic drawing imported into a virtual digital environment, inaccuracies may be identified which exist only in the virtual world and entirely negligible in the physical world.

Furthermore there exist inaccuracies that depend on graphical procedures—as is the case in Piero della Francesca's second method of transposition by points—or to imperfections specific to the wooden models used in the *perspectiva mechanica* due to errors in manufacturing [14]. Other signs, instead, do not follow perspectival rules because they were traced directly on the paper in what could be defined as pseudo-axonometry (this appears in most of the geometric capriccios and in the base plane of Table 11) perhaps to permit the reading of an element which otherwise would be too foreshortened, as was used in stage scenographies of urban scenes, as known. But this does not preclude the effective possibility of retracing onto them the necessary elements to trace back to the hypothetical perspectival layout (Fig. 11).

Object that appear frontally with respect to the drawing plane provide the first indications of the orientation of the scene; we can then imagine that the edges in perspective, which have their origins in the vertices of these figures, would be orthogonal to them and thus to the picture plane, thus identifying the principal vanishing point O'_0 in the point—or rather in the region—to which they converge. The imprecise determination of the vanishing points can be traced back to the observations regarding the distance between the analog drawing and the digital environment, but also to the actual execution of the woodcuts which can vary the inclination of a single straight line in the carving of the wooden plate, albeit imperceptibly.

The perspective is one on a vertical plane because the straight lines we assume to be vertical in the scene turn out to be parallel to each other in the perspective image, therefore they vanish at a point at infinity. Thus, the horizon passes through the principal vanishing point and leads in a parallel direction to those lines that can be identified as horizontal edges parallel to the picture plane. Comparing the traceable constructions in the eleven woodcuts some constants emerge. The horizon is at a very similar height, with a few exceptions, Table 3, in fact, presents two points of view, while in Table 11, besides the aforementioned pseudo-axonometry, the lines presumably horizontal and perpendicular to the picture plane seem to converge in two distinct principal vanishing point at different heights, making it impossible to determine the perspective layout. The principal vanishing point alternates between right and left side, except for Table 2 where both appear (in this table the straight lines belonging to the main subject and the ruins converge on the left, while the

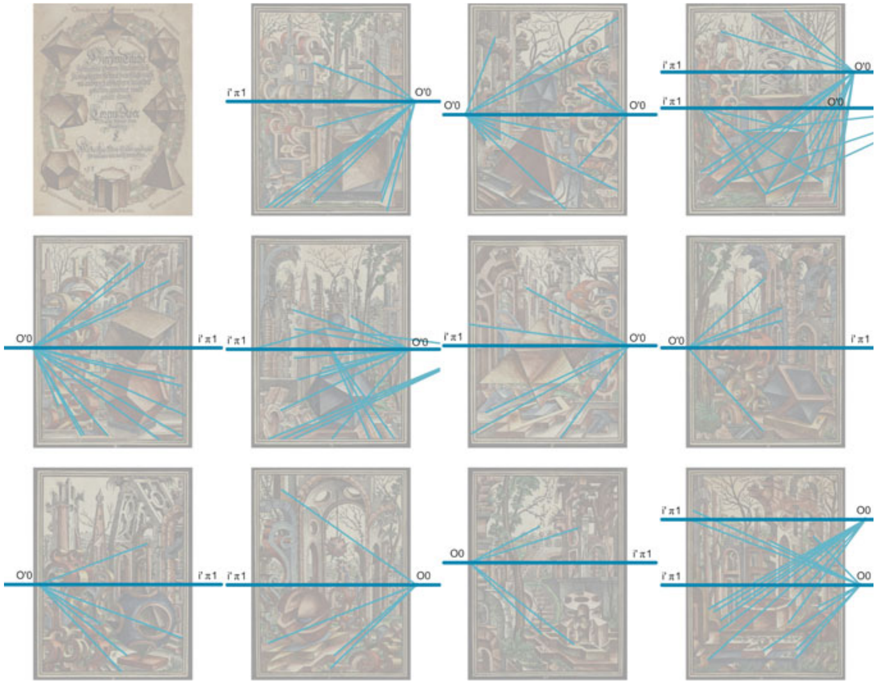

Fig. 11 Decoding the tables to trace the main elements of the perspective structure and identify the possible presence of constants among their composition (*Image processing* M. Ceracchi, M. Fasolo and G. Spadafora)

straight lines belonging to the capriccio converge on the right). But in all the tables the principal vanishing point is always proximate to the borders of the frame (Fig. 11).

To identify the distance of the observer from the picture plane it is instead necessary to operate differently for each picture, depending on the elements being represented. It is the treatises of his contemporaries Augustin Hirschvogel and Paul Pfinzing that offer the instruments to reconstruct the position of the observer.

For example, in the case of Table 1 (Fig. 12a), given the similarity with the configuration illustrated by Hirschvogel in Table 20 of his treatise, it is possible to conjecture that the same graphic procedures were used for the construction of the perspective image.

Replicating the illustrated process, the correspondence of some elements seems to validate this hypothesis. Subsequently, by identifying the vanishing point of the diagonals of the base square on the previously traced horizon, it is possible to reconstruct the distance points and therefore the position of the observer in the digital environment. On the other hand, in Table 3 (Fig. 12b), it is possible to reason as if we had had the physical model of the composition disposed on a perspectograph: the object in its physicality, despite possible imperfections, has known geometric characteristics, such as the dimension of an angle between the edges of the equilateral triangle being

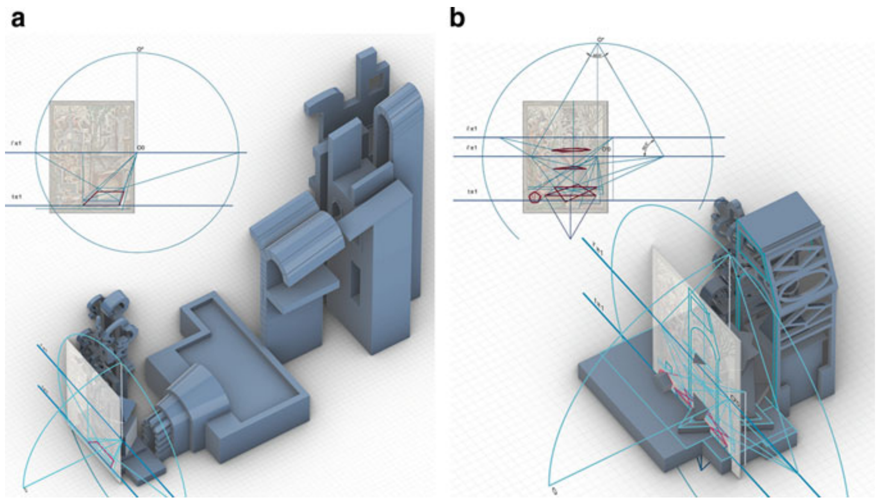

Fig. 12 The two procedures followed to determine the main distances in Table 1, on the left **(a)**, and in Table 3, on the right **(b)**. The other elements in the scene are rendered by projecting the graphic signs in the first case, and in the second case they are reconstructed as they are perceived (*Modelling* M. Ceracchi, M. Fasolo and G. Spadafora)

60°. The main distance, in this case, is determined by identifying the revolution of the observer on the picture plane, at the intersection between the revolution of the projecting straight lines parallel to the edges of the triangle (these lines are identified by following the vanishing points on the horizon lines aligned at 60° with respect to the horizon). The main distance is completely comparable to that identified in Table 1. On top of this perspective, Stöer must have superimposed another to create the image of the rest of the scene. In fact, a higher horizon can be discerned; this was probably chosen at a higher elevation so as to allow the base of the compound of two square-based pyramids above the octahedron to be seen. This shows the ease with which he adapted perspective to his communication requirements.

The characteristics that unite the different tables are useful for advancing some hypotheses on the procedure adopted by the Artist to represent the protagonist of the scene. The coherence, which emerges from these analyses, which relate the picture plane, the composition of polyhedra in the foreground, and the position of the observer with respect to them, suggests that Stöer may actually have used a perspectograph to represent the composition of solids.

The idea that the Artist created the image starting from the representation of a physical model, which almost becomes a sculptural object on a human scale in the scene represented, and that he subsequently imagined around it the world he wanted to evoke in the mind of those who were to look at his work is particularly striking. But in the current state of understanding there are still not enough elements to advance an irrefutable hypothesis, so the hypothesis of the use of graphic procedures with a coherent approach between the different tables also remains valid. The collection of instruments proposed by Paul Pfinzing in his treatise, emblematic of the widespread interest in the *perspectiva mechanica* [14], provides a useful case study for identifying the machines that could have been available to Stöer.

The multimedia exhibition considers the possibility of virtually replicating the fundamental elements that make up a perspective machine (Fig. 13). The three-dimensional target that simulates the wooden model of the composition of solids activates the contents in Augmented Reality: the position of the point of view (corresponding to the peephole for the eye materialized in Leonardo Da Vinci's perspectograph) and the rays projecting from the peephole delineate the features of the figure constructing the image point by point on the veil that coincides with the surface of the woodcut, also appears here in AR. Starting from the intuition whereby Stöer created the image by drawing directly on the two-dimensional space, not concerned with the actual shape he was building this way, it is possible to reconstruct the other space, as we defined it, with its three-dimensional forms corresponding to the image but differing from the shape perceived in the experience of reality.

By placing the point of view in a digital environment starting from the elements deducible from the perspective image of the main subject, it is possible to reconstruct the conformation of the elements that the Artist has illustrated on the plane, re-projecting the graphic signs onto the surfaces as they are positioned in the digital space depending on the clue elements that suggest its position. But these, as we

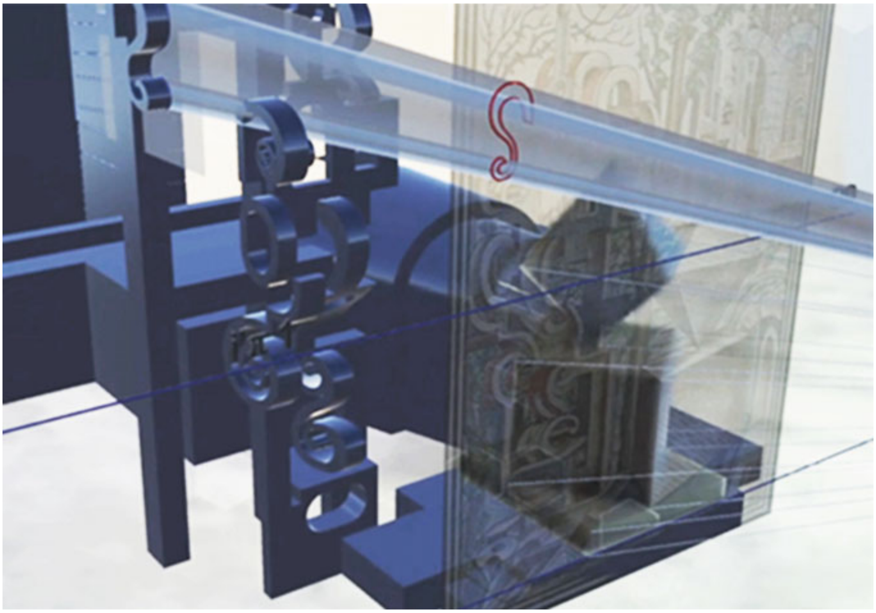

Fig. 13 The application in AR with a model-target is a simulation of a perspectograph in which all the elements materialize starting from the physical model of the composition (*Modelling and application development* M. Ceracchi, M. Fasolo and G. Spadafora)

foresaw, appear substantially different from what one would expect given their drawn image. And it is here that the difference between imaginary space and drawing space lies, between represented space and illustrated space, ultimately between other space and perceived space.

While the process of reconstructing the perceived space becomes a redesigning, adapting the represented object to one of the possible corresponding mental models, the restitution of the other space becomes a journey into an unreal world, where objects become deformed from the shape perceived from the observation of the illustration, but magically correspond to it once more if observed in a constrained view point.

The possibility of placing, in Augmented Reality, the point of view in space, albeit virtual, in the correct position reciprocal with the picture plane and the object being represented, allows the user to identify himself as the observer, or even with the Artist, entering a constrained view and experimenting with the coincidence between a three-dimensional object, a perspective construction on a two-dimensional plane, and the image contained in the woodcut (Fig. 14).

Thanks to the AR experience it is possible to experience the discrepancy that exists between represented objects, objects (probably) imagined by the Author and objects perceived by each observer, but, going back to observing the same images in the real world, we will continue to reconstruct in our minds a world populated by uniform objects and composed of geometrically known shapes, in conformity with the reality we know, because everyone is capable of imagining and therefore "of ordering in the

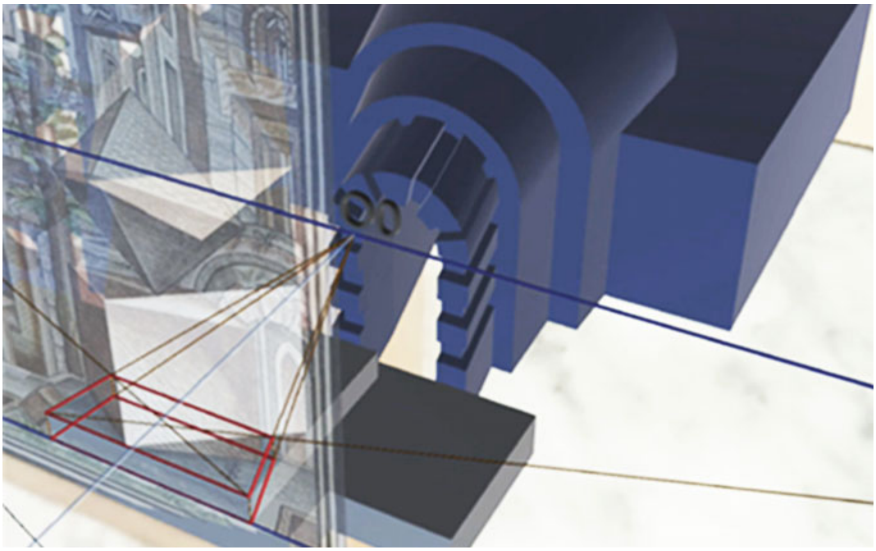

Fig. 14 The application in AR with image-target, coinciding with the reproduction of Table 1, becomes a background perspective on the imaginary world of Lorenz Stöer (*Modelling and application development* M. Ceracchi, M. Fasolo and G. Spadafora)

darkness of one's braincase a configuration of thoughts and images that describe a possible and different reality with respect to that deduced from the information" [11]. Augmented Reality therefore offers itself as a valid aid in understanding the possible processes of image composition, insofar as it renders the principles of projection that generate the perspective image visible in our surrounding space, regardless of the procedure used.

But the experience proposed in the multimedia exhibition is not limited to this, because the possibility of seeing the possible worlds that may be generated by the same image also allows us to understand how what we have defined as an other space can correspond to it an imaginary space, but not necessarily imagined, thus appreciating how in a constrained view everything once again coincides with the space of the drawing. This way, AR becomes a tool to appreciate and disseminate the intangible cultural heritage contained in the pages of the treatise through the experiences with Augmented Reality that make it possible to make the two different processes of image construction explicit but, above all, to understand how geometric subjects in the foreground become the key to understanding the perspective construction. Closing with a thought: perhaps this was the meaning behind the title *Geometria et Perspectiva*?

Acknowledgements Although the research was carried out by all the authors and the conclusions are part of the shared research project, paragraphs 1 and 2 are to be attributed to Giovanna Spadafora, paragraph 3 to Marco Fasolo and paragraph 4 to Michela Ceracchi.

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Digital Turris Babel. Augmented Release of Athanasius Kircher's Archontologia

Francesca Condorelli, Barbara Tramelli, and Alessandro Luigini

1 Introduction

Given the importance stressed by UNESCO on the documentation and valorization of tangible cultural heritage, the aim of this project is to show scholars and citizen what they cannot see because it is enclosed within the pages of the book, i.e. the most noteworthy images of the *Turris Babel*. This was done thanks to the implementation of a workflow divided into more parts. The first part concerns the placing of the Opera in his context, the analysis of graphic illustration and the reconstruction of the tridimensional model of the tower. This represents the most challenging part of the entire pipeline as it involves creating a model of an imagined architecture that never existed and of which we only have a single representation.

By combining advanced photogrammetry and 3D modelling techniques, the model was created from the images in the text and compared with other designs of the tower. The second part of the software is the design of an augmented reality app to make the model of the tower navigable in 3D and available to the public.

Both the reconstruction of the tower and the implementation of the app were carried out with low-cost tools and using open source software, ad explained below.

Augmented reality is undoubtedly an excellent way not only for visual communication as a tool for knowledge but also to give an effective interpretation to tangible cultural heritage.

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Markerless technology was used in the development of the application to make the experience more immersive and user friendly. Recent studies have shown that this technique contributes to the optimal levels of user interaction that are required in this type of experience.

2 Turris Babel

The Jesuit scholar Athanasius Kircher (Geisa, Fulda, 1602–Rome 1680) was an eminent representative of seventeenth century encyclopedism, as his eclectic interests ranging from the field of linguistic studies to geology, from philology to optics, to collecting antiquities testify to. Teacher, writer and philosopher, his rich collections of findings of classical, oriental, and Amerindian art constituted the museum collection known as the Kircherian Museum housed in the Collegio Romano (1651) [1]. Aside from the *Turris Babel* (1679), among his most important works we could mention the *Oedipus Aegyptiacus* (1652), the *Mundus subterraneus* (1665) and the *China illustrata* (1667). When looking at the surviving copies of some of these book, one could tentatively infer that some books such as the *Magnes Sive De Arte Magnetica Opus Tripartitum* (1650, 81 surviving copies) had a better fortune than books such as the *Turris Babel*. We do not know at present how many surviving copies there are, the ones we find online are in the Biblioteca, one copy is at the Biblioteca of the seminar in Bressanone, two copies at the Biblioteca Municipale de Lyon, three copies in the Bodleian Libraries, one at the Bibliothèque Nationale de France and one at the Pontificia Univeristà Greogoriana. The USTC catalogue, which does not list all the surviving copies of this book. The publisher, Johannes Janssonius van Waesberge, secured in 1661 the contract for the exclusively printing of all the work of Kircher for 2200 *scudi*. However, the latter is interesting in many respects, as it gives us a clear idea of the scholar's interest for the mysteries of the ancient world.

The book contains a beautiful fold-out engraving of the tower of Babel, as well as different representations of the magnificent city of Babylon, of Egyptian tombs and other marvels (including a pictorial map of the Tigris-Euphrates Valley from the Persian Sea to the Caspian). The architecture of the tower of Babel holds a prominent place among the illustrations presented in the book, and this is clear from the very beginning of the whole work, as when we look at the frontispiece to Book I (Fig. 1), which represents the planning of the tower's architecture, we see a scene with three allegorical figures in the act of studying the plan for the design of the tower, as if to supervise the works that are already taking place (as the sketch of the tower in the background shows).

As already noted by Peter Harrock, the frontispiece to Book I is exquisitely baroque in form and style. The evolution from the Renaissance frontispiece is evident, as the decorative architecture is abandoned in favor of an illustrated take on the episode, where all the figures are playing an active role in the designing of the tower [2].

Fig. 1 Frontispiece to *Turris Babel*, Book I, Athanasius Kircher, Amsterdam 1679 (Photo: F. Condorelli, B. Tramelli and A. Luigini)

From this first image, one can already derive the intent of the author of the book: *Turris Babel* is evidently a theatrical work, in line with the Baroque intents of dramatizing the narrative it recounts, and this is clear from this first scene which has all the figures (presumably the protagonists of the biblical episode, namely Noah, Nimrod and his son Ninus) playing their roles in classical costumes.

The second Frontispiece to Book II (Fig. 2) is what interests us the most, as it represents the whole architecture of the tower. It shows the tower extending towards the sky limit, embedded into an idealized landscape of the city of Babylon. The tower is presented as a giant construction whose grandeur is traditionally viewed as the symbol of human pride. As the biblical passage states:

"The whole world spoke the same language, using the same words. While men were migrating in the east, they came upon a valley in the land of Shinar and settled there. They said to one another—Come, let us mold bricks and harden them with fire. They used bricks for stone, and bitumen for mortar. Then they said,—Come, let us build ourselves a city and a tower with its top in the sky, and so make a name for ourselves; otherwise, we shall be scattered all over the earth. The Lord came down to see the city and the tower that the men had built. Then the Lord said: If now, while they are one people, all speaking the same language, they have started to do this, nothing will later stop them from doing whatever they presume to do. Let us then go down and there confuse their language, so that one will not understand what another says. Thus, the Lord scattered them from there all over the earth, and they stopped building the city" [3].

The tower is here conceived as a paradox: from one side it is meant to be a perennial construction, and on the other side we know that its fate is to be destroyed by God as a punishment for the *ubris* of men. Different pictorial examples show this duplicity, such as the famous Vienna Tower by Brueghel the elder for instance, who inserts in the painting incomplete elements and the decadence of the construction itself. In other examples, such as the one form the *Turris Babel*, the focus is on the beautiful and intricate architecture rather than on its unfortunate final destiny. This choice can be traced in other prints from earlier periods, as for instance in the illustrations by Bernard Salomon and Pierre Eskrich in Lyon printed one century before. If we look at the recurrent images they made for the printers of the city (namely Jean de Tournes and Guillaume Roville), we see that the intent is similar: showing the construction rather than the destruction (Figs. 3 and 4). In these two very similar images, the focus is on the chaotic and muddled process of the building, which is almost non-sensical but still very much active. In the *Turris Babel* [4] however, the image is more static, there are no people on the tower itself but rather on the foreground (recalling the scene of the first frontispiece). The tower is always a symbol of the un-finished, that is of something that cannot be achieved in its entirety.

This is clear in the engraving of the *Turris Babel*: the top is still under construction, and it looks almost like a ruin. The annihilation of the tower is implicitly hinted at, although it is not predominant in the picture, which is focused on rendering the majesty and the esthetic quality of the massive architecture, described here in the smallest details. Comparing it with other images, the picture of the *Turris Babel* seems more a celebration of the skillfulness of men rather than a chaotic attempt to

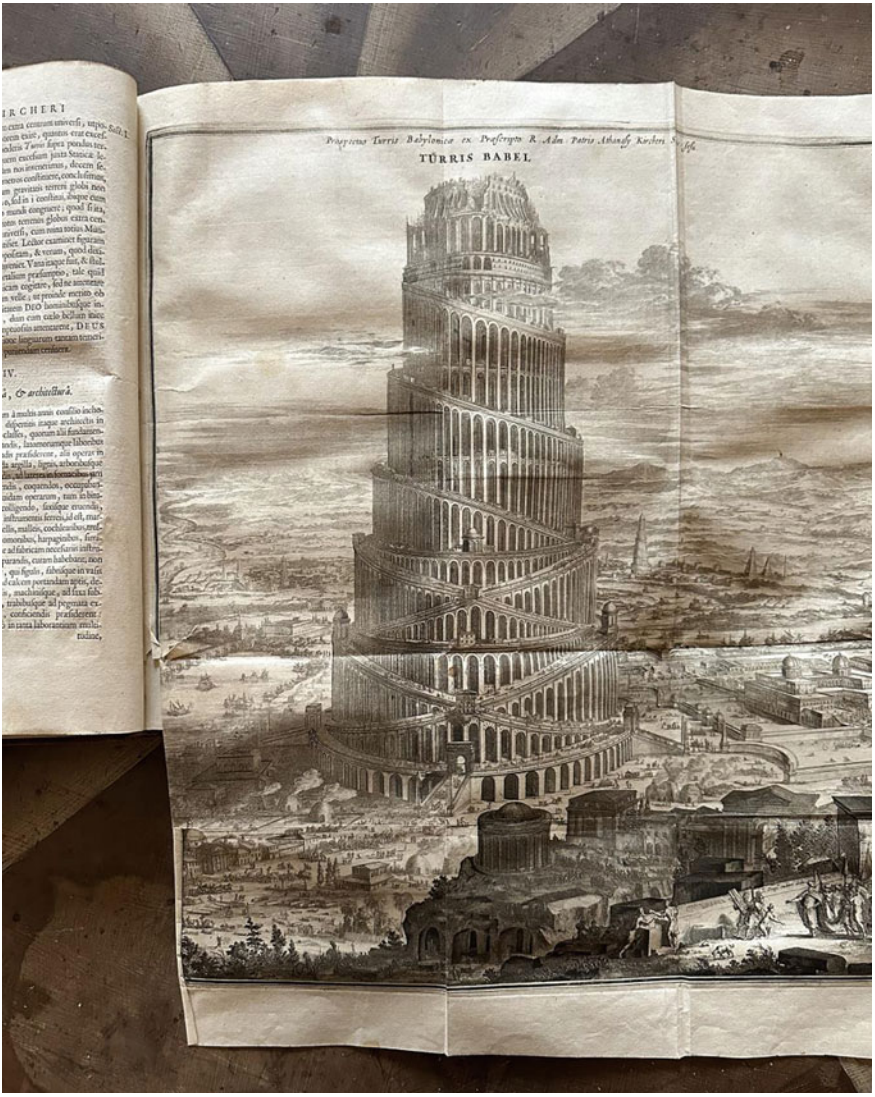

Fig. 2 Frontispiece to *Turris Babel*, Book II, Athanasius Kircher 1679 (Photo: F. Condorelli, B. Tramelli and A. Luigini)

surpass human limits. There is no real judgement here, but rather a visual attempt to describe the effort of men to unite themselves, an attempt that as we know failed, as the biblical episode was written to try to explain the multiplicity of languages on earth.

Fig. 3 Bernard Salomon, The Building of the Tower of babel, woodcut. *Source* Les Quadrins Historiques de la Bible, Lyon, De Tournes, 1553 (Photo: B. Tramelli)

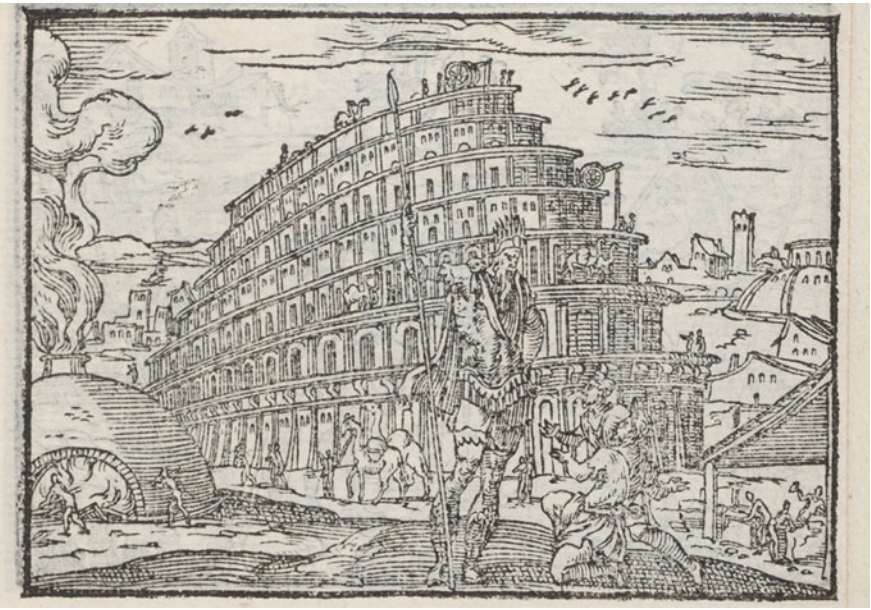

Fig. 4 Pierre Eskrich (also named Vase, or Cruche), The Building of the Tower of babel, woodcut. *Source* Les Figures de la Bible, Lyon, Roville, 1564 (Photo: B. Tramelli)

3 Methodology

The methodology used was designed to solve the specific problem of the three-dimensional representation of a known work of architecture by means of some graphic representations made from the descriptions contained in the biblical scriptures (Fig. 5).

Following a detailed explanation of the workflow is reported. First of all is was necessary to expand the database of images available on the tower. For this reason images similar to the one in the text were taken from web crawling. Starting from this dataset, the photogrammetry workflow was implemented to extract known points that were useful for reconstructing the model (Fig. 6).

The photogrammetric software used in this work is the open source pipeline of COLMAP. he standard SfM sequential processing pipeline for the iterative reconstruction in COLMAP was customised [5] in order to extract the coordinates of specific points in the images. The presence of some specific known points, selected by the human operator, will allow the correct modeling of the object of study.

The first step of Feature detection and extraction find sparse feature points in the image. After a preliminary automatic selection of feature points, point of interest for the next phase of the metric evaluation are manually selected with an additional step of Manual selection of feature points (highlighted in red in Fig. 7) was added, after the Feature detection and extraction phase in order to guarantee the presence of tie points in the point cloud to use during the subsequent Feature matching and

Fig. 5 Proposed workflow (Editing: F. Condorelli, B. Tramelli and A. Luigini)

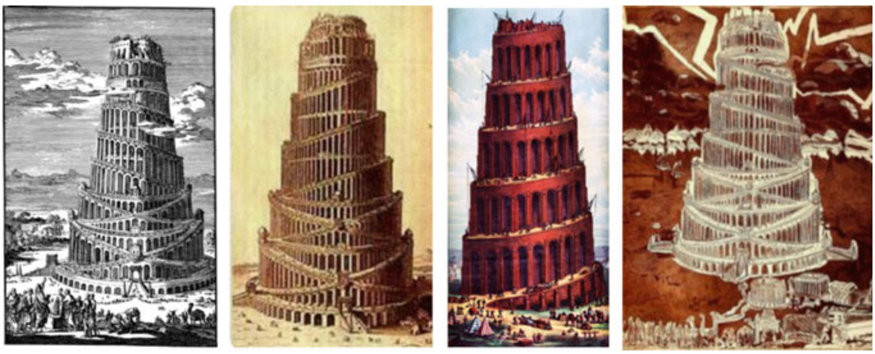

Fig. 6 Some images of the Babel Tower from image retrieval step. *Source* web crawling

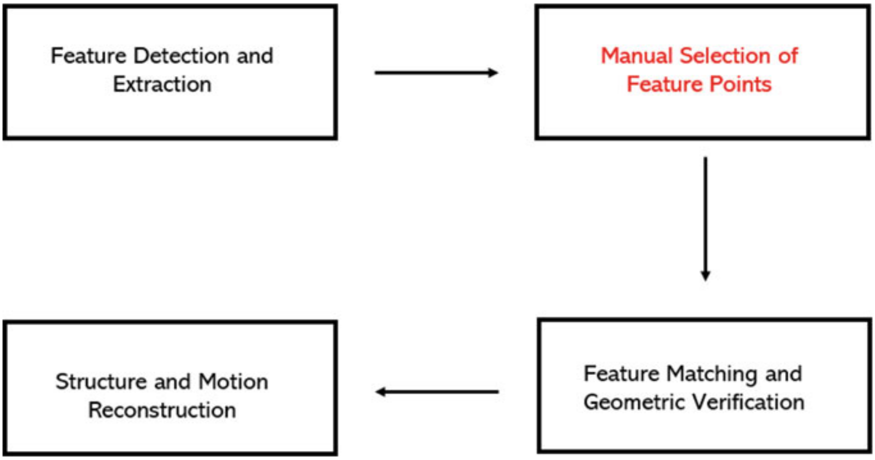

Fig. 7 The customized photogrammetric pipeline (Editing: F. Condorelli, B. Tramelli and A. Luigini)

geometric verification step. In the third step, Feature matching and geometric verification find correspondences between the feature points in all the images. As result of the matching, a point cloud is obtained with the Structure and motion reconstruction step. Although being sparse, it includes the points used for the 3D modelling of the object of interest. For what concerns the second phase of the proposed workflow, the development of an Augmented Reality is undoubtedly an excellent way not only for visual communication as a tool for knowledge but also to give an effective interpretation to tangible cultural heritage. Markerless technology [6] was used in the development of the application to make the experience more immersive and user friendly. Recent studies [7] have shown that this technique contributes to the optimal levels of user interaction that are required in this type of experience [8].

4 Results

Thanks to the detection of specific points in the photogrammetric step, the 3D models of the tower and the labyrinth from the book's illustration were created (Figs. 8 and 10). Following the results of the AR apps developed for the Athanasius Kircher's Archontologia are shown. Thanks to the implementation of Vuforia tool in the Unity environment, the app shows the navigable model of the tower in real time by simply pointing the device at the corresponding image in the book. Vuforia is a cross-platform platform for augmented reality and mixed reality app development with robust tracking and performance on a variety of hardware (including mobile devices and head mounted displays (HMDs)) (Figs. 9, 10, and 11).

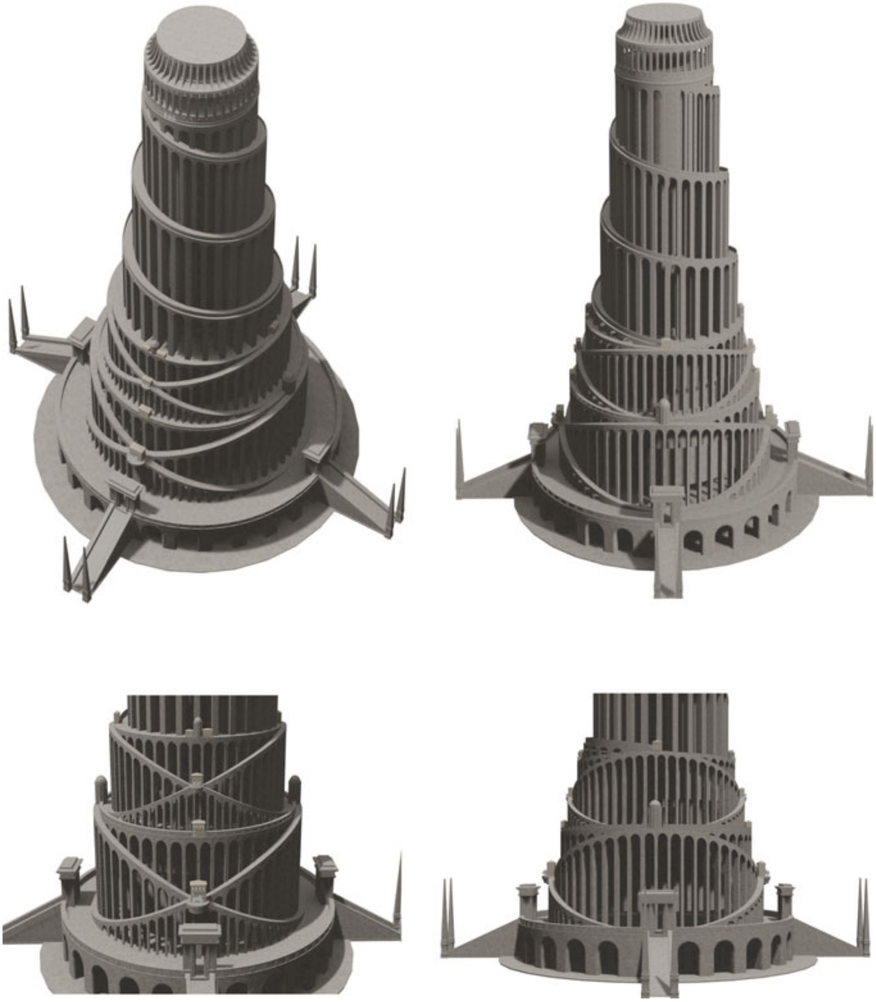

Fig. 8 3D model of the tower (Editing: F.Condorelli, B. Tramelli and A. Luigini)

Vuforia's integration with Unity enables the creation of apps and vision games for Android and iOS using a drag-and-drop creation flow. In AR, markers are images or objects stored in the application that serve as triggers for information in the application. When the device's camera detects these markers in the real world (while running an AR application), it triggers the display of virtual content at the marker's global location in the camera view. Tracking with markers can use different types of markers, including QR codes, reflective physical markers, image targets, and 2D labels. The simplest and most commonly used type of marker in gaming applications is the image target.

Fig. 9 AR app for the visualization of 3D model of the Babel Tower (Editing: F. Condorelli, B. Tramelli and A. Luigini)

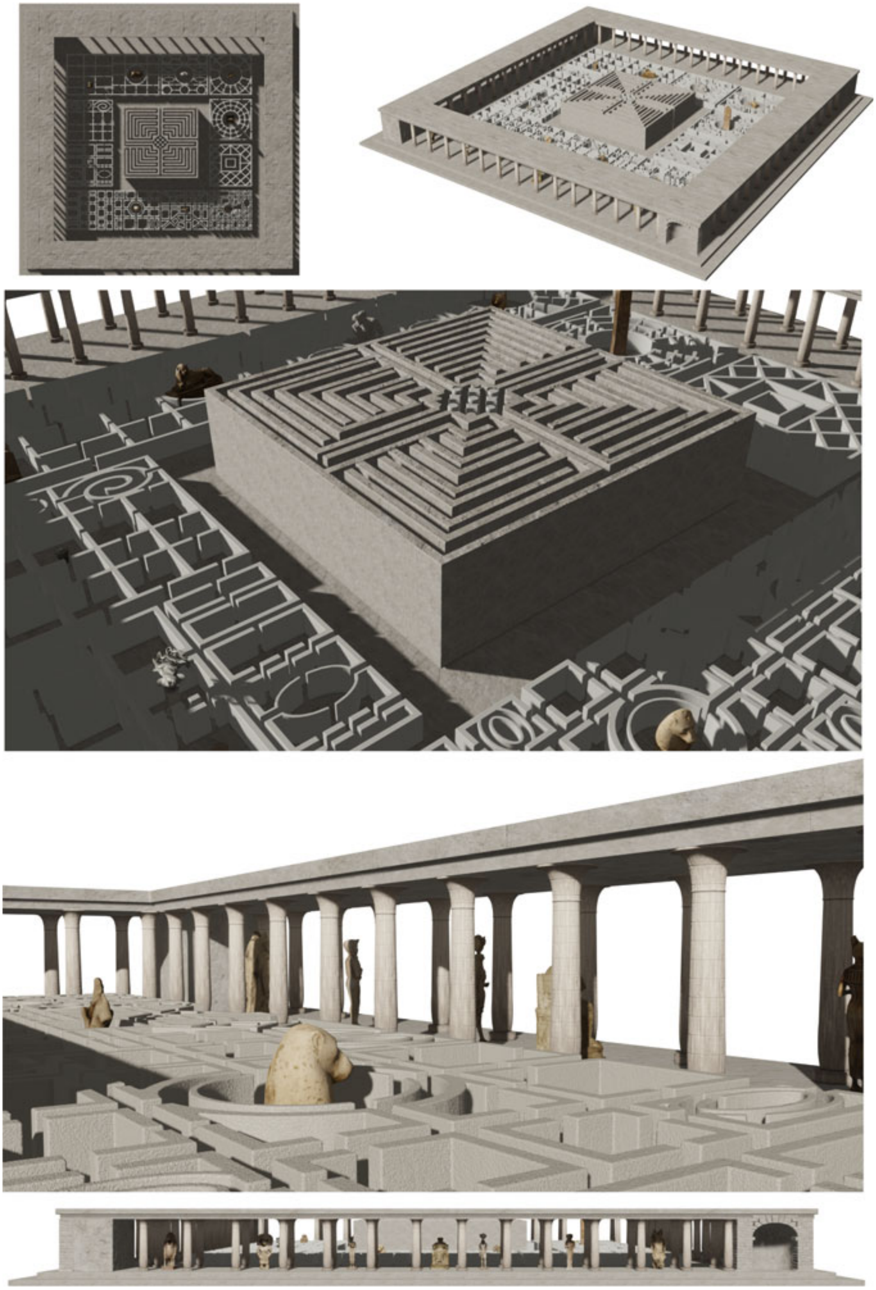

Fig. 10 3D model of the labyrinth made (Editing: F. Condorelli, B. Tramelli and A. Luigini)

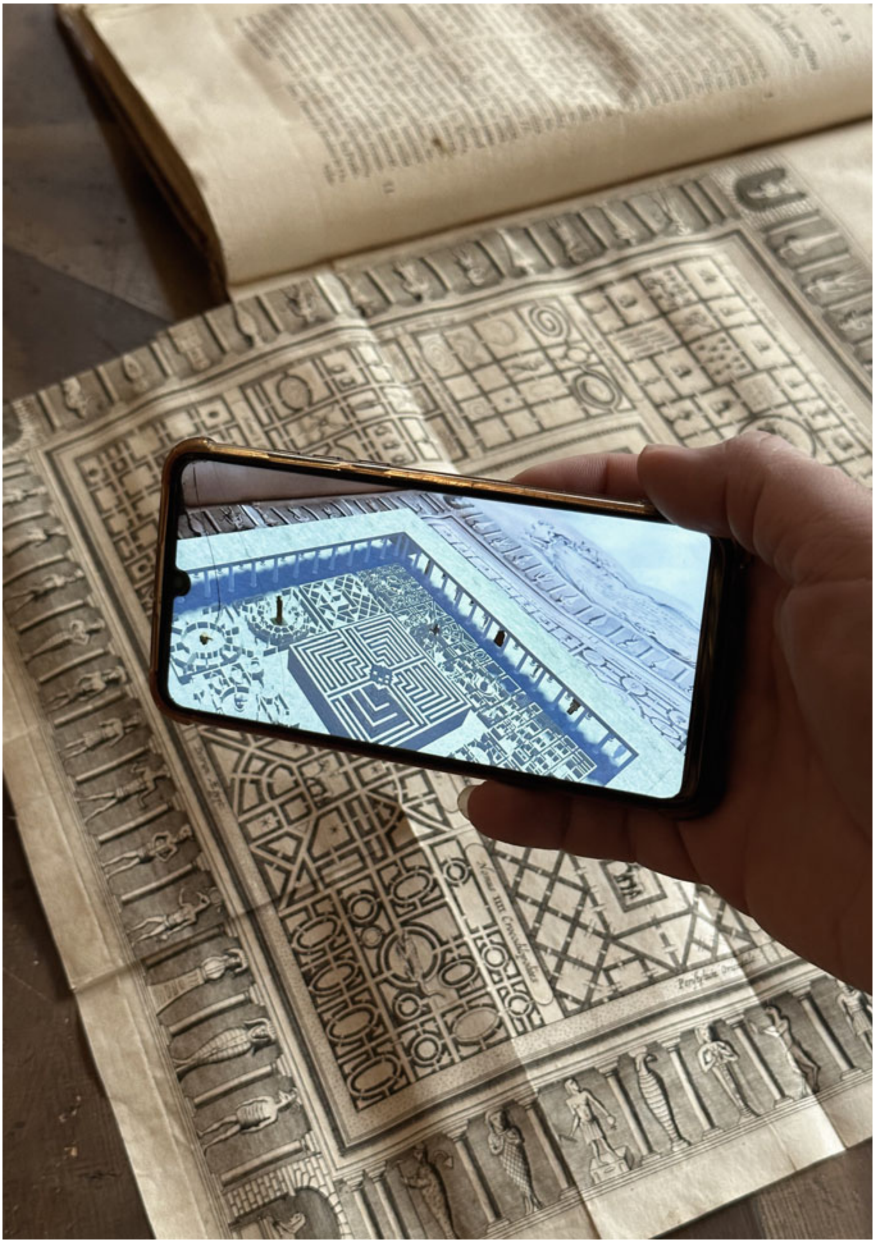

Fig. 11 AR app for the visualization of 3D model of the labyrinth (Editing: F. Condorelli, B. Tramelli and A. Luigini)

5 Conclusions

The augmented navigation device will be optimized and the narration of the book content and illustration descriptions will be improved to ensure a smooth and engaging experience of the book. Future research will explore the use of visual search engine algorithms in combination with AI. Moreover the improvement of the matching phase in the proposed workflow using recent algorithms such as SuperGlue could be a good solution for the obtaining of the 3D model of imagined architecture as the *Turris Babel*.

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A Gnomonic Hole Sundial Between Reality and Simulation

Cristina Càndito

1 Introduction

This paper proposes integrating a visit to the University Palace of Genoa with the applications of digital panoramic photography and augmented reality. The intention is to show how it is possible to reconcile a real visit with a virtual one, without sacrificing, at least in part, contact with the cultural object. In particular, the aim is to illustrate a scientific instrument found inside the Palace functions: the sundial with a gnomonic hole created in 1771 by François Rodolphe Corréard, Jesuit astronomer and mathematician.

2 University Palace and University Education

The University Palace of Genoa was born as the headquarters of the Jesuit College thanks to an agreement between the Order and the important Balbi family of Genoa. In the seventeenth century, the members of the Balbi family built an entire street to accommodate their residences and dedicated a lot to the Jesuit order, which finds its permanent headquarters for its courses here. Paolo Balbi left his inheritance to his brothers, receiving in exchange the lot and part of the funds to build the College of which he became rector.

The project was developed by the architect Bartolomeo Bianco (1579–1640) beginning in about 1630. The design phases of the building also engaged the mathematician Orazio Grassi (1583–1654), rector of the college from 1646, in his previous role as examiner in Rome for the first projects of the Genoese Jesuit college. These

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Fig. 1 The University Palace. **a** view from the beginning of Strada Balbi; **b** the front with the two windows of the Sundial Hall (Photo: C. Càndito)

projects are stored at the Bibliothèque National of Paris, catalogued in 1960 by Jean Vallery-Radot and Edmond Lamalle [1], and at the State Archives of Genoa (Notaio G.B. Cangialanza, filza 11, 1629–1630) [2]. The construction phases are partially contained in the manuscript by Nicolò Gentile written in 1686 (Annue memorie del Collegio di Genova, Archivum Romanum Societatis Jesus, Med. 80).

After a decade of interruption due to the great plague epidemic, work resumed under the direction of Grassi in 1650. It would then be the architect Pietro Antonio Corradi (1613–1683) who would carry out new expansion works [3–7] (Fig. 1).

From the entrance hall (level 1), the monumental staircase leads to the single courtyard (level 2) which is over-looked by two orders of classrooms arranged along either side (Fig. 2). At the third level there is also the main Assembly Hall [8]. The residences of the fathers overlook it from the top floor, set back for reasons of privacy, and are distributed along the corridor of Saint Ignace (Fig. 3), at the end of which the domestic library is located. It is this last room, now used as a university classroom and conference room, which hosts the gnomonic hole sundial in the eighteenth century (Fig. 4).

The educational role of the Genoese College, in analogy with other places, has a significant social importance. The financial function of the Colleges is also an international phenomenon, since they are allowed to accumulate assets in derogation from the principles of begging imposed by the Constitutions of the Order. Young people belonging to the most notable families study in the College or enter the Order.

Recent studies place the Genoese college in the broader historical dimension of the phenomenon of Jesuit teaching of the College, paying particular attention to the scientific aspects [9–12].

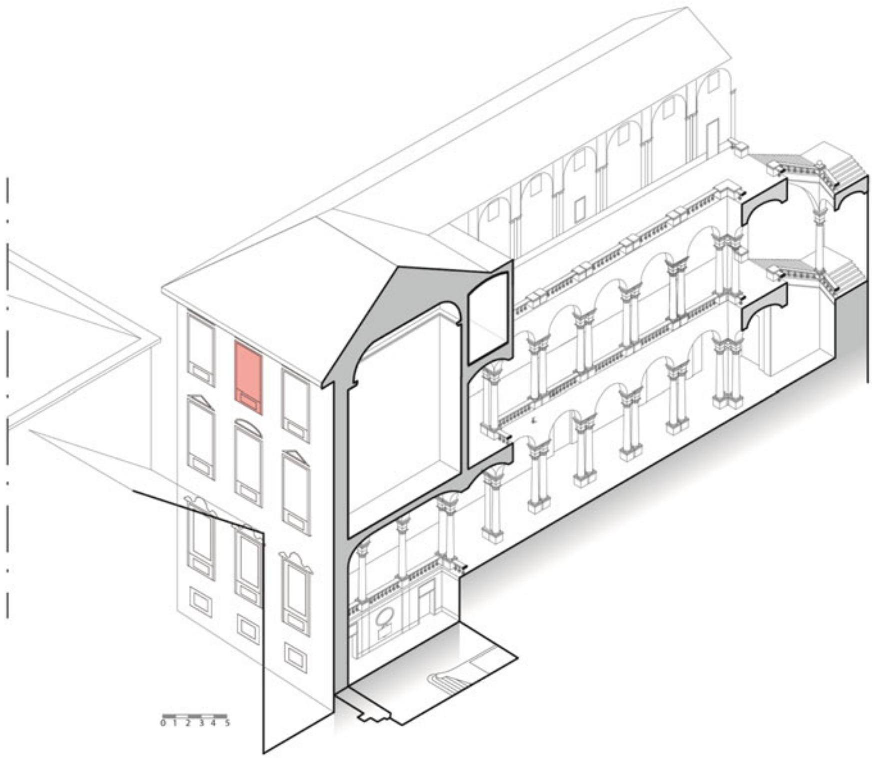


Fig. 2 Cross Section of the virtual model of the University Palace. The windows of the gnomonic hole (Modeling: Alessandro Meloni)

3 The Sundial Hall

A gnomonic hole sundial (or pinhole sundial) must consist of two elements: a meridian line and a narrow pinhole positioned in an internal space that could be partially obscured. The meridian line—horizontal and oriented north–south—is obtained by the intersection with the great maximum meridian circle of the celestial sphere that passes through the North and South poles. The pinhole can be placed in a south-oriented wall or on the roof, and it should be little as much to obtain the camera obscura effect. That means that the distance with the meridian line must be more than 1146 times the pinhole diameter. With these conditions, the inverted solar image is projected at noon on the same meridian line [13].

In other words, a gnomonic hole sundial work with the light instead of the shadow, and the gnomon is not an opaque body that casts its shadow, but a hole placed at a distance from the floor hosting the meridian line: the gnomonic height.

Fig. 3 The Saint Ignace corridor and the access to the Sundial Room (Photo: Ilenio Celoria)

Fig. 4 The Sundial room and the Sundial line (Photo: Ilenio Celoria)

The Sundial Hall of University Palace is connected with the balcony of the Main Assembly Hall and the meridian line, in marble and brass inserted in the floor, is conserved, but we no longer have the gnomonic hole.

The sundial was built in 1771 by the Jesuit François Rodolphe Corréard (1725–1794) [14, 15] and was documented for the first time in the plan of the engineer Giacomo Brusco in 1773 (Manoscritto Brusco, Biblioteca Universitaria di Genova, 1773, plate 5).

The construction of the sundial is linked to the adoption of French or astronomical time (with the change of the date at midnight) to replace the Italian time (with the variable change of the date at sunset), in use in Genoa until 1771. This makes it necessary to adjust mechanical clocks with the local noon, correctly identified by gnomonic hole sundial.

The projection of the solar image on the meridian line takes place during the year with inclinations that place it between the furthest limit of the winter solstice and the closest one of the summer solstice, when the elliptical projection approaches the circular shape.

Corréard had been in Genoa since 1766 following his astronomical studies at the Marseille Observatory, which he published in his *Mémoires de mathématique et de physique* (Avignon, 1755–1756). In 1762 the Jesuit was forced to leave France due to the suppression of the Order and went on to teach mathematics in the Genoese college, remaining there even after the suppression of the Society in Italy (1773).

In Genoa, Corréard designed, but did not build, another example of the sundial with a gnomonic hole for the Duke Palace in Genoa, in which, with Glicerio Sanxay, he carried out static consultancy at the request of the Senate [15].

The sundial of the College finds important precedents in that of Paolo dal Pozzo Toscanelli (1397–1482) built in 1475 in Santa Maria del Fiore in Florence, linked to the summer solstice (gnomonic height 90,11 m), and again in Florence, in the one designed by the Dominican Egnazio Danti (1536–1583) in 1580 for the façade of Santa Maria Novella (1580), where today the gnomonic holes have been reopened and the sun's rays once again indicate the equinox and the winter solstice (gnomonic height 21,35) [13].

Egnazio Danti also built the first version of the gnomonic hole sundial of San Petronio in Bologna in 1576, destroyed in 1653 because of the lengthening of the church. The new version was made by Gian Domenico Cassini (1655) and it is still functional thanks to a careful restoration [16]. Cassini began his studies right at the College of Genoa and perhaps made a sundial with a gnomonic hole at the SS. Annunziata del Vastato of Genoa, which may have inspired the later example by Corréard. The great sundial of Santa Maria degli Angeli in Rome was commissioned by Clement XI and built in 1702 (gnomonic height 20,30 m) by the astronomers Francesco Bianchini and Giacomo Filippo Maraldi, the latter of whom was the nephew of Gian Domenico Cassini. A further example is the one made in 1786 in the Milan Cathedral by the astronomers Giovanni Angelo De Cesaris and Guido Francesco Reggio. These are only some of the most well-known examples of this kind of astronomic tool.

There were several scientific, civil and religious reasons for building gnomonic hole sundials. Among the scientific reasons [17] was the calculation of the latitude and the obliquity of the ecliptic and its possible variation, but also the determination of the instant of the equinox, the calculation of the exact value of the precession of the equinoxes and the right ascension and declination of the stars.

The civil reasons were substantially linked to chronometric progress, as we said, the measurement of time with the highest possible precision in order to check mechanical watches that are still inaccurate.

Among the religious reasons, the most important is the complex issue of determining the date of Easter stands out, due to connecting the Jewish lunar calendar to the solar one used in the Christian Church.

4 The Virtual Tour

The sundial of the University Palace of Genoa is currently the subject of a reactivation project capable of reconciling the current function with the historical and scientific one [18].

To achieve this goal, the techniques of virtual tour and augmented reality can be useful, capable of virtually integrating a visit to the sundial in the event that the hall is unavailable to visitors.

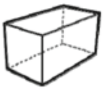
Considering the premises described, the use of a multimedia Virtual Tour was designed to respond to the various accessibility needs of potential users. The accessibility of the space and the information for reaching it, as well as historical and scientific information related to the sundial could be provided with multimedia methods. The visualization of the model of the environment, obtained with photogrammetric methods, lends itself to the completion or replacement of the real visit, thanks to the inclusion of historical and scientific information, contents and the simulation of the functioning of an evocative instrument of historical importance.

4.1 The Structure

The virtual tour is not intended as a simple succession of 360° images, but rather as a way to show different materials: videos, historical photos, audio descriptions, and subtitles in different languages. We can call this tool *MultiPano*, to point out its multimedia dimension (Table 1).

A simplified linguistic tone is adopted to match the needs of children or people with cognitive difficulties, but the contents are organized with different degrees of detail to be suitable to the interests of users. The communication is designed for on-site use, but an online mode is also possible, with variations in the arrangement of the contents.

Table 1 *MultiPano* contents and features

	Tool	Accessibility and expressive improvement
	Written texts and subtitles	For hearing disabilities; foreign languages
	Audio descriptions	For visually disabilities Integration and understanding
	Music	Expressive imprints
	Images	Integration and understanding Expressive imprints
	Video	Integration and understanding Expressive imprints
	3D model	Integration and understanding Expressive imprints
	360° panorama	Integration and understanding Expressive imprints

The first panoramic image of the virtual tour concerns the atrium of the Palace (Fig. 5) as a place that shows the different directions to follow, according to the possible objectives. It is the place of the monumental staircase with the two lions designed by Domenico Parodi at the beginning of the eighteenth century and it is from here that the different features of the building's history are shown through the insertion of a sort of virtual exhibition supported with texts (written and audio) and with drawings, photos and videos. An introductory knowledge of the different rooms of the Palace can be obtained, supported with reconstructions obtained through virtual models.

A very important aspect to provide at the beginning of the visit is that of the possibilities of physical accessibility, which is illustrated not only through the floor plans but also through videos (https://www.youtube.com/watch?v=ujpD7j7HHl8)

Fig. 5 *MultiPano* of the University Palace: the entrance and the illustration of the Palace and its accessibility (Images: C. Càndito)

that show the route to overcome architectural barriers: a very useful method for preparing a visit remotely.

At the same time, we can offer an overview of the opportunities available in terms of multimedia multisensory tools that can be implemented during the visit vis-a-vis accessible content for people with sensory disabilities, such as audio descriptions and subtitling.

The following panoramic images show the stages of reaching the center of the courtyard (Fig. 6): another privileged point of view for appreciating the specific characteristics of the Palace. The Genoese Jesuit College, in fact, was built with significantly different characteristics from all the coeval colleges: in Genoa there is only one of the two courtyards that encompasses both public and private functions. This choice was caused by the orographic configuration of the terrain which would have required extensive excavations. To combine the two functions, the private quarters of the fathers appear elevated and set back, so as not to be visible from the courtyard itself [19].

At the same time, the courtyard makes it possible to locate the main public spaces and its panoramic photo therefore lends itself to showing them through direct connection hotspots.

4.2 From Drawings to 3D Models

The sundial can therefore be presented starting from the connection from the courtyard, first of all through its panoramic photograph (Fig. 7), capable of making one observe the different views and details of the room and of the meridian line.

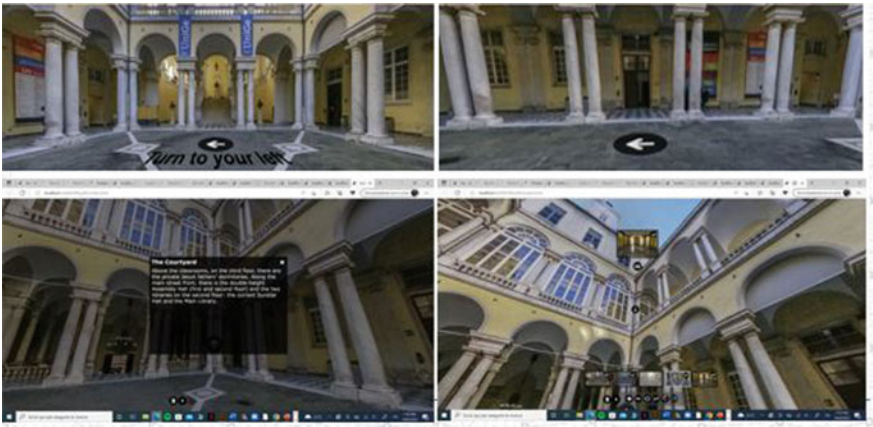


Fig. 6 *MultiPano* of the University Palace: the courtyard and the Sundial (Images: C. Càndito)

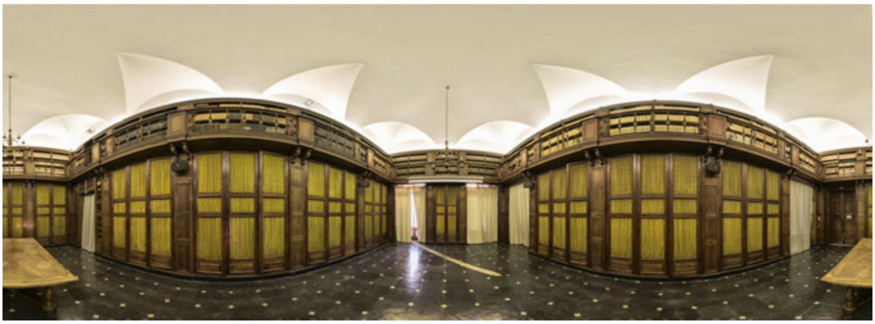


Fig. 7 Panorama equirectangular projection of the Sundial Hall (Photo: C. Càndito and Ilenio Celoria)

The functioning of the instrument can find a more precise explanation through the aid of drawings (Figs. 8 and 9) that illustrate the relationship between the instrument itself and the architectural environment through the representation of planimetry and section. Moreover, images show a different situation from that found in everyday life as, due to the functions it performs, the meridian line is occupied by furnishings, such as the teacher's desk (Fig. 10).

A more evocative simulation can be realized through a virtual model and a video showing the modification of the inclination of the solar rays during the year to explain the calendrical function (Fig. 11) or other important tasks of the astronomical instrument. These contents can be seen online too and find indeed a more effective expression in the virtual form that integrates the real one, by its nature dependent on the date but also by the weather conditions. The virtual model exploration or the video simulation could be also activated during an on-site visit by a QR-code placed closed to the entrance of the Sundial Room using Augmented Reality techniques.

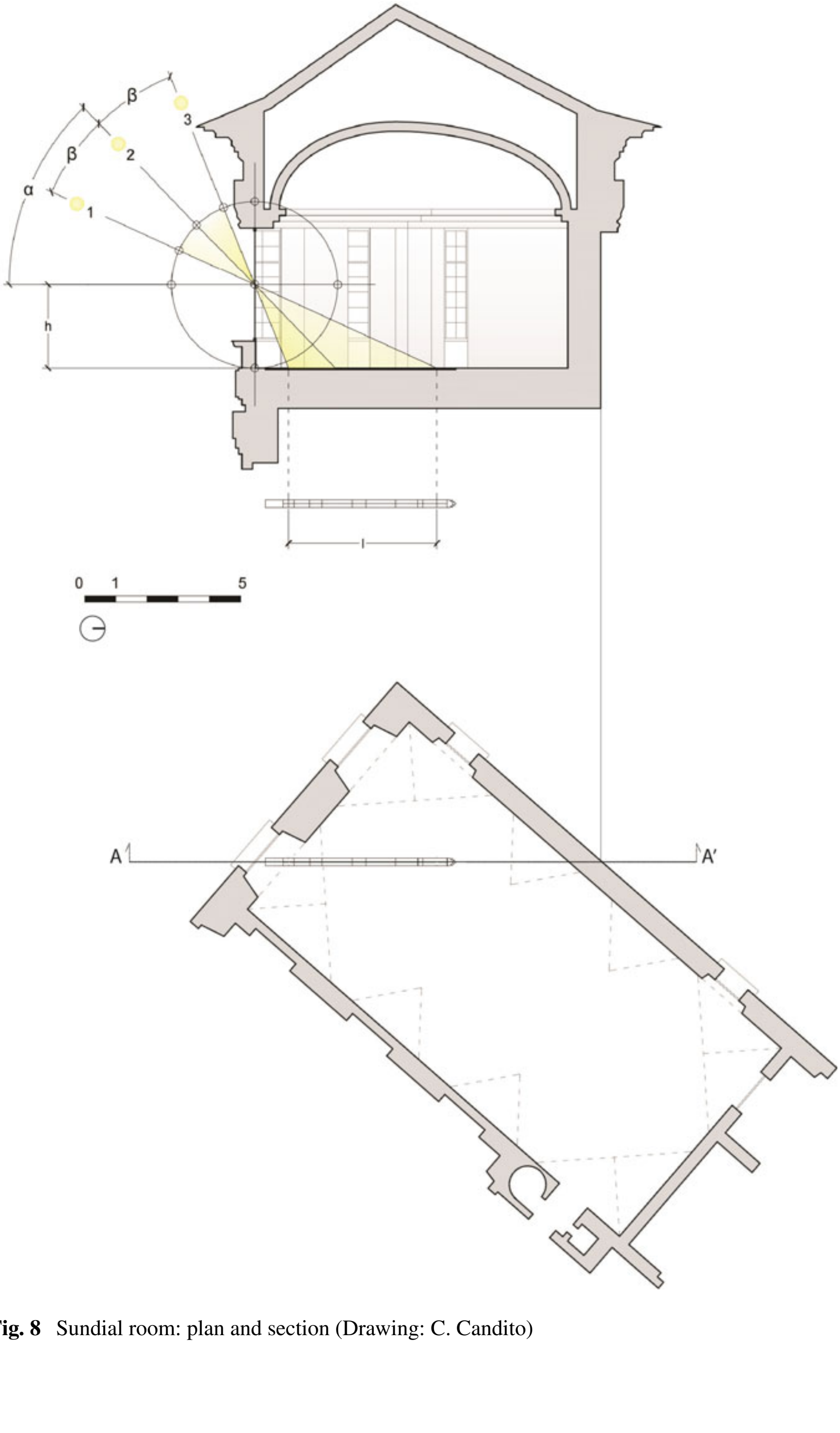


Fig. 8 Sundial room: plan and section (Drawing: C. Candito)

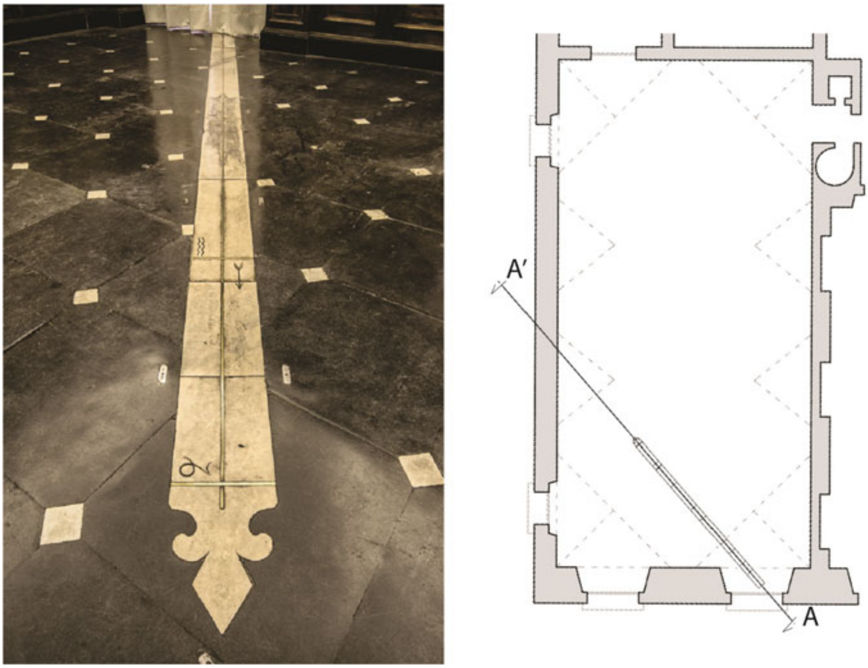


Fig. 9 The meridian line (Photo and drawing: C. Candito)

Fig. 10 The hidden sundial (Photo: C. Candito)

5 Multimedia and Flexibility

A rare astronomical instrument can find its revitalization through the physical re-functionalization that makes it visitable and appreciable as a vehicle of ancient scientific knowledge but also as an opportunity to illustrate astronomical phenomena of great popular and scientific interest. This function can be integrated through virtual tools, such as a multimedia virtual tour (*MultiPano*) which constitutes a container

Fig. 11 The activation of the video simulation on-site with a QR-code and Augmented Reality (Modeling: C. Càndito and Ilenio Celoria)

for textual, audio, image and video contents that communicate, in an accessible way, descriptions and simulations also evoked on-site through Augmented Reality techniques.

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Drawing of the Space Between Tradition and New Media

Isabella Friso

1 Introduction

1.1 The Courrent Situation

In the last quarter century, the concept of digital culture has become increasingly rooted in the forms of communication and dissemination of what is the enormous wealth of cultural heritage whose historical and artistic value is certainly the symbolic form of the social context that produced it, that is, the highest expression that identifies a community. At the same time, there has become ingrained in the collective consciousness the awareness that we are living in a historical epoch characterized by the increasingly pervasive presence of technology and digital tools in our daily lives, also affidating to them much of our communication and interaction with other individuals. This radical transformation of communication systems has also coinvolved the world of art and culture in general, codifying new and increasingly complex systems of storytelling and fruition of tangible and intangible content based on the perception (for now only visual) and remote action of the user [1].

The ever increasing presence of ICT in contemporary society has inevitably pushed cultural institutions to update themselves and begin a complex process of digitization carried out at several levels, keeping always well in mind, however, that the fruition of Cultural Heritage through mobile devices and from the online mode achieves its purpose if it fulfills the functions of research, teaching and alternative information, without aspiring to replace the real, but standing alongside it in the revitalization of cultural objectives and contributing to the success of educational action.

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Exploring dynamic interfaces, interactive graphics systems, querying databases accessible from thematic and sensible maps, 2D/3D tours, and a whole range of activities are designed to arouse and stimulate curiosity and creativity.

Certainly we need to take note of how current communication technologies have incentivized the pursuit of multiple forms of learning and a different way of interacting with knowledge content, fostering much more widespread promotion and dissemination, but also generating a growing impatience with the digital paradigm. If, on the one hand, technological devices and social platforms have redesigned the grammar of seeing, focusing on forms of narrative that are increasingly interrelated to digital logic, on the other hand, institutions are turning toward experimenting with hybrid exhibition models in which the virtual component, juxtaposed with traditional analog media, creates places of multidisciplinary knowledge by fostering possibilities for expression and inclusion. It is not, in fact, a matter of preferring digital to analog, but rather of developing an integrated system of communication.

1.2 Description of Research

It is in this cultural context that the research entitled *The Representation of Architecture: the drawing of space between tradition and new media* is set, which intends to affront, on the one hand, the critical study of the work of the multifaceted figure of Gaspard Monge and, on the other hand, to develop and experiment with a new form of visualization of the most famous of the French mathematician's treatises, titled *La Géométrie descriptive. Leçons données aux Écoles normales, l'an 3 de la République* published in Paris in 1827.

With the digitization of Monge's treatise, we want to begin a path of access to information that, embracing a wider sphere, could be of interest to the field of ancient treatises in general and not only to those that, dealing pretely with geometric apparatus, are instead aimed at an extremely sectoral audience.

In the case of ancient treatises, the purposes of 3D virtual models and their visualization through a tour could have substantial spin off both in the educational sphere for greater understanding of the texts, facilitating learning, but also as a tool for checking and verifying data.

The research followed a well defined methodological procedure; the sequence of steps enabled not only reconstruction but also philological validation of the archival documents accessed:

- Historical research: archival documents and analysis of texts allowed not only to recognize key moments in Gaspard Monge's life but also to establish a network of possible connections between the French mathematician and other scientists as well as illustrious coeval figures.
- Study of treaties: in this specific case the focus is on *La Géométrie de-scriptive. Leçons données aux Écoles normales, l'an 3 de la République* of which the autor of this paper is also the translator of the relevant parts.

- Digitization of the treatise: redesign of the 25 planchets that solve complex geometric exercises through the application of the double orthogonal projections, developed by Monge himself.
- 3D model creation: for each repurposed exercise and starting from the graphical solution given in the planche, a virtual model was created that repurposes the entities in their geometrical and spatial conformation and configuration. This verified the two-way relationship existing between the entities in physical space in three dimensions and their images on the two dimensional plane.
- Creation of a storytelling in order to visualize every planche.
- Study of virtual tour graphic layout.
- Selection and creation of content suitable for explaining the tables accompanying the treatise: at this stage, not only static images but also multimedia files such as video and audio as well as text files that can help the user understand what is represented in the tables were created.
- Realization of the virtual tour: at this stage, the 'learning files' were imported into the Pano2VR software and appropriately linked to the tour structure in such a way that they could be easily queried once exported and made permanently accessible from its online portal.

2 The Research

2.1 About Gaspard Monge

Gaspard Monge born in Beaune, France, was a very important scientist. Polyhedral, eclectic and versatile, he was a bold person both as a civil servant and in his role as founder of the prestigious École Polytechnique in Paris. Politically engaged, he was always on the side of Napoleon Bonaparte (1769–1821). With him he established a relationship of true friendship based on deep esteem and mutual respect. Monge was in fact at the French Emperor's side first during the Italian Campaign and, later, during the Egyptian one: it was Napoleon himself who stubbornly wanted him with him in Egypt as well and conferred on him the appointment of Count of Pelusium.

Gaspard Monge's political career took a significant turn in 1792, when he met and became part of Napoleon's trusted people, but what he aspired was to pursue the profession of teaching. As soon as he had completed his studies at the College of Oratorians in Beaune, Monge had the opportunity to make his talent known as a drawer in 1764 when, after collaborating on a topographical survey of his hometown, he redrew its plan.

Beyond all the public, private, and political events that significantly marked his life, the French mathematician was rememberede as the founder of that branch of geometry that he named Descriptive and the encoder of the method of double orthogonal projections, still known today as Monge's method (Fig. 1).

Fig. 1 Timeline of Monge's life (Editing: I. Friso)

Monge developed a new universal graphical, scientific and technical language which was common to everyone and understood by all engineers and technicians responsible for the design, direction of execution and operation of engineering works.

The Method is extensively explained in all its complexity within *La Géométrie descriptive. Leçons données aux Écoles normales, l'an 3 de la République* published in Paris in 1827.

In terms of scientific production, Gaspard Monge was a researcher and professor in various disciplines: from teaching Physics to Mathematics, from Statics to Geometry. The lecture notes of his courses, given in various Schools, were often reworked by the scientist himself aided also by distinguished students. Returned to readers in a new form, the Treatises are still a source of inspiration and models to which young researchers often refer. Most of his studies are contained in the publications *Application of Algebra to Geometry* (1809) and *Application of Analysis to Geometry* (1813). The latter contains his solution of a differential equation to partial derivatives of the second order.

Buried in a mausoleum at Père Lachaise, Gaspard Monge died in Paris on July 28, 1818 [2].

2.2 Treaty Digitization

The second phase of the research focuses not only on digitizing the 25 planchets, which occupy the final pages of the famous treatise, but also on studying a strategy for displaying the same planche, set on the use of new technologies and recent techniques of user education based on e-learning.

Planche shows the representation of complex geometric exercises solved graphically using the double orthogonal projection method. At first related to problems of a purely geometric nature, the method has spillover into the field of engineering even before architecture and mechanics, developing not only in France but also all over Europe and in the rest of the countries overseas. To date, it is considered the first of the methods of representation through which architects and engineers communicate their design ideas: a graphic language that associates the two images—first and second—of geometric entities that occupy physical space, through the simultaneous and orthogonal projections on two planes, from two different centers of projection (directions also orthogonal to each other), univocally linked, as well as providing for the use of different styles and line thicknesses depending on what is being represented and what is being communicated. In fact, it is the first among the methods of representation to establish a biunivocal relationship between the entity in space and its representation, through a process of projection. By way of example, it is possible to show the methodological process applied to the first of the twenty five planches. The process was then also reiterated to the entire graphic apparatus accompanying the treatise. The table summarizes through the sequence of three images—whose reading is clockwise—what is the nature of the method applied to the representation of a line generically inclined in space. Beginning with Paragraph 7 and ending with Paragraph 9 of *La Géométrie descriptive*, Monge describes this first graphic elaboration of which the author's translation is given below.

2.3 La Planche 1

Paragraph 7

- Figure 1. If, from all points of an infinite line AB, positioned in any way in space, we devise perpendiculars to a plane LMNO, given a position, all points where these perpendiculars meet the plane will be in another infinite line ab; because they will all be included in the plane passing through AB and perpendicular to the plane LMNO, and they can meet the latter only at the common intersection of two planes, which, as we know, is a straight line. The line ab, which thus passes through the projections of all points of another line AB on a plane LMNO, is what is called the projection of line AB on this plane.

  Since two points are enough to determine the position of a line, to construct the projection of a line it is enough to construct those of two of its points, and the line guided by the projections of these points will be the required projection. It follows that if the proposed line is itself perpendicular to the projection plane, its projection is reduced to a single point, which will be that of its intersection with the plane.
- Figure 2 Given two non parallel planes LMNO, LMPQ, the projections ab, a'b', of the same indefinite line AB, this line is determined: in fact, if with one of the projections ab a plane perpendicular to LMNO is conceived, this plane, known from the position, will necessarily pass through the line AB; likewise, if with the other projection a'b' a plane perpendicular to LMPQ is conceived, this plane, known from the position, will pass through the line AB (Fig. 2). The position of this line, which lies at the same time on two known planes, and consequently at their common intersection, is thus absolutely determined.

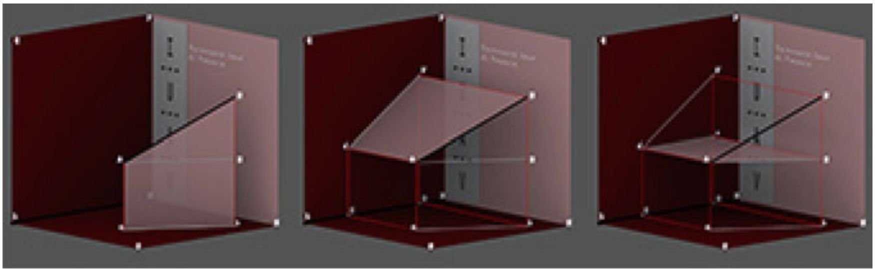

Fig. 2 Digitization of Fig. 2 of planche I of Monge's treatise (Graphic processing: I. Friso)

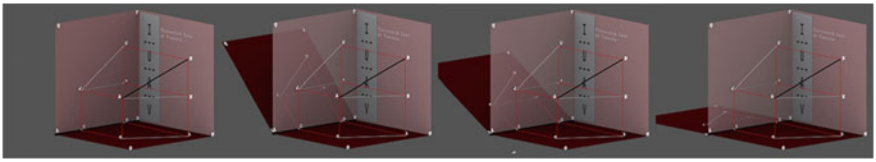

Fig. 3 Overturning the vertical plane onto the horizontal plane (Graphic elaboration: I. Friso)

Paragraph 8. What we have just said is independent of the position of the planes of projection, and takes place equally, whatever angle these two planes form. But if the angle formed by the two projection planes is very obtuse, the angle formed between them by those that are perpendicular to them is very acute; and in practice, small errors could lead to very large ones in determining the position of the line. To avoid this cause of inaccuracy, unless one is diverted by some considerations that present greater facilities, one always makes sure that the projection planes are perpendicular to each other. Moreover, since most users of the projection method are very familiar with the position of a horizontal plane and the direction of the plumb line, they are accustomed to assume that the planes are perpendicular to each other, assuming that, of the two key projection planes, one is horizontal and the other vertical.

The need to ensure that in drawings the two projections are on the same sheet, and that in large scale operations they are on the same area, has further determined the operators to conceive that the vertical plane rotates around its intersection with the horizontal plane, like a hinge, to fall on the horizontal plane and form the same plane with it, and to construct their projections in this state (Fig. 3).

Thus the vertical projection is always actually drawn on a horizontal plane, and it is necessary to conceive that it is perpetually put back [in its original position ed.], by means of a quarter turn, around the intersection of the horizontal plane with the vertical plane. For this, it is necessary that this [line of] intersection must be drawn very visibly on the drawing.

Thus, in Fig. 2, the projection a'b' of the line AB is not conducted on a truly vertical plane: it is conceivable that this [vertical] plane has rotated around the line LM taking the position of LMP'Q' and it is in this position of the plane that the vertical projection a'b' takes its place. This arrangement has the advantage of shortening the work of the projections. For assuming that the points a and a' are the projections in the horizontal and vertical plane of point A, the plane led by the lines Aa, Aa' will at the same time be perpendicular to the two planes of projection, since it passes through lines that are perpendicular to them; it will also be perpendicular to their common intersection LM; and the lines aC, a'C, according to which they cut these two planes, will themselves be perpendicular to LM.

Now, when the vertical plane rotates around LM like a hinge, the line a'C does not cease, in this movement, to be perpendicular to LM; and it is still perpendicular to it, when the vertical plane is rotated, it has taken the position Ca". Thus the two lines aC, Ca", both passing through the point C, and both perpendicular to LM, are in the extension of each other; the same is true of the lines bD, Db", with respect to any other point like B. It follows that if we have the projection on the horizontal plane of a point, the projection of this same point on the vertical plane assumed to be rotated will be in the straight line, led by the horizontal projection perpendicular to the intersection LM of the two key projection planes, and vice versa.

This result is in very frequent use in practice.

Paragraph 9. So far we have looked at the straight line AB (Fig. 2) as infinite line, and then we have only had to deal with its direction but it may be that this line is considerated as terminated by two of its points A, B; and then we may also be need to know its length. We will see how this can be inferred.

When a line is parallel to one of the two planes to which it is projected, its length is equal to that of its projection on this plane; for the line and its projection, being both terminated at two perpendiculars to the plane of projection, are parallel to each other, and included between parallels. Thus, in this particular case, the projection being given, the length of the line equal to it is also given.

We are assured that a line is parallel to one of the two planes of projection when its projection on the other is parallel to the first plane.

If the line is at the same time oblique to both planes, its length is longer than that of each of its projections; but it can be deduced from a very simple construction.

- Figure 2. Let AB be the line whose two projections ab, a'b' are given, and whose length must be found; if from one of its ends A, and in the vertical plane containing the straight line, conceives a horizontal AE, extended until it meets in E the vertical lowered from the other end, a right angle triangle AEB will be formed, which must be constructed to have the length of the line AB, which is its hypotenuse. Now, in this triangle, regardless of the right angle, we know the side AE, which is equal to the given projection ab. Moreover, if in the vertical plane we conduct through the point a a horizontal a'e, which will be the projection of AE, it will intersect with the vertical b'D, at a point e, which will be the projection of the point E. Thus b'e will be the vertical projection of BE, and will consequently be of the same length as it. Thus, by connoting both sides of the right angle, it will be easy to construct the triangle, whose hypotenuse will give the length of AB.
- Figure 3. The line LM is assumed to be the intersection of the two planes of projection, and the lines ab, a"b" being the given projections of a line, to find the length of this line passing through the point a", the infinite horizontal He will be conducted, which will intersect the straight line bb" at a point e, and on which, from this point, ab will be a point e, and on which, from this point, we will carry ab from e to H. The hypotenuse Hb" will be drawn, and the length of this hypotenuse will be that of the required line (Fig. 4).

Since the two projection planes are rectangular, the operation we just did on one of these planes could be done on the other, and it would have given the same result. From the foregoing, we see that if we have the two projections of a body consisting of plane faces, rectilinear edges and vertices of solid angles, projections that reduce to the systems of those of the rectilinear edges, it will be easy to deduce the length of those dimensions that will be desired: because either this dimension will be parallel

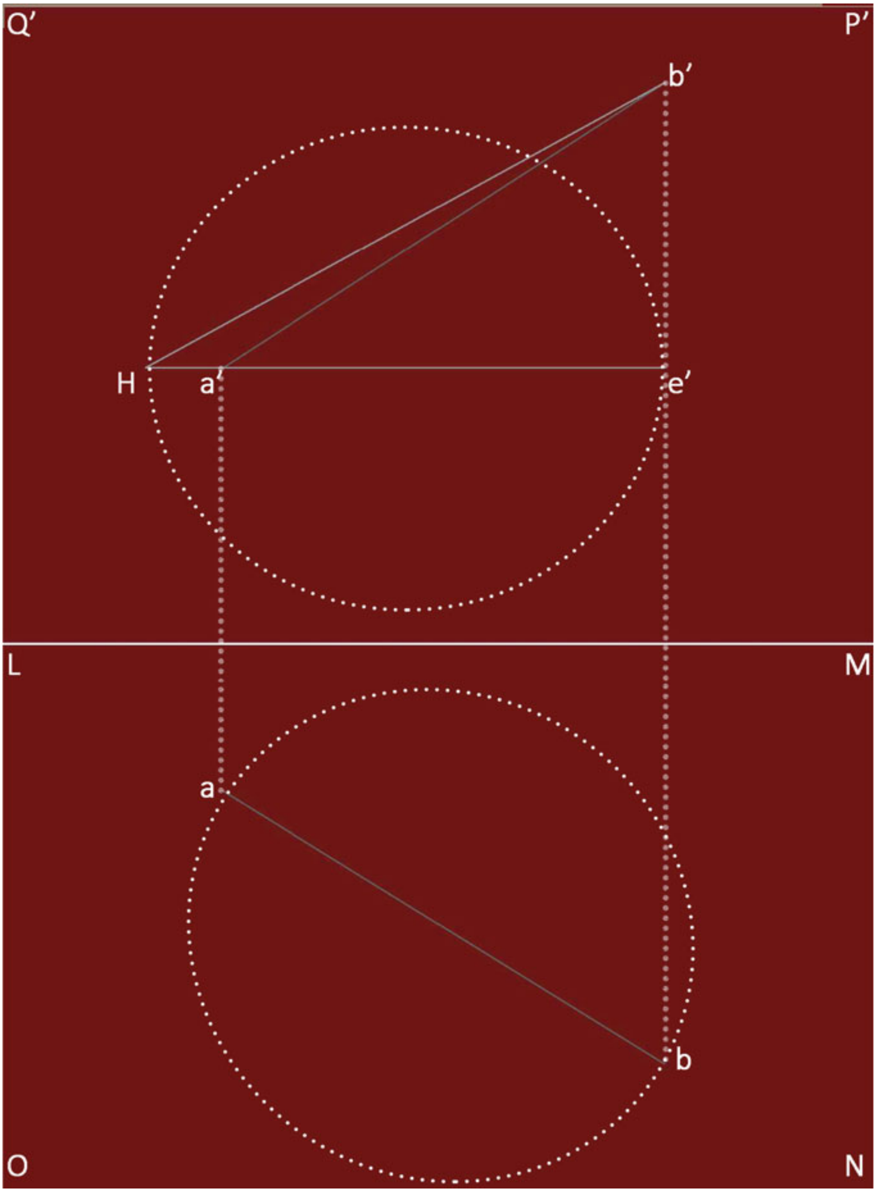

Fig. 4 Digitization of Fig. 1 of planche I of Monge's treatise (Graphic processing: I. Friso)

to one of the two planes of projection, or it will be at the same time oblique to both; in the first case, the required length of the dimension will be equal to its projection; in the second case, it will be deduced from its two projections by the procedure we have just described [3].

2.4 The Virtual Tour

Cinema and photography represented the main form and cultural interface of the twentieth century, the means through which it was possible to achieve a recording and storage of visible data on material support for writing and describing movement. In the age of digital representation, it is virtual reality—necessarily produced through the use of computers—that steals the show from common forms of data storage. Computer has become the processor of the new media understood as a locus of moving images independent of us [4]. A not insignificant consequence is the importance that the screen has assumed in recent years and continues to assume today. It constitutes in fact the limit of virtual vision, the instrument with which the operator/observer is forced to interface by means of windows onto an illusory space. These are thresholds that offer the possibility of viewing a mosaic of information perceived from multiple points of view with respect to as many different planes of reading [5].

Over the past few decades, with the advent of the socalled Digital Age, cultural institutions—not only museums and foundations but also national libraries rather than secular or religious institutions—have seen a significant expansion of the spaces and means for disseminating knowledge about their collections, demonstrating a growing interest in the Web, no longer considered merely as a promotional space, but as a valuable and innovative tool for user interaction and involvement. In this panorama, new systems for sharing and consulting catalogs in digital format present themselves as an innovative means of accessing information.

Indeed, they can be effectively complemented by their online counterpart and Immersive Reality experiences in the performance of their functions, participating in the dissemination of Cultural Heritage knowledge. The online version also ensures global visibility through the display of digital copies, and above all brings an extremely heterogeneous audience closer to the world of art.

In recent decades, the gradual introduction of digital devices has found its way into multiple areas, ranging from the management and preservation of databases to the cataloguing of materials to the increasingly frequent use of technologies applied to restoration interventions and virtual reconstructions. Also increasingly common today are digitizations of ancient treatises, especially those dealing with architectural elements rather than engineering works. But while digitalization is advancing overwhelmingly, it is also true that the strategy of visualization and dissemination of content is less effective. Thus, the case study fits into this cultural context. After digitally reproducing the 25 planches accompanying the treatise, it was decided to exploit the potential of the Virtual Tour to disseminate the digitized content.

The Virtual Tour is a communication tool with a strong emotional impact, allowing you to create paths of images to explore.

Exploiting the logic of streetview, which, thanks to the combination of 360° panoramic photographs, returns a reproduction of spaces and environments closer to reality, whether indoors or outdoors, the virtual tour also has the advantage of being able to add to the digital simulation multimedia information useful for learning. It is no coincidence that this type of application often complements the websites of the world's most important museums by simulating the indoor enjoyment of rooms and showing digital copies of the art collections on display there.

In the case of ancient treatises, the purposes of 3D virtual models and their visualization through a tour could have substantial spin offs both in the educational sphere for a further understanding of the texts and thus facilitate learning, but also as a tool for checking and verifying data.

The creation of a virtual tour allows for experimentation with new strategies for displaying information interactively through popular technologies (web, smartphones, tablets, etc.), based on such an organized methodology:

- Optimization of digital models.
- Study of museum mediation tools.
- Object based learning.
- Digital storytelling design.
- User education based on e-learning.

In this specific case, the graphic layout has provided a succession of three virtual rooms the first of which is the one that introduces the user to the virtual trip within La Géométrie Descriptive: a sort of vestibule in which on the vertical walls take their place the documents that can be interrogated to obtain general notions respect to the author and the analyzed treatise before being able to choose, in a completely arbi-trary manner, which planche to visualize (Fig. 5).

In this case, the user is not obliged to follow a path dictated by the numerical succession of the plates but can choose completely autonomously stage by stage (it would still be desirable to preference a linear sequence of the plates in succession).

Virtual fruition of the hall and the ability to view its interior in 360° is achieved through the creation of spherical images. Of panoramas mapped onto the inner surface of an ideal sphere, so as to simulate a 360-degree view.

The spherical images, produced digitally with 3DStudioMax software, appear significantly deformed and lacking in perspective logic, but when imported into Pano360 software—a specific program for the creation of virtual tours—they return their coherence by restoring the geometric-spatial conformation of the environment represented in them (Figs. 6, 7, and 8).

The presence of links makes it possible to create a link between one room and another by facilitating navigation using the mouse.

On the other hand, the possibility of accessing informative and queryable links allows for the inclusion of text files, images, video and audio files that enrich the tour with multiple pieces of information (Fig. 9) that aid reading and facilitate learning. Through virtual navigation, it is in fact possible to move among the rooms in the

Fig. 5 Introductory room to the virtual tour (Graphic processing by I. Friso)

Fig. 6 Spherical images of the first three virtual tour rooms related to planche I

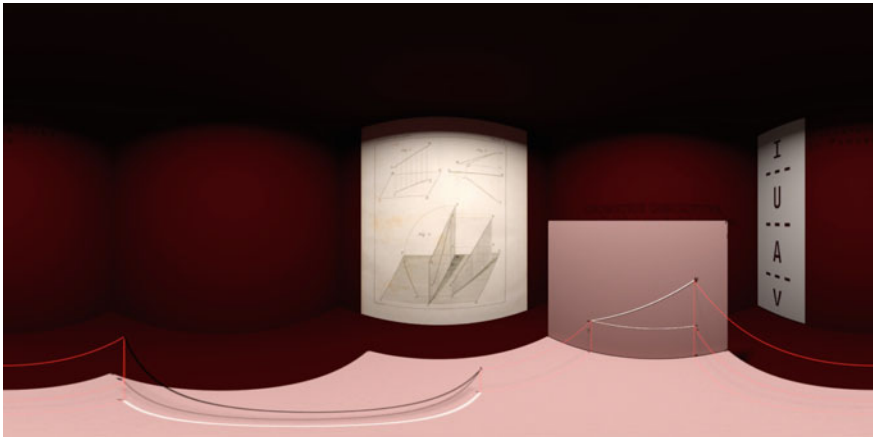

Fig. 7 Spherical images of the first three virtual tour rooms related to planche I

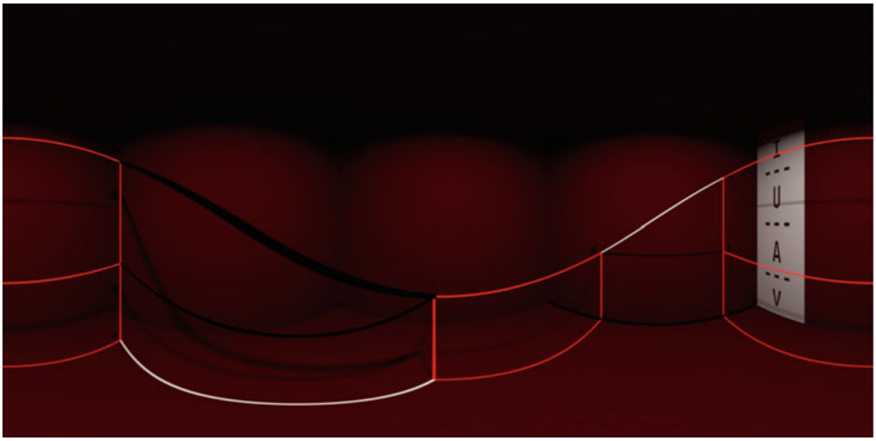

Fig. 8 Spherical images of the first three virtual tour rooms related to planche I

room through a path indicated by the central icons referring to the spherical images. The purpose of the virtual exhibition is to accompany the visitor on a journey toward a deeper understanding of both the artist and his works.

A virtual tour aims to expand the spaces and means for the dissemination of knowledge without aspiring to replace a real fruition, but by flanking institutions in the revitalization of cultural objectives and contributing to the success of educational action.

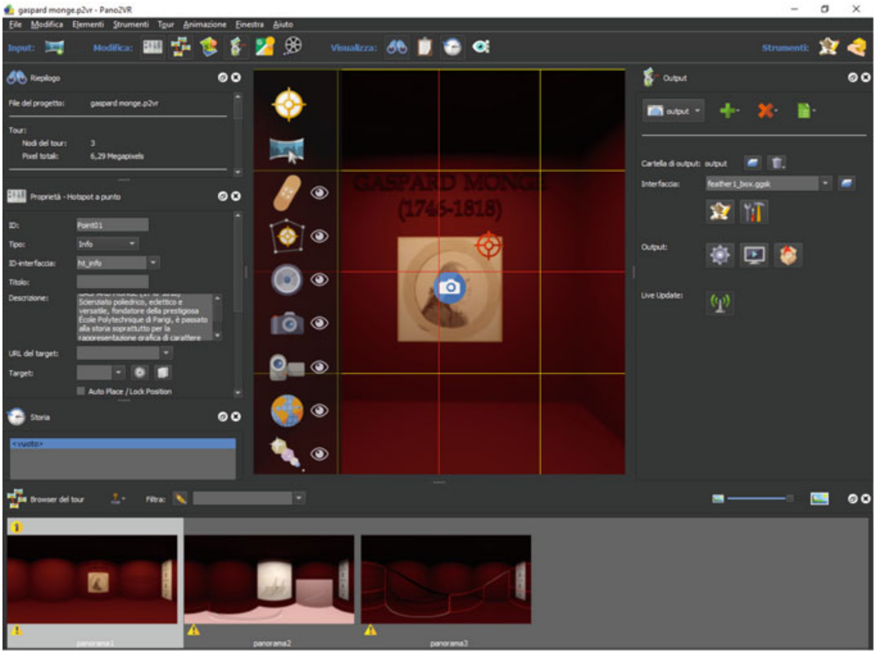

Fig. 9 Pano 360 software interface

3 Conclusion

In this panorama, the new systems for sharing and consulting catalogs in digital format present themselves as an innovative means of accessing information.

The tour occupying a place in what can be considered the broader sphere of virtual museums, achieves its purpose if it fulfills the functions of research and alternative information, without aspiring to replace the real museum, but standing alongside it in the revitalization of cultural objectives and contributing to the success of educational action.

In addition, the exploration of the treatise through a multimedia media can be of great help for didactic learning: the visualization in three dimensions—albeit developed in virtual space—of a complex geometric exercise allows the user to immediately verify and visualize its solution, thus facilitating learning and mastery of the solving method.

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Frank Lloyd Wright and the Vertical Dimension. The Virtual Reconstruction of the Rogers Lacy Hotel in Dallas

Cosimo Monteleone and Federico Panarotto

1 Introduction

This paper concerns the design of the Rogers Lacy Hotel, an unrealized work by Frank Lloyd Wright for Dallas [3]. We deal with the reconstruction of the historical and geometric events related to the project, tracing the cultural and architectural influences, who have left their mark on the project and the American architect.

To understand better this project, we have to keep in mind that the skyscraper has always provoked opposing emotions in the Master, since it was considered both as a symbol of technological progress and, at the same time, a cause of the inexorable degradation of the American city.

Starting from the original drawings (plans, elevations and sections) it is possible to give a virtual life to the Rogers Lacy hotel and experiment with Wright's technological vision, focusing our attention on the external façades, which are composed by revolutionary glass walls filled by a fiberglass insulation.

What is strange in this specific choice is that this construction system allowed ambient light to penetrate the building in a diffuse way but preventing hotel guests from looking outside [4]. So, the questions to which this virtual reconstruction has tried to answer are the following.

Considering the construction technologies of the time, could Dallas, the sunny metropolis of Texas, be considered a suitable city to host a glass skyscraper?

Since Wright preferred to insert skyscrapers in the boundless American natural space to enhance the symbol of human progress with isolation, what would the

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relationship between the skyscraper and the city have been if the Rogers Lacy Hotel had been built in Dallas?

Considering the characteristics of the curtainwall, which is made by glass and an insulating layer of fiberglass, a hypothetical lighting assessment of the panel's performance was made in order to analyze the visual comfort inside using the LEED certification.

The research about the Rogers Lacy Hotel revealed the presence of generic sources on it, despite the fact that it is a unique work within Wright's architectural repertoire, where all the compositional and structural themes addressed during his career converge and are enriched by a unique and unexpected analysis, such as the coexistence of the skyscraper in the chaotic American city.

2 Case Study

2.1 Project History

In 1946 Wright was approached by banker Gordon Rupe, intermediary for the Texas patroller Rogers Lacy, who wished to build an innovative hotel in the heart of Dallas.

Wright initially drew up a proposal for an 862-room hotel that would cost $7 million, later increased to $10 million. He also demanded payment of one-third of the commission after the preliminary design was delivered.

When a compromise for the commission payment was established, he began to develop the project. Wright worked for weeks, generating a plan, section, and elevation, merged into a single page (Fig. 3), gathering the main themes of his career [5]. Later, with the help of apprentices, he transformed his conceptual vision into a preliminary design and presentation drawings. In July of that year, the architect invited Lacy with Rupe and the Dallas Morning News reporter John Rosenfield to Taliesin to present his architectural vision. He illustrated the project starting with the tower, which featured the construction system first implemented in 1929 in St. Mark's Tower, namely a series of cantilevered floors, developed around a central concrete core, bordered by a glass and steel facade. This solution made the tower one-tenth as heavy as skyscrapers such as Rockefeller Center [6].

In addition, he had drawn on another earlier design for the tower, namely the Romeo & Juliet windmill dating back to 1896. In fact, also in the Rogers Lacy Hotel he used a second tower, with a rhomboidal plan, 350 feet high that served as an outrigger of the main tower, and housed the ventilation shaft and some service rooms. This would have allowed the entire building to reach 50 or 60 stories if necessary [6].

The skyscraper rose within a building, 12 stories high, that covered the whole block southwest of Commerce St. and Ervay St. (Fig. 1). The latter featured an interior patio that allowed lighting for the various floors, which developed as concentric rings around it, receding inward as height increased.

Fig. 1 Location of the Rogers Lacy Hotel. Author: F. L. Wright. *Source* Frank Lloyd Wright Foundation

Facing the courtyard were not the rooms directly, but the corridors accessing the hotel rooms, referred to by the architect as sun galleries. This feature, recalled in different forms in many of his other projects, seems to be transposed from the interior courtyards of the commercial buildings designed according to the rules of the Chicago School [4]; in particular, the use of corridors facing the interior courtyard recalls the Burlington Quincy Building by Burnham & Root.

The offset of the floors occurred also in the outer perimeter of the building and in the tower. It is interesting to note, in this regard, the contrast between the height development of the main tower, which increases its area, and the stabilizing tower, which gradually shrinks; this design choice was not functional to the structural scheme, but purely aesthetic, as admitted by Wright himself.

Both the main body and the tower were wrapped in double-glazed panels to simulate the shape of a diamond with a fiberglass glazing, allowing light to enter the building during the day and shine through at night. Each panel overlapped vertically with the one below, preventing streaking as rain would drip away from the lower panels.

Wright's vision achieved the desired result, so much so that Lacy, visibly satisfied, left Taliesin with the presentation drawings rolled under his arm [5]. Wright was reassured of Lacy's financial situation and that the project would begin as soon as building economic conditions improved. However, on the evening of December 9,

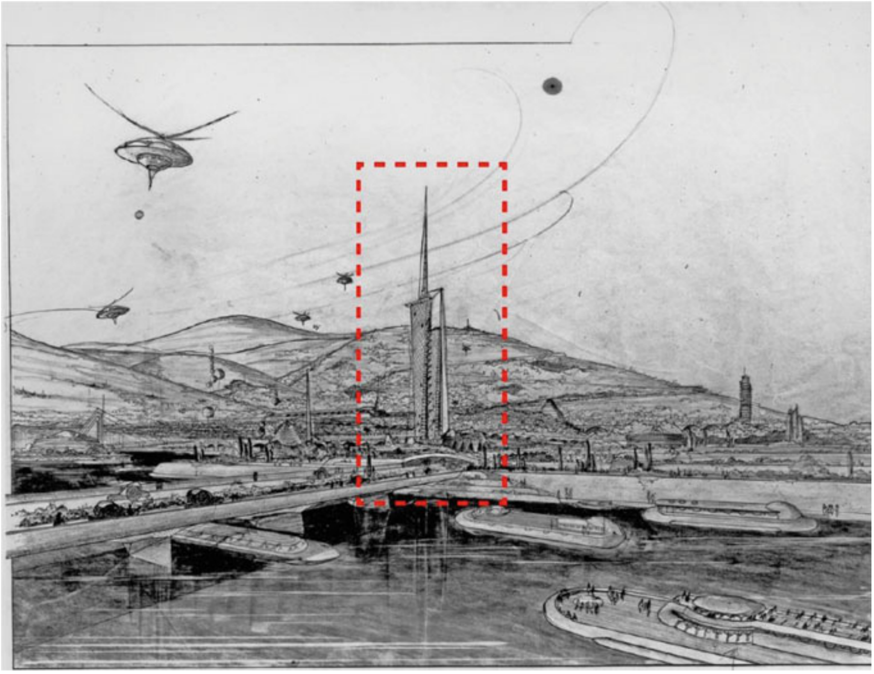

Fig. 2 The Rogers Lacy Hotel within the illustrations for Broadacre City. Author: F. L. Wright's Apprentices. *Source* Frank Lloyd Wright Foundation

1947, Wright received a telegram from John Rosenfield, informing him that Rogers Lacy had died that afternoon, following complications from a heart attack that had occurred in October of that year, thus halting construction of the hotel forever.

Despite the unhappy outcome of the project, Wright never abandoned the design of the Rogers Lacy Hotel, placing it at the center of his idea of America, as evidenced by the drawings prepared for the 1958 book *The Living City* (Fig. 2).

2.2 Genesis of the Project Idea

From the writings of architect Curtis Besinger, who was an apprentice at Taliesin from 1939 to 1955, it is possible to outline the initial design choices implemented by Frank Lloyd Wright for the construction of the Rogers Lacy Hotel.

Besinger points to a conceptual design, saturated with ideas to the point of being difficult to comprehend, as the first draft. In this preliminary vision, Wright had identified the coexistence of two elements in the design: a body of square plan, covering the entire area of the block, and the skyscraper, from which it towered.

Although the project developed from the earliest stages on this compositional idea, making small variations as it went along, a second hypothesis, referred to by Wright as Scheme B, is present in the graphic drawings. In this second solution the choice falls on developing the hotel in height, placing three skyscrapers in the block, recognizable in plan by the typical structural system used by Wright, linked together in a triangular formation. A Similar solution was used in the Grouped Appartment Towers Project. However, this design alternative seems to have been abandoned early, given the lack of further elaboration. The main work underwent a fairly linear development, as can be seen from the realized perspective views. From the analysis of the drawings, it is difficult to place the different modifications in the time frame; however, by analyzing the views and comparing them with those in the conceptual drawing, it is possible to hypothesize the chronological development of the project.

The first version of the building presented on the south and west elevations a shelter that partially covered the exterior walkway at the height of the mezzanine. On the top of the building was an additional shelter, which covered the entire perimeter of the lot. The tower was characterized by a particularity: the presence of an additional body that went to widen its base for about a quarter of its height, culminating in a masonry facade, in complete contrast to the glazed cladding of the entire building. The chronological order of the successive variants is problematic to determine. As testified by architect Curtis Besinger, there were about twenty preliminary drawings made for the presentation [5], yet both versions are present in the preliminary drawings; this allows one to speculate that the two designs were developed in parallel.

One of the two designs (Fig. 3a), of which plans are present in the preliminary drawings, is characterized by the elimination of the shlters, both at the top and in the two elevations, present in the previous design. This variant of the building features a double widening of the base of the tower, generating the formation of two bodies of the building enveloping the main skyscraper; the solid masonry façade at the top of the two elements is removed in favor of a glazed cladding, which allows the uniformity of the building curtainwall to be maintained.

The second design (Fig. 3b), recognized by almost all biography on the subject as Wright's final work, keeps the aesthetics in the low building unchanged, concentrating the changes in the highest one. Noticeable is the elimination of the two modules leaning against the tall building, and the creation of a two-story building body with a pitched glass roof at the base of it. In the high-rise building, the staggering of the panels in the façade is much more pronounced, and the southeast quadrant is interrupted in elevation. The complex designed by Wright had collected and emphasized most of the themes dear to the architect, making it a unique and visionary project that anticipated the posthumous development of high-rise buildings.

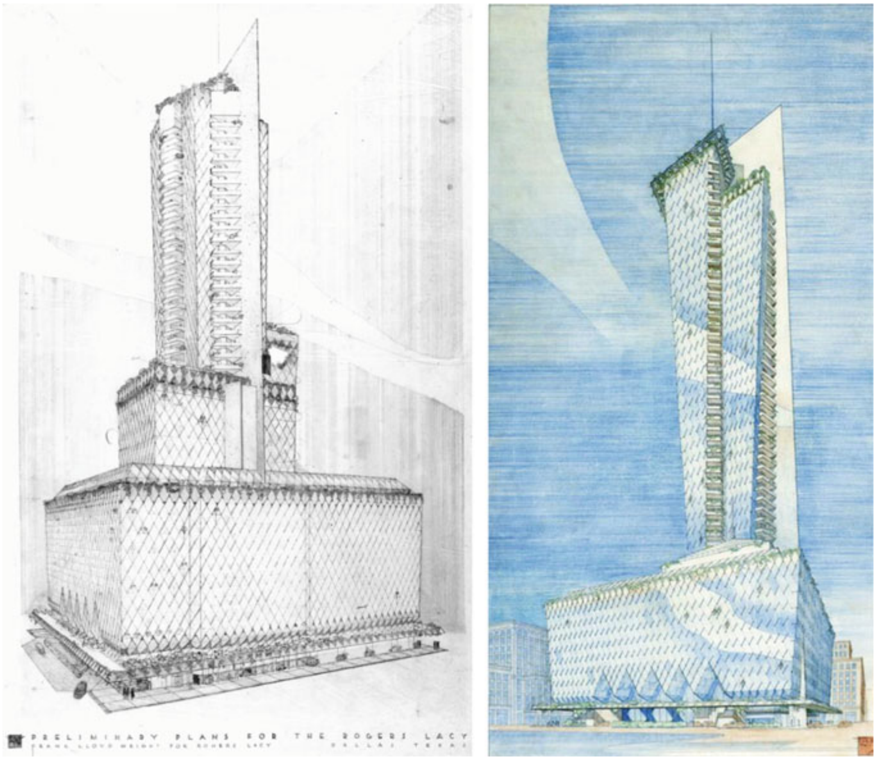

Fig. 3 Left: southeast perspective of the second variant. Right: south perspective of the third and final project. Author: F. L. Wright's Apprentices. *Source* Frank Lloyd Wright Foundation

3 Modelling the Rogers Lacy Hotel

3.1 Assessments in the Modelling Phase

Given the non-uniformity of the graphic designs, mainly due to the coexistence of two projects, a number of assessments were necessary before tackling the modeling phase.

First, we chose to model the project in which the two modules leaning against the high-rise building are missing, of which we have two sections. One crosses the low-rise building from north to south, while the other cut the skyscraper from east to west at the two southern quadrants.

However, the lack of the plans related to this project pushed to make some changes in the model. We decided to rely on the plans of the preliminary design, despite the fact that they did not correspond to the same design, excluding the modeling of the two buildings flanking the tower; in addition, basing on the perspective views, the two-story, pitched-roof element located near the base of the skyscraper was modeled.

As for the ventilation tower, we relied on the plans, as they allowed for a more accurate modeling, thus keeping the tower inside the low-rise building.

For the realization of the niches in the south elevation, it was necessary to simplify the geometries given the complexity of the curtainwall, replicating the niches present in the perspective views in the floor plan design.

In the sections, at the high-rise floors, there is no uniformity in the quadrants. Having no opportunity to evaluate the floor plans of individual suites, we decided to make the mezzanines uniform, making the floor plans similar in all four quadrants, as had been designe by Wright in St. Mark's Tower and Price Tower.

Finally, with regard to the glazed facades of the tower, the panels were reduced to match the floor bands of the tower, so as to make the joint of the facade with the floor slab easier and to reflect the idea of standardization dear to Wright, given the use of the same type of curtainwall for all floors of the tower.

3.2 Building Modeling

The Autodesk Revit 2022 program, a software designed for architectural design that takes advantage of BIM methodlogy, was used for the 3D model creation phase. We generated an interdisciplinary model that gathers all information about the entire life cycle of the work [7]. Considering the preliminary nature of the project and the lack of design information, we decided to use a low-level detail, considering only the building volumes.

The first step was the import into the work environment of the plans in.dwg format, previously corrected and regularized based on the historical plans obtained from the Artstor website [8]. Later, the two section lines were identified. Having fixed the references, the modeling phase began; an attempt was made to limit the use of in-place families, so as not to further burden the model, by using both system families and specially created parametric families as much as possible. As for the walls, families of generic masonry were used and duplicated, to which the structure was varied, adjusting the thickness as needed. Similarly, the different types of floors were realized.

At this stage, hypothesis were made at critical points in the design, basing on other Wright's designs or assuming his choices, in order to develop the model as closely as possible to reality. Through the use of the section, the inclination of the ventilation tower was estimated, identifying a 1.5° angle of the two north-facing walls; it was possible to impose the inclination from the Properties panel, selecting the Oblique parameter at the Transverse Section. Creating the central load-bearing core, given the low level of detail in the preliminary drawings, we relied on the Price Tower drawings. The vertical structures were made by intersecting three walls in such a way as to create a hollow triangular pier (Fig. 4). The low building has floors that decrease in thickness as they advance to the outer perimeter, an Edge Slab family was added to the uniform interior pavement, going to vary its dimensions at different floors of the building through the use of a parametric Profile family.

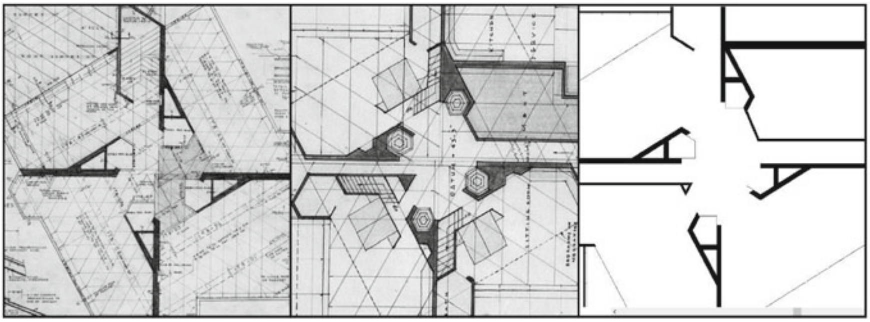

Fig. 4 Compering the plan of the tower between Price Tower, Rogers Lacy Hotel and the Revit model (Editing: L. Targhetta)

The same modeling was used for the tower floors, which have the same characteristics; an Edge Slab family was applied to the square floor of the core, and as the tower increased in area, a portion of the floor of uniform thickness was added, following the design implemented by Wright in the Price Tower.

Subtraction voids were used to regularize the plan area and make the elevator shafts, so that the hole could be created in the Slab Edge element.

Next came the modeling of the building curtainwall; the Continuous Facade family was used to model the glazed skin, going to import the vertical and horizontal grid at an angle of 30° and 60°, respectively. To render the effect envisioned by Wright, the curtainwall goes in front of the floor slab, from the upper floor slab, so that the interior structure is completely covered. A System Panel was used to make the ventilated element, an offset has been imposed on it and superimposed on the facade mullions, so that the corresponding panel is set back, thus recreating the optical illusion Wright wanted (Fig. 5). The joints of the curtainwall are not treated by means of an Angular Upright, but by over-positioning or going into rebate with the end mullions, since the Angular Upright does not allow the overlap of the facade panel.

The most critical element for the realization of the curtain wall was the creation of the recesses in the south elevation; given the non-coplanarity of the element, a Conceptual Mass family was created by exploiting reference planes. At this point, the Continuous Facade System command was used from surface, to which the mullions were subsequently inserted. This solution was chosen because there was a need to create multiple recurring elements with the same dimensions, making it unnecessary to use a parametric family as a result. In Figs. 6b and 7, the results of the modeling can be seen.

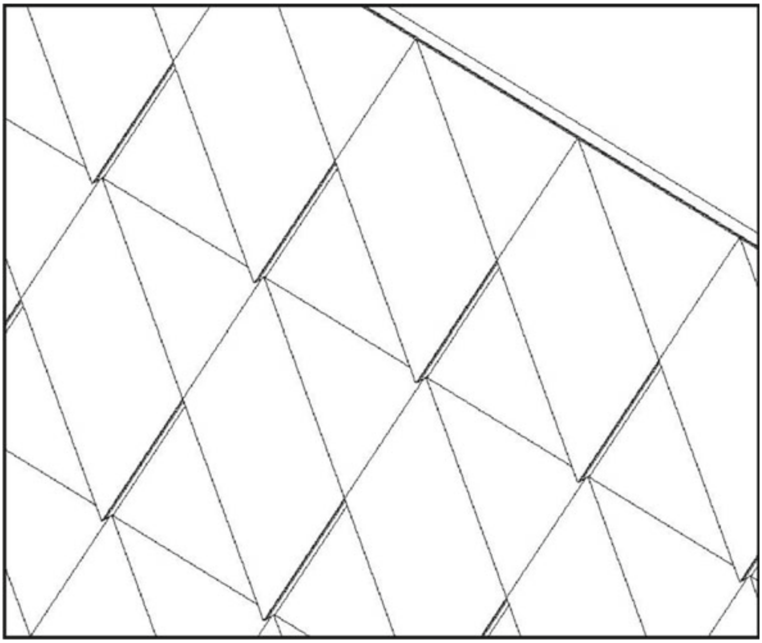

Fig. 5 Curtainwall detail in Revit model (Editing: L. Targhetta)

3.3 Set the Building in the Urban Context

In order to assess the impact of the building in today's urban context of the Texas, Dallas, a special image has been created.

Not having detected adequate photographs that would allow clear visualization of the plot of interest and its context, it was necessary to obtain an image from the Street View mode of Google Maps. Next, the perspective of the image was analyzed in order to obtain the location and angle of the camera.

We considered an image of the building currently occupying the lot by extending the contour lines of the building, thus identifying three perspective vanishing points. By drawing the line joining two of them, the horizon line was identified.

From these two information, the corresponding view has been created using the Cine Camera command of Revit. Enscape, a Revit plug-in, was used to create the photorealistic render. Once the photorealistic render has been realized we insert the rendering of the Rogers Lacy Hotel inside the urban context using the Adobe Photoshop CC program (Fig. 8).

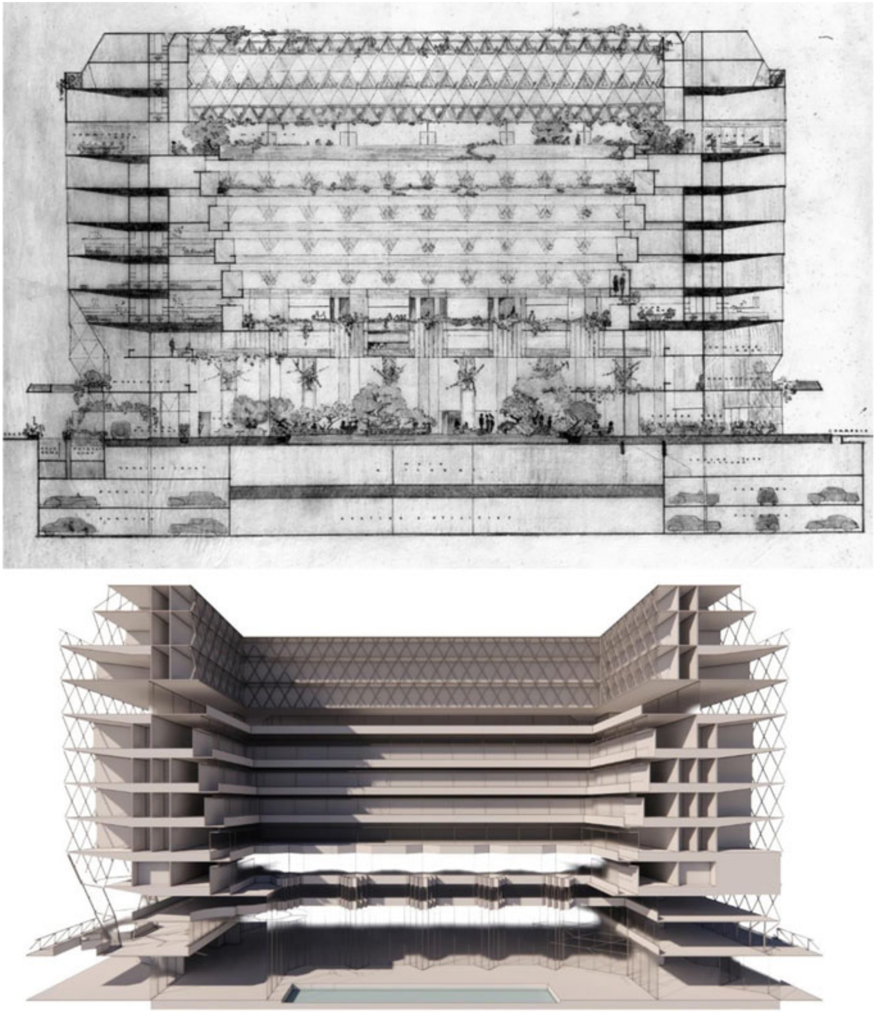

Fig. 6 Above: section of the Rogers Lacy Hotel. Author: F. L. Wright's Apprentices. *Source* Frank Lloyd Wright Foundation. Below: Perspective section of the model (Editing: L. Targhetta)

3.4 Lighting Analysis

To perform the lighting assessments, we chose to use the environmental performance analysis software ClimateStudio available as a plug-in for Rhino 7 and developed by Solemma LLC. In order to use ClimateStudio, it was necessary to export the model to Rhino. Given the complexity of the geometries, particularly the ones of the curtainwall, the appropriate file format for importing into Rhino had to be identified; the choice was created exporting the model in DWG format, selecting the export of

Fig. 7 Perspective of the model (Editing: L. Targhetta)

visible elements as ACIS solids. Also, to avoid the burdening of the model, by means of the section pane, only the portion of interest has been isolated.

Before going on with the simulation, it was necessary to set the settings for a proper simulation calculation. We started with the analysis of Daylight Availability, using the Custom criterion, which allows obtaining the results of several parameters, including the sDA parameter, ASE, and average annual illuminance. The first parameter to be set was Location; by selecting the appropriate geographic location, the plug-in obtains climatic information by loading a TMY (Typical Meteorological Year) climate file, which contains all the ambient parameters necessary for the analysis of environmental performance, measured hourly throughout the year. Having set the file concerning the Dallas metropolis with the coordinates closest to those of the plot of interest, the north position was rotated by correctly orienting the model.

Next, a material from the ClimateStudio library was assigned to each layer. These are divided into two categories: Glazing Assembly for glazed materials and Others for opaque materials. Given the lack of information regarding the opaque materials assumed by Wright, the materials indicated by the IES LM 83-12 standard for

Fig. 8 Rogers Lacy Hotel in Dallas (Editing: L. Targhetta)

preliminary analysis, found within the library, were used. The following materials are subdivided by element type, going by various characteristics of interaction with light, and are: Wall LM83, Floor LM83, Ceiling LM83, Supplies LM83. Glazing having a daylight transmittance rate between 50 and 15%, with steps of 5 percentage points, were identified for the panel material (Fig. 9).

Finally, the analysis plans were set up, selecting the affected area with the Add Occupied Floor Areas command. The total areas identified were two, covering the living and sleeping areas of the duplex suites. Having completed the assignment of the analysis areas, it was possible to start the simulation and obtain the results.

The values obtained from the simulations revealed the key role of the sunlight-screening system identified by Wright, through the use of the translucent glass-to-glass panel, in order to ensure adequate visual comfort conditions.

In fact, the presence of large, double-height windows on two sides of the room and the reduced floor of the suites result in a very high ratio of illuminating area to usable area, making it difficult to control the brightness within the room.

Interestingly, the mezzanine has much lower illuminance values than the day area, as opposed to high light exposure conditions in the day area; this is caused by Wright's choice to use a partition wall with hexagonal openings between the day and night areas. In particular, the lighting analysis of the sleeping area was limited to a percentage range of light transmission between 50 and 30 percent, since for lower values the output data lost meaning. Below is an example of the maps for the analysis plane with a light transmission percentage (Tvis) of 50% (Fig. 10).

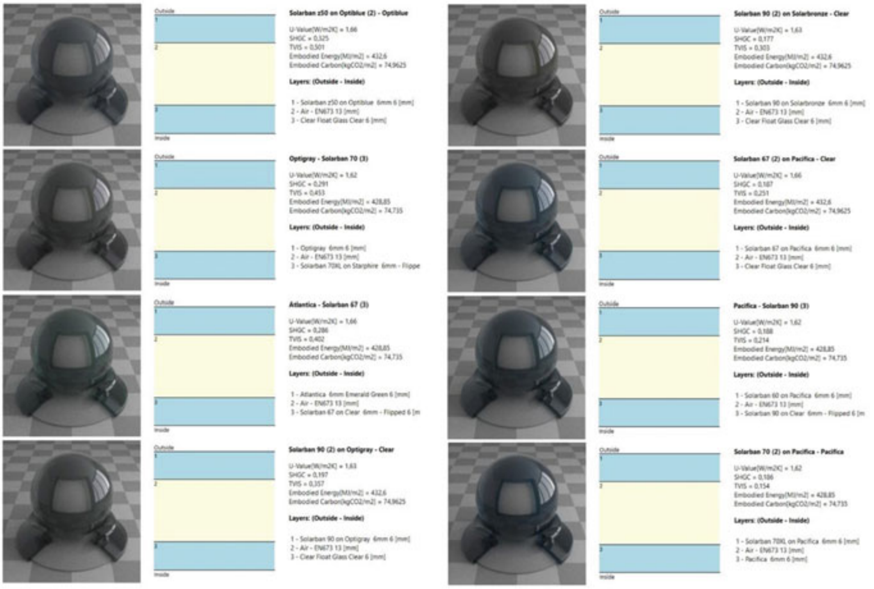

Fig. 9 Glazed materials used in the analysis, in descending order of percent light transmission (Tvis) (Editing: L. Targhetta)

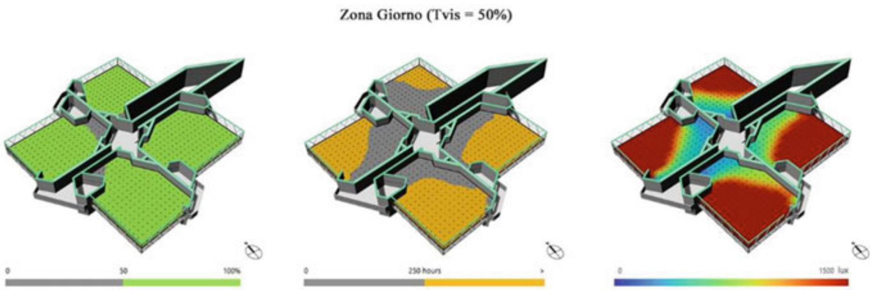

Fig. 10 Maps related to the analysis with light transmission rate (Tvis) of 50% (Editing: L. Targhetta)

4 Conclusions

As in all of Wright's works, the reference to the gifts and occupations of the Froebelian childhood garden appears decisive. The use of grids, aimed at spatial control of the elements, is explicit even in the curtainwall of the building, and in the integration and development of complex geometries, such as the stabilizing element given by the ventilation tower and the windmill scheme in the floor plans of the skyscraper.

Dwelling on the structural scheme of the tower, that has innovative characteristics, posing as a model towards the future development of architectural typology. There is an implicit debt to Japanese architecture, identifiable in the management of overhangs and the rigid central core typical of the pagodas admired by Wright in his travels in Japan. It is complemented by the innate inclination to recall nature in his architectural works, as found in the structural scheme with the tree essence of his skyscrapers.

The project seems to recall the most successful previous works, such as the Romeo & Juliet windmill and St. Mark's Tower, while adding innovative technological elements, such as the cladding given by translucent panels, useful for the integration of the work in an environment historically uncomfortable for the architect. Indeed, the Rogers Lacy Hotel turns out to be the only attempt to address the theme of the skyscraper within the urban environment, positing it as a solution and not a cause of urban decay.

The modeling phase made it possible to analyze the graphic drawings of the project, denoting some inconsistencies within them, probably dictated by the preliminary nature of the project. The presence of different versions makes it difficult to collocate chronologically the design; this complicated the 3D modeling phase, forcing some considerations in order to obtain a consistent virtual model. These choices were made basing on similar projects of the architect, such as the realized Price Tower, since this building has documented construction solutions.

Finally, an analysis was made of the most interesting features of the building, such as the use of solar shading inherent in the building curtainwall material. Given the physical complexity of the material and the consequent randomness of the technical characteristics, lighting simulations were done considering a plausible range of light transmissibility. From the results obtained, some considerations were made in the composition of the interior spaces, noting how the problems identified were solved in similar designs like the Price Tower.

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The Development of the Projects for Villetta Di Negro

Alessandro Meloni

1 Introduction

This contribution analyses the current architecture, that of the past and which has never been built, of the park of Villetta Di Negro in Genoa (Italy) of which the Edoardo Chiossone Museum of Oriental Art is today the main building. However, the currently visible building has a characteristically complicated history, which dates back to the nineteenth century. The first project dates back to 1800 and was commissioned by the Marquis Giancarlo Di Negro to the architect Carlo Barabino (1768–1835) and was destroyed during the Second World War. The reconstruction was entrusted to the local architect Mario Labò who presented the first design idea in 1948 to later modify it in 1952. The current building dates back to 1971, during the period from the first idea to the completion there were several important variations to the project, the most important being that of 1955.

The history of the building was defined thanks the critical literature [1–3] and to the analysis of the archive material: the Fondo del Genio Civile dell'Archivio Generale Regione Liguria (AGRL) and the Archivio Progetti Comune di Genova (APCG).

We will conduct an analysis on the different design phases, using an immersive visualization mode such as Augmented or Virtual Reality, to emphasize the importance of a little-known architectural subject.

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2 Villa Di Negro

The park of Villetta Di Negro is located in the heart of the city of Genoa, originally it was a military bastion of the eighteenth-century walls. The person responsible for the transformation of this area was the Marquis Gian Carlo Di Negro (1769–1857) who, in 1802, bought it from the Municipality. The general structure of the Park is attributable to the English typology, where the paths are curvilinear, sinuous and immersed in an enthrallingly natural setting. The presence of scenically suggestive elements, such as caves and waterfalls, are aspects that characterize the entire park (Fig. 1).

Along with the planning of the park, the Marquis commissioned the Genoese architect Carlo Barabino, one of the most important figures of the period, to design a villa for him: Villa Di Negro [4]; however, it is a building which was conceived for events rather than as a home. According to the testimonies of Federigo Alizeri, taken from his Artistic guide for the city of Genoa [5] the Villa was characterized by its works of art and by the cultural activities that took place within. Barabino's architecture is a choreography capable of enhancing the richness of the works of art and, at the same time, fitting perfectly into the park itself. In fact, the proposal envisaged the use of classic forms on the outside, which relate well to the natural context, while inside, linearity is the most evident element.

The entrance and the exhibition space are the two main volumes of the building (Fig. 2). The testimony of the compositional characters present is visible today thanks to historical photos and, above all, to the surveys, preserved in the archives of the Liguria Region (AGRL) and the Municipality of Genoa (APCG), carried out by Mario Labò, scholar of Barabino [6].

Externally, the building presents itself as a system of regular facades that follow the canons of classicism. The classic imprint is emphasized in correspondence with the entrance area, along the short side of the building. The large portal is arranged in the center of the four columns that support the entablature and interrupt the regular distance between the columns, enhancing the symmetry of the entire façade (Fig. 2b). This revisited pronaos takes up the main canons of classicism by reworking them, as also happens for the crepidoma: a monolithic block that defines the base of the access with the steps that develop only in the center and not along the entire perimeter, as occurs in the reference model.

The larger elevation facing the park and the city has a regular shape made up of two rows of windows of different architectural orders, with small projecting balustrades.

The interior is characterized by a full-height central hall from which balconies overlook and is illuminated from above thanks to a large skylight (Fig. 2c) [4]. A simple, symmetrical system that presents a geometric rigor on a planimetric level which is lost in the experiential vision, which is engaging and satisfying, and this can also be affirmed thanks to the testimonies of the people who frequented the original Villa [5]. The bombings that destroyed much of the Ligurian capital in 1942 also hit the Villa, causing extensive damage that prompted the Municipality to commission Labò for its reconstruction.

Fig. 1 Villetta Di Negro Park: **a** Planimetric drawing (APCG, cat. n. 496/1985); **b** Waterfall (Photo: Ilaria Camprincoli, http://creativecommons.org/licenses/by-sa/3.0/, Wikimedia Commons)

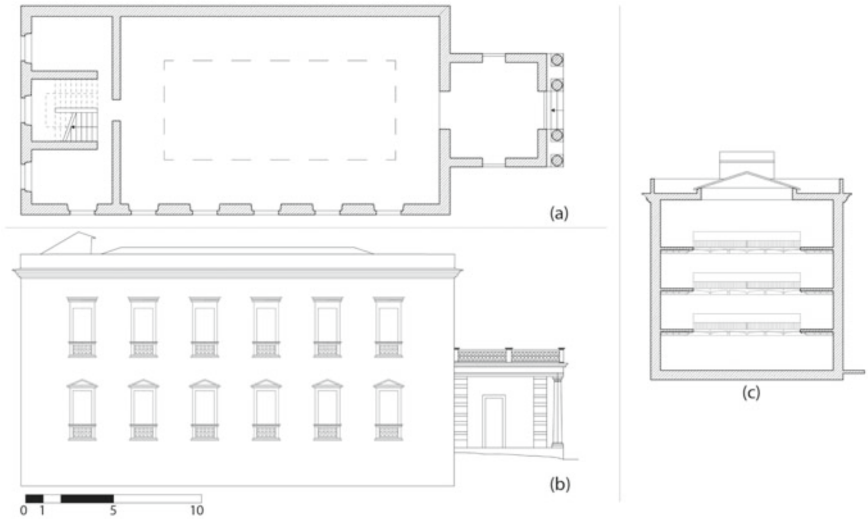


Fig. 2 Villa Di Negro: **a** plan; **b** facade; **c** section (Drawing: A. Meloni)

3 A New Museum for the Park

The reconstruction of the museum was characterized by an important debate in the city, in which Caterina Marcenaro (Director of the Fine Arts Office of the City of Genoa) played an important role, Mario Labò was proposed by her for the reconstruction.

Previously the material collected in Japan by Edoardo Chiossone, artist and important person for the Genoese culture, was hosts by Ligustica Academy of Fine Arts in Genoa. Mario Labò's projects were two: the first unbuilt project of 1948 and the second designed between 1952 and 1955; the second is characterized by numerous variations and would only be completed in 1971, after the death of the designer [7].

3.1 1948, The First Step

Genoa, at the end of the Second War World, was an important city for the reconstruction process, especially in the musealization field. The projects design by Franco Albini (1905–1977) was an important reference for the Italian and international architectural movement; we can cite two important examples like Palazzo Rosso (1953–1961) [8] and the redesigning of Sant'Agostino Museum (1963–1979) [9, 10]. In this context the Museum of Oriental Art is important because was the first museum to be built from scratch.

The Museum coincided with the planning and design of the Villa Di Negro, in the same position inside the park. The main volumes were three: the entrance, the stairs and the exhibition hall; elements characterized by pure forms, and there was some relation to the previous project.

The access was lower compared to the other part of building (Fig. 3a). The various sectors of the museum were clearly recognizable from the view of the façade and the plans. The south-west elevation, was characterized by a glass block wall corresponding to the stairwell, this form was between the entrance and the exhibition hall (Fig. 3b); on the planimetric view it is possible to clearly see the stair space.

The exhibition hall was simple: a free space interrupted only by the presence of pillars, there were two types of large windows, arranged alternately, along the main sides of the space; this arrangement was repeated on all floors (Fig. 3). This project brought to the fore the vision of a space capable of adapting to different exhibition needs according to the time, where the viewer would be involved only through the exposition of the art itself and not by the spatial characteristics; unlike that which can be observed in the second project, where the architecture is an integral part of the museum experience (Fig. 4).

3.2 From 1952 to 1971: Towards an Oriental Conception of the Museum

In 1952 Mario Labò presented a new version of the project; this change was determinate by some legal problems between the municipally and a property neighboring the museum. The different style used by Labò leads us to believe that the bureaucratic and legal problems were a useful pretext to radically change the design.

The Project underwent many variations, and the completion of the works dates to 1971. In this contribution we will analyze, in particular, the 1952 and 1955 versions, focusing more precisely on the theme of the whole space and the arrangement of the stairs.

The 1952 Project is characterized, on the outside, by a pagoda roof that recalls some forms of oriental buildings (Fig. 5). The South-West façade, like the entire Project, is radically changed, the building is composed of two main volumes: the entrance and the exhibition hall. The first two levels are characterized by large windows facing the urban city center [11], while the opposite elevation faces the winding paths of the park. The exhibition hall is the main space: it is determined by five staggered levels arranged close to the longer sides and which internally overlook a full-height central void. The floors are connected by stairs positioned along the short sides of the building, which are mainly visible from gallery 1 on the ground floor. This arrangement is simple from plan drawing (Fig. 6a) but may be more complex when observed in section (Fig. 6b). The interesting aspect that makes this museum one of a kind is the internal path: the alternating stairs with respect to the floors, define a cyclical path composed of a different ascent and descent.

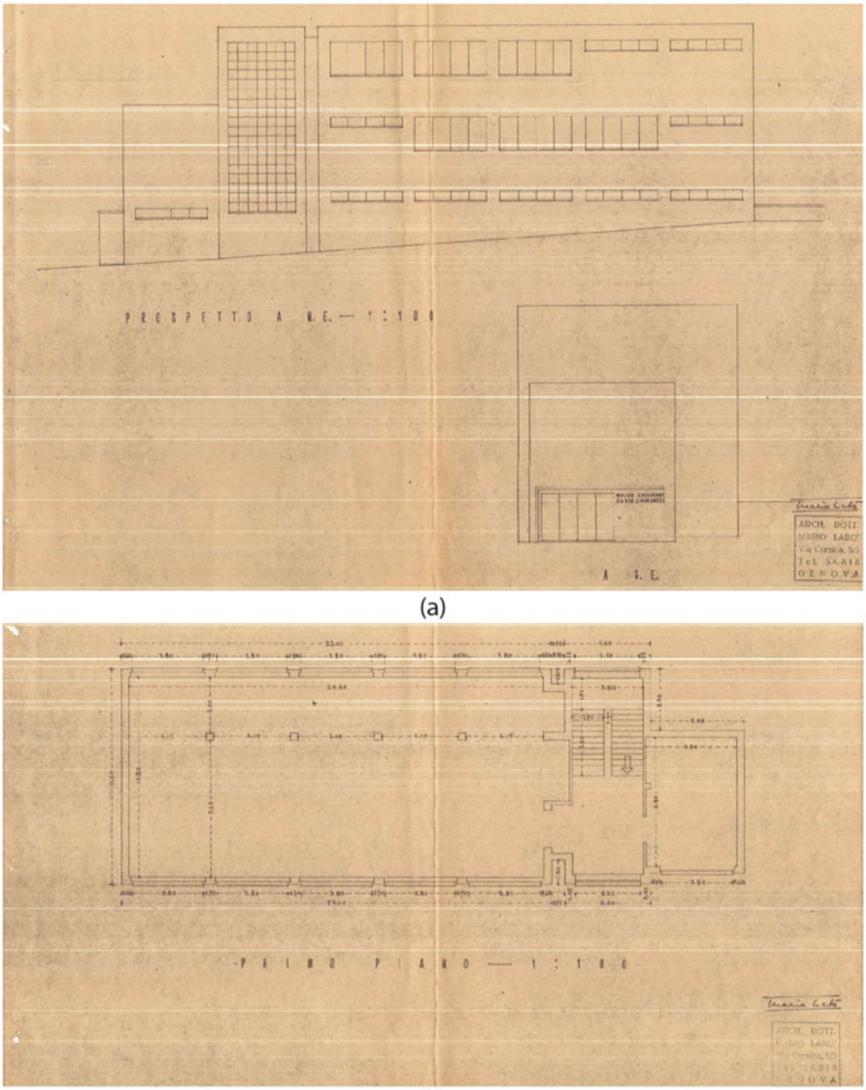


Fig. 3 The 1948 project: **a** plan; **b** facades (APCG, cat. n. 231/1948)

The most important point is where the change of direction between the two movements takes place: the connecting stairs between galleries 4 and 5. Mario Labò was aware of the importance of this part of the project and in fact often changed his idea.

In 1952 the conformation included three staircases along the short side of the building, the last one was characterized by the presence of a gallery floor that allowed you to reach gallery 4. This solution highlighted the symmetry of the layout of the

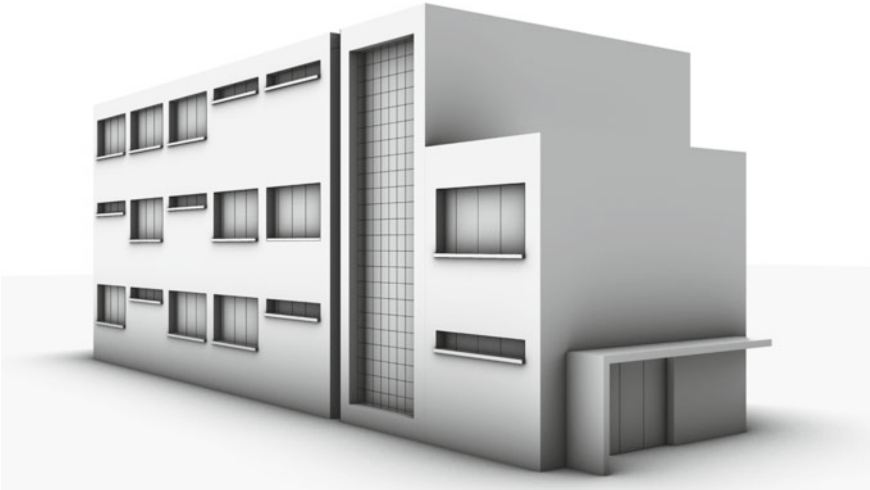


Fig. 4 The 1948 project: 3D model view (Modelling: A. Meloni)

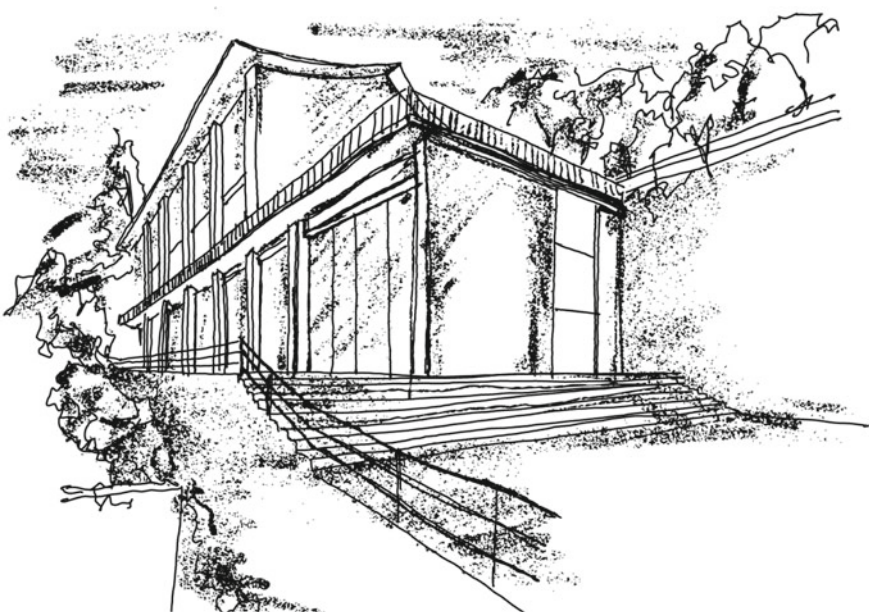
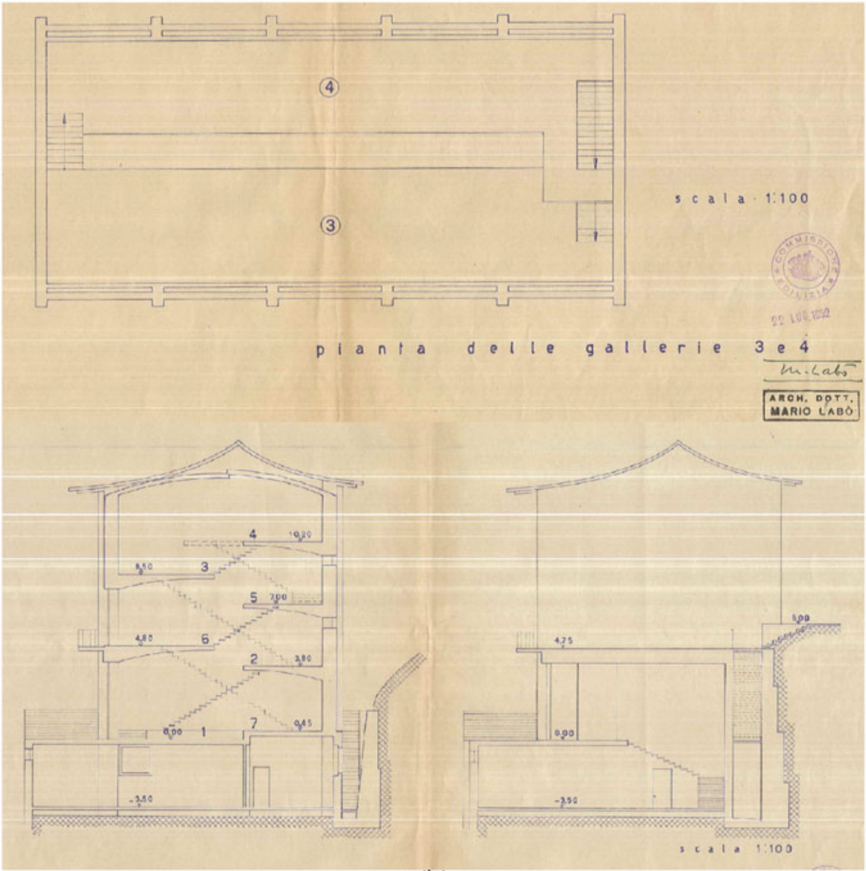


Fig. 5 The 1952 project: perspective view (Drawing: A. Meloni)

(a)



(b)

Fig. 6 The 1952 project: **a** plan; **b** section and facade (APCG, cat. n. 969/1952. mc/f/4-mc/f/7)

stairs (there were in fact three ramps per side) but perhaps reduced the effect of the full-height void.

The 1955 design the change concerned the roof, no longer pagoda-shaped but double-pitched (section), and above all the stairs (Fig. 7). In this case, the linearity of the staircase was preferred over symmetry: the connection between gallery 4 and 5 was determined by a single staircase positioned at the corner. It is also interesting to note the addition of a landing in the center of the other flights of stairs: it is a resting place that allows a view towards the central void (Fig. 7b); a design solution that can lead back to the principles of indoor wayfinding described by Ruth Conroy Dalton [12] where the view is essential to facilitate the internal orientation process.

In 1971 the connection stairs were modified again to take on the structure visible today. It is possible to compare the different design versions to observe the different

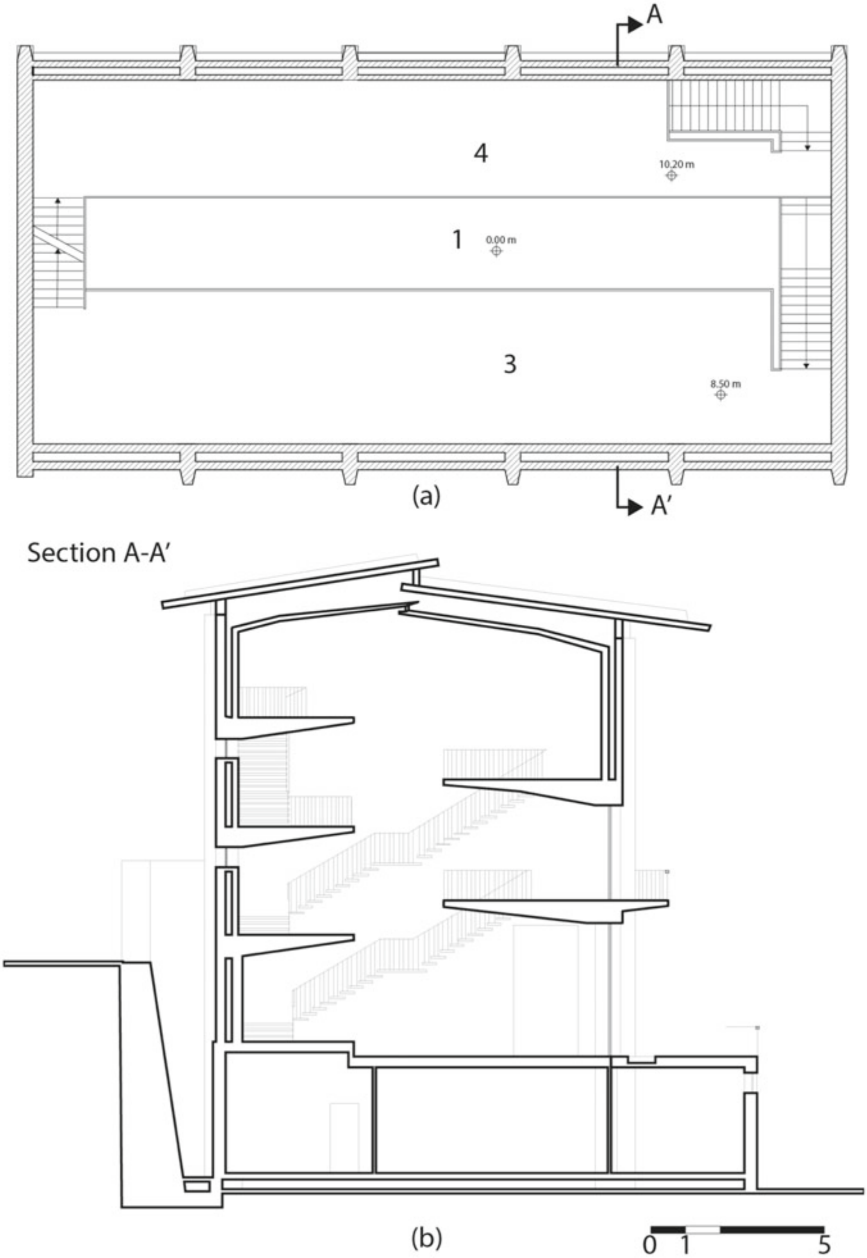


Fig. 7 The 1955 project: **a** plan; **b** section (Drawing: A. Meloni)

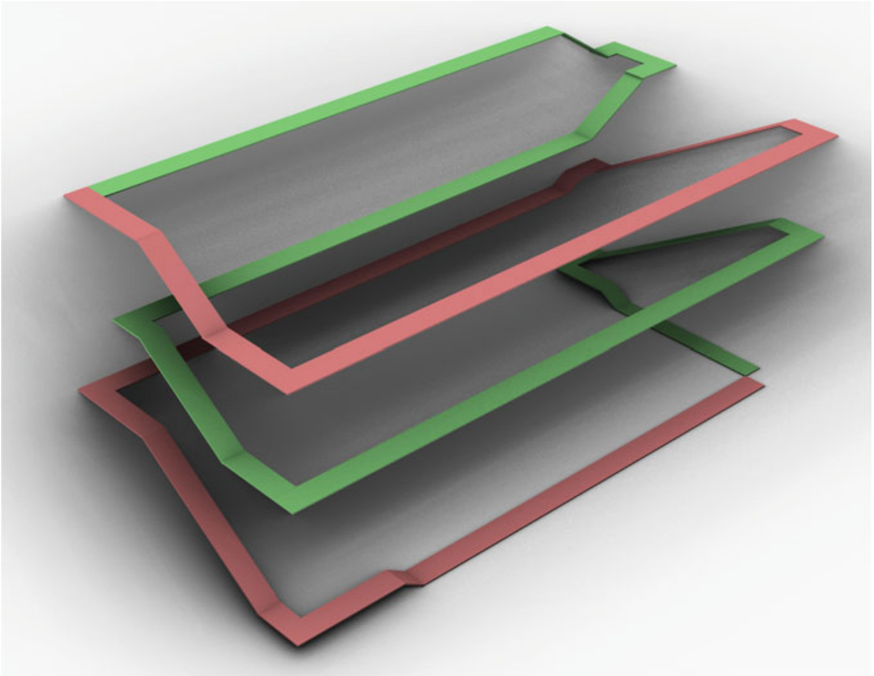


Fig. 8 The Museum's cyclic path, 1971 solution: ascent (green), descent (red) (Modelling: A. Meloni)

impact and how these modifications do not affect the exhibition itinerary, in fact, the cyclical nature of the movement is maintained (Fig. 8):

- A rise path, galleries 1, 2, 3 and 4, alternately cantilevered on the south-west and north-east walls.
- A descent path starts from the galleries 4 and connects 5, 6 and 7.

The construction was completed in 1971 by Giorgio Olcese; he made some changes in addition to the aforementioned stairs. The differences concerned the ground floor material and the wood floor on the gallery: the luserna stone designed by Labò was changed were replaced by Serena stone and a similar situation concerns the wood material surfaces, no longer in teak because was considered too expensive. The external coating, on the other hand, was greatly changed: the glazed terracotta tiles for the external walls and the plastering of the structural elements chosen by the Engineer Olcese are in contrast with the more materical vision of Labò, that envisaged exposed concrete for the structural pillars and granite tiles for the external surface that is rougher to the touch.

The design for the exhibition asset was by Luigi Grossi Bianchi and Stefano Fera [13] they payed particular attention to the Mario Labo idea: the last gallery on the South-West elevation has no windows to reduce light and allow more light-sensitive materials to be displayed. The study of the installation not only expressed Labò's wishes but emphasized the relationship between space, light and Japanese architecture, also thanks to the use of an external wooden in front of the windows and to the ceiling inside the exhibition all: rectangular joists intersect each other defining a rectangular surface; at the windows, the structure moves on rails allowing different levels of opening and filtering of natural light. This set and the possibility to move it is typical of Japanese homes [14].

The actual version does not preserve the symmetry but maintains the spatiality that characterizes the building which becomes "an architecture of the void" [15].

An interesting aspect is that the Labo's idea is connected with the space of the neoclassical Villa, especially for the central void in the exhibition hall. It should be noted, however, that the open and dynamic space also incorporates the spatial characteristics typical of Japanese architecture [14] which is also revealed in other choices that do not involve the materials identified by Labò and which refer to the use of wood as a reference material and to the solutions proposed by the subsequent outfitting.

The characteristics still strongly linked to modern architecture were modified to create a new project, capable of responding to the needs of the contemporary museum. The desire to abandon the language of the past was explicitly expressed by Mario Labò himself in one of his writings, published by Casabella, on the Museo del Tesoro di Genova designed by Franco Albini: Labò described how the spatial arrangement of Albini's project was an example capable of "Disengaging from a tired rationalist formalism" [16].

4 The Use of AR for the Communication of Architectural Space

The study of archival data allows lost architecture to be reconstructed in three dimensions in order to thus be able to develop communication methods, useful for disseminating the little-known information of an important building of the city. It will be possible via a QR-code to access the 3D model and, at the same time, receive information about the history of this building, through audio and also text contributions (Fig. 9a), the latter being essential for people with hearing disabilities.

The study of the founding literature relating to this field of research is fundamental, especially in the field of museums [17, 18].

However, the aspect that we intend to highlight concerns the architecture, the space of the building rather than focusing on the exhibits present inside the museum itself; a theme highlighted, for example, in the text *Ricostruzione virtuale, VR e AR per la visualizzazione dell'aula provvisoria del I Parlamento italiano* [19].

In the case of the nineteenth-century Villa Di Negro, it will be possible to access the virtual material directly from the park: the QR-code will in fact allow you to connect

Fig. 9 The virtual model of the 1948 project inserted in the current urban context: view from the city center (Editing: A. Meloni)

with the visualization of a 3D model and therefore know the historical characteristics of the park and of the building without necessarily having to enter the Museum of Oriental Art. 1948 will be visible inside the museum via a QR-code. Access to the material will also allow you to interact with contents that show the first solution of Labò inserted within the city context, a photo-insertion where the current image of the museum is replaced with the solution from the late 1940s (Fig. 9). As regards to the internal solutions referring to the 1952 and 1955 projects, the display will be similar, but will be held directly inside the museum. In this way it will be possible to observe the current state and, through the image of the model superimposed on the real one, to know the different arrangements of the internal stairs (Fig. 10).

Fig. 10 Example of Augmented Reality and the different solution for the stairs: **a** 1952; **b** 1955 (Editing: A. Meloni)

5 Conclusion

This contribution illustrated the genesis of a fundamental design project for Italian museum architecture, analyzing its crucial points: the history and the choice of the cyclical path.

Future developments will focus on improving the way we interact with people and we can also think of the possibility of a more immersive visualization, contemplating the use of virtual reality (VR) devices.

The archival study made it possible to create 3D models of each solution and thus bring to light, albeit virtually, the buildings; the lost 19th-century Villa, the never built 1948 project and the changes made during construction to the current Museum, 1952–1955.

The goal is to identify effective communication methods regarding virtual architecture. The use of augmented reality will in fact be able to reveal the complicated historical phases that led to the creation of the current Museum, through an engaging language capable of communicating with a large audience in simple and intuitive ways.

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AR&AI and Museum Heritage

AR for Virtual Restoration

Luca James Senatore and Francesca Porfiri

1 Introduction

Augmented Reality, as is well known, makes it possible to enrich, on a sensorial perception and cognitive level, a wealth of information conveyed by a tool (such as a tablet or smartphone) within a given context, in particular that of a museum exhibition. The physical boundary between the user and the surrounding space becomes a frame with increasingly permeable boundaries, allowing a continuous exchange of information between them. In fact, it is the dissemination of information itself that makes use of new potentials that are enriched in time and space, being strongly connected to the examined Cultural Heritage, in a perspective of continuous evolution [1, 2].

Analysing the ways of fruition of the traditional museum, it is evident how the visit can find its *raison d'être* in the moment in which it is carried out by following a path predetermined by the curator of the event. Conceptually, the museum, as a container circumscribed to a well-defined physical space, appears limited to rare possibilities of personalization by the user. Therefore, the approach to the works appears to be reactive, guided exclusively by the established sequence of the works, which, with the exception of brief informative summaries describing their origin, give the user little information about the very essence of the artwork. In contrast to this approach, the contemporary museum seeks to break down these barriers, subverting real space, proposing more interactive and participatory fruition solutions, transforming traditional physical limits into permeable filters capable of guaranteeing articulated and

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customizable knowledge paths. In this type of context, it is therefore evident how the use of tools capable of favoring visitation is desirable, almost necessary, having as a nodal point the centrality of the role of the user with respect to the fruition of the artwork [3]. A museum visit organized according to a proactive approach to Cultural Heritage cannot but be equipped with all the knowledge aids capable of narrating the story behind the exhibits. This need appears even more relevant when considering archaeological artifacts, which, despite their beauty, require a necessary contextualization in order to be correctly assimilated by users [4]. Therefore, from this point of view, it is evident how augmented reality can be an important aid that can give new life to the artworks through the creation of a narrative, which becomes dynamic and transforms the user into a director of his or her own visit.

In this context, the contribution analyses one of the possible ways to implement this process of interactive dynamic fruition, integrating the visit process of the physical work, with new representations of it, in an attempt to integrate history and knowledge, showing what time has defaced. Going beyond the cultural limits of a direct action to be carried out digitally on the original artifacts, the contribution proposes an integration model of selected works, in particular through the virtual construction of models to complete the gaps present, in an action that can be defined as virtual restoration [5]. It is necessary to clarify what the concept of virtual restoration means: i.e. an opportunity to develop and then examine different intervention hypotheses with a focus on shared experimentation, a valuable analysis opportunity for experts in the field of cultural heritage (architects, archaeologists, restorers, art historians). Among the basic objectives of the activity is undoubtedly the recovery of the formal unity of the object studied, and its quality of historical testimony, since they are often silent works, with the aim of having, at a perceptive level, a correct interpretation of them as they originally appeared, starting from the systematic study of the traces still present; a further objective is the reinsertion of the object within a broader narrative, through the creation of dynamic paths that place the work within its historical context [6]. The realization of these objectives takes place in a digital environment, without in any way modifying the artworks in their current state of preservation, in order to keep their evocative power unchanged and, in particular, without making invasive interventions on the signs left by time.

In this research framework, aimed in particular at sensitively involving users in the field of Cultural Heritage fruition, bringing the user emotionally closer [7] and amplifying the experience [8], AR constitutes a privileged tool. Emotion is generated by the meaning we give to reality: through the new technologies, it is possible to transfer the sensations we feel into the digital world, actuating in the user a sense of wonderment that transcends his or her classic mental schemes, realising a greater emotional involvement, thus enabling an almost natural interaction between human being and digital content. It is precisely this experiential and emotional approach that guarantees an improvement in the enjoyment of the Cultural Heritage under investigation. The interaction between museum, collection and visitor redefines the museum space, placing the user at the center of the experience.

2 Case Study

Within this theoretical framework is the OSTIA 3D Project, which proposes new digitisation solutions for the protection and enhancement of cultural heritage in the field of archaeology. The project includes several case studies, declined at different scales, and making use of technological solutions built on the basis of specific objectives. The research is carried out on the works kept in the *Ostia Antica* Archaeological Park, in particular in the Antiquarium Hall, and sees the active participation of several members of the Park's staff. The contribution aims to present the results of virtual restoration operations carried out on some works of ancient statuary in the collection of the Museum of the Archaeological Park of Ostia Antica in Rome, where innovative technologies are confronted with the immense Heritage of the Museum, with the aim of animating the exhibition itinerary and offering new points of view of the works through the creation of an interactive AR application. Specifically, the study activity proposed here, while analysing various works of statuary on a medium and small scale, focuses on the integration of a Head of Augustus datable to the first century BC (Fig. 1).

The reasons for this choice, in addition to the historical importance of the artefact, lie in its state of preservation. The Head of Augustus, in fact, is in an excellent state of preservation, except for the presence of two important lesions: the first affects the entire facial area and part of the chin, and the second is found in the area of the nose. Both lesions, particularly the one on the nose, disfigure the face of the character depicted and contribute to making his identity difficult to recognize. It

Fig. 1 On the left two pictures of the Head of Augustus during the acquisition phase (Image: F. Porfiri, L. J. Senatore). On the right the Augustus of *Prima Porta*, which constitutes the main element of comparison (Image: Joel Bellyiure, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=129823838)

will be precisely the digital elimination of the disfigurement on the face and the integration aimed at completing the missing element that will be the subject of the study, aimed at restoring formal unity to the work, i.e. to allow, in parallel with the vision in its real version, a reconstructed version based on historical sources and where, with a few interactive elements, it will be possible to reveal the story behind the artwork [9].

The process carried out so far has a prototype character, but the project is currently being developed to prepare the final model that will find its place in the new museum display next to the original.

3 Data Acquisition Workflow

In order to prepare the necessary model for the construction of the AR application, a specific operational workflow was put in place to obtain scientifically reliable data. The workflow includes well-structured work steps shared by the experts in the field. The following steps were then implemented:

- Study of the artworks under examination, aimed at identifying and classifying the object of study.
- Data acquisition (both of the object of study and of the artwork taken as reference for the reconstruction of the additions).
- Data processing for real time use within an AR application.
- AR application and communication construction.

The study was conducted under the supervision and with the support of the Park's archaeologists. The analysis of the work showed that it can be traced back to the first century B.C., thus coeval with the Augustus of Prima Porta, which constitutes the main element of comparison. The dimensions of the object of study, the Head of Augustus, are approximately 30 × 20 × 20 cm. For the data capture phase, it was decided to use different acquisition methodologies, necessary to validate the metric reliability and to verify the best solution capable of returning surfaces with less noise, to be subsequently subjected to the modelling phase, and the low-res transformation phase. Considering the use of data for interactive applications, and therefore greatly simplified in order to reduce its weight in terms of bytes, the opportunity offered by the research made it possible to verify some of the most commonly used techniques, and in particular those based on the logic of Structure from motion and those based on the use of LIDAR systems.

Two specific data acquisition sets were therefore developed:

- The first aimed at capturing photographs to be used for the construction of models on the basis of Sfm algorithms.
- The second aimed at capturing geometric and RBG data with Structured Light scanner.

For the realisation of the photographic images, with the aim of having maximum coverage and chromatic detail of the surveyed surfaces, a photographic set was organised trying to limit the presence of direct light to a minimum. With a series of opaque panels, the presence of direct reflections on the work was eliminated. Considering the illumination of the environment, realised with skylights, the positioning of artificial completion lights was not necessary. Once the photographic set was created, the Head was photographed with a Full Frame camera with a 26 mpx sensor and a 50 mm fixed focal length lens. The good ambient lighting made it possible to take shots with iso 100 (native), focal length f 8 and shutter speed 1/250 s. Given the shutter speed, it was possible to use the camera without the aid of a tripod, thus limiting the presence of micro-blur to a minimum. A total of 73 shots were required to cover the entire head area, ensuring an overlap of approximately 50%.

In order to metrically consolidate the model generated via SFM, we proceeded by inserting a number of targets into the photographic set, which were collimated with a total station (Leica, TCR 805) by setting the station points on a closed polygonal, to check the reliability of the acquired data. Once the data had been acquired, the models were processed using two different Sfm software, specifically: Zephir and Metashape. For both software, the different operational steps (sparse cloud—dense cloud—surface generation) were carried out at the highest quality level. The two elaborations allowed the construction of two models of good density both at the numerical level of the point cloud and at the geometric level of the mesh. The surface analysis revealed the fact that, although they were metrically comparable with insignificant deviations (standard deviation calculated over the entire surface of approximately 1.5 mm), the presence of noise, particularly in areas where the surface of the original was smooth, was particularly evident. In order to solve this specific problem, the models were processed with specific software through smoothing operations with obvious positive effects on the quality of the surface and negative effects on the metric validity of the model itself.

For the structured light laser acquisition, a dedicated set was again set up. The scanner used, Scantech iReal, was set to acquire a mesh of points of 0.2×0.2 mm, with the smallest possible distance from the instrument. The acquisition covered both the high-detail geometry and the colour aspect of the work. Particular attention was paid to all those areas that would later have to be integrated in order to ensure the best possible quality of the geometric data. Once the point cloud was acquired, it was processed to create a mesh surface that was subsequently textured with the RGB data acquired by the instrument. The analysis of the surface showed good quality for both the originally smooth areas and those with rough surfaces (Fig. 2).

A critical comparison between the different surfaces obtained, realised with Sfm and Lidar techniques, showed that: while on a geometric level the differences are essentially negligible, the quality of the surface realised with Laser acquisition does not in fact require manual intervention to eliminate noise. For this reason, it was decided to set the model realised with Structured Light Laser as the reference model.

Using the same technology, in addition to the Head of Augustus, it was decided temporarily to acquire the nose of a statue preserved in the Park, which was formally compatible with the subsequent integration process. The instrumental acquisition

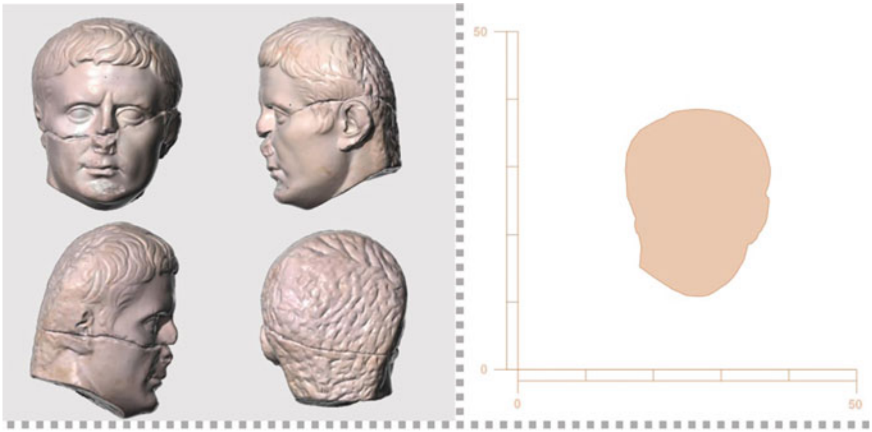

Fig. 2 Image of the Head of Augustus, textured mesh model obtained from structured light scanner acquisition and orthogonal projection of the same with metric scale (Modelling: F. Porfiri, L. J. Senatore)

settings were kept the same as those used for the study object, again obtaining a surface of high geometric definition and excellent surface quality.

4 Data Processing Workflow

Once the two models had been obtained, both of the original and of the work used as a reference for the integration of the missing parts, we proceeded to the actual data integration operation, using different techniques: regarding the deep lesion that crosses transversally the face and part of the chin, the missing portion of the object was reconstructed by working on the geometry of the statue's surface, going on to integrate the missing parts through a digital sculpture operation. In this case, the geometric analysis of the lesion edges constituted the main reference, and the sculptural operation was limited to reconnecting the edges of the surface discontinuity, keeping the curvature of the two portions unchanged. The modelling and curvature control tools are used to verify the formal correctness of the entire process, highlighting any sudden changes in curvature, which would have rendered the intervention unrealistic and geometrically incorrect (Fig. 3). This operation involved both the facial area, where the surface appears smooth, and also the area behind the hair, by locally analysing the surface patterns in order to ensure a new surface compatible with the surrounding areas.

With regard to the integration of the missing element, the nose, the operation required further processing of the head chosen for the typological comparison, i.e., the extraction of the nose area from the acquired surface. Once this last operation had been carried out, the surfaces were put into relation, initially by superimposing the

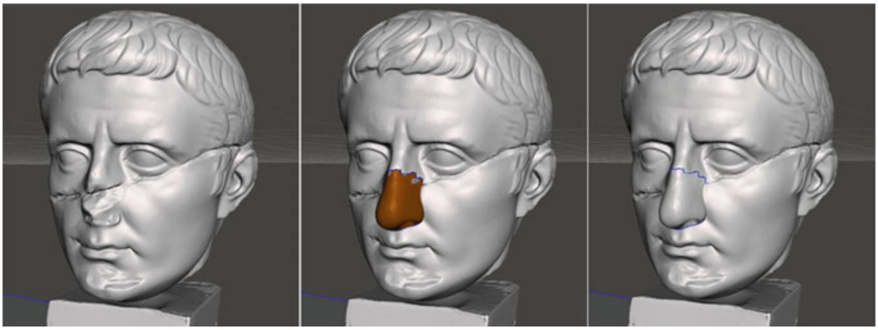

Fig. 3 The process of integration of the missing part on the three-dimensional model of Augustus' Head (Modelling: F. Porfiri, L. J. Senatore)

geometries and subsequently identifying the contact points necessary for the correct positioning of the nose portion on the Head of Augustus.

The integration process was carried out by bringing together a first phase of analysis and intervention on a visual and empirical basis with a supporting geometric analysis.

Going into the details of the procedure used, the original model with lesions and gaps was subjected to the following workflow:

- Restoration of major discontinuities using a digital sculpting process.
- Integration of missing parts with digital portions acquired from other statues.
- Verifying the geometric correctness of the work carried out on a geometric basis and in particular by verifying curvatures.

The first phase, the restoration of the surfaces, was carried out using digital sculpting software (Meshmixer) by acting directly on the mesh surface of the statue, which underwent numerical simplification following acquisition, in order to make the work more agile for the available computing power. The elimination of a considerable number of meshes at the preliminary phase, and not at the end of the operation, took into consideration the specific objective of the project (application in AR) and above all the possibility of considerably reducing (approximately 50%) the meshes produced after the acquisition, without the result in any way affecting the understanding of the object and its component surfaces. Acting with modifiers capable of filling in the gaps, reconstructing the traces left by the various *lacunae*, an empirical approach was taken, attempting to reconstruct the shape of the face and the missing portions of hair where, in the original statue, an obvious fracture is visible.

In the phase of integrating the missing parts, the nose was reconstructed. In this case, as it was not possible to have access to a statue with the same iconography, it was decided to select, from the statues in the Park's deposits, one that corresponded proportionally to the original statue and, based on the study of images of the iconography of the original, that had a nose similar in type and size. Once the statue with the required characteristics had been identified, it was scanned with particular attention to the nose. The acquisition was carried out with a Scantech iReal 2S HandHeld Laser Scanner with a scanning step of 0.2×0.2 mm. Once the point cloud had been obtained and the mesh created, it was processed by going on to identify, through a verification of dimensional compatibility with the missing portion of the nose, the few points characterising the nose, still present on the original. Having carried out various operations concerning the measuring of the component portion, the boundary contour of the fractures on the original was identified, which was used to cut, only for the necessary portion, the face area of the reference statue. Once this operation had been carried out, the result was optimised and some excess parts eliminated to obtain a model composed of two elements: the missing portion of the nose and the face itself. Once this phase was completed, it was necessary to reunite the two models by welding them together to recreate a single continuous and coherent surface. To carry out this operation, particular attention was paid to the points of junction between the surfaces which, once identified, had to be regularised and made coherent with an organic subject, i.e., without obvious edges or points of discontinuity. This was also performed through a digital sculpting operation by smoothing the ridges formed in the merging operation.

After the construction phase of the new face configuration had been completed, the surface was analysed in order to identify potential errors of a geometric nature and, in particular, to identify areas where it was necessary to focus on the elimination of ridges. The mesh surface was then exported to a Reverse Engineering software (Geomagic Design X) for the necessary verifications. In this case, too, the analysis was carried out in two ways, basing it first directly on the mesh surface and then, through a reverse modelling process, on the Nurbs transposition of the mesh surface for further verification. With regard to mesh analysis, the surface was analysed using visual verification tools with the creation of environment maps (Neon) and Zebra maps, and it was checked in detail how these maps rendered the surface. This type of solution, and in particular the Neon environment map, is able to show with a good approximation how the simulated effects of virtual refraction on the object change, offering an agile and effective tool for identifying the possible presence of discontinuities or ridges on the surface (Fig. 4). Once the result had been empirically verified, the mesh surface was reverse engineered to create a Nurbs surface in order to also carry out analyses relating to the Gaussian Curvature of the surface. In fact, the continuous Nurbs surface can be subjected to a Gaussian curvature analysis, returning a result that shows the punctual trend of the surface, i.e. whether the curvature for different points on the surface is positive, negative or zero. This type of analysis appears very useful in particular for the detection of sudden and continuous changes in the surface, such as the presence of ripples that are not compatible with the object of study but, above all, not evident from a simple visual inspection of the digital object (Fig. 4).

After this analysis had been carried out and it had been verified that the result that was visually acceptable was also geometrically acceptable, it was possible to create the file in a format compatible with the AR software (Fbx) for the development of the application. Considering the approach used, it was possible to keep the models separate and thus allow for a segmentation that was later made evident in the augmented

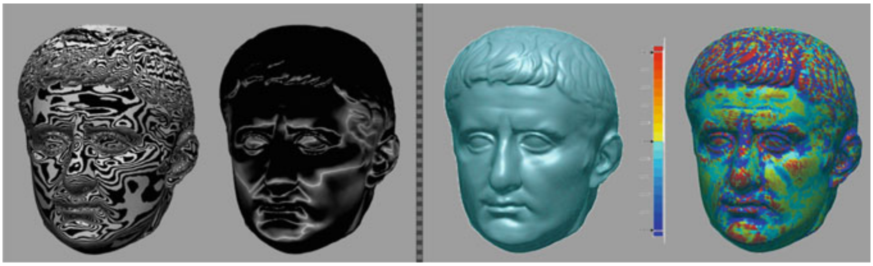

Fig. 4 **a** On the left: the surface analysis with visual verification tools: the creation of Zebra maps and environment maps (Neon); **b** On the right: the reverse engineering process: the creation of a Nurbs surface that can be subjected to a Gaussian curvature analysis (Modelling: F. Porfiri, L. J. Senatore)

reality application, within which it is possible to activate the vision of a model where the parts added compared to the original ones appear easily recognizable. Considering some problems of a logistical nature, namely the fact that there is no statue of the same period at the Ostia Park to be used for the acquisition of the portions of the surface to be used for integration, the experimentation carried out here was purely prototypical in nature, but contributed to the definition of the operational protocol.

In view of the excellent results obtained from the application of the workflow (Fig. 5), activities are currently underway for the acquisition of the Statue of Augustus of Prima Porta, preserved in the National Roman Museum in Rome, which constitutes the reference model for the iconography of the case study. The result of the acquisition process will be subjected to the same workflow in the future in order to be able to include the experimentation in the communication program of the museum visit.

Finally, a brief note must be made regarding the appropriateness of verifying the difference between the two models, point cloud and digitally restored object. In view of the objective, although easily achievable, it was decided not to carry out

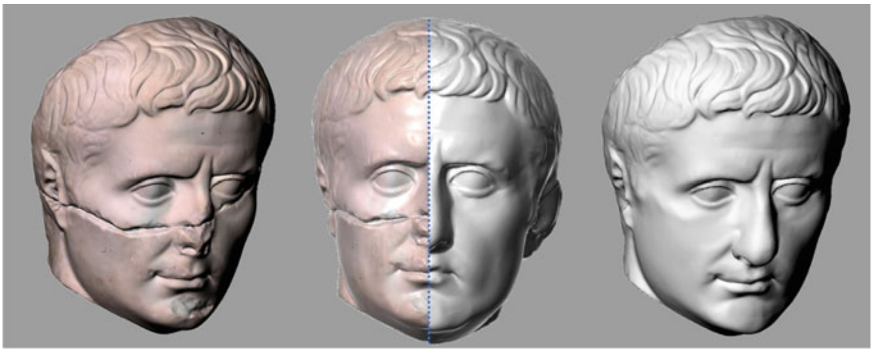

Fig. 5 Comparison between the original three-dimensional model and its reconstruction after the virtual restoration (Modelling: F.Porfiri, L. J. Senatore)

verifications to quantitatively establish the standard deviation of the two models. The choice was due in particular to the fact that this information could be misleading with respect to the quality of the model obtained by virtue of its use within an AR application.

In fact, precisely due to the communicative aspect of the model created, and having operated exclusively in a punctual manner in the areas where the lesions were present, without in any way intervening on the non-damaged areas, it was decided to prioritise the image returned by the model that was as realistic as possible and capable of returning a coherent image of a human face [10].

5 The Application of AR

For the construction of the AR application, the open-source software Unity was chosen. The models, of the current state, the state with additions and the segmented model with the added areas highlighted, were loaded into the AR platform and formed the basis for the entire interactive experience, aimed at narrating the work.

The 3 models were classified and linked to buttons to make them appear on the viewer alternately, following the interaction with the visitor user. Once the models were set up, a Target image was created, using the logo of the Ostia Antica Park, to activate the visualisation of the first model. By clicking on the buttons on the screen, each user can access the documentation used as the basis of the reconstruction, comparing the reality according to his or her own purposes, integrating the visit in real time with new information, guaranteeing a better understanding of the perceptive aspect of the work. Through the standard visualisation functions, from the moment the chosen Cultural Heritage is visited, each model (original—reconstructed) appears on the screen of the device in the configuration recalled by the user.

The visualisation not only allows a dynamic vision of the digital object, making use of the gyroscope of the viewing device, but can also be managed by the user who, with his or her touch, is able to interact with the digital object to make it rotate in the digital space, thus visually investigating the element in every detail that constitutes it (Fig. 6).

The interaction between the artwork and its spectator becomes active and participatory, thus more emotionally involving for the viewer. In addition to visualisation, particular attention was paid to narration using AR tools. In order to improve knowledge of the artefact, a number of buttons have been inserted which, once touched by the user, can refer to different types of information such as text, reference images, videos, functional to a greater understanding of the work. Among these, in a prototype version, the app allows the user to view an image of the iconographic reference, the Augustus of Prima Porta, with some data on its current location, as well as textual data to allow the user to delve into the story behind the object.

Fig. 6 Below are the different steps of interaction between the visitor and the artwork: the original model, the reconstructed model and the information linked to it (Image: F. Porfiri, L. Senatore)

6 Conclusions

In conclusion, it is possible to assert that AR within a museum setting enhances the concept of democratising art, redefining the museum space, allowing each visitor to personally interact with the work at 360 degrees, both in the physical and conceptual sense of the term [11]. The visitor can choose what and how to get to know a work within a multiple exhibition space, grasping even intangible information, with the aim of enriching his or her experience and cultural background. In this way, a new way of exchange between the archaeological cultural asset and the general public is offered, where knowledge of a work is not precluded to the uninitiated. The use of AR, declined in its meaning as a tool for the virtual restoration of the work, can be functional precisely in bringing users closer to archaeological heritage that is often not adequately narrated. In fact, it is capable of explaining in a visual and immediately comprehensible manner all that is hidden behind a work, making the user participate in its history and the various transformations it has undergone over time [12].

Virtual restoration is a non-invasive intervention and it returns the user's perception of the original object, any additional information comes from a continuous dialogue and exchange with experts, it is a critical interpretation of the object aimed at its communication. In this context, AR, as a privileged tool for the creation of a narrative experience, constitutes its appropriate fulfilment.

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Cultural Sprawl: The Opportunities of AR for Museum Communication

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1 Introduction

Extended Reality (XR), a term used to refer to complementary set of technologies including Augmented Reality (AR) and Virtual Reality (VR), offers a wide range of possible methods, techniques, and tools that may open new research opportunities in the cultural heritage field including museums and cultural institutions.

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Within the XR domain, AR is now considered also in the Cultural Heritage field as a strategic technique that allows the visualization of digital elements (informative layers) overlapped with real objects or sites. Thus, this technique can implement the dissemination of cultural heritage knowledge to a broad public engaging different visitors' targets.

In this process, the concepts of edutainment and gamification become relevant in the design of the users' experience.

Within this framework, this contribution illustrates an educational and entertaining experience, deploying AR technology to communicate the tangible and intangible aspects associated with some of the objects of the Museo Egizio collection.

Thanks to the collaboration between the Fondazione Museo delle Antichità Egizie di Torino, the Department of Control and Computer Engineering, the Department of Architecture and Design, and the VR@POLITO Laboratories, an AR app has been developed. The multidisciplinary research group involved experts and scholars from different fields including archaeology, art history, computer science, computer graphics, digital representation, graphic design, visual communication, and film engineering.

These heterogeneous competencies have been fundamental to achieve the research objectives providing the theoretical knowledge and the practical skills needed.

Proposing an interaction between indoor museum environments and outer spaces, the app enables users to connect urban spaces in the city of Turin to the museum collection.

Focusing on the funerary set of Kha and Merit, part of the permanent exhibit of the museum, users are given the possibility to interface with their avatars for the entire duration of the experience, going through some moments of Kha and Merit's past life, thanks to an effective choice of their stories and an accurate setting of the storytelling. Each stage of the app path—accessible from different points of interest displaced in the Turin city center—includes a description of the exhibit, to explore past historical contexts, as well as social and religious meanings.

2 State-of-the-Art Analysis on the Opportunities of AR Applications in Museums

In defining the term Onlife, in 2015, the Italian philosopher Luciano Floridi understood the transformation of contemporary reality where the separation of the real from the virtual became practically impossible [1]. Considering the deep integration of the two categories, Floridi suggests that would be more appropriate to speak of a single reality derived from the hybridization of digital into reality. Moreover, as described by several scholars, this Onlife reality is, at the same time, visual, sensorial, and with an ever-increasing degree of interactivity and intelligence [2, 3].

Digital techniques and tools demonstrated their opportunities in defining new approaches allowing users to augment their perceptions and experiences. This new condition is currently defined as post-media in reference, among others, to the overcoming of traditional media devices [4].

Concerning the advantages of digital visualization, including AR and VR, a recent study—developed by Cuseum [5] and the Massachusetts Institute of Technology (MIT) in the Boston Museum of Fine Arts—demonstrated the benefits of digital interfaces on the brain activity of the users. The study titled *Neurological Perceptions of Art through Augmented and Virtual Reality* measured the non-conscious engagement of users in four discrete environments: AR, VR, two-dimensional photographic reproduction, and real environment. The study exposed the participants to observe original works of art and their reproduction in 2D or 3D in virtual or augmented reality, recording the neurological activity of each participant [6]. The results showed that digital interfaces enhance user experience augmenting brain activity in comparison to the simple vision of original artistic/historic objects or artifacts [3].

Within this framework, museums became places where technological mediation—whether it is proposed by the curatorial choices or introduced by the users themselves, for instance, the autonomous visitor's choice to use media devices—is part of the experience of a visit. In a new media logic, museums assume that the encounter with the collections now takes place in an extended and diffused space, with no clear distinctions between material and virtual [7].

In this context, the Museo Egizio tested different visual communication strategies in the domain of XR, focusing on AR solutions.

Considering the potential of AR for dissemination and its interaction with physical space, the museum developed several projects heterogenous for narrative strategies, topics, AR techniques, and interaction with physical space that have been tested in different empirical applications. These include the app Stone. Pietre Egizie, the projection mapping on the Butehamon coffin, a section of the temporary exhibition Archeologia Invisibile [8], and the installation developed for the new exhibition space In search of life.

The app Stone. Pietre Egizie consists of a new tool available to the public to understand and know the type and properties of the rocks of the collection's statues, sculptures, and objects as well as those employed for the museum's building. The app allows visitors to observe different rocks, discovering their nature, composition, origin, and the reasons why they were chosen by the Ancient Egyptians [9] Regarding the project mapping of the Butehamon coffin, the installation was set up as a section of the temporary exhibition Archeologia Invisibile. The exhibition—opened on March 13th, 2019—illustrates the principles, tools, and results of the meticulous work of recomposition of information, data, and knowledge made possible today by the application of science to other disciplines and, in particular, to the study of archaeological findings. The installation consisted of a projection mapping on the copy of Butehamon's coffin, reproduced through 3D printing. The 3D printing of the coffin has been used as support to represent and visualize, through dynamic projection mapping, the transformations, and construction processes as well as the needed know-how to realize [10].

The installation In search of life is a permanent exhibition space that expands the visit path of the museum. It is dedicated to life in ancient Egypt through the study of human remains. The fulcrum of the new space is a showcase set up to contain 91 mummies that are part of the museum's collection. It performs the double function of deposit and showcase. Therefore, it was designed to guarantee the highest conservation standards for the extremely fragile human and organic remains conserved inside the showcase.

Thanks to a special film in Liquid Crystal Display (LCD) applied to the glasses of the showcase, six of these mummies are revealed to the public, to represent the fundamental stages of life. The revelation of the object inside the showcase is temporized with a video projection on the showcase that anticipates the story and the features of the object that is going to be shown. Indeed, the Liquid Crystal Display (LCD) film on the showcase allows to use of it as a projection surface (when the LCD is off) or simply as glass (when the LCD is on) (Fig. 1).

In the broader framework of the application of digital visualization techniques and tools in museums, the described examples, characterized by a common transdisciplinary approach, underline the potential of digital representation and its role in the development of AR solutions.

The common feature of the mentioned creative AR applications, developed by the Museo Egizio in a cultural sprawl logic, is the dissemination of humanistic and technical knowledge embedded in archaeological objects.

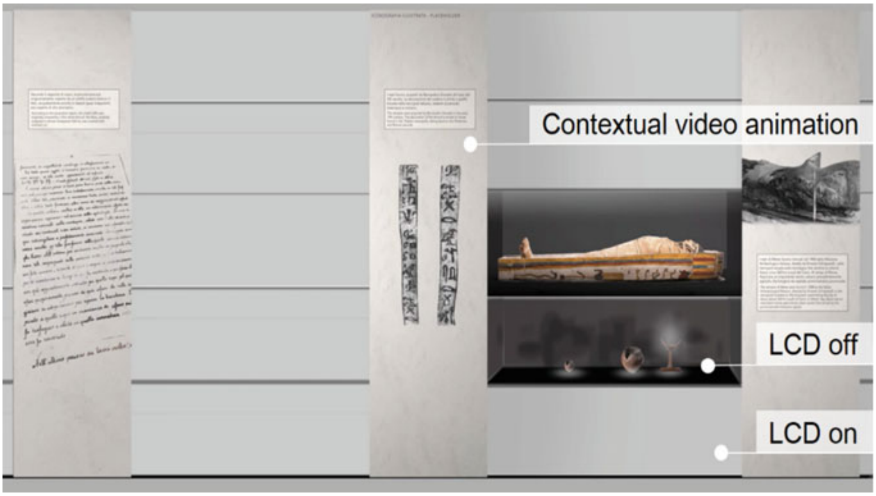

Fig. 1 The installation In search of life, in the permanent exhibition path of the Museo Egizio. *Source* Museo Egizio, processing: D. Mezzino

3 Case Study: The Funerary Set of Kha and Merit

The case study considered in this work focuses on the funerary set of Kha and Merit, part of the permanent exhibit of the museum.

The intact tomb of Kha and Merit (TT8) was discovered on 15 February 1906, by the Italian Archaeological Mission (M.A.I.) headed by the then director of the Museo Egizio, Ernesto Schiaparelli [11–13]. The burial was found in the necropolis of Deir el-Medina, a village founded at the start of the 18th Dynasty, around 1500 BC, on the western bank of Thebes. The settlement housed the workmen in charge of building the tombs of the pharaohs in the nearby royal cemeteries known today as the Valley of the Kings and the Valley of the Queens. Kha, who lived in the second half of the 18th dynasty (1425–1353 BCE), was Overseer of works and directed the construction of the royal tombs. His whole burial assemblage, consisting of more than 460 objects, is today preserved at the Museo Egizio in Turin. It is one of the most important discoveries displayed in the museum, a perfectly preserved funerary context, shedding light on aspects of Egyptian culture such as religious and funerary beliefs and the concept of life beyond death. The artefacts within the tomb are of a variety of types: coffins, furniture (such as beds, tables and chairs), clothes, food, work tools and everyday objects. Everything inside the tomb was meant to help the deceased continue his journey in the afterlife and reach the god Osiris, obtaining eternal life (Fig. 2). The importance of this extraordinary untouched grave assemblage lies in its ability to reveal the story of Kha and Merit, who lived over 3000 years ago. More specifically, it reveals many details concerning the fears and desires of the ancient Egyptians and their conception of life and the afterlife.

For this reason, it is of fundamental importance to share the cultural and material heritage preserved at the Museo Egizio not only with the scholarly community but with all the people who visit the museum every day. Starting from the idea of creating new links between the city and the museum, the proposed AR app focuses on some important artefacts that were part of Kha's burial assemblage, linking them to specific urban spaces in the city of Turin. The user will be able to easily approach the rich history of these artefacts and their symbolic meaning and function while moving around the city. Once outside the museum, he or she can decide to learn more about them by visiting it. The three selected objects are: the game of senet, the Book of the Dead and Merit's toiletries. These finds are representative of the great variety of artefacts found in the tomb of Kha and Merit. Each has a specific function, aimed at assisting the deceased in their afterlife journey.

The game of senet consisted of a grid of 30 squares drawn on a surface. The rules of the game are still not completely clear, but we could compare it to the modern Game of the Goose. *Senet* also means to pass, and the game is called thus because the player had to eventually get all his or her pawns off the chessboard. The concept of passing was also associated with the journey of the deceased into the afterlife and therefore the game had a symbolic value linked to the funerary world.

The Book of the Dead is one of the most spectacular objects among Kha and Merit's grave goods. It was found folded above the middle coffin of Kha. It is almost

Fig. 2 Kha and Merit's funeral chamber, at the time of discovery. *Source* Torino, Archivio Museo Egizio, C. 02,070

14 m long and lists 33 spells, some of them illustrated with colourful vignettes (Fig. 3).

These 33 spells were magical-religious formulas that help the deceased on their way to the afterlife, to face any kind of danger they might encounter. Some of them provide protection against dangerous animals, while another series of spells address the ability of the deceased to move between the earthly world and the afterlife. Merit's toiletries were inside a beauty-case fitted with internal compartments (Fig. 4 left). Among the objects it contained was a small tube made of blue glass, with white and yellow decorations, containing kohl and a small stick applicator. Kohl was a black substance resembling our modern kajal, which was applied to the eyes as a protective filter against the rays of the sun and as an antibacterial agent (Fig. 4 right).

4 Relationship Between City and Museum

Among the Museo Egizio's programmatic goals, that of bringing the museum outside the museum, explained as the aim of making the contents of the collections accessible to those who cannot visit the museum, was the main inspiration for the present project. Taking tourism as the target audience, the idea was to build strong links between the museum and the city through a pathway.

Fig. 3 Kha's Book of the Dead, detail of the couple worshipping the god Osiris. Cyperus papyrus, ca. 35 × 1380 cm. New Kingdom, 18th Dynasty. Deir el-Medina, Tomb of Kha (TT8). *Source* Torino, Museo Egizio, S. 8316/3 = S. 8438

Therefore, the concept expressed by the institution was interpreted through a different declination in two interrelated ways. On the one hand, an effective link was created between the city and the museum; on the other hand, the metaphor of the museum outside the museum was made effective by visualizing from outside the building some of the objects in it, contextualizing them in interactive experiences with digital representations of Kha and Merit themselves.

Therefore, the objectives pursued are broadened from those enucleated by the museum, allowing, first, for the museum to be perceived not as a closed place but, conversely, as an opportunity to create new links of meaning with other places and buildings in the city. This implies, among other things:

- That the museum is also active at times other than when it is open.
- That certain cultural points of interest in the city are enhanced.
- That the invitation to enter and repeat the experience can be scaled up to other content offered by the museum.
- That other places in the city can be included in different itineraries, establishing additional sense-making relationships.
- Not only that, the app, currently focused on the step-by-step game centered on a few artifacts on display, could be enriched with an explanation of the places visited and the activities contained at the buildings as well as recommend visits to other places depending on users' interests.

Fig. 4 On the left, Merit's toiletry box, wood, ca. 22 × 29.5 × 49 cm. New Kingdom, 18th Dynasty. Deir el-Medina, Tomb of Kha (TT8). *Source* Torino, Museo Egizio, S. 8479. On the right, Kohl tube with wooden applicator. Glass, ca. 9.2 × 3.7 cm. New Kingdom, 18th Dynasty. Deir el-Medina, Tomb of Kha (TT8). *Source* Torino, Museo Egizio, S. 8489

The tourist route involves three points of interest, in the central area of the city (Fig. 5): the Sambuy gardens in front of the Porta Nuova station, the façade of the stables of Palazzo Carignano, in whose building the Biblioteca Nazionale di Torino (National Library of Turin) is housed, the Mole Antonelliana, which currently houses the Museo Nazionale del Cinema (National Museum of Cinema), and, of course, the palace of the Collegio dei Nobili, a portion of which is home to the Museo Egizio of Turin.

The entire route, done on foot, takes a little more than 30 min, to which must be added the time to carry out the experiences.

The tour ideally starts right from the gardens, imagining that a portion of the tourists come from the city's main train station or otherwise via public transportation, including the subway line, of which the station is an important junction.

The small Sambuy gardens, of late nineteenth-century design like the area of city expansion in which they are located, conform to the model of the green oasis, and are equipped with a pond, gazebos, meandering paths, centuries-old trees and English lawn. They constitute the passageway, an alternative to porticoes, to the streets leading to the first expansion of the Baroque city (Carlo di Castellamonte from 1621), hinged on the northern section of the current Via Roma. It is precisely because of this character, and the fact that it represents an initial stopping point for

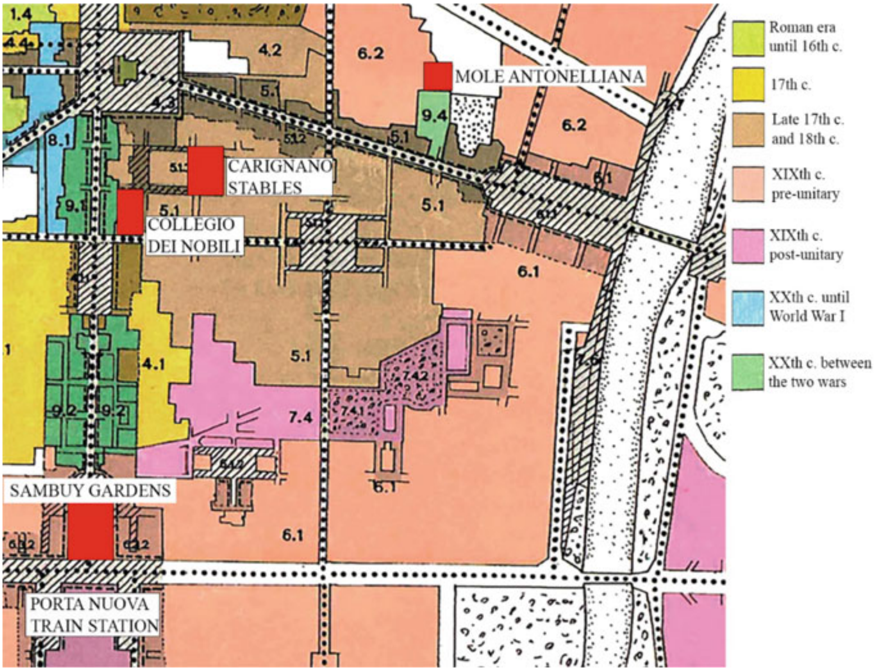

Fig. 5 Excerpt of the map of historic urban settings in the central area of Turin [14] with localisation of the points of interest: Porta Nuova (Turin train station), Sambuy gardens, Mole Antonelliana (Museo del Cinema), Carignano Stables (Biblioteca Nazionale) Collegio dei Nobili (Museo Egizio) (Editing: R. Spallone)

visitors to the city, that it has been paired with the table game of senet intended as the emblem of the stopover.

The other two destinations, the Mole Antonelliana and the stables of Palazzo Carignano, can be reached along the way in no particular order.

The Mole Antonelliana, a bold 167.5-m-high symbolic construction of the city, is named after its designer, Alessandro Antonelli, who undertook its construction in 1862. It originally served as a synagogue, but was taken over by the city before the construction site was closed and now houses the Museo Nazionale del Cinema, one of the city's main museum attractions. The Mole is located in the area of the second expansion (Amedeo di Castellamonte from 1673) that has Via Po as its axis. Reaching it from the gardens allows you to explore the streets and palaces of this urban portion. The building's current function has made it juxtaposed with experience related to Merit's toilet accessories.

The façade of the stables of Palazzo Carignano (1750), now separated from the palace by a large garden, is also part of this area. It currently serves as the front of the contemporary building, seat of the Biblioteca Nazionale. The similarity in content led to the idea of anchoring the long scroll of the Book of the Dead to the facade.

The Collegio dei Nobili (1679), built by Michelangelo Garove still in the area of the second expansion, is the seat, as noted above, of the Museo Egizio, the repository of the artifacts that are the subject of the digital experience. The room of Kha's tomb is located on the first floor of the building and overlooks Piazza Carignano. The depth of the square made it possible to carry out the experience by completely framing the façade and superimposing in AR the digital models of the display cases placed in the room and the exhibits, as if it were viewed in X-Ray.

5 Storytelling and Gamification

The app, which has been created using Unity, is designed to be accessible from the personal mobile device of potential users before visiting the museum, to introduce the public to Egyptian culture and intrigue them enough to get in in person. The idea was to introduce gamification elements, creating real interactive playful experiences, at the center of which there is a particular element of Kha and Merit's funerary set. The aim was to create a connection between the museum and the city of Turin. Hence, as said, four key locations were selected to display the artefacts in question, seeking a link between the object and the place where it is displayed.

- In the Sambuy garden it is possible to engage in the game devoted to playing the senet game. This choice was made because of the proximity of the location to Porta Nuova train station, a place of passage for travellers. In fact, the word senet means to pass and is mentioned in several funerary scenes to indicate the transition between life and death.
- The Mole Antonelliana was chosen as the location for playing with the Merit's dressing table, which contains several items used daily by women. This choice is motivated by the fact that the Mole Antonelliana hosts today the Museo Nazionale del Cinema, and makeup and hair is a department of the entertainment industry.
- On the walls of the Biblioteca Nazionale it is possible to engage in the experience related to the Kha's Book of the Dead. Although it is not a real book in the modern sense of the term, it contains a series of religious formulas for surviving the journey to the afterlife and, thus, was placed there as a binder of knowledge.
- Finally, the museum building (precisely, its façade on Piazza Carignano) was conceived as the final stop as a connection and culmination of the experience that could entice visitors to enter it for a visit. In this case, an X-Ray like experience has been conceived, to remove the walls and let the user have a preview of (and engage with) elements contained in the physical exhibit rooms.

In these four designated locations, the user has to locate and frame a QR-code (identifying the particular experience) to see two ancient Egyptians, i.e., Kha and Merit, appear in the city overlapped to today's real content using AR, inviting him or her to live the interactive experience with them.

It was chosen not to set a predefined order to engage with the four experiences, in order to let the user choose the most convenient path through the city according to his or her plans. The X-Ray experience, however, is suggested to be the last one, so that the user can engage in a game that requires him or her to recall what was presented in the other three experiences and recognize the artefacts encountered while playing with them.

As said, the focus of this project is the funerary set and, more generally, the story of Kha, an architect working in the village of Deir el-Medina, and Merit, his wife. Based on available information, researchers believe that Merit died prematurely and Kha donated one of his coffins in order to let her survive in the afterlife.

The story is introduced through a video, which is played automatically when the user launches the app. In this brief snapshot of the couple's daily lives, it is possible to sense the affection that binds the two, but also get aware of the conclusion of Merit's earthly life. The video concludes with Kha's words declaring his undying love for his wife and inviting the user to visit the places indicated on the app's map to relive their happy memories. Each of the four experiences features one of the characters, or both, and focuses on different subsets of the objects in their funerary set.

At the end of the experience located near the museum, a closing video is shown in which Kha's coffin is placed next to Merit's one, thus reuniting the couple thirty years later. The video ends with the final call to action to enter the museum to learn more.

Each experience can be regarded as split into three, similar parts:

- An initial part in AR, where the user can interact with the avatars of Kha and/or Merit, which are superimposed on real city elements and invite him or her to play.
- A central part, which is the most interactive one, where the user is first provided with a tutorial about the game and its mechanisms, then he or she has to play it.
- A final part (for all the experiences except the X-Ray one), in which the avatars provide an explanation about the history, use, and meaning of the objects seen/used in the previous parts; in the X-Ray experience, an explanation is not provided since, as said, the game is about what tackled by the other experiences.

The tutorial and the explanations are supported by static and animated images as well as by textual descriptions, which are displayed on the app's screens but also uttered by the avatars, who are depicted in front of their home.

6 App Design and Technological Choices

The design of the app started with a search of references that could be used for the creation of a moodboard, i.e., a visual presentation or collage of images, text, and samples of elements that are used, in the design of digital experiences, to convey a general idea or feeling about a particular topic. This output was exploited to create a design for the aspect of Kha and Merit.

To this purpose, a picture from Kha's Book of the Dead was used as inspiration, not just for Kha and Merit's body features and colours, but also for their jewellery and wigs.

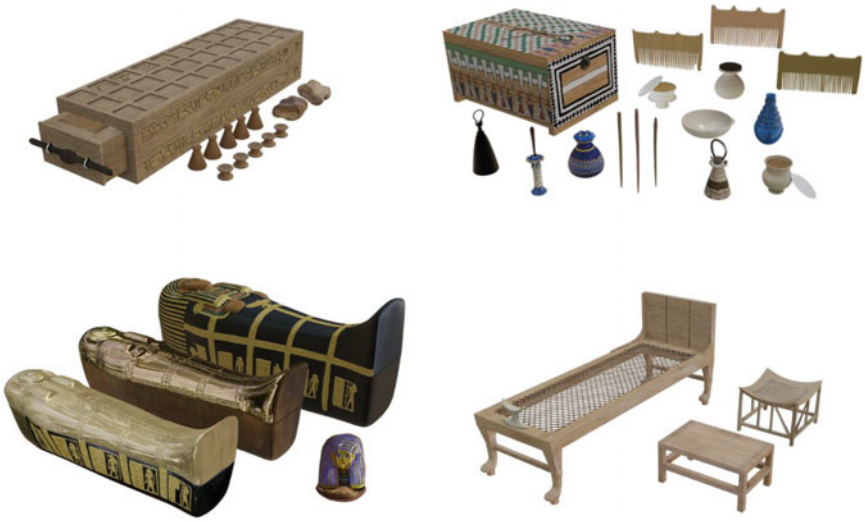

Fig. 6 Reconstructive 3D models of the senet game, Merit's toilet set, Merit's sarcophagus and funerary mask, and furniture of Kha and Merit's home (Modelling: R. Filippini)

Then, the assets required for the app were created. Almost all of the 40 objects displayed in AR were modelled in Blender [15] (Fig. 6). A key objective was to keep the complexity of the 3D models low: to this aim, low-poly modelling techniques were used [16], in combination with a careful texturing stage. Thus, textures were created ad hoc with Substance 3D Painter [17] by using many different channels (colour, normal, displacement, etc.), and prepared for UV mapping.

Specific care was devoted to recreate the appearance of materials: to make an example, for wood, reference images have been used to properly align the fibres to preserve philologic coherence.

Objects and texture were modelled and textured starting from the references in the museum's collection, with the exception of two boxes which had been digitized by the museum via photogrammetry and were recreated from scratch to reduce the number of polygons while preserving the visual quality [18].

For the modelling of Kha and Merit's home, inspiration came from a video produced by the museum, in which the curator Cédric Gobeil illustrates real life and habits of the New Kingdom, with a special focus on the Deir el-Medina site and its houses. Just the façade was modelled since it is the only part shown in the app.

2D animations used, e.g., in the tutorials, were built in After Effects. 3D animations, in turn, have been created in Blender or directly in Unity. The rigging and skinning of avatars [19] were managed using Mixamo [20]. Models and rigs were then imported into Blender, where animations were created using key-framing and blend shapes. Animated models were finally imported into Unity, where they are activated using finite-state machine-based scripts. Facial animation (e.g., lip synch) is handled with SALSA [21].

The user interface was created directly in Unity. The colour palette includes warm tones, aligned with the colours of the desert and of Ancient Egypt. The background of windows and banners displayed during interactions with Kha and Merit as well as during explanations include a papyrus texture. In the experiences, different types of user feedback are provided, using visual and aural cues. In order to let the user interact with the app at his or her own pace, at any time the app displays buttons that allow the exit the game, activate/deactivate the sound, as well as to complete the current game and move directly to the final part with the explanation by Kha and Merit. Music is based on Egyptian melodies. Similarly, for the sound effects, tunes from string and wind instruments were used. Kha and Merit's voice-over was created using text-to-speech, by leveraging the services provided by TTS Free's website.

Regarding the building of the app's core, i.e., the AR part, the choice of the framework to use was greatly influenced by the requirements related to the case study. Being the experiences targeted to casual users interested in the museum field, the hardware selected for the use case was the personal mobile device (i.e., AR-enabled android smartphones and tablets) in order to reach the widest possible audience. The version of Unity chosen was 2020.3, and development was grounded on AR Foundation [22] and Google ARCore [23]. These two solutions allowed to manage the 6 Degrees-Of-Freedom (6-DOF) positional tracking of the device (via Simultaneous Localization and Mapping, SLAM), as well as the anchoring of the virtual elements onto the real world (Fig. 7).

Fig. 7 The senet AR experience (Processing: R. Filippini and G. Da Vià)

As mentioned, the four experiences were designed to be accessible at predetermined locations throughout the city center. Two of them (that on Book of the Dead and the X-Ray one) were designed as Mixed Reality (MR) experiences and built around the interaction between real and virtual elements. To achieve this functionality, the Vuforia [24] AR engine was exploited. Vuforia allows the recognition of particular targets in the real world, being images (Vuforia Image Target) or 3D shapes of real objects (Vuforia Model Target).

Regarding the Book of the Dead, the use of a Model Target was immediately discarded due to the lack of visual features on the wall of the Biblioteca Nazionale (Fig. 8). Thus, it was decided to resort on a Vuforia Image Target (a QR code printed and placed on the wall), as it proved to be a valid 6-DOF marker-based tracking solution for handheld AR devices [25]. For what it concerns the X-Ray of the museum, the initial idea was to use some of the elements present inside Piazza Carignano (e.g., streetlamps, parts of the building, the advertising boards) (Fig. 9).

However, the test provided poor results due to the variable availability of these elements (some requalification interventions were underway in the square, and most of the potential targets were covered by scaffolds).

To cope with this issue, it was decided to rely again on a QR code to initiate the experience. The other two experiences (the one on the senet and that on Merit's toiletry) were designed as mobile games. However, to uniform the user experience among the four scenarios, it was decided to maintain the QR code recognition as starting trigger for them too.

Fig. 8 The Book of Death AR experience (Processing: R. Filippini and G. Da Vià)

Fig. 9 The X-Ray AR experience (Processing: R. Filippini and G. Da Vià)

7 The Gaming Experiences

In the following, a description of each of the four experiences is provided, in the order they have been introduced above.

Near Porta Nuova, by framing the QR code, it is possible to view in AR Kha and Merit while they are playing the game of senet (Fig. 10). After talking to Kha via the appropriate button, the user can play against him directly. The rules, laid out in the tutorial, refer to modern senet, since it is not known exactly how it was played in antiquity: the goal is to get all one's pawns off the board by choosing which pawn to move from time to time after the two astragals are thrown. The simple and intuitive interface allows the user to throw the astragals using the appropriate button and choose which pawn to move from those that can be moved with the result obtained from the throw (highlighted in yellow), briefly reminding the user of the rules each time a new situation is encountered (e.g., attacks or special squares). The game is played on the screen of the user's mobile device, not in AR, for greater usability; in addition, the user can decide whether to play the game to the end or switch at any time to the final part of this experience, going to listen to Merit who recounts the origins and evolution over time of the ancient board game, dwelling in particular on the historical, socioeconomic and religious aspects.

Near the Mole Antonelliana, it is possible to meet Merit intent on choosing what to use among the items on her dressing table for her daily beauty routine (Fig. 11). The experience, in this case, experienced on the screen of the user mobile device and therefore not in AR, is divided into two parts: in the first one, the user has to prepare kohl, a substance used for eye makeup, thanks to the step-by-step instructions provided (it involves dragging or hitting several times certain items present in the funeral equipment visible at the museum), while in the second, he/she has to apply to Merit's eyes the substance he/she has just helped prepare, tracing with his/her finger the character's eye contour.

Fig. 10 The Senet game enjoied in the Sambuy gardens (Processing: R. Filippini and G. Da Vià)

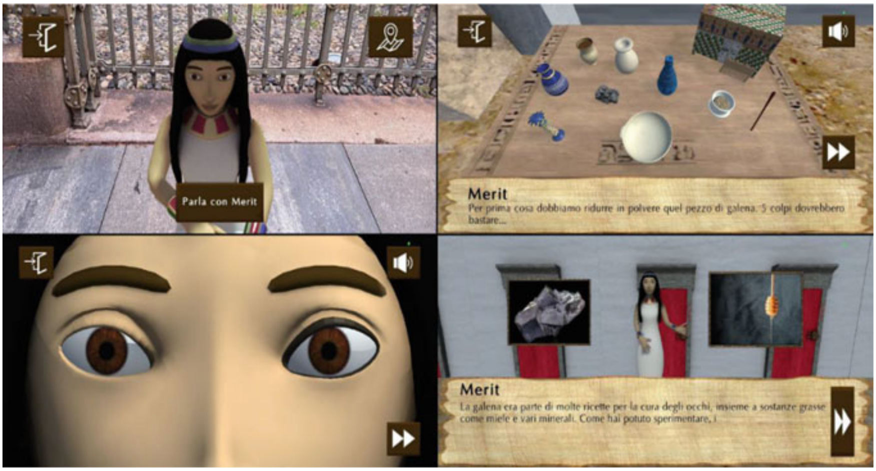

Fig. 11 The Merit's toilet game enabled on front of Mole Antonelliana (Processing: R. Filippini and G. Da Vià)

When both parts have been completed, Merit explains what the kohl is. She does so by paying particular attention to its dual aesthetic and antibacterial value, as well as to help against the glare of the desert sun.

The Book of the Dead appears on the walls of the Biblioteca Nazionale by framing the QR code, with Kha and Merit intent on reading the long papyrus (Fig. 12). Interacting with Merit through the appropriate button allows the experience to begin following the viewing of the tutorial. In this case, AR is used more intensively than in the previous scene, as the experience takes place entirely in AR: moving with the mobile device along the walls of the building makes it possible to view the papyrus in its entirety. The goal here is to associate a set of definitions with the images in

Fig. 12 The Book of the Dead game anchored to the façade of Biblioteca Nazionale (Processing: R. Filippini and G. Da Vià)

the Book of the Dead by first touching the label in the user interface and then the papyrus itself. The images represent the different magical formulas in the Book of the Dead that the deceased could use to survive in the Afterlife, for example, turning into a swallow or a snake. Once all the formulas have been associated with the relevant depictions, the experience concludes. Shortly afterwards, Kha talks about the meaning, history, and use of the Book of the Dead, dwelling in particular on the content of the formulas.

Finally, at the stop near the Museo Egizio, framing the QR code allows the user to see three display showcases on the walls of the museum containing some of the many artefacts that are part of Kha and Merit's funerary equipment in the room of the museum dedicated to them, especially all the items in the other experiences. The experience consists of an AR quiz with two types of questions: multiple-choice questions regarding what has been learned from the explanations available in the other experiences around the city, or requests to select one of the objects displayed in the showcases, which can be observed in more detail by approaching one showcase at a time at a fixed distance from the virtual camera of the device used.

8 Conclusions

In the present project, AR constitutes the central technology for achieving the goals of expanding the museum experience through gamification and creating new connections between exhibits and urban space. The different digital products involved in the project (i. e. point clouds resulting from the artefacts scanning, reconstructive models of artefacts and s contexts of the experiences, 2D graphics and 3D models of the characters with movement animations, animated sequences and their montage including written and spoken texts) are integrated into a digital *continuum* adapting to the storytelling that frames the project. AR allows the enjoyment of such content.

The project, currently in the prototype stage, is scalable to other museum and urban settings, easily implemented and usable by a wide audience through personal mobile devices.

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Towards a Virtual Museum of Ephemeral Architecture: Methods, Techniques and Semantic Models for a Post-digital Metaverse

Maurizio Unali, Giovanni Caffio, and Fabio Zollo

1 Introduction

The essay summarises the latest results of an experiment, between research and didactics, on the general theme of the Virtual Museum (VM) in architecture and design (Fig. 1), explaining the workflow used and the semantic models elaborated for the realisation of a prototype (called *VM5*), conceived as a thematic metaverse of ephemeral architecture. In order to summarise the main outcomes of the carried out research, the contribution has been articulated with respect to three main thematic areas addressed in the study, each treated individually by one author. The first theme—Sect. 2. The State of the Art Survey: Conceptual Map, Timeline—was elaborated by Giovanni Caffio, and summarises the project and the contents of the conceptual map and timeline realised, where the most significant works were classified, also attempting to highlight the different types of application and use of the VM. In the third part of the experimentation.

The second topic—Sect. 3. The VM Project of Ephemeral Architecture, Between Research and Teaching—was elaborated by Maurizio Unali, and introduces some of the foundational aspects inherent to the structure of the entire research, summarising the design contents that nourished the realisation of the VM5 prototype, both in compositional terms and with respect to the type of fruition experience. The main results achieved are also analysed and some possible developments are highlighted—Sect. 4. The Processing of the Workflow to Realise the VM5 Prototype, here written

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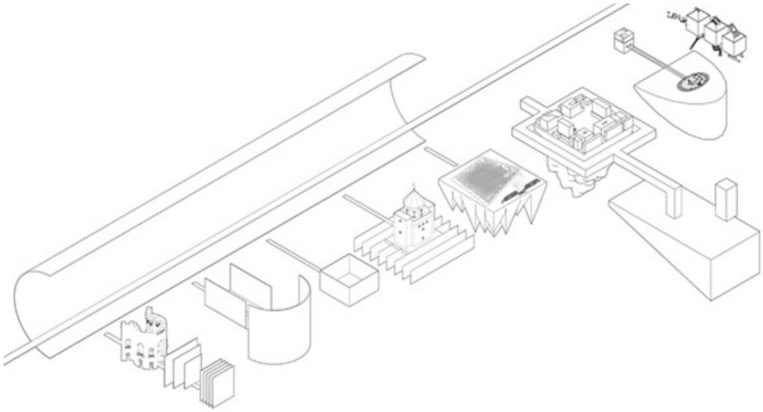

Fig. 1 Project sketch of the Virtual Museum of Ephemeral Architecture, adopted as the general composition scheme—red carpet; information videowall; exhibition pavilions—of the research carried out within the five-year degree thesis workshop in Architecture, coordinated by Professors G. Caffio and M. Unali, the Department of Architecture of the University G. d'Annunzio of Chieti-Pescara

by Fabio Zollo, the methods and techniques (workflow) used to realise the VM5 project were defined, a graduation theme of the same author, elaborated within the five-year degree thesis workshop in Architecture (a. a. 2021/22), coordinated by Professors G. Caffio and M. Unali, of the Department of Architecture of the University G. d'Annunzio of Chieti-Pescara (Figs. 2, 3, 4, 5, 6, and 7).

2 The State of the Art Survey: Conceptual Map, Timeline

The Virtual Museum is a subject of debate and research that encompasses the preservation and dissemination of knowledge and culture through digital networks. Since the late 1980s, techno-culture has been introducing developments that cross various disciplinary fields, and the Virtual Museum, as a composite and experimental digital artifact, is an ideal field of investigation. It encompasses aspects of historical culture on the one hand, and the conformative and representative dimensions of virtual living [1] and the new forms of human-digital interaction through an increasing number of technological devices.

We have collected many examples in the form of interactive timelines that can be navigated online [2]. This sequence has unfolded over the years and includes well-known authorial projects, such as the Virtual Museum commissioned by the Guggenheim Foundation in 1999 to the Asymptote Architecture studio (Rashid and Lise Anne Couture), as well as more eclectic experiences that are no less interesting or useful in projecting forward a new model of art consumption. We also cover the

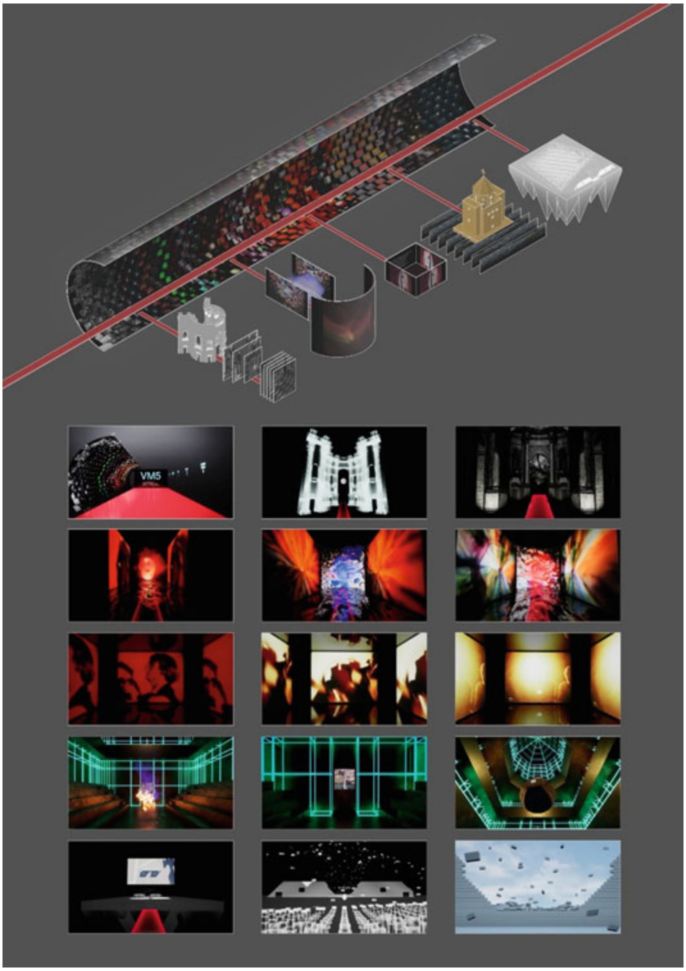

Fig. 2 Overview of the overall structure of *VM5* and views of the five exhibition halls. Five-year degree thesis workshop in Architecture: graduating student F. Zollo; relator Prof. M. Unali, co-relator G. Caffio, Department of Architecture, University "G. d'Annunzio" of Chieti-Pescara

most recent developments linked to the birth of NFTs, new systems capable of generating value through multiple series of graphic or three-dimensional digital works. The conceptual map organizes events temporally, revealing affiliations and kinship between fragmentary projects. It brings out a hidden red line within a succession of apparently fleeting and disconnected elaborations. When put in sequence, these elaborations reveal an adventure of ideas [3] that is fascinating and a harbinger of future developments.

What unfolds before our eyes is a process of transforming an idea that has always been ingrained in culture. This idea fruitfully intersects with the vicissitudes of

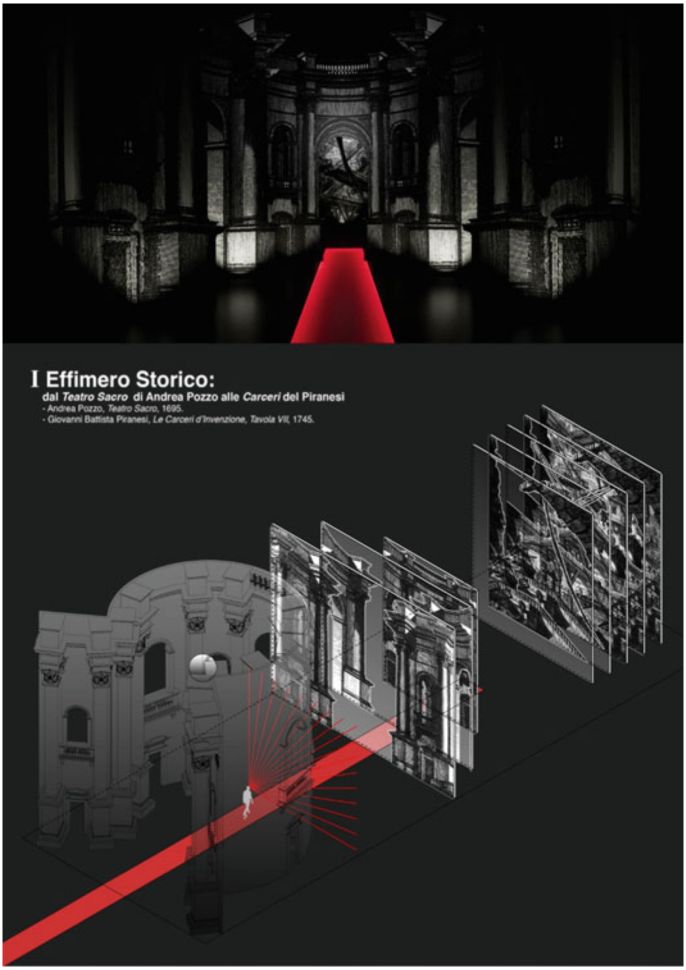

Fig. 3 Room I of VM5, Historical Ephemera: from Andrea Pozzo's Teatro Sacro (1695) to Giovanni Battista Piranesi's Carceri d'Invenzione (Table VII, 1745). Five-year degree thesis workshop in Architecture: graduating student F. Zollo; thesis supervisor Prof. M. Unali, co-supervisor G. Caffio, Department of Architecture, University "G. d'Annunzio" of Chieti-Pescara

architectural representation and constitutes a fertile terrain for freely experimenting with methods, techniques, and processes of simulation and interactive visualization. These methods allow for the creation of potential spaces in which to move and travel in the form of virtual personae and imaginative avatars.

The Virtual Museum (VM) is an ideal platform to explore the various forms of architectural and urban ephemera. It is a hub for utopian and radical projects that exist in the continuous immaterial flux of the web. The map presented here is a work in progress, useful for classifying and organizing the various manifestations of the Virtual Museum that have emerged in different years and in different technological

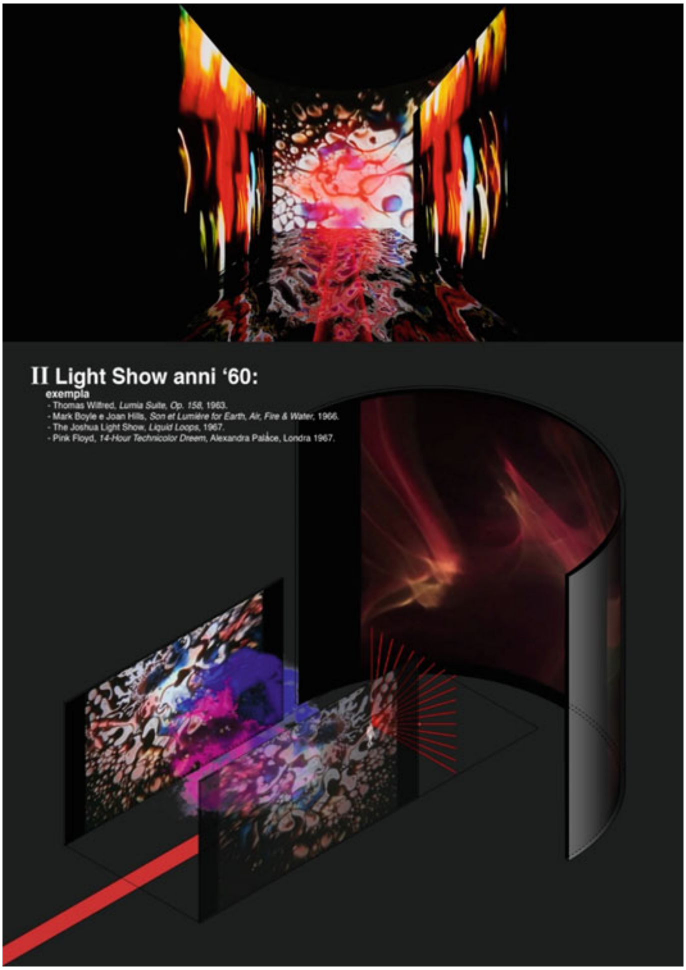

Fig. 4 Room II of the VM5, 60 s Light Show: Thomas Wilfred, Lumia Suite, Op. 158, 1963; Mark Boyle and Joan Hills, Son et Lumière for Earth, Air, Fire and Water, 1966; The Joshua Light Show, Liquid Loops, 1967; Pink Floyd, 14-h Technicolor Dream, Alexandra Palace, London 1967. Five-year degree thesis workshop in Architecture: graduating student F. Zollo; thesis supervisor Prof. M. Unali, co-supervisor G. Caffio, Department of Architecture, University "G. d'Annunzio" of Chieti-Pescara

cultures. It is a partial and incomplete selection of the most emblematic cases, based on a precise typological distinction. This typological differentiation is based on an analysis of the most frequently found cases in digital networks, resulting in a tripartite simplification: (A) digital archive; (B) virtual tour; (C) metaverse.

(A) The VM is designed as a replica or reproduction of the existing museum in the form of a website. We are dealing with a web transposition of the museum's catalogue, a sort of digital version that exploits the telematic archives and

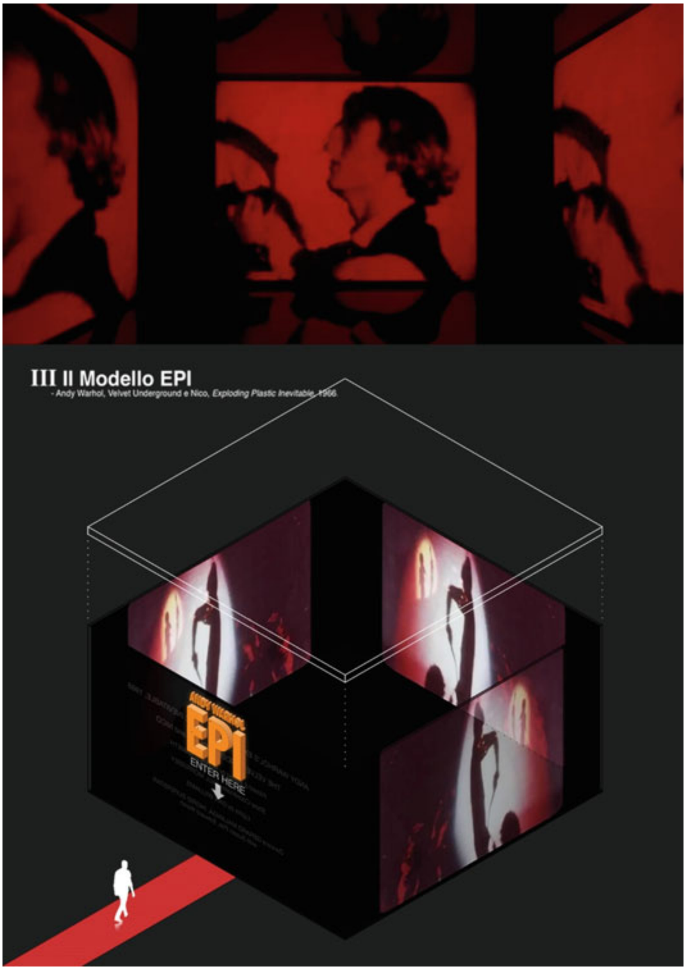

Fig. 5 Room III of VM5, Il Modello EPI: Andy Warhol, Velvet Underground and Nico, Exploding Plastic Inevitable, 1966. Five-year degree thesis workshop in Architecture: graduating student F. Zollo; relator Prof. M. Unali, co-relator G. Caffio, Department of Architecture, University "G. d'Annunzio" of Chieti-Pescara

multimedia of the new platforms to make the different contents housed in the halls and archives of the analogue museum usable. These are the first forms in which the VM also begins to appear in the most widespread publicity and thus receives its own recognisability and popularised functionality. Examples of this type are the websites of major museums such as the Vatican Museums [4] and the Metropolitan Museum of Art in New York [5].

(B) The virtual museum (VM) is a networked representation, a kind of virtual tour or digital clone of real museum spaces. The first model of the VM (website and digital archive) is extended by other possibilities for interactive exploration,

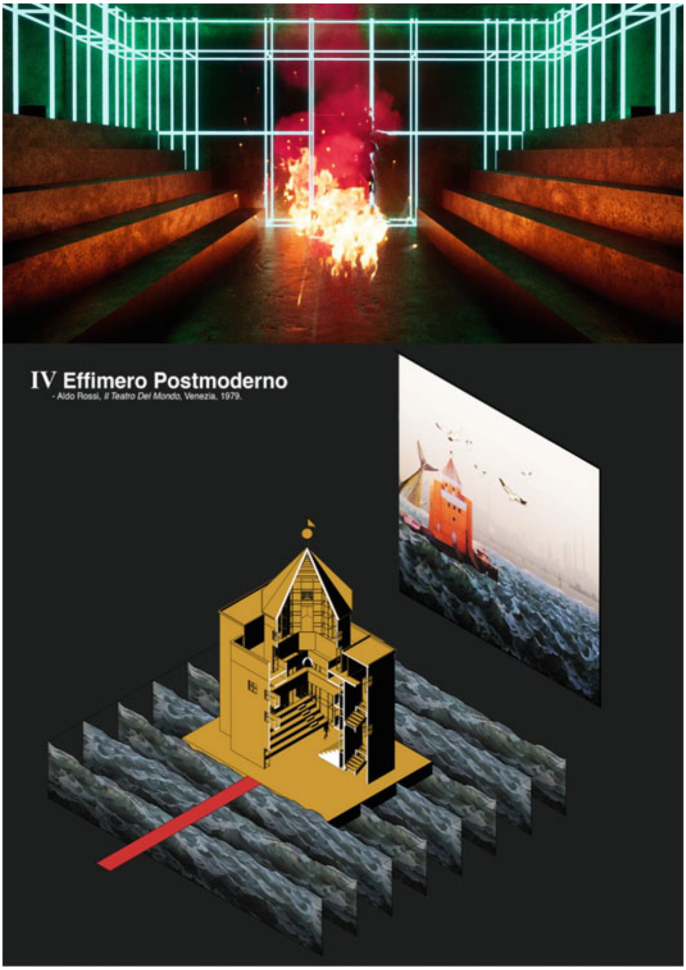

Fig. 6 Room IV of VM5, Postmodern Ephemeral: Aldo Rossi, Il Teatro Del Mondo, Venice 1979. Five-year degree thesis workshop in Architecture: graduating student F. Zollo; relator Prof. M. Unali, co-relator G. Caffio, Department of Architecture, University "G. d'Annunzio" of Chieti-Pescara

in which the museum rooms themselves become an opportunity to browse the collections. The museum is mainly rendered through the use of 360° panoramic photos or navigable photos, with systems borrowed from other fields such as the well-known Google Street View. As a result, the visitor moves between corridors and rooms, experiencing a substitute experience in which the visual dimension is prevalent. Unlike a real visit, the visitor is not sharing space and views with other users, and can see the work down to the smallest details, thanks to the high definition of the digital photos. This experience is similar to the real one, and has become increasingly popular due to the pandemic and the

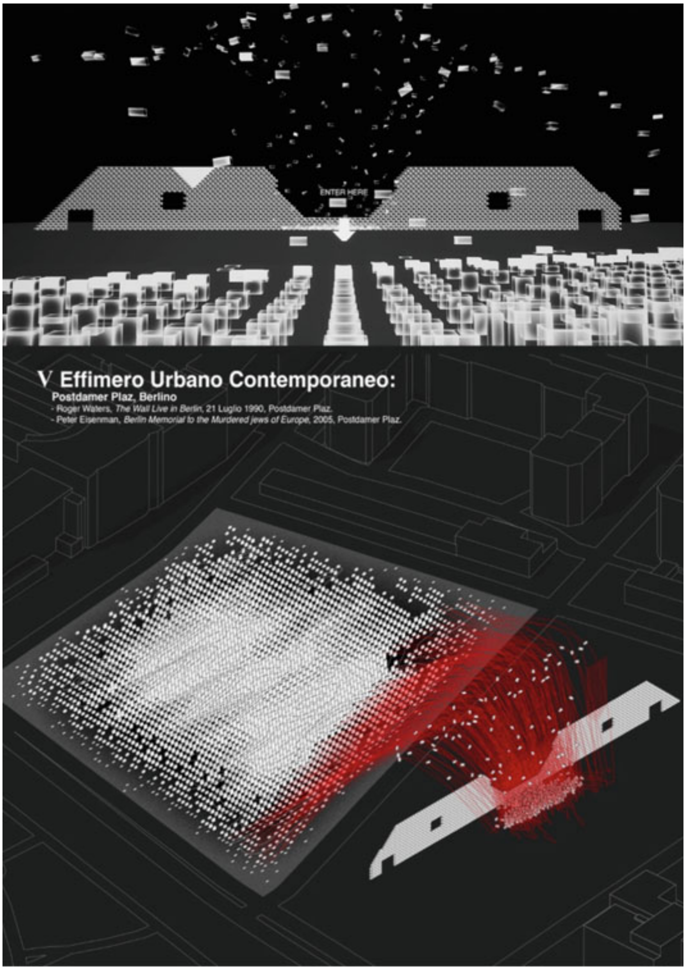

Fig. 7 Room V of VM5, Contemporary Urban Ephemeral, Postdammer Plaz, Berlin, 1990–2005: Roger Waters, The Wall Live in Berlin, 21 July 1990, Postdamer Plaz; Peter Eisenman, Berlin Memorial to the Murdered Jews of Europe, Postdamer Plaz, 2005. Five-year degree thesis workshop in Architecture: graduating student F. Zollo; thesis supervisor Prof. M. Unali, co-supervisor G. Caffio, Department of Architecture, University "G. d'Annunzio" of Chieti-Pescara

inability of people to travel to places of artistic preservation and dissemination. An interesting example of this type of VM can be found on the website of the Dalí Theatre-Museum [6], which features an interactive 3D visualization of its rooms on the Matterport platform.

(C) The last case, which is perhaps the most interesting due to the direct and synergistic relationship created between digital artworks and their hosting medium, is represented by the VM as a virtual space in its own right. This is an autonomous but virtual architectural organism that has no concrete counterpart that can be experienced physically. These are all the experiments that arise within the digital space of shared networks, immersive environments that exploit the narrative and experiential potential of multi-user virtual worlds to host and enjoy works born and conceived to be immaterial and made by sequences of bits. An interesting example of this type of VM can be the Metaverse Arts Museum created on The Sandbox platform [7].

Given the vastness, diversity, and complexity of the Virtual Museum's potential history—with its numerous semantic, disciplinary, and techno-cultural references to the broader evolution of the concept of virtual living—we can only highlight two projects in this particular context. Though they represent only a small fraction of the metaverse's history, these works have contributed significantly to the Virtual Museum's development as a digital exhibition space through their technological, semantic, and representational innovations.

The *Virtual Guggenheim Museum* is an appropriate starting point for our study. The Guggenheim Museum Foundation commissioned this project from Asymptote Architecture, a New York studio led by Lisa Anne Couture and Hani Rashid [8]. In 1997, the Guggenheim Museum launched a major initiative funded by the Bohen Foundation [9] to commission, acquire, and exhibit works of emerging digital art. Net-art, a new and interesting branch of art designed to be exclusively digital at the time [10], stimulated major institutions in the art world to question themselves on how to exhibit and enjoy new works and how to be present and recognizable in the increasingly crowded web space. The *Virtual Guggenheim* was the first project of a major US museum in the direction of virtual space. It was intended to complement the Guggenheim's other museum spaces, including Frank Lloyd Wright's iconic building in New York, the Bilbao construction designed by Frank Gehry, as well as the Berlin and Venice venues.

The Virtual Museum directly confronts architectural venues that represent landmarks of modern and contemporary architecture. As an established presence within a world-class museum offering, it aimed to expand its scope by experimenting with new digital frontiers. The stated ambition was to create the first fully functional virtual museum dedicated to the exhibition and presentation of Net-Art and to provide an online digital archive for all other forms of new media art. The two commissioned designers imagined a fluid, three-dimensional virtual space whose characteristic spiral shape seems to be inspired by Wright's architecture. The large vortex that rises upwards to form an enveloping and dynamic hollow space seems to become a malleable band, a Moebius strip that stretches to connect bloblike and transparent semantic spaces, each specialized to house digital artworks. The thematic areas are named Artscape, Azone, Mediasphere, Virtual Architecture, and GVM Archive. Rendered through luminescent colored ribbons and isocurves, like those describing NURBS surfaces in three-dimensional modeling, they characterize the sections that are to house the unprecedented works. In other images presented as renderings, the museum's galleries appear as the result of the interweaving of meandering forms, opaque flexuous structures that intertwine with transparent fluid blobs within which, like synthetic amniotic sacs, float spheres that allude to interactive works and performances, visitors, and artists' avatars. The entrance space to the virtual museum consists of a ramp that starts from a white podium and wraps around itself, leaving a central void (perhaps reminiscent of the wraparound atrium of the New York building), while a red mesh forms the backdrop. According to Hani Rashid, We set out to design a fully interactive computer-generated environment that would enable new ways of disseminating and providing access to complex, data-rich environments [11]. This project, though it remained in the embryonic form of a prototype, represented a fundamental moment in the culture of digital architecture. It had the ability to foreshadow forms, functions, and technologies that were not yet as widespread at the time as they are today, such as Virtual and Augmented Reality systems, parametric design, and the use of Artificial Intelligence. It also served as a bridge between the new possibilities offered by digital networks and the tradition of utopian and radical architecture.

Looking ahead 20 years, we see the Asymptote vision of digital space [12, 13] taking on various forms in today's metaverse. Mark Zuckerberg defines the metaverse as a virtual world in which the lines between the real and virtual blend together [14]. The metaverse requires a complex system of technologies: a connected network, extended reality (XR), and financial systems based on cryptocurrencies and NFTs. The emergence of cryptocurrency and NFTs is crucial for the metaverse's future because they support a transparent economy free from centralized authorization. NFTs are spreading across various industries, including architecture and design. The purchase of the digital artwork *Everydays: The First 5000 Days* by Beeple for $69 million, the first digital work sold for this amount [15], has led to the creation of digital environments tailored to NFTs. In 2021, Zaha Hadid Architects designed *NFTism*, a virtual gallery exploring new forms of cultural processing and fruition associated with digital art and virtual art museums [16]. The gallery was commissioned by the German gallery Nagel Draxel [17] and features artist Kenny Schacter [18] as curator. For the virtual spaces of NFTims, it was developed a Software as a Service (SaaS) based on proprietary MMO (Massively Multiplayer Online game) technology, integrated with audio–video interaction capabilities, and provided network and cloud-hosting services. The project applies the well-known parametric procedures used in Zaha Hadid Architects' projects around the world, hybridizing them with the needs of a virtual public that interacts with the simulated space and perceives the exhibited works through a variety of electronic devices such as VR visors, desktop computers, tablets, or a LED Wall installed at the Miami fair during the days of the exhibition. The team behind the project includes Cesar Fragachan, Vishu Bhooshan, Henry David Louth, Shajay Bhooshan, and Patrik Schumacher. In a 2021 interview [19], Patrick Schumacher outlined the objectives of a virtual architecture designer. He noted the importance of traditional architecture and the semiological profile that is linked to design questions, such as the type of space, event, and context. A virtual environment is purely phenomenological and sign design, requiring architects to focus on organization, connection, and cognition. Social meaning and protocols are important considerations, rather than the physical and technical constraints of building. Ultimately, architects must create meaningful cyber-spaces that enhance the end-user's experience, which requires eloquent, readable, and information-rich environments. For the architect, both real and digital architecture share the same goal of guiding users to perform tasks using a particular set of protocols and signs, whether physical or immaterial, which are clear, intelligible, and simple. This vision closely relates architectural design to the design of digital interfaces, where the UX/UI (user experience/user interface) binomial is fundamental. The exhibition space consists of two communicating spaces of different shapes and colors in the parametric style typical of the Hadid studio. One space features sinuous green surfaces hosting rectangular sunken blocks that display videos by the artists in the exhibition (including Schacter, Kevin Abosch, Olive Allen, Sarah Friend, Rhea Myers, Kenny Schachter, and Theo Triantafyllidis). The other two spaces, with a circular layout, have surfaces that function as wraparound video walls displaying videos and three-dimensional images.

The gallery also showcases several objects defined as hybrid furniture-sculptures, previously commissioned by Kenny Schachter to Zaha Hadid. These include the Z-boat, the Z-Car One, the Belu bench, and the Orchis stool. Although only visible during the art fair in Miami, the digital space of *NFTism* represents an interesting starting point for the synergy between digital architecture and NFT, whose future implications are yet to be discovered.

3 The VM Project of Ephemeral Architecture, Between Research and Teaching

As part of a broader study on the conformation of Virtual Living [20] which, between research and teaching, has long involved a number of professors from the Department of Architecture of the University G. d'Annunzio of Chieti-Pescara, we present the latest results of an experiment (still in progress) on the interdisciplinary theme of the Virtual Museum in architecture and design (Fig. 1).

In particular, we would like to reflect on the workflow adopted and the semantic models elaborated for the realisation of a prototypical *Virtual Museum for Ephemeral Architecture*—named VM5 (Figs. 3, 4, 5, 6, and 7)—conceived as a post-digital thematic Metaverse [21]; a digital architecture in which to experiment, in the awareness of today's techno-cultural potential—especially in the field of artificial intelligence, VR and AR—habitable spaces in the Web through avatars.

As emerged from the survey of the history of the phenomenon—cf. Chap. 2. The State of the Art Survey: Conceptual Map, Timeline—since its beginnings in the 1980s, the interdisciplinary idea of VM, following the techno-cultural conquests of the times, has explored multiple conformative dimensions of digital space, experimenting with various visualisation systems and different forms of interaction, both in the online and offline dimension. The examples studied and included in the conceptual map created [4] have been many, from the now historical Virtual Museum commissioned by the Guggenheim Foundation in '99 to the Asymptote Architecture studio, to the great theme of digital heritage preservation and exhibition (cf. the 2003 UNESCO Charter for the Preservation of Digital Heritage)—e.g. the exhibition *Archaeology of the Digital*, curated by Greg Lynn in 2013 for the Canadian Centre for Architecture in Montréal—up to the recent proposal of the Virtual Museum *NFTism* by Zaha Hadid Architects, a fascinating adventure of ideas emerges, which above all in representation finds the reasons, metaphors and sense of its being inhabitable space.

In this phase of surveying the state of the art of the VM idea—which is especially fundamental for didactic training—after having studied the main conceptual and visual references, the most significant works were then catalogued and classified, also attempting to highlight the different types of application and use of the realised digital architectures.

As we have already discussed in more detail in the previous chapter, we can remember, with other words, the three different types of VMs.

- The VM as a simple website of the real museum; these are the first forms of digitisation of museum centres.
- The VM as a kind of digital copy of the existing museum, represented above all by means of 360° photographic visualisation (panoramic photos), in a kind of virtual tour of the spaces and works.
- The VM as an autonomous digital architecture, a metaverse that can be explored in network space. This is a structured set of thematic environments designed for the use of digital works; interactive environments created with different media, which aim to present works and objects created and designed for virtual space.

Having thus assimilated the history of the VM in architecture and design, including its main conceptual and visual references, the design contents of the VM5 prototype were then defined, both in compositional terms and with respect to the type of hypothesised user experience. With respect to the prevailing types of VM previously noted, we decided to experiment with the third form, namely the design of an architecture explorable in FPV (First Person View).

The choice of the VM's exhibition theme is ephemeral architecture [22], temporary works that require posthumous representation-documentation projects in order to be historicised; immaterial representations that reconstruct the events, rearranging the sense of the ephemeral work, from the spatial–temporal forms set up to the performative actions.

Thus, five semantic models were designed for the VM5 project of ephemeral architecture, each corresponding to what we can call an 'exhibition hall'.

In Room I (Fig. 3), examples of Historic Ephemeral were represented: from Andrea Pozzo's Teatro Sacro (1695) to Giovanni Battista Piranesi's Carceri d'Invenzione (Table VII, 1745).

In Room II (Fig. 4), some historical examples of 1960s Light Shows were represented: Thomas Wilfred, Lumia Suite, Op. 158, 1963; Mark Boyle and Joan Hills, Son et Lumière for Earth, Air, Fire and Water, 1966; The Joshua Light Show, Liquid Loops, 1967; Pink Floyd, 14-h Technicolor Dreem, Alexandra Palace, London 1967.

In Room III (Fig. 5), The EPI Model was reconstructed: Andy Warhol, Velvet Underground and Nico, Exploding Plastic Inevitable, 1966.

In Room IV (Fig. 6) an example of Postmodern Ephemeral was simulated: Al-do Rossi, Il Teatro Del Mondo, Venice 1979.

Finally, in room V (Fig. 7) an example of a Contemporary Urban Ephemeral was simulated: Roger Waters, The Wall Live in Berlin, 21 July 1990, Postdamer Plaz; Peter Eisenman, Berlin Memorial to the Murdered jews of Europe, Postdamer Plaz, 2005.

Finally, as we will discuss in more detail in the last chapter of the essay—see Chap. 4. The workflow to realise the VM5 prototype—we proceeded to define the workflow to realise the project, defining simulation methods and techniques, and verifying the feasibility of the work in digital space.

In conclusion, at the end of this research path, designs emerged that enable new transitions of meaning on the VM theme.

Digital architectures continually fed by cultural hybridisations and aesthetic recycling, which find in the representation a profitable laboratory of experimentation to historicise the forms of ephemeral architecture, translating them into new spaces that can be inhabited virtually, even in the dimension of the metaverse, in which the divide between analogue and digital (between real and virtual) is reduced.

By also highlighting some possible research developments, we can hypothesise a new design experimentation where we can develop more immediate simulation methods and techniques that are more characterised by the recent potential of artificial intelligences.

4 The Processing of the Workflow to Realise the VM5 Prototype

After analysing the complex characteristics of architectural design in digital space—primarily in relation to the awareness of the different physicality of the project's space of action—we try to summarise the working method used here.

In this phase, we proceeded to define the methods and techniques for setting up the project (workflow), verifying the feasibility of realising immersive environments, navigable in real time in digital space.

In particular, the main phases of the set-up, script and elaboration of the VM5 project can be summarised as follows:

- Realisation of the 3D digital models of the works exhibited in the VM5.
- Digitisation of the virtual museum space and its import into the real-time 3D creation tool software (Unreal Engine).
- Importing of the digital models into the Twin Motion real-time visualisation software and exporting of the 360° panoramic photos, usable through web pages retrieved by QR code.
- Editing and post-production, from video editing to the use of sound (sound design) and special effects.

- Programming of interactions between actor (or avatar) and objects through technology level blueprints.
- Finalisation and testing of the final project.

The first phase of the work was mainly developed using 3ds Max, Autodesk's modelling, animation and rendering software. The majority of the polygonal modelling elements within VM5 were processed and produced on this programme.

Subsequently, all models were mapped using the UVW map and UVW unwrap modifiers, generating the relevant channels for mapping and subsequent texture insertion. Again in 3ds Max, the animations were processed (timeline activation), using in particular the internal 3ds Max plugin Massfx for simulating the gravity of objects.

Once the modelling was finished with the relevant mappings, we moved on to the positioning and modification of the pivots (local axes) on each element of the various models. This part of the initial process is very important, as incorrect positioning of the pivot will not allow easy movement/rotation of the elements in subsequent work steps. In this case, it is necessary to select the pivot and centre it on the object and reset XForm (Transformation) to align the spatial coordinates with the universal coordinate system.

Regarding the export of the various models, we have two distinct modes. We proceed with the export of static models in Fbx format, trying to keep the amount of polygons for each object unchanged and exporting them separately from each other. In a second step, the dynamic models are exported, in Alembic format, which will maintain the temporality of the movement in three-dimensional space; in this export mode, a reduction in the number of polygons (low poly) is recommended.

Let us now move on to the next phase of the work, carried out within the real-time render and game development software; Epic games' Unreal Engine.

First, a basic World Level was created, where all three-dimensional models were imported in Fbx and Alembic format. The models were subsequently textualised, and in some cases animated video-textures were created.

Once the various models were inserted, the goal was to make the VM5 visitable. This is where the Collisions Complexity comes into play, which allows, when entering the VM5, to cross or not cross certain geometries.

At the same time as the work on the Unreal Engine, certain spaces were experimented with in Twinmotion, a real-time rendering software (also developed by Epic Games), especially for architectural visualisation.

This experimentation was done in order to realise panoramic images of certain works within VM5, which are subsequently uploaded to a 360° visualisation platform and then inserted into Unreal Engine via links.

Now let's delve into what is defined as the editing and post-production phase of the visual parts to be inserted into VM5, here in fact the graphic and audio/video components realised for the project come into play.

Textures and images were processed in Adobe Photoshop and then exported in PNG format without background. The audio/video components, on the other hand, were designed and processed in Adobe Premiere Pro. After a process of image construction and composition, video and audio editing, the export in mp4 format takes place. All this will then become textures/videos, environmental audio and images in succession that will characterise certain exhibition spaces through various software processing (Adobe Premiere Pro).

Once all the necessary components for the realisation of VM5 have been imported into Unreal Engine, the programming part of the museum events takes place. This process is carried out via a code writing language (converted into a graphic visualisation) called 'level blueprint'. On this interface, all interactions between actor (avatar) and exhibition space are written and linked. Through the insertion of Trigger Boxes (volumes of interest) located within the model, it is possible to trigger these events and interactions with the surrounding virtual space; the passage of the avatar in these areas triggers all interactions (event begin overlapping).

The last phase of experimentation is dedicated to the finalisation and testing of the various components of VM5. During this process, it is verified that all interactions and collisions are in synchrony with the actor (avatar), paying particular attention to the three-dimensional physical components, animations, audio/video components and lighting. In the light of the experimentation carried out and with respect to the recent innovations offered above all by artificial intelligence software, it seems necessary to update the workflow described here and to discover further potentialities of architectural design in digital space.

5 Conclusions

At the end of this phase of research on the general theme of VM in architecture and design, which is the result of a broader study program on Virtual Living, the experimentation provided many data and interesting critical insights that we can refer to two foundational themes, which are closely related to each other: methods and techniques of representation and shaping of spaces, and the design of immersive thematic environments for digital living.

The first topic, which is often noted, belongs to the techno-cultural order and is part of the history of the science of representation. Specifically, it concerns the evolution of systems of visualization, simulation, shaping and interaction of a space inhabited through avatars, and immersive environments capable of broadening the idea of the Museum. In this dimension of design, the complex relationships between representation and techno-culture of one's time are also expanded, as well as a mirror of the different socio-political contexts of reference; an interdisciplinary thesaurus of knowledge that can also become a valuable shaping medium for the project.

Thus, the main foundational themes of the second topic emerge, which is the representation project of digital space. This topic is fueled by the creative role of the VM project, which is designed here, in particular, to elaborate the poetics of the ephemeral in architecture. This is a complex aspect that is always approached in continuity with the historical immaterial, virtual, ideal, utopian, and radical design of architecture.

This project, which is between research and teaching, is still open. In the current post-digital context, we hope to propose it as an active proposal to set up shared spaces to inhabit in the network.

Acknowledgements Section 2. The State of the Art Survey: Conceptual Map, Timeline—was elaborated by Giovanni Caffio; Sect. 3. The VM Project of Ephemeral Architecture, Between Research and Teaching—was elaborated by Maurizio Unali; Sect. 4. The Processing of the Workflow to Realise the VM5 Prototype, was written by Fabio Zollo.

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Salvatio Memoriae. Studies for the Virtual Reconstruction of the Medieval Sculptural Heritage

Greta Attademo

1 Introduction

This paper aims to show analysis and results of a study based on the use of ICT as a tool capable of expanding the horizons of medieval art history. The research, specifically, focuses on the phenomenon of the reuse of medieval sculpture in the Modern Age (fifteenth–eighteenth centuries), being part of the more general project Memory and Identity. The reuse, reworking and repurposing of Medieval sculpture in the Modern Age from historical research to new technology (MemId) [1].

This project, funded by a two-year research grant from the Ministry of University and Research (FISR, duration 2021–2023), enabled three research units, led respectively by Clario Di Fabio (University of Genoa), Laura Cavazzini (University of Trento) and Paola Vitolo (University of Naples Federico II), to undertake an innovative program of in-depth study on the topic in question. In fact, the phenomena of reuse of medieval sculptural pieces is investigated through the selection of specific case studies located in Italy, analyzed by a multidisciplinary group of young researchers, such as art historians, restorers, draftsmen, architects and paleographers.

The heterogeneity of the research team is necessary to the project purposes: on the one hand to recreate the contexts in which decorative and liturgical components were placed, and on the other hand to trace the motivations and processes that, over many centuries, influenced communities' approach to material heritage of the medieval period [1]. Indeed, there are still few studies on medieval sculptural sets that, as early as the Modern Age, were subject to architectural reorganizations, decorative modifications and functional rearrangements aimed at the appropriation of past values, the acquisition of new meanings and functions, or the generation of new aesthetics [2]. It is precisely representativeness and adaptability that have made sculpture a

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useful tool for the reuse and reinforcement of social, political, religious and cultural messages throughout history. The ways in which these sculptural pieces have been approached, although they have brought losses of parts, changes in location, use and meaning [2] have been accepted by art historians almost as a necessary evil that has allowed their preservation to the present day.

Aware that “the world’s cultural heritage has always been subject to conflict, natural disasters and human negligence, so it is absolutely necessary to document its values,” [3] it is interesting to understand the role that new technologies and strategies of representation can play in this area. Tracing the temporal life of the sculptural work means, in fact, understanding how society has processed its past and the ways in which we give meaning to the contexts we experience today [2]. The drawing, in fact, by hinging expressive meanings in a visual system of signs, has always constituted an immediate and universal code placed at the basis of the whole humanity’s way of communicating, proving capable of “bridging that distance between what is perceived and the underlying meanings” [4].

The purpose of the research, then, is to understand how technical and technological advances in the field of representation can be used to reformulate the complex relationship between the community, both expert and non-expert, and medieval heritage. The question is, in fact, how to activate new cognitive processes [5] of knowledge of medieval sculptural reuse based on active and interactive experiences, mediated by the potential offered by technological innovations [6], and how to redefine its ways of perception and enjoyment, contributing, thus, “to the preservation of the cultural identity of places, the dissemination of culture and the production of new cultural offerings” [7].

2 The Case Study

In order to identify the role that new technologies and representational strategies can play in this area of research, we present a case study of the MemId project, the Fieschi mausoleum: this is a funerary monument, currently completely fragmented, designed to hold the remains of Cardinal Luca Fieschi, a member of the Guelph lineage of the Counts of Lavagna, a prestigious family of Genoa [8]. Luca Fieschi was, in fact, a prominent figure in Genoese history, both because of his lineage—he was grandson of Adrian V and great-grandson of Innocent IV—and his role as a benefactor, politician, diplomat and scholar [8].

Constructed between 1330 and 1340, the monumental tomb, whose original conformation is still the subject of research and debate among scholars [9], is an important testimony to medieval Genoa both historically and artistically. It represents, in fact, one of the oldest examples of Italian Gothic, in which architectural structure and plastic decoration complement each other in an elaborate and complex construction that has its focus in the sculptural figure of the lying cardinal. Moreover, it was the first private funeral monument to be erected inside the Cathedral of San

Lorenzo, a privilege granted by virtue of the character's dynasty and indicative of a clear assertion of power that the Fieschi lineage had until the sixteenth century [10].

However, following the political decline of the Fieschi family, the monument underwent numerous relocations and rearrangements [11]: first it was disassembled and moved inside the cathedral itself and to adjacent outdoor spaces; then, in the mid-seventeenth century, it was reduced by choosing only a few figurative pieces that, reworked, were reassembled in the lunette of the Door dedicated to Nostra Signora del Soccorso [10]; other pieces were relocated elsewhere and were reunited with the spirit of enhancing them only in the '900 s.

The monument, today, appears as a puzzle of 124 sculptural remains of different consistencies piled up in the underground deposits of the Diocesan Museum of Genoa [12]. A circumscribed number of elements, whose precise location in the tomb context has been established, are being rearranged in the museum's crypts, thanks to work coordinated by director Paola Martini with architect Giovanni Tortelli and art historian Clario Di Fabio. The rearrangement will make it possible to restore, at least in part, one of the city's major Gothic symbols, evoking the majesty of the artwork through the recomposition and rearrangement of some of its most significant elements. On the other hand, the pieces will be incorporated into a new architectural structure, which operationally consists of an eight-meter wall, a double-height floor slab, and a gallery, necessary for museum use; this intervention will, inevitably, lead to a reduction in the possibilities for scientific studies, configurational testing, and comparative analysis among the fragments. The main topic, therefore, is to use the new technological instrumentation and advanced techniques of representation for the purpose of minimizing the risks of museum refitting.

3 Digital Twins

The rearrangement of the Fieschi Monument inside the crypt of the Diocesan Museum of Genoa involves the assembly and recomposition of some sculptural fragments within a new eight-meter-high wall, with the purpose of allowing the viewer to perceive the real dimensions of the 14th-century funerary monument and thus evoke the full majesty of the sculptural artifact. As previously noted, however, the reconstruction of the monument is not integral, both because its original features are not known precisely today, and also because the monument survives to us in an extremely fragmented manner, due to the continuous alterations that have taken place over the centuries. In addition, the sculptural pieces belonging to the Fieschi Tomb have had multiple lifetimes, which appear equally indispensable for understanding the complex and articulated meaning of the plastic artwork and the features of the single fragments.

In the research project, therefore, it was decided to start from the sculptural pieces that will be remounted in the Diocesan Museum and build a catalog of digital twins [13]. The building of a library of digital copies (Fig. 1) will allow scholars a continuity of investigation of both the single sculptures that will be embedded in the new

Fig. 1 The sixteen pieces of the Fieschi Tomb selected for the construction of a catalog of digital twins. The sculptural pieces were surveyed, 3D modeled, and represented in scale (Drawing and modeling: G. Attademo)

arrangement and their mutual relationship in the different decorative configurations that have followed one another over time.

In order to determine the most appropriate methodological approach, a preliminary site survey was carried out that highlighted the critical issues of the working environment and of the sculptural remains. In fact, the crypt is an extremely dark space in which a large number of sculptural pieces are piled up, hindering free movement, given also the weight, size and fragility of specific artifacts that cannot be moved manually. We should also consider that the upcoming rearrangement imposes tight deadlines to take action on the sculptures' digitization.

The method of digital photogrammetry seemed, therefore, to be the quickest for the acquisition of the survey, ensuring, moreover, that this would take place without direct contact with the objects. Another advantage of digital photogrammetry is the low cost of equipment. A limited area of the crypt was cleared for the purpose of building a small photo studio through four muslin panels with neutral backgrounds and LED spotlights with softboxes for light diffusion and stabilization. The set concurrently allowed the preparation for the rearrangement work and the shooting operation with the exclusive use of a Nikon D5200 SLR camera and an AF-P DX NIKKOR 18-55 mm VR wide-angle zoom lens. In addition, close-range photogrammetry ensures excellent accuracy in detecting each object [14], which is captured with convergent or parallel axes according to its shape and geometry. In fact, the photographic shots were taken in succession with both camera systems, each time choosing the most appropriate strategy depending on the specifics of the sculptural fragment (Fig. 2). A converging axis camera system was used for most of the pieces, creating a circular photographic path around each sculpture.

Photographs were taken at different heights and from different vantage points to allow each individual point of the sculpture to be captured. Parallel-axis acquisition,

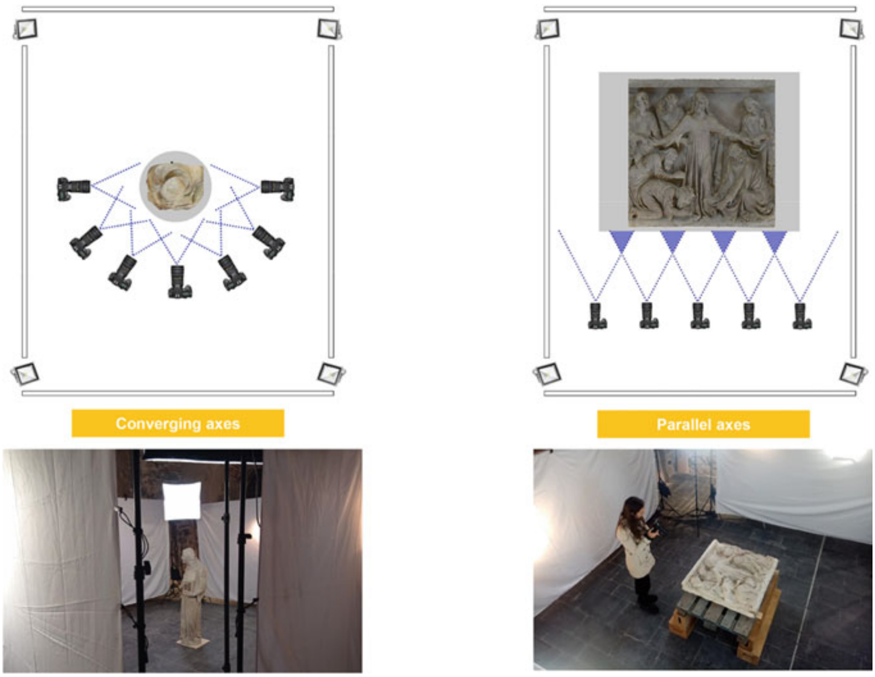

Fig. 2 The acquisition phase of the photographs for the digital photogrammetric survey was conducted using a convergent-axis and/or parallel-axis camera system, depending on the characteristics of the sculptural fragment (Drawing and photos: G. Attademo)

on the other hand, served as a supplement to the previous one for those pieces that, due to their size and fragility, could not self-support themselves in height, as in the case of the two Curtain-holding Angels, which most likely constitute the largest angelic statues in the history of funerary monuments [15].

Photos were taken at a resolution of 6000 $\times$ 4000 pixels, ensuring no less than 80% of overlap between one photo and the subsequent in both horizontal and vertical directions. The aperture value of the camera selected as a fixed parameter is f/8, because this value allows to widen the area in focus and have a greater depth of field in the image. The working space permitted to take photos from a maximum distance of 1.50 m to a minimum distance of 0.50 m from each sculptural piece. Therefore, we obtained very accurate surveys, with an average GSD parameter of 1.5 mm/pixel.

During the shooting acquisition phase, great attention was paid to lighting conditions and their effects on colorimetric data and shadow areas. The sculptural fragments were, in fact, surveyed individually, so as to avoid obstruction or the production of additional shadows, given the already poor lighting conditions of the working environment. The temperature of the lights was appropriately varied for the purpose of not affecting the realism of the sculptures' colorimetric data.

The photos were taken in RAW format so that a Color Checker could be used. This was photographed in the same location as the sculptural fragments, then proceeding in post-production to color calibration and white balance, as well as the elimination of unwanted elements and shadows. Data restitution was done according to established digital photogrammetry practices; through the Metashape software, the computational technique known as Structure From Motion [16] was used. SfM allows to automate the processes of three-dimensional model reconstruction through automatic collimation of points from the set of photos (Fig. 3). The key points were then triangulated to derive the spatial coordinates, materialized into a point cloud, which was subsequently densified to reconstruct the high-quality mesh surface. The modeling work was then concluded with texture mapping from the mosaicing of the survey images (Fig. 4).

In order to improve the texture quality, we chose to exclude images with a quality value less than 0.5 units, which is automatically calculated by the software based on the sharpness level of the most in-focus part of each single photo.

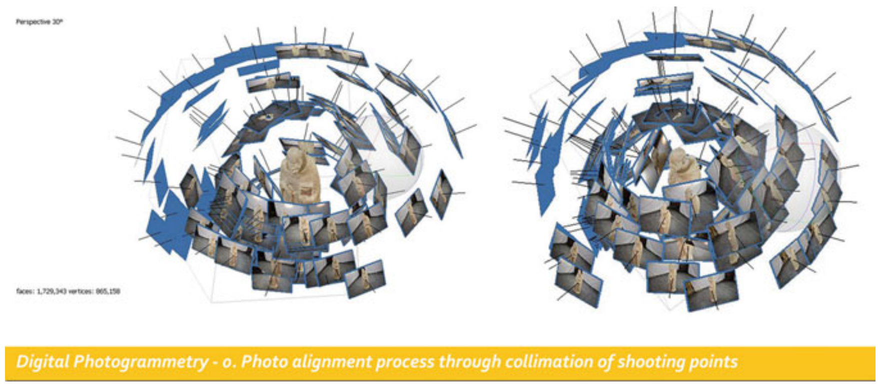

Fig. 3 Digital Photogrammetry using Metashape software. The photo alignment process is done through automatic collimation of shooting points (Image: G. Attademo)

Fig. 4 Digital Photogrammetry using Metashape software. The steps in the automatic 3D modeling process (Image: G. Attademo)

Digital twins, in addition to providing a comparative dimensional and metric overview of single fragments, constitute interpretive models of reality; interactive navigation and virtual manipulation allow to identify compositional rules, to define geometric laws and to perceive details of the object. In fact, the possibility of rotating, translating and orienting the sculptures allows, also, to establish possible sequences and compositional hierarchies among the parts, becoming the basis through which to conduct historical-philological hypotheses on the uses, functions and scenarios related to the artefact in the past time.

Through the support of bibliographical [10] and iconographical [17] sources, we have in fact worked on the virtual reconstruction of the sculptural pieces that were relocated in the Porta del Soccorso of the Cathedral of San Lorenzo in the mid-seventeenth century (Fig. 5). The digital modeling operations in the 3D environment enable the analysis of the relationships between the figured sculptural fragments and implement the search for the actual configuration of the entire composition.

Existing two-dimensional drawings of the remains of the Fieschi monument reused in 1526 in the Porta del Soccorso [17] show the lunette exclusively through frontal views. These images, although they allowed, in the past, to carry out some compositional verifies, such as the dimensional correspondence between the three frontal slabs on which is depicted the Verifica delle piaghe di Cristo da parte di san Tommaso alla presenza del collegio apostolico, have not allowed the analysis of the

Fig. 5 Virtual reconstruction of the Porta del Soccorso (Cathedral of San Lorenzo) where sculptural pieces were relocated in the mid-seventeenth century (Modeling: G. Attademo)

Fig. 6 Reconstructive hypothesis about the positioning of the sarcophagus slabs in relation to the lion statues. Perspective views (Modeling and image: G. Attademo)

three-dimensional aspects of the piece, such as, for example, the effective position of the slabs in relation to the lion sculptures.

As shown in Fig. 6, the slabs could rest on the lions, fitting between their posterior base and the mane; the position of the lions is obligated and, therefore, it constitutes the limit along the y-axis beyond which the slabs could not slide without generating conflicts with the other sculptural pieces.

The operations in the virtual environment also make it possible to reconstruct the architectural elements that no longer exist and that completed the seventeenth-century scenery, ensuring an overall reading of the work and a possibility for further verification. For example, in the drawing of the Porta del Soccorso made by Giuseppe Frascheri [17], the curtain-holding Angels are represented complete in the upper corner of the wings, although this has come down to us cut off. From the tests conducted in the digital environment (Fig. 7), the curvature of the wings of the angels seems to correspond to that of the circumference arch that overhung the width of the lunette in the Porta del Soccorso; it is plausible, therefore, that these sculptural portions were cut off precisely during the setting up of the angels in the door, in order to ensure their inclusion in the new architectural structure. This hypothesis is supported by the written source: as Di Fabio [10] notes, in fact, a large part of the pieces was reworked to obtain a symmetrical and orderly composition, allowing the pieces to fit together and be reassembled on a flat surface.

Another point of interest concerns the placement of the sculpture depicting Luca Fieschi. In some drawings, such as the one by Giuseppe Frascheri [17], the cardinal is in fact represented orthogonal to the plane of the Porta del Soccorso; in other cases, the cardinal is disposed vertically such as in the drawings by Venceslao Borzani [18] and

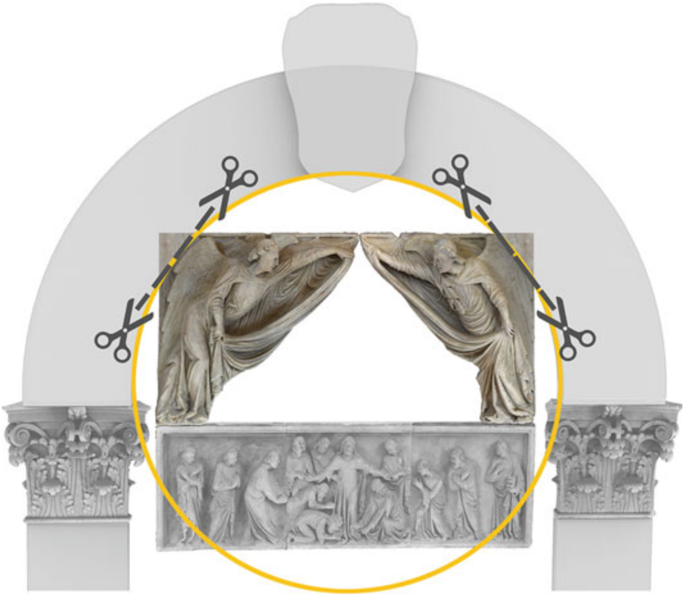

Fig. 7 Reconstructive hypothesis regarding the composition of the angels in the Porta del Soccorso (Modeling and image: G. Attademo)

by Marco Aurelio Crotta [11]. Assuming the plausibility, from an art-historical point of view, of both solutions, tests were carried out in a virtual environment regarding the placement of the statue. The horizontal position of the Cardinal statue seems credible because it does not generate points of conflict with the nearby sculptures of angels, located on the ends of the slabs. The vertical position of the statue, on the other hand, was discarded because the sculptures would have intersected with each other (Fig. 8). Thus, it may be possible that the images showing the Giacente in an upright position were intended in a logic of graphic representation, allowing both sides of the Cardinal's face to be shown, otherwise not visible from other positions.

4 Augment Fruition of Digital Twins

The aim of the research is not only to recreate the contexts in which medieval decorative elements were reused, but also to enable the understanding of their meaning to the wider community by tracing the motivations that led to this process, which can be as much about practicality as it is about the reiteration of specific cultural, political or religious messages. The valorization of a cultural good, in fact, acquires meaning only if the "invisible mass of information that each object conveys in itself beyond the mere material dimension" [19] is made available to humanity and, therefore, if

Fig. 8 Reconstructive hypothesis regarding the statue of Cardinal Luca Fieschi. The vertical position is discarded because it produces points of conflict points (Modeling and image: G. Attademo)

their history is transmitted through "a cultural and communicative action that takes place within a community that recognizes itself in a system of values" [20].

Today, the ability of cultural heritage to "arouse emotions, establish connections, awaken curiosity" [21] can only become effective by considering that contemporary cultural users have completely changed and made up of both digital immigrants and digital natives [22]. They, having different expectations, pre-existing knowledge, historical/cultural backgrounds and interpretative strategies, need diversified communicative modes in order to be able to perceive the historical and social traces embedded in the cultural heritage itself, which, otherwise, would risk "remaining mute in the absence of individuals capable of perceiving and interpreting them" [23].

The most profound change of our era, in fact, while basing itself on technological innovations, can be found above all in the structural transformation of communication processes through increasingly playful, dynamic and interactive approaches. The museum system, in particular, is among cultural institutions the one that today, from the aspect of communication, is trying the most to innovate and actualize its way of narrating the artwork, collections, and exhibitions it hosts [24]. The contemporary user, in fact, is increasingly enabled to participate in the visiting process, because this modality of fruition follows the interactive and experiential communicative models to which he is continually exposed through today's media and technologies.

These are models that foster a totalizing immersion in the world of cultural heritage and that leave behind the linear and circular transmissive line typical of the last century [25]. In fact, visitors require not only to choose according to their own interests and through varied levels of insight, but also to have experiences stimulated by factors such as curiosity, discovery, interaction and sharing.

In light of these considerations, we decide, for the research project, to include digital twins in specific augmented reality narratives that will allow to combine the necessity of scientific studies with the requirements of fruition and communication to a non-expert audience. Augmented reality can, in fact, become a tool capable of modifying the relationship between the museum and its users, making it fuller, more interactive and engaging, with positive repercussions on the very motivations of users [26].

Medieval sculptural pieces, especially when they have undergone phenomena of reuse, are not always easily understood by non-expert audiences: they are often time-marked, fragmented and incomplete, or extracted from their original context. Augmented reality, by allowing additional narrative content to be superimposed on the material dimension of sculptural works, can enrich the ways in which the artifact is known, encouraging community understanding and enjoyment [27] and, therefore, the preservation of the historical memory and identity of the artifacts.

We choose to use Artivive [28], a free augmented reality app, by designing video content in which 3D models are accompanied by information about the history of each sculpture and the relative transformations it has undergone over time. Each video and, therefore, each sculptural piece, is associated with a different reference marker, meaning an image that the technological device, smartphone or tablet, will have to recognize in order to activate the virtual content (Fig. 9). In fact, the marker images are printed on postcards that will be placed in the vicinity of the new museum rearrangement. The user only needs to download the free app on his mobile device and frame the postcard, which he chooses from those available, to enjoy the augmented content.

The real world is thus virtually enriched, increasing the user's perception and interaction with the environment and providing information that the user could not directly detect with his senses, without being isolated from the visit. At the same time, the augmented reality experience allows museums to get rid of traditional, cluttered

Fig. 9 Fruition of augmented reality videos through the Artivive app (Image: G. Attademo)

display boards with fixed content, to the benefit of a more engaging and dynamic custome experience [29]. A remarkable feature of heritage enhancement through new digital survey technologies, however, is precisely the virtuality of the model itself and its capacity to adapt to a multiplicity of representative, cognitive and communicative purposes [30]. Today the Porta del Soccorso of St. Lawrence Cathedral not only has no medieval sculptural apparatus that enriched it in the past era, but it is also bricked up and covered with liturgical furniture. The lack of visibility of the material remains contributes, therefore, to the absence of knowledge about the seventeenth-century life of the Fieschi Monument's sculptural pieces. The rearrangement of the marble fragments in the Diocesan Museum of Genoa therefore provides an opportunity to narrate that phase of the monument's life. In this regard, the project includes the placement, near the museum's refitting, of a board emptied of six pieces, on which are printed as many portions of the same QRcode. The QRcode constitutes, in fact, a marker, to which is associated the 3D model of the reconstruction of the Porta del Soccorso (Fig. 10) through the AR studio software [31]. The open source software AR studio allows, in fact, to import 3D models with obj extension and the corresponding jpeg texture.

Once the model is successfully read, the software allows to make some state changes (rotation, translation, scale) and then to associate to it a QRcode with marker function. Then the museum user will insert the pieces with the enigmatic QRcode fragments into the blank board. The user, only after correctly reassembling the QRcode, will be able to activate the AR media player, displaying the 3D model of the Porta del Soccorso whose shape, geometry, texture and position was previously established in the design phase of the augmented content.

In order to achieve truly interactive augmented content, it was necessary to work on the surfaces that make up the three-dimensional model. The polygonal meshes,

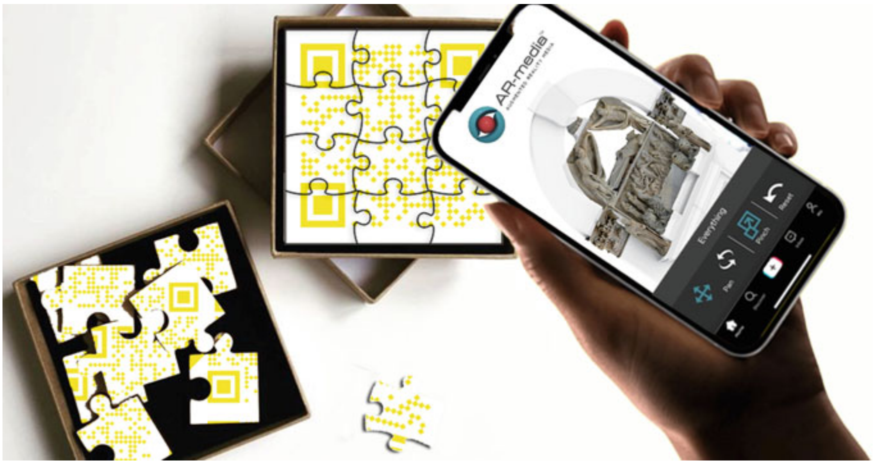

Fig. 10 Example of the QRCode Puzzle linked to augmented reality 3D model of the Porta del Soccorso (Image: G. Attademo)

in fact, were decimated by reducing the number of polygonal faces. The reduction took place with acceptable values that allowed obtaining a less complex 3D model but without excessive loss of visual information; in this way the model, occupying less space, requires shorter time to be visualized and processed in the augmented reality narrative strategy.

The augmented reality puzzle thus allows the visitor an epiphanic vision but also an active and playful role in the construction of the model, activating a process of involvement and eliminating cognitive barriers for those audiences who do not recognize themselves in traditional models of cultural offerings.

The rearrangement of the monument is currently in progress; once this is completed, and thus the architectural space is arranged and the individual statues have a correct and defined position, it will be conceivable to intervene with further playful strategies in Augmented Reality capable of relating the virtual models of the sculptures and the existing physical spaces.

5 Conclusions

The paper aims to show how the use of new technologies and advanced techniques of representation can contribute to the preservation and enhancement of the medieval sculptural heritage that for centuries has been in danger of suffering a *damnatio memoriae*.

The digital twins' catalog becomes a documentation tool for the scientific community, which can access continuously editable and implementable data, use the models to hypothesize scenarios or validate theses, and ideally restore some past configurations. The three-dimensional models can be processed in a common database that other researchers in the MemId project are building [1], with the possibility of combining virtual volumetric models with metric, historical information and descriptions of the sculptural pieces. Digital twins become, moreover, an active and dynamic entity in the knowledge of the medieval sculptural heritage also for the more general public.

Differentiated cultural services are provided for museum users through AR narrative strategies, making their fruition experience more engaging and playful, and responding to those purposes prefixed by Ministry of Cultural Heritage and Activities for Italian museums to "formulate contents and modes of communication that, integrating different languages, are effective because they are simple and clear, without losing scientific rigor and adequacy" [32]. Thus, the topic is a re-signification of cultural heritage through the possibility of inventing new forms of knowledge and enjoyment that can lead people to look at medieval heritage as a starting point for the preservation of a city's historical memory and for understanding the collective identity of a people.

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Unquiet Postures. Augmented Reality in the Exhibition Spaces of Sculptural Bodies

Massimiliano Ciammaichella, Gabriella Liva, and Marco Rinelli

1 Introduction

The ever-increasing digital technology's introduction for the fruition of artistic and cultural heritage, in institutional environments, fosters its learning processes where the very definition of a museum today has been reformulated according to considerations made by the ICOM Extraordinary General Assembly held in Prague in 2022.

From being a place that conducts research and offers a non-profit service to society—in collecting, preserving, and exhibiting tangible and intangible assets—the museum's focus has been on issues of accessibility and sustainability, with an inclusive perspective that promotes diversity and encourages participatory processes of knowledge sharing, by the communities involved [1].

Forms interaction, therefore, expands, and direct subjective observation of the works is accompanied by input and output devices and graphical interfaces that can amplify their informational potential, fostering collaborative practices that emulate the relational dynamics typical of 3D video games.

In fact, this entertainment market sector is the one that offers the most solutions in investing in virtual, augmented, and mixed reality environments suitable for thinning the degrees of perceptual separation between the existing and imaginary. Thus, the scientific contents of the artifacts on display are reworked, in forms of digital

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storytelling in step with today's needs of the heterogeneous visitor, to facilitate the multiple benefit of a choral collective understanding [2].

The democratization principle of open access to knowledge reworks the social and interpretive paradigms of the individualities to be called in question: no longer elitist presences nor passive spectators, but rather active users to whom mere work contemplation is the result of a posture entirely superseded by direct and interacting involvement.

But this condition requires a certain skill in mediating individual cognitive horizons, to be customized according to the interests and expectations supported by teaching methodologies that are mixed with the entertainment logics, so much so that the two components merge into the very concept of edutainment [3].

Learning, interacting, amazing, participating and performing become the key words of a collective actor experience, however much the technologies to be employed will never be the only protagonists to decree the success of a museum—because their rapid rate of obsolescence, cost and eventual replacement are not sufficient to justify them –, as much as, if anything, the communicative strategies designed to adopt them according to a precise direction [4].

In accepting this perspective, digitization processes capture people's interest both in the presence and absence of the work, when, for example, it undergoes restoration or is on temporary loan in other exhibitions. Therefore, virtual reconstructions, interactive dynamic explorations, and 3D animations can also make up for the narrative of a lack, arousing curiosity and increasing the desire to return to visit the museum.

These considerations were reflected in the various outcomes expected from the two-year research project—funded by the Department of Architecture and Arts, Università Iuav di Venezia 2019–2021, in partnership with Direzione Regionale Musei Veneto—titled: The Statuary of National Archaeological Museum of Venice. Digitization, graphic restitution, and display project.

Main study objects were those Greek and Roman models characterized by obvious signs of physiognomic discontinuity, due to sixteenth-century removals, adaptations and restorations that altered their primal conformation.

The application of digital photogrammetry, with Structure from Motion algorithms, made it possible to bring back the free form of bodies, generating digital twins in which the use of mesh surfaces, mapped with ultra-high-resolution textures, allowed non-invasive intervention in highlighting the breakage signs and layering present in the finds.

By means of virtual surface section operations, the different anatomical and vestigial parts, belonging to different eras, were separated to facilitate digital anastylosis processes suitable for the decompositions and reconstructions of these stone bodies, whose posture has changed over the centuries. Hence the need to document their value and centuries of historical vicissitudes in multimedia, temporary and permanent display projects to be implemented both inside and outside the museum, in enhancing both the collections and the places that housed them.

2 The Statuary of the National Archaeological Museum of Venice

The circumstances surrounding the birth of the National Archaeological Museum of Venice have distant and varied origins, charting the history of lagoon collecting on the threshold of the sixteenth century.

Belonging to one of the most influential patrician families in the city, Captain da Mar Antonio Grimani—commanding the Venetian naval fleet in the war against Turkey—in 1499 suffered defeat at the Battle of Zonchio. An unforgivable stain for which he is first sentenced to death, then the sentence is commuted to life exile on the Cres Island. But two years later he fled for Rome, where his son Domenico already resided following the investiture in 1493 of the cardinal's robes received from the greedy Pope Alessandro VI, who granted it thanks to a substantial money handout, offered by Antonio himself, who could return to Venice only when his position as procurator was returned to him in 1509 [5].

Perry and Grimani [6] is an intellectual, humanist, art, and literature enthusiast. He collected many sculptural works, and some of them probably emerged from the excavation campaigns of the vineyard attached to the residence he owned, located on the northern slopes of the Quirinal. At his behest, several valuable antiquities are also had transported to the family's Venetian palace in Ruga Giuffa, near Campo Santa Maria Formosa. Father and son die in the same year, 1523.

The nearly 90-year-old Antonio has been Doge of Venice since 1521, and the 60-year-old Domenico, already ill for some time, perhaps out of a sense of gratitude to his native city that rehabilitates and elevates his father's social rank, bequeathed part of his collection to the Republic in his will. Thus, 16 precious marbles are displayed in the Sala delle Teste in the Doge's Palace where various artists, such as Titian and Tintoretto, can draw sources of inspiration for their paintings.

A former patriarch of Aquileia since 1546, Giovanni Grimani was also a patron of the arts and a collector. He had the family palace renovated and in the 1960s added two wings to the building to obtain a central courtyard in which to house the larger statues, while the more valuable ones were placed inside the so-called Tribuna: a small private museum with a central plan, clearly Roman-inspired, made up of niches and brackets in which to house busts, heads, and smaller stone bodies (Fig. 1).

Many of these marbles are purchased in Rome and Greece, thanks in part to the help of friends holding government positions.

With the idea of imparting a sense of completion to the mutilated finds, he commissioned Tiziano Aspetti to restore them, and the sculptor, with interpretative flair clearly derived from Mannerism, gave unprecedented postures to the incomplete torsos, to the limbs, giving back a face to the headless bodies [7].

In addition, in 1586, the models from his uncle's bequest were also returned to Giovanni Grimani, because the room housing them in the Doge's Palace was converted into the Chiesuola della Signoria [8].

Fig. 1 Palazzo Grimani's Tribuna, Exhbition *Domus Grimani* 1594–2019, May 7, 2019–May 30, 2021 (Photo: G. Liva)

On February 3, 1587, Giovanni presented himself to the Serenissima's Collegio dei Senatori, with the intention of donating part of his collection so that one of the first public statuaries in Europe could be established.

The agreed upon location is the prestigious Antisala of the Marciana Library, at the time used for the study of philosophy, rhetoric, and Greek literature. The work of restoring and reconfiguring the space is entrusted to Vincenzo Scamozzi, who, in keeping with the Tribuna's distribution system, decorates the four walls with niches, entablatures, and pedestals in such a way as to place the statues at different heights (Fig. 2) [9].

Giovanni Grimani passionately supervised all the work but died in 1593 without the opportunity to see his work completed. The senators appointed as his replacement the *Procurator de supra*, Federico Contarini, also a collector, who added other statues in his possession to the Grimani bequests.

The Public Statuary was inaugurated in 1596 and for more than two centuries was a place to visit and admire by travelers from Italy and abroad [10]. Its closing, instead, depended to the Republic fall and the French rule, because in 1811 the Viceroy of Italy Eugene de Beauharnais ordered the marbles to be moved to the Ducal Palace, freeing, and restoring the Antisala space to be annexed to his own apartments [11].

Fig. 2 Anton Maria Zanetti il Giovane, *Statuario Pubblico della Serenissima*, entrance wall. *Source* Biblioteca Nazionale Marciana, Venice, Cod. It. IV, 123, 10,040

For the statues back, to the Procuratie Nuove in St. Mark's Square, we had to wait until December 23, 1920, the day Vittorio Emanuele III assigned several rooms on the first floor to the Ministry of Education, allocating them to the National Archaeological Museum of Venice.

Setting up is cured by University of Padua archaeology professor Carlo Anti who, between 1923 and 1926, chronologically distributed the collections in the circular visit path articulated by the 13 rooms.

With strict modernist spirit, oriented to the enhancement of the finds as hypothetically rediscovered, he frees the bodies of the completion additions produced in the centuries-old restorations, making them mutilated again. In any case, those artifacts according to which the removals could have disfigured the stability and aesthetics of the parte antica are spared [12].

Today the National Archaeological Museum in Venice still retains many of the features wanted by Carlo Anti, both in the set-up and in the formal configuration of the models exhibit. However, design proposals are being experimented with aimed at enhancing and distributing them according to thematic cores that do not necessarily follow the scheme imposed by chronological order.

3 Survey and Reconstruction of the Marble Bodies

The survey campaigns involved about ten copies of Greek and Roman originals belonging to the collections of the Grimani family, with particular attention to the heads, busts, and statues engaged in the Renaissance restorations, carried out mainly by Tiziano Aspetti.

Among indirect surveying methodologies, active and passive, you notice that in recent years there has been a reversal in the increasing use of 3D laser scanning for large environments, instead demanding to digital photogrammetry the task of representing the formal complexity of small objects. But the optimization of radiometric quality of the data, acquired from passive systems, depends on the capturing distance, light conditions, and sensor characteristics [13].

Therefore, we chose to work with the digital photogrammetry tools and Structure from Motion (SfM) software [14] that generate a mesh numerical model to be mapped with ultra-high-resolution textures.

Photographic images were produced with a Nikon D800 E full frame digital camera, favoring a lens with a 24 mm focal length, because it is more suitable for focusing on semi-reflective surfaces such as the statues' marble surfaces.

Given the impossibility of completely darkening the museum rooms, in order to optimize colorimetric performance with flash lamps equipped with soft boxes, the natural and artificial light effects of the rooms were calibrated by shielding possible light reflections projected by the artifacts to be detected with movable black panels. This also reduces the contextual information to process in dense image matching phases.

However, it is well known that under hybrid lighting conditions—natural and artificial—it is almost impossible to equalize the output, given the varying color temperatures of the different light sources in museum rooms. But the use of shielding black panels and the introduction of color references, offered by a color checker [15] inserted laterally to the statue pedestals, made it possible to optimize the results.

In addition, in the early survey stages, several photographs were taken at the same location and with the same framing, but with different values of exposure time, by means of the bracketing function available to the digital SLR camera. This, of course, increases data computation time because the images are processed by algorithms for balancing in HDR.

In any case, a certain redundancy of data was ensured in the various survey campaigns, producing a large number of frames for processing, in the camera alignment phase useful for recognizing homologous points present in multiple pairs of frames.

For example, in the case of the Ulysses statue, which is about 105 cm tall, 25 surveying stations positioned around it on a circumference 210 cm in diameter were traced, acquiring 222 frames from 7 different heights (Fig. 3).

This valuable example belongs to the Domenico Grimani's collection and is a 2nd-century AD Roman copy of a proto-Hellenistic model, possibly attributable to the third century BC [16].

Fig. 3 Ulysses statue, photos alignment and construction of the dense point cloud. Elaboration in Agisoft Metashape Professional, version 1.6.1 (Modelling and rendering: M. Ciammaichella and G. Liva)

The completion interventions implemented by Tiziano Aspetti concern: the right arm with the sword handle, its scabbard, the left hand, the lower flap of the chlamys, and the legs.

For these reasons, once the mapped numerical model was obtained, its parts were sectioned through digital anastylosis processes geared toward recognizing the exact curve profiles of the limb connections.

But this can be done by working directly on the 3D model, checking the correct polygons distribution and their positioning with respect to the image that maps between them.

Generally, software for multi-stereo matching operations has semiautomatic procedures for reconstructing textures that, often, are fragmented by arbitrary triangle regions. But retopology algorithms [17] interpolate polygonal surfaces by subjecting them to unwrapping processes so that a new homogeneous texture is obtained in U and V coordinates.

The results of all the operations described so far have multiple impacts: the reconstruction of digital twins lends itself to the study and interpretation of the originals, even simulating the effects of eventual restoration, even before intervening directly on the material; 3D prints can be reproduced to be rearranged in the halls and Palazzo Grimani's Tribuna; they facilitate the knowledge processes of the works in heterogeneous multimedia setting up (Fig. 4).

Fig. 4 Leda and the Swan statue. 3D animation frames, size 1920 × 1080 (Editing: M. Ciammaichella and G. Liva)

4 Multimedia Exhibits Configurations

After completing the survey and digital reconstruction phases of the statuary, in agreement with the direction of the museum, the research continued experimenting with some exhibition proposals that could be integrated into the new museum layout design, which has been under development for years and is close to the start of work.

The statues are being redistributed by new thematic groups, moving away from the chronological order chosen by Carlo Anti in the 1920s, and, with the aim of enhancing the valuable ancient collections, the potential of digital technologies is being exploited to improve communication and cultural offerings, according to the principles of customer experience (CX) [18].

In particular, a permanent solution and a temporary one, non-invasive but with great visual impact, were tested respectively in the current Room VIII, and in a space now used for educational activities, referred to as Room XII (Fig. 5).

In both cases, the 3D animations produced from the virtual clones derived from the photogrammetric survey—projected on the walls or exhibited in the monitors—become an integral part of the exhibition, reconfiguring the existing space, and allowing a greater deepening of the contents.

In particular, the disassembly and reassembly of Renaissance anatomical parts are revealed to the viewer for the first time, guiding in a conscious historical investigation of the postural transformations and stratifications of single artifacts.

Projected images, audio effects closely related to the storytelling, and punctual technological mechanisms applied to reality are the basis of an intervention strategy

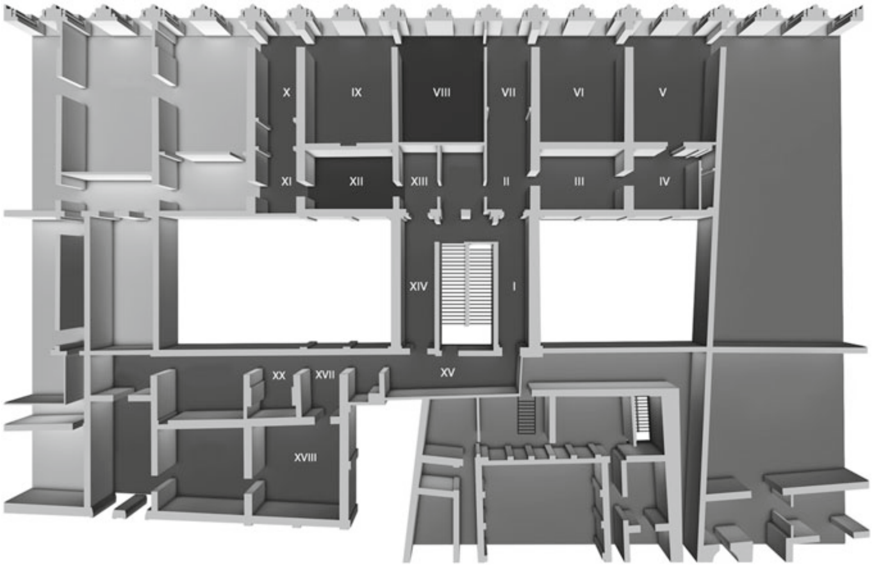

Fig. 5 National Archaeological Museum of Venice, plan reconstruction with the room distribution (Modelling and rendering: G. Liva)

that allows to valorize and connect physical artifacts, in line with the *Piano Triennale per la Digitalizzazione e l'Innovazione dei Musei*, 2019 [19].

The permanent exhibition proposal, centered on Room VI, includes the Renaissance restorations of some valuable marbles: Ulysses (2nd cent. CE), the Philiskos Muse also known as Cleopatra (2nd cent. BCE), Artemis on the march (1st cent. BCE), Leda and the Swan (2nd cent. CE), placed along the walls covered with black panels, in which LED light strips are installed on the tops.

To appreciate their forms and details, each statue is fixed motorized revolving pedestals, whose rotation is activated by optical sensors placed in the white supporting plinths. The visitor at about 1.5 m starts the movement, synchronized with the 3D animations visible on the screens placed close by.

This creates a direct dialogue between classical antiquity and the digital twin, guarantee for the public an effective critical reading of lost archetypes, surviving bodies that are subject to completion actions over the centuries (Fig. 6).

Instead, for the temporary exhibition, a problem emerged first, common to many museum realities: the work absence attributable to a temporary loan, at another museum institution, necessarily creates a physical void constantly resolved with a small information poster, alerting the public to the temporary lack.

It is inevitable that such a totally unexpected solution will generate disappointment in the visitor and allow one to forget the valuable connection between the missing artifact and the museum institution that preserves it.

During the two years of research, the actual loan of the Ulysses statue occurred. Its temporary relocation to Athens, to the Cycladic Art Museum, and its consequent

Fig. 6 Set-up in room VI dedicated to Renaissance restorations (Set-up design, modelling and rendering: M. Ciammaichella and G. Liva)

absence in Room VIII provided an opportunity to reflect on exhibition solutions in which highlight the missing antiquity.

An initial design proposal provided for the inclusion, where the statue was located, of a white totem displaying Ulysses journey from Venice to Athens, through a film made by photographer and video maker Joan Porcel. The visitor witnessed the precise sequence of the packing, ground handling, and sea transport of the precious sculpture, informing him of the many difficulties involved in museum loans.

A more articulated second solution followed this quick proposal: it dedicated an entire room to the missing statue, planning multimedia contents whose interaction involved sight and hearing, while respecting the safety conditions imposed by the pandemic situation (Fig. 7).

The set-up provided controlled access for small groups, five people maximum, staggered at regular intervals.

The room, evenly painted with immersive black max contrast color, was obscured by long black velvet curtains placed at the entrance, exit and at the two imposing windows facing an inner courtyard of the Procuratie Nuove in St. Mark's Square.

Some LED light strips, an integrated system of three video projectors, and a 5.1 Dolby surround sound system were mounted in the existing false ceiling, which, from different points alternated short monologues, recited by actors on the reading of famous literary texts, in circular sequences.

Upon entering, the visitor could remain, to his right, near a white totem that contained general textual information in two languages, Italian and English, and documented, through a film, the artifact's cleaning, and restoration operations. Behind it, the large opposite wall held a loop-shown projection of the metamorphoses and additions undergone by the statue, revealing the initial fragmentary state of the artifact and its subsequent completions.

Next to it, scrolling text summarized the methodological sequence adopted for the creation, modeling, and disassembling of the digital twin.

Fig. 7 Set-up in room XII dedicated to Ulysses statue (Set-up design, modelling and rendering: M. Ciammaichella and G. Liva)

Finally, morphing projections of similar statues, belonging to other museums, could be seen on the entrance and exit walls.

This design hypothesis aimed to enhance the Ulysses or any other missing statue by reflecting on the value of the images, static and in motion, that evoke the artifact, guiding the visitor in the discovery of the centuries-old stratifications and configurational alterations undergone by the work.

5 Holograms on Stage

In 2022, the research continued with further exhibition experimentation, which focused on deepening HoloLens technology through synergistic collaboration with software house Geckoway [20].

Among the emerging communication tools, the wearable holographic device [21] enables interaction with multimedia content while remaining anchored in the real environment that becomes an integral part of the user experience.

Thus, the augmented reality dimension hybridizes with the mixed reality dimension and allows the user to reproduce a hologram of artifact, being able to animate it with only hand movement and/or voice commands.

The viewer, equipped with motion and depth sensors, video cameras, microphone, and spatialized audio—with acoustic diffusion analogous to Dolby surround sound—provides the user with a faithful copy to manipulate, interrogate and explore. This facilitates the statuary comprehension, in delving into its centuries-old historical stratifications and transformations, but also compensates for the lack of the original by the light of possible loans to other museum institutions, as is often the case.

The authors focused on Room VIII of the archaeological museum, testing in situ the technology in use directly on the Ulysses statue. The case study involved testing its logic of interaction with the virtual clone hologram, verisimilitude, audience response and any critical issues.

Once the viewer was put on and activated, the mapped 3D model immediately revealed itself to the eyes of the museum staff, and to some visitors involved in the test (Fig. 8).

The ease of proceeding with intuitive movements of displacement, rotation, enlargement, reduction, and anatomical disassembling demonstrated the effectiveness of the interactive interface.

In addition, the polygon mesh simplification operations, to which the hologram is subjected in its first stage of data processing, ensure the effectiveness of a lightweight prototype suitable for easy handling, by means of grasping tools associated with sensitive points.

The user response has been positive: an initial fear of inability to manage the hologram has been succeeded by curiosity and resourcefulness in interacting with the digital twin, in understanding its limitations and potential, stepping out of a comfort zone, and actively participating in the game of knowledge [22].

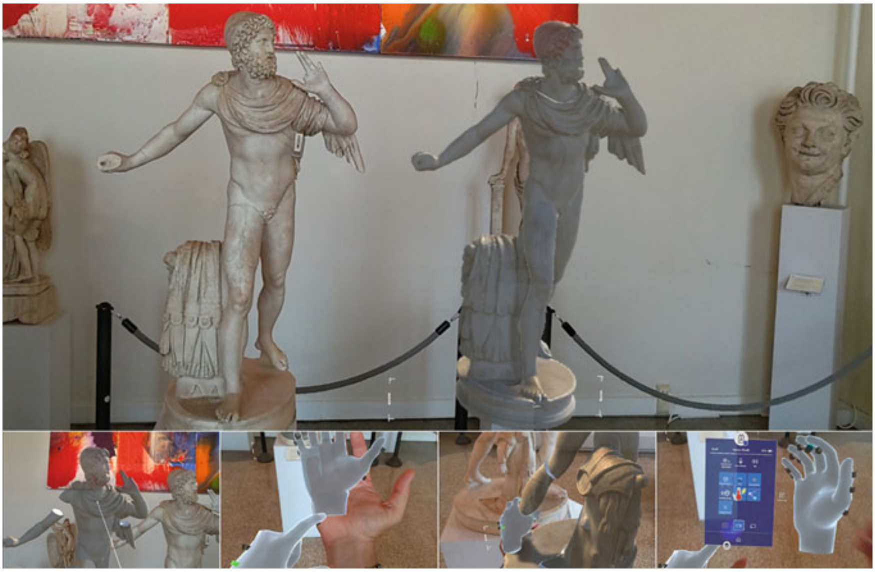

Fig. 8 Ulysses statue, interaction with Hololens technology at the National Archaeological Museum of Venice (Modelling and texturing: M. Ciammaichella and G. Liva, interactive configuration and photos: M. Rinelli)

Real vision is overlaid with virtual information embedded in tangible space, so the user observes and interacts with objects connected and added to reality, participating in an immersive hybridization of one's senses.

Getting again Marshall McLuhan's thought, media become an extension and externalization that amplify the individual potential [23]. In the current overview, understood as an expanded sensory universe, technologies regulating virtual, augmented, and mixed reality are powerful aids in the entertainment dynamics, research, education and game, uniting into one paradigm.

Although the HoloLens costs are still high, it is assumed that market in the shortest time will be able to contain them and move forward with the offering of increasingly high-performance visors. After all, it is well known that the future of display devices will be increasingly related to glasses or wearable prosthetics that break down the barriers between the eyes, screen and interactive gestural [24]. In any case, the latest research, conducted by the authors, has highlighted their main characteristics as powerful means of enhancing and disseminating artistic and cultural heritage.

In this regard, further verification of the results achieved was confirmed by the authors' participation in the CES 2023 international exposition [25], held in Las Vegas from January 5 to 8, 2023.

The software house GeckoWay was selected by ICE [26], Agency for the Promotion Abroad and Internationalization of Italian Companies, and Eureka Park [27], supporting the Italian startup for Made in Italy innovation with the VirtualCrab project. This is a collaborative platform that involves entities and institutions in enhancing the tangible and intangible heritage through technological innovation.

In the dedicated Venice section, statuary was a protagonist in the goal of facilitating the meeting between the demand for fruition and the Italian artistic and cultural offer, through the combination of holograms and gamification applied to the case studies discussed here.

6 Conclusions

The essay argued the outcomes and multiple develops of a current research project, in which the cultural heritage offered by the Grimani collections has been the study subject, survey, and digital reconstruction, to understand and interpret the metamorphoses of these stone bodies that have undergone various restoration interventions over the centuries.

To be able to give again the complexity of their stratification processes, requires a careful communication strategy that must deal with an enlarged audience.

Hence the need to test advanced digital technologies, in multimedia exhibition projects ranging from audio and video installations to 3D animations, some applications of interaction design, and even solutions that intercept the augmented and mixed reality environments.

It is well known that the fields of holographic visors application mainly concern the design area, engineering, and medicine sectors, but in recent years concrete proposals for the art and culture exploitation are being developed through immersive experiences that involve spaces, museums and institutions interested in welcoming the HoloLens use.

For example, the Microsoft company that produces them has collaborated with Hevolus Innovation [28] and Infratel Italia [29] to create a prototype HoloMuseum dedicated to Castel del Monte, in Andria [30].

The substantial reasons for the use of such visualization tools relate to the possibility of enhancing the narrative ability of what is being observed, amplifying the involvement degree of users who can interact with the tangible works, or in their absence, by accessing additional information contents.

Thus, the museum becomes a hybrid experiential space that opens to active learning, connecting the accomplished form of the artifacts with their digital twins, which explain their genesis and historical evolutions, while at the same time allowing them to fill the void of lack whether temporary or permanent.

The success found at the most important international exhibition, dedicated to innovation [25], demonstrates precisely how it is possible to interconnect and enhance cultural heritages taken for granted or sometimes forgotten, to be returned in all their value both inside and outside institutional museum locations.

The CES 2023 experience, in fact, allowed users from different countries around the world to use the device and interact with the statue holograms, accessing all information about the works such as descriptions, photos, videos, audio, and geolocation on 3D maps (Fig. 9).

Fig. 9 Hera bust, interaction with Hololens technology at the CES 2023, Las Vegas 2023. (Modelling and texturing: M. Ciammaichella and G. Liva, interactive configuration and photos: M. Rinelli)

Acknowledgements The authors shared methodologies, contents and results achieved by the research. In the specific, paragraphs 1. Introduction, 2. The Statuary of the National Archaeological Museum of Venice and 3. Survey and reconstruction of the marble bodies are written by Massimiliano Ciammaichella; paragraph 4. Multimedia exhibits configurations is written by Gabriella Liva; paragraph 5. Holograms on stage is written by Massimiliano Ciammaichella and Gabriella Liva. Conclusions are cured by all three authors.

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Augmented Reality and Avatars for Museum Heritage Storytelling

Roberta Spallone, Fabrizio Lamberti, Luca Maria Olivieri, Francesca Ronco, and Luca Lombardi

1 Introduction

The present work involved a multidisciplinary team of scholars with expertise in Indian art and archaeology, digital representation, and information processing systems, with the support of the VR@POLITO and MODLab Design Laboratories at the Politecnico di Torino.

The aim is to communicate the evolutionary process in Buddha iconography in the Mathura area (Uttar Pradesh, northern India) through three statues from the permanent collection of the MAO.

This aim is connected with the general goal to increase inclusivity and remove spatio-temporal barriers in museums and their collections by meeting the diverse needs of visitors related to age, physical, sensory, cognitive, and cultural factors.

The pipeline is articulated from digital survey and 3D modelling of the artworks to the philological reconstruction modelling of the missing parts to the creation of an avatar guide to the elaboration of the tour path in augmented reality (AR).

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This experience is characterised by the avatar's presence linked to AR experience. This virtual guide allows the selected works to be connected in a pathway to build storytelling. It was realised using a Virtual Human (VH), i.e., a virtual character with anthropomorphic features, who guides the visitor through the path. Digital storytelling connected to the avatar enriches the experience by providing information about the context, history, and characters related to the works.

One of the values that characterize the entire process is the predominant use of free and open-source software (FOSS) up to the prototype stage.

2 ICT for Museum Heritage

Today, a kind of revolution is in progress, fostered by Information and Communication Technologies (ICT), which is reshaping the mission and roles of museums and cultural heritage organizations from all over the world. This revolution, or evolution, combines consolidated content (represented by the historical collection, and the strategies traditionally adopted to preserve and valorize it) with new ways to make the various stakeholders experience it [1].

Museums are experimenting with different types of ICT-driven innovation, which are significantly impacting the way exhibitions are organized, services are offered and, generally, many kinds of both internal (research- and administration-oriented) and external (visitor-oriented) activities are handled [2].

The innovation and the forms of creativity that are explored by the said organizations, e.g., by developing cultural heritage digitization strategies and leveraging, among others, mobile and immersive technologies, widen their value proposition and, purposefully, the level of users' experience, also contributing at opening the cultural offer to a larger public and the output researchers' work more accessible [3–5].

For instance, in [6] an analysis of mobile devices as activity aids in museum is provided, together with a comparison with other technologies used for this purpose. In [7], the possible uses of mobile devices for implementing gaming applications targets to cultural heritage are reviewed. In [8], the use of mobile devices for offering multimedia-powered context-aware assistance to visitors is investigated.

Most of the disruptive power of ICT in museums and cultural heritage, in general, appears today to be brought by eXtended Reality (XR) and the umbrella of technologies under these terms, i.e., Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) [9, 10]. In this perspective, the combination of XR and other technological enablers of the metaverse are redesigning the physical-virtual continuum, introducing new ways for humans to interact with technology and with other humans [11, 12]. Cultural heritage organizations are investigating ways in which XR can be exploited to overcome the limitations of physical environments in the setup of their exhibits and to virtualize and enhance/augment the traditional visitor's experience within their walls [13]. They are pushing towards transforming the visitor into an active (proactive) consumer of cultural heritage content, letting him or her engage in innovative experiences incorporating education with entertainment and socialization features [14]. Immersive and other technologies act as enablers (and amplifiers) of the museum's value, by making it possible to combine traditional as well as digital narrative strategies with powerful forms of experiential and recreational learning [15–17].

As a matter of example, in [18] the use of XR technology for educational purposes in museums is studied, leveraging a 3D avatar as a means for providing interactive storytelling experiences. In [19], projected AR-based holographic exhibits are explored to let visitors interact in a natural way with displayed objects. In [20], a similar scenario is explored, but focusing on wearable AR. In [21], the impact of virtual tours on the business organization of museums (especially after the covid-19 pandemic) is studied. In [22], the use of XR technologies to reach specific targets (in the specific case, children) is analyzed.

Museums and similar organizations are also interested in finding ways to empower their internal activities. For instance, in [23], management aspects are explored, focusing on the use of the XR-based visualization of Building Information Modeling (BIM) data. In [24], ways in which XR can be used to support the work of researchers (in particular, in archaeometry-related tasks) are presented.

By leveraging on the growing amount of research being carried out in this field as well as promising experiences that are being deployed in many museums worldwide, this paper specifically builds on a previous experience made on the use of a mobile AR application to support the fruition of the Museum of Oriental Art's collection and presents the strategy devised to improve its capabilities by adding a natural way for interacting with it and with managed content using virtual humans.

3 AR for Accessibility and Inclusion

Museums, traditionally centers of cultural dissemination, are becoming places to experiment with digital technologies aimed at improving the visitor experience inside and outside the museum [25]. The Covid-19 pandemic has contributed to the growth of this technology trend in tourism, which could be considered the first step in the migration process from traditional tourism to the smart tourism industry [26]. The need to overcome the purely conservative and expositional vision of the museum has therefore led, through a process that is still in the making, to attribute it a more active role, giving it also an educational and communicative function. The Western world is witnessing a real proliferation of new museum edutainment activities.

New technologies, which are visually based and interactive, allow an enormous extension of the sense-motor modes of knowing because they make visual perception and action applicable to objects that no longer have to be physically present or even exist.

Globally, great attention is paid to the interactive and immersive aspects.

As seen above, XR presents a challenge to the traditionally consolidated practices of accessible web design, illustrating the need for personalization, and customization of the user's experience [27–31].

In this sphere, AR can achieve educational functions, and different researchers highlight that it encourages learning processes [32, 33]. In particular, AR can be applied, in addition to school, also in informal learning environments such as museums [34], parks, archaeological sites, etc. [35], constituting an advantage of motivating users to learn about the resources they have been presented with, enhancing natural interaction [36] and accessibility.

Museums and cultural heritage sites that offer accessible exhibitions are increasing, but in general, it still remains relatively uncommon for cultural heritage centers to have developed ways of facilitating access for "casual visitors who are visually impaired, deaf or who have learning disabilities" [37]. In this sense, AR can facilitate museums to construct their interactions with the public, in particular with those with sensory impairments or learning disabilities.

AR, in fact, is generally mentioned for the superimposition of visual contents, like texts, images, and videos, but different applications exist for the expansion of human senses. AR technologies, for example, can increase the autonomy of blind or visually impaired people in exploring known and unknown environments and transform unseen visual object data into accessible auditory information [38–40].

The current trend is to populate these worlds with virtual humans (VHs) with the appearance and behaviour of the original inhabitant. There are commonly two main types of VHs in VR applications: avatars (graphical 2D or 3D digital representation of the user) and virtual agents (computer-guided interactive characters, with or without human appearance).

The virtual agents can have different roles: mere decoration, to populate the reconstructed environments; or immersive tools of knowledge, used as conversational agents acting as tour guides for virtual or real heritage.

Modern cultural heritage applications involving virtual humans (VHs) encourage the enhancement of interaction between the user and the virtual agent, through natural and body language or other nonverbal means of communication [41].

Generally speaking, the implementation of ICT enhances the level of inclusion in cultural heritage sites [42].

4 Digital Storytelling: A Path Between the Buddhas of Mathura

The digital technologies that complement traditional museum tools can offer visitors an interactive, multisensory and possibly multimodal experience that brings them closer to the works, making them the protagonists of their own learning [43].

The traditional learning process of visitors happens through interaction with exhibition guides, other visitors, audio or video guides, and other non-interactive media such as exhibition labels.

XR and VHs offer the user another possibility to learn and travel through time in an immersive way. All kinds of combinations of digital technologies are more effective in conveying heritage information if accompanied by storytelling that adds information about the context, events, and characters related to the object. In this way, the visit is more immersive and tailored to the user who can find out the story behind the cultural heritage [44].

A successful virtual heritage application, in fact, "should be the result of a well-balanced synergy between representation (enabling the visualization of cultural data), experience (integrating elements that can provide in a captivating way enhanced knowledge) and interaction (engaging the user actively in the virtual world)" [41].

Specifically, we present here an avatar-guided AR experience applied to a statuary tour (Fig. 1) focusing on the anthropomorphic evolution of the Buddha figure in the Mathura region, which includes:

- A Yaksha, a sylvan semi-deity of the Indian cult that coincides with one of the earliest anthropomorphic depictions in Hindu, Buddhist, and Jain contexts. The stone statue at MAO is one of the first examples of the Kushāna art (I–III centuries a.C.) of Mathurā, where naturalistic research can be observed in the rendering of certain body elements and ornaments.
- A Kapardin Buddha head, carved in spotted red sandstone, representing one of the earliest depictions of the Buddha. The facial features, inspired by a certain naturalism, almost seem to foreshadow the stylistic qualities of Gupta art, although the globular eye line still recalls earlier depictions of Yakṣha.
- A standing Buddha, made up of red sandstone, one of the best examples of the Gupta school of Mathura (IV–VI centuries a.C. The figure of the standing Buddha,

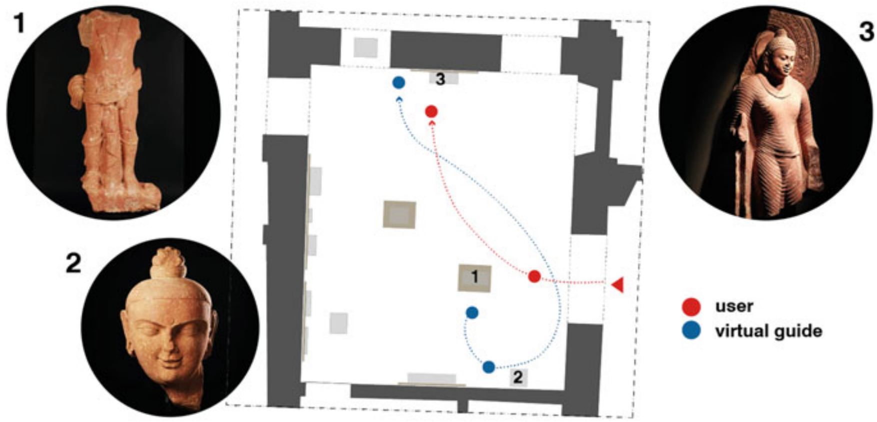

Fig. 1 Pathway of user and virtual guide inside the exhibition room (Editing: F. Ronco)

with hands and lower limbs broken off, stands out for the composure of the depiction and the measured proportions.

Here the VH acts as a virtual guide and fulfils two roles: navigation aid, which accompanies the visitors towards the entire itinerary, and information provider, which speaks about the artefact and its original location, with a positive effect on the learning outcome.

The story thus is developed on two levels: the more general one that links the various works and the one related to the single work connected to its contextualization and reconstruction of the missing parts.

The three-dimensional model is associated with an audio track; it interacts with the framed works and provides the user with an accurate and engaging description, as well as indications about the visit path. Virtual guide movements were made with the aim of providing added value through expressive gestural language. The VH indicates, for example, the elements he is describing and the direction in which the visitor must head in order to activate the next AR experience.

Digital storytelling complements the traditional one (captions and panels, printed guides, audio guides, audiovisuals), reinforcing the visitors learning and understanding of cultural content.

The use of VH can stimulate a high-quality learning experience, especially for young users, as they are based on the concept of edutainment, in which learning is associated with entertainment.

The presence of a virtual guide intends to recreate the social interaction that is the key to strengthen learning [45]. The design of virtual guides (human behaviour realism and human-like voice) can affect the motivation to engage with exhibition content and increase the sense of social presence, offering a valuable cultural knowledge transfer. In this way, the flow of this process changes from a linear, unidirectional one, to bidirectional, where the visitor retrieves information through his interactions with the virtual environment and its inhabitants.

A promising direction of research in the virtual guide for contemporary museums is the use of intelligent agents, with human-like personality traits and abilities, that in addition to entertaining and engaging visitors, also offer personalized feedback, contributing to the learning process.

5 The Statues at MAO and the References for the Philological Reconstruction

Digital tools were then used on the one hand to provide keys to understanding the missing parts and the related different reconstructive hypotheses, able to deepen the research and generate debate. As seen, for each work, a 3D reconstruction has been planned, starting from iconographic documentation related to similar and contemporary works from other museums, thanks to the contribution of Claudia

Ramasso, curator of MAO, and Luca Maria Olivieri, director of the Italian Archaeological Mission in Pakistan. The missing parts, according to the principles of digital archaeology, have been modelled without the application of textures to ensure the distinguishability of the original part and the reconstruction.

The Yaksha and the other pieces considered as *comparanda* in this study belong to the early phases of the Mathura school of sculpture. The school is characterised by the existence of numerous workshops and ateliers, well established already by the early-first century BCE at various sites around Mathura. The art of Mathura, especially in its early phases, is characterised by the almost absolute use of a specific local lithotype that is very well workable, and locally available in abundance, a red and red-spotted sandstone.

Early Mathuran yakshas and other male figures depicted with the flywhisk (*camara* or *caur*i) include the "*cauri* bearers" discussed in the book of Quintanilla [46] (e.g. at pages 19–20, 67–68, 83–84; see e.g. Figures 7, 19, 42–45, 62). The left-handed male *cauri* bearers from Jamalpur-Tila, Mathura, Uttar Pradesh in Fig. 7 in [46], and from Kuan wali gali, Mathura, Uttar Pradesh in Fig. 62 in [46], although each carved in bas-relief on the side of a pillar (?), are the most representative examples. These examples are dated by Quintanilla to around 150–100 BC. Coeval or slightly later figures of *cauri* bearers are also represented at Sanchi I in Fig. 138 in [46]. Standing yakshas comparable to the piece under study are a piece from Parkham, Mathura, Uttar Pradesh in Fig. 15 in [46], and one from Baroda, Mathura, Uttar Pradesh in Fig. 18 in [46], but also the *naga* from Mathura in Fig. 20 in [46].

The Buddha Kapardin too belongs to the early stages of the Mathura school of sculpture (red and spotted red sandstone). The main characteristic of these representations is that they can be considered among the earliest anthropomorphic representations of Siddhartha at Mathura. Siddhartha is represented both initially as a Bodhisattva, i.e. before the Enlightenment, and as an accomplished Buddha. In fact, in some cases, Siddhartha's spiritual status is indicated in the inscriptions when they are present. The term Kapardin derives from the snail-like hairdress of these pieces (*Kaparda* means both wearing knotted hair or waring matted locks, and snail). The dates of many inscriptions refer to the early years of Emperor Kushana Kanishka's reign (starting reigning in 127 CE [47]). The s.c. Katra stele features a seated Bodhisattva with attendants, from Katra, Mathura, Uttar Pradesh, Government Museum, Mathura, published in Fig. 1 in [48]. Comparisons can be done with: the seated Bodhisattva with attendants from Ahichhatra, Uttar Pradesh, dated from the inscription 159 CE (year 32 of Kanishka's era), National Museum, New Delhi in Fig. 137 in [46]; seated Bodhisattva from Sonkh, Mathura Uttar Pradesh, dated from the inscription 150 CE (year 23 of Kanishka's era), in Fig. 36 in [46]; seated Bodhisattva with attendants, from Mathura, Uttar Pradesh, dated from the inscription to 132 CE (year 4 of Kanishka's era) [49]. A further comparison can be found in a coeval fragment from Harvard Art Museum in Fig. 2 in [50]. One can also consider for their original features also a seated Bhagavan Śākyamuni in Fig. 8 in [46], and the Buddha from Anyror, Mathura, Uttar Pradesh, Government Museum, Mathura (no. A.65; not to be confused with the proper Mathuran-styled seated Buddha no. A.20 Government Museum, Mathura) in Fig. 6 in [46]. On the Mathura school of sculpture and inscriptions, the first commented catalogue with inscriptions is that of Vogel [51]. For the features of the Kapardin Buddha statues and stelae, the main works are [52], but especially [46, 48] with their references; for the inscriptions, besides [51], see also [53].

The Gupta Buddha, preserved in the Rashtrapati Bhavan, Presidential Palace, New Delhi, with other correlated pieces are the masterpieces of a later and accomplished development of the Mathura school of sculpture. Although they are a genuine expression of the late Mathura school of sculpture, these forms go under the generic label of Gupta art. They can all be dated around the fifth century CE.

Most of these late pieces are carved in immaculate red sandstone. The subject of these pieces is always a standing Buddha depicted in the act of reassurance (with the palm of the right hand at torso level), while the left-hand holds the hem of the monastic robe. The statues may or may not have a large round halo (in some cases an assembled element). Formally, the origin of these pieces, standing, sculpted in the round, has to be searched in the early Mathuran art, such as, for example, the famous Bala Bodhisattva from Sarnath, kept in the Sarnath Museum, which is dated 131 CE (year 3 of Kanishka's era) in Fig. 5 in [49]. Other two earlier comparisons of the proper Gupta standing Buddhas' series are two pieces from Mathura illustrated in Figs. 3, 4, 5, 6, 7, 8, 9 and 10 in [49]. The second represents a Maitreya Bodhisattva, kept in the National Museum of New Delhi and coming from Ahichatra, Uttar Pradesh.

Other references for the reconstruction are: the Gupta period standing Buddha, from Govind Nagar, Uttar Pradesh in Fig. 7 in [49]; an outstanding piece of art is also the sculpture from Manoharpura, Mathura, Uttar Pradesh [54, 55]. Other important pieces are those preserved in the Freer Gallery at the Smithsonian Institution, Washington, D.C. [56] and the Metropolitan Museum of Art [57].

6 Reconstructive 3D Modelling Aimed at AR Communication

After the photogrammetric digital survey of the sculptures, realised through the well-known structure from motion (SfM) technique, the alignment of the photos, and the creation of the virtual model of each artwork, a critical step was the philological reconstruction of the missing elements. It is the topical moment that involves the knowledge of the multidisciplinary group [57]. The model that integrates the representation of the real statue with the reconstruction of the missing parts must deal with the goal of AR enjoyment by the public through personal devices (Fig. 2). This implies the need for lightweight models for the broadest possible fruition.

The models obtained through photogrammetry, and the reconstructions made through digital sculpting, presented a high level of detail characterised by a high number of polygons (Fig. 3). This made the files heavy and unsuitable for an augmented reality experience.

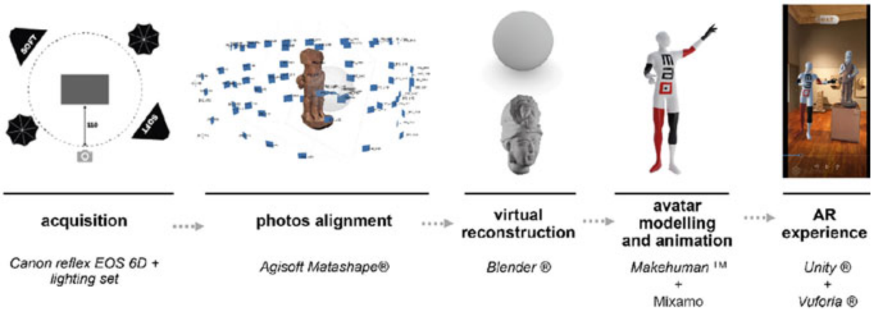

Fig. 2 Pipeline of the research work (Editing: F. Ronco)

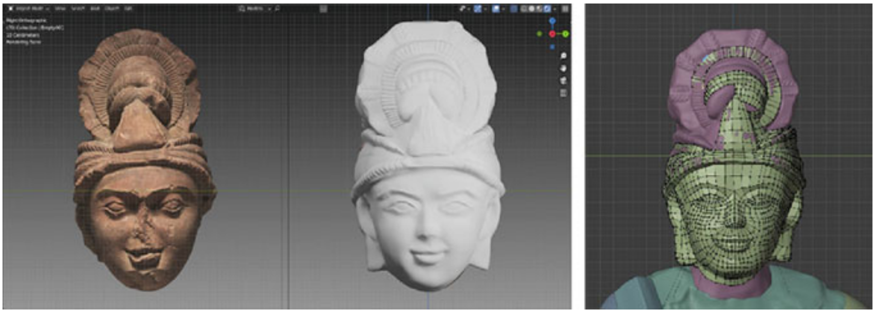

Fig. 3 Yaksha's head reconstruction. Partially re-topologized polygonal mesh overlaid on the digital model (Modelling and editing: L. Lombardi)

To lighten the files and allow their export and final use, it was necessary to perform a process called Retopology which aims at reducing the faces of a mesh. In this case, retopology was done manually using Blender's Poly Build tool and the Shrinkwrap modifier.

Moreover, the outcomes that must be communicated to the public must share the results of multi-disciplinary research work, consisting of historical description, philological comparisons, reconstructive models, and animations, without losing its scientificity and transparency concerning the reconstruction criteria.

The London Charter [58] and the Principles of Seville [59] could be considered the main and general methodological references in virtual reconstruction and heritage presentation.

As stated in the preamble, the first reference aims to enhance the rigour with which computer-based visualisation methods and outcomes are used and evaluated in heritage contexts. For this reason, the Charter defines principles for using these methods in relation to intellectual integrity, reliability, documentation, sustainability and access.

The second reference, by assuming the concepts of the London Charter, specifically focused on virtual archaeology, which is the scope within which the reconstruction activity presented in this research moves. Among the new objectives defined in the Principles, two of them seem to be perfectly adequate to address the present research. The document promotes the generation of easily understandable and applicable criteria for the scientific community and the improvement of current archaeological heritage research, conservation, dissemination and interpretation processes using new technologies.

Regarding the latter reference, Brusaporci [60] highlighted that, in the scope of tangible cultural heritage, archaeology first showed attention to computer visualisation as a scientific methodology and raised problems of philological interpretation regarding digital reconstructions of artworks of the past, largely based on indirect information, comparative analysis, and interpretive hypotheses.

More recently, Schäfer [61] compared methods, techniques, and strategies of 3D digital modelling and reconstruction dealing with uncertainty visualisation in archaeology, and Pietroni and Ferdani [62] developed an extensive theoretical discussion to clarify and define concepts, functions, fields of application, and methodologies related to virtual restoration and virtual reconstruction of Cultural Heritage.

Lastly, it is essential to remember the final report, published in April 2022, *Study on quality in 3D digitisation of tangible cultural heritage: mapping parameters, formats, standards, benchmarks, methodologies, and guidelines* [63], financed by the European Commission.

The project deals with a field of interest, i.e., the movable and immovable tangible cultural heritage, coincident with current work. The last section of the report, devoted to the "Forecast Impact of Future Technological Advances", underlined that over the last 30 years, digital technologies have become the primary means of collecting, conserving and disseminating European and International Cultural Heritage. Moreover, it affirmed that the continuing emergence and deployment of extended reality (XR), which includes augmented/virtual/mixed realities (AR/VR/MR) technologies, will play an indispensable role in the management, conservation, and protection of CH.

A critical point concerning digital reconstruction and integration between existing artworks and hypothesised missing parts, is the visualisation technique to be used. In this regard, the Charter of London stated that "it may not always be possible to determine, a priori, the most appropriate method, the choice of computer-based visualisation method (e.g. more or less photo-realistic, impressionistic or schematic; representation of hypotheses or the available evidence; dynamic or static) or the decision to develop a new method, should be based on an evaluation of the likely success of each approach in addressing each aim".

In the experience developed here, we chose to distinguish the reconstructed parts using the so-called clay render that enhances the geometric and plastic qualities of the reconstruction while standing out from the existing parts. Moreover, animation has been used to demonstrate the technique of assembling the parts of a sculpture.

The three sculptures that constitute the cultural path were modelled and integrated using different attention to the contents they aim to communicate. While the Yaksha's missing arms and head were reconstructed based on the philological comparison and visualised in AR as a completion of the statue, the Buddha Kapardin, hypothesised as a seated statue in the lotus position was contextualised in the stele that might have contained it and displayed in AR at a slightly reduced scale so that it rests on the floor alongside the exposed head.

Finally, the reconstruction of the nimbus, the lower part of the two legs and the hem of the robe, the left hand and the right forearm of the Buddha Gupta have been enriched by the animation of the right forearm assembly to the arm, usable in AR, and suitable for communicating the hypothesised methods of realisation.

7 The Avatar and the AR Experience

The reconstructive modelling has been flanked by creating an animated virtual guide to describe and guide the visitors through the experience. A digital model of a human-like avatar was chosen as the guiding and implementing element of the experience.

The Base Mesh of the anthropomorphic digital model was generated through MakehumanTM, an open-source tool to make 3D characters, and then imported and modified in Blender. Once the desired likenesses were obtained through a slight sculpting process, starting from a low-resolution polygonal model, the materials were created and then texturing was performed. At this prototype stage, the virtual human (VH) has the appearance of a mannequin simply clad in the colors and logo of the MAO.

The model was initially imported into the Mixamo database and associated with the animation of a basic walk used as a reference to develop the entire animation. Mixamo is a web-based services software for 3D character animation, freely distributed by Adobe Mixamo's technologies use machine learning methods to automate steps in the character animation process, including 3D modelling to rigging and 3D animation (Fig. 4). Mixamo's online services include an animation store with downloadable 3D models and sequences.

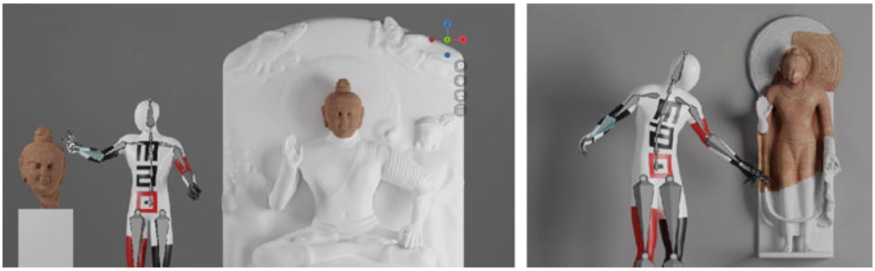

Fig. 4 VH rigging and pointing setting for Kapardin Buddha and Gupta Buddha (Modelling and processing: L. Lombardi)

The VH, linked to an audio track, allows the viewer to be guided through the evolutionary processes of Indian art and the reconstructions of the works. It was thus used as the main communication subject to convey information related to the reconstructed works.

Once reimported into Blender, the model was placed side by side with the artwork referenced during the experience, scaled and positioned in the correct way it appears in AR.

At the same time, an audio track was generated to describe the statues, explain the reconstruction, and guide the app user through the tour. The process started with writing text that was converted to a voice track through the Woord speech synthesizer, a Web service free for standard uses. The audio track was then imported into Blender so the VH movements could be associated with the spoken text.

Since these are three distinct artworks characterized by different locations, explanations and sizes, three different animations were created, each with its own audio track and reference models.

Next, work began on the existing keyframes and adding new ones through the animation tools and functions provided by Blender, to optimise the movements and match the explanation.

For other VH animations, modifiers were also used on the animation curves, i.e., functions that allow the parameters to be changed by repeating or altering the movement. More specifically, the noise modifiers, which randomly allow for an animation curve characterized by slight sinusoidal alterations, were used in specific keyframe intervals for head and arms animation. Adjusting the intensity and repetitiveness of the variations made it possible to generate the desired motion effect.

The VH's movements were created to provide added value through expressive gestural language. For this reason, the language of pointing (indicating, pointing toward) has been used both to show virtual elements present in the visitor's field of view and indicate or suggest the direction in which to move to enjoy further AR experiences anchored to the works (Fig. 5).

The AR application was developed through the use of Unity 2020.3.19f1, implemented with Vuforia and Google ARCore (a Unity plugin) to allow it to run on a mobile device running the Android operating system. Unity and Vuforia are free for prototype development.

To enable Unity to develop and run an AR application on a mobile device, some setups had to be done within the software, aimed at use in the Android environment. The same should have been done for the iOS environment. It is important to remember that the software development kits (SDK) ARCore (for Android) and ARKit (for iOS) work only with rather recent operating systems. The former is compatible with devices that have at least an Android 7.0 operating system (first release in August 2016). The second requires a device with at least iOS11 (first release in June 2017).

3D models of the statues, their integrations, the avatar, and the animations developed in Blender were imported into the Unity database to create the AR application. The import phase within the software requires special attention for the assignment

Fig. 5 VH rigging, animation and pointing setting for Yakhsa statue (Modelling and processing: L. Lombardi)

of materials and for the correct reading of the animation. Textures, which had previously undergone the baking process in Blender, were imported and inserted into the corresponding slots prepared by the software and again applied to the model.

In order to import the animation from Blender to Unity, it was necessary to carry out some steps that allow its reading and execution: creating an animator controller within the dataset, which allows organizing and generating the animation clips, and associated transitions for a character or object, inserting the imported animated clip into the animator section that controls the execution of the animation through nodes, and linking it with the newly created controller through a system of nodes prepared by Unity. This allows the software to read the animation and play it.

Once these steps were taken, the textured models and animated VH could be inserted into the scene.

The application of AR involved the recognition of the artworks (object recognition) as activators of the experience. This was made possible by the model target technology, through which Vuforia Engine allows the mobile device to recognize and track real objects and use them as targets to trigger the application.

The application also made it possible to generate guide views, which are silhouettes of the actual object that appear on the display when opening the application and suggest to the user the optimal framing for object recognition within the recognition range. Once the polygonal mesh of the object was converted into a 3D model ready to act as a target with the respective guide view, it was possible to import the dataset generated by the model target generator directly into Unity. At this point, the model target was inserted into the scene, superimposed on the reconstructive digital models, and placed correctly alongside the animated model of the VH.

In the case of the Yaksha and Gupta Buddha, the additions of the missing parts were placed in continuity with the existing statues. The stele and body that completed

Fig. 6 Steps of AR experience: object recognition, artwork integration, description by VH, users guide inside the exhibition (Modelling and processing: L. Lombardi)

the Buddha's head were placed at the side of the exhibited work because of its large size, which is not compatible with the current arrangement.

In all three cases, the VH places and moves alongside the works to precisely indicate the parts of the work described through the audio track during the experience (Fig. 6).

8 Conclusions

As seen, digital storytelling presented in this research involve multiple artifacts, in order to give rise to a historical-stylistic connection between the exhibited works in the form of a narrative. It makes use of numerous digital products and content: point clouds generated through SfM surveys, 3D models of the statues on display, reconstructive models of the gaps, written and oral texts, and, finally, a virtual guide that accompanies the public, engaging them in the visit. AR takes a central role in the process, allowing such products to be offered as information layers that overlap with the exhibit. The experience is user-friendly with personal devices and can contribute to the inclusion of populations of different ages, schooling, and cultures, but also, with appropriate implementations, of people with sensory and cognitive disabilities. In fact, AR, while typically linked to visual experiences, can include auditory, haptic, and olfactory experiences, expanding the channels of knowledge transmission. AR, therefore, similar to direct tactile experience, offers new opportunities for interaction, including:

- The direct sensory experience that, maintaining its centrality, can be amplified by the virtual component, through a balanced enrichment of information and sensations.

- Any digital intervention that needs an adequate preliminary study phase, and at the same time is adapted to the work on which it is being acted upon.

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Tactile and Digital Narratives for a Sensitive Fruition of Bas-Relief Artworks

Francesca Picchio and Hangjun Fu

1 Introduction to Digital Museum Narrative

The development of increasingly inclusive and engaging narratives of works of art has now become a prerogative of museums, which, thanks to the massive use of digital technologies for both documentation and communication, are collectively moving towards a general rethinking of exhibition itineraries.

Narrating an artwork implies establishing a multitude of dialogues, with the artifact, with the author of the piece, with the space in which the work is experienced, and, finally, with the user of the work. Therefore, representing it digitally goes beyond the simple concept of reproduction and copying. Its interpretation, even simplified forms or new significances, transforms the artwork into something else [1]. And it is precisely this something else, augmented with information that are useful to describe the artwork from other points of view, that has to find its own narrative logic within the museum itinerary. The museum is no longer a container of artworks but a place where knowledge is gradually created. It uses new digital technologies to communicate new information contents and to initiate new ways of interaction between these contents and the subject who benefits from them (through immersion, virtual reality applications, augmented reality, etc.) [2]. In the action of communication between the designer and artwork, the designer seeks to establish a dialogue with the work to elaborate a form, i.e. a drawing. In this sense, reproduction should not be a sterile copy, but a basis for a critical and specific reading of its components, enhancing those forms that characterize its values and meanings.

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The research experience presented is part of the development of a digital narrative of a sculptural work—as elaborate as it is complex—within an exhibition.

In particular, through the digitization of the original parapet of Donatello's pulpit in Prato, it was possible to start a reflection on the value of the 3D database and on the concept of copy, accessible both through its solid prototyping and its virtualization.

The premise for the research stems from the temporary absence of part of the work within the exhibition itinerary. On behalf of the itinerant exhibition Donatello, the Renaissance, the Ufficio Beni Culturali Musei Diocesani Prato and the Palazzo Pretorio Museum of the Municipality of Prato have temporarily loaned the artist's works, including two of the 15th-century pulpit panels, which will be exhibited in museums in Florence, Berlin, and London until 2023.

To overcome the temporary absence of the main examples of Donatello's work in Prato, from July 2021, the city's Ufficio Beni Culturali Musei Diocesani has promoted the creation of a temporary exhibition in the pulpit Hall in the Museum.

The research actions undertaken sought to fulfill a twofold purpose. On the one hand, the digitization of the original pulpit has been aimed at the production of a digital 3D database. This database, obtained by integrated image-based and range-based instrumentation, facilitated the production of drawings (vector reproductions, photomosaics, 3D models) aimed at an accurate and detailed description of the sculptural work. On the other hand, the generation of a database thus established made it possible to structure a digital presentation of the artwork through the use of 3D-printed models at different scales, as well as the use of the work from mobile devices, both on-site and remotely [3]. The two 3D-printed tiles of the pulpit fulfilled the task of visually filling the space left by the artworks on loan, with the possibility of being touched and enjoyed in a more stimulating and participative visit. Using augmented reality applications and markers placed near the pulpit, visitors can visualize the tiles on their mobile device and understand aspects not immediately perceivable by standard observation.

2 Foreword to Digitization for the Fruition of CH: The Case Study of Donatello's Pulpit

Donatello's pulpit, located on the right corner of the façade of St. Stephen's Cathedral in Prato, represents an architectural-sculptural work closely connected to the city and its relic, the Sacra Cintola. or Holy Girdle, the rope put by the Apostles around the Virgin's waist before her assumption into Heaven. On the occasion of the First Crusade (1096–1099), a nobleman from Prato, Michele Dagomari, in 1141 left the relic as a gift to the former Pieve di Santo Stefano, which, for this reason, it became a place of worship for the devotees. With the expansion of the church, due to the rapid and growing pilgrimage of the faithful, attracted by the Holy Girdle, the new pulpit was built in 1428. This element, which represents the last stage of the Ostension ritual,

Fig. 1 The external copy of the Donatello's pulpit, put in relation to the facade of the Santo Stefano Cathedral. Below, images from the decorative parapet (Editing: C. Rivellino)

was realized at the intersection of the south and west elevations of the Cathedral [4]. From this, even today, the Bishop shows the Holy Girdle to the crowd. (Fig. 1).

The artwork appears as a small round temple. Consisting of a 175 cm radius structure, placed more than 300 cm above the ground, the pulpit has an umbrella-shaped roof crowned by the statue of St Stephen, the city's patron saint. The circular marble parapet is composed of seven panels, separated from each other by pairs of fluted pilasters with Corinthian capitals. The refinement of the piece is mainly due to the decorative and sculptural tiles motif: a series of festive spirits, five per tile, joyfully dance for the Ostension of the Girdle, articulated on different depth backgrounds. To design them, Donatello was inspired by the figure of the putto, which in antiquity was believed to inhabit the paradise of Dionysus. The three-dimensional and dynamic effect, masterfully realized by Donatello in a thickness of a few centimeters, is made possible by the technique of stiacciato. The movement effect is amplified by a golden mosaic background that changes with the light effects, enhancing the Dionysian dances of the sprites. Unfortunately, the angular exposure of the artwork, which is strategic from a functional point of view, has also been the reason for its progressive deterioration. Since 1776, the artwork has undergone several restorations of its surface, which has been subject to constant erosion. The original pulpit was replaced in 1972 with a copy in resin and marble dust: this copy is the parapet currently visible on the right side of the Cathedral façade [5].

The original parapet, together with the bronze capital underneath, is now preserved in the Museo dell'Opera del Duomo (Fig. 2).

The undertaken documentation project, aimed at constructing a memory and a new digital narrative of Donatello's artwork, involved the copy—the external pulpit [6] and the original—the marble parapet displayed in the Museum rooms. The fast

Fig. 2 Images of the original marble parapet, conserved in the Museum of opera del Duomo di Prato. In the image above are visible the target positioned for integrated data acquisition (Photos: F. Picchio)

technological evolution applied to Cultural Heritage has provided increasingly accurate measurement tools but has also witnessed a substantial transformation in the type of databases. From such three-dimensional digital products, the drawer can read in detail the texture and imperfections of the material, its colorimetric component as well as its processing. About the communicative purposes to which the drawing must respond, processes of analysis, discretization, and segmentation of the data must then be implemented.

3 Procedures for the Production of Integrated Digital Databases

Donatello's original pulpit is located in the room of the same name in the Museum and is placed on a plinth 150 cm above the ground. Image-based (cameras) and range-based (laser scanners) instruments were used to make a digital duplicate of it. They have been applied to keep different distances between the instrument and the surface to be acquired, depending on both the performance characteristics and the communication goals to be achieved. To further increase the level of metric accuracy and textural detail, in parallel to the TLS Faro CAM2 S150 Terrestrial Laser Scanner and the Canon EOS 77D camera, the Artec Eva was used. This is a precision scanner that works with structured light to obtain metrically accurate and already textured 3D models of small and medium-sized objects.

Digital duplicates with a high level of detail have been produced for each of the seven parapet tiles, with reliability on the surface and material texture of the bas-relief in the millimeter range.

Thanks to the use of calibrated cameras and lenses, it was possible to obtain a photogrammetric model of the entire parapet, colorimetrically verisimilar to the different colors of the background mosaic and the sculpted surfaces of the original pulpit [7]. The photogrammetric model obtained by applying the Structure from Motion (SfM) methodology was appropriately scaled, based on homologous points, to the point cloud generated by the laser scanner application. The resulting orthometric unfolding on the plane of the seven circular crown tiles allowed for the representation of all elements in true size. This output becomes significant for a global vision of the system, as it allows each element or portion of it to be analyzed in relation to the others, understanding certain phenomena (e.g. compositional logic, chromatic choices, narrative decisions, but also aspects related to the monitoring and conservation of surfaces) not easily analyzed through a partial vision.

From the general orthomosaic, the images of the two panels III and IV were selected and optimized to produce a high-resolution for reproduction on a 1:1 scale. Once printed, this work replaced the two tiles removed from the plinth, producing a visual chromatic continuity with the original pulpit. (Fig. 3).

To enhance the three-dimensional component of Donatello's artwork, a detailed 3D model of the entire pulpit was produced with range-based tools, from which portions of the same panels were extrapolated, optimized, and processed to be prepared for 3D prototyping.

4 Reverse Modeling Processes for 3D Prototyping

In the field of cultural heritage, 3D printing finds its most specific application in museums and museum collections: here, the touch-accessible reproduction of sculptures, bas-reliefs, artifacts, mosaics, etc., drives the user into a new and in-depth type of knowledge [8]. The digital reconstruction process, developed from the use of laser scanners and photogrammetric technologies, enables non-invasive heritage analysis. When this process is realized in prototyping and 3D printing, it offers the advantage of reliable, lightweight, manageable, and reproducible copies. By working with these technologies, it is possible to model and produce copies at different dimensional scales while maintaining the correct proportions and textures of the material component [9]. The study of the digital duplicate of Donatello's pulpit was an opportunity to experiment with 3D printing to offer a more attractive tour. The two tiles were digitized and prototyped for 3D printing, enabling a new type of fruition, visual but above all tactile, of the sculptural work [10].

Fig. 3 Photogrammetric acquisition methodology and orthomosaic process for the positioning of the final photoplan on the pulpit **a**, that can be substitute with 3D printing **b** (Editing: C. Rivellino)

Starting with range-based instruments acquisition (Artec Eva, a structured light 3D scanner for small and medium-sized objects), a 3D database—consisting of 75 scans—was produced. Even though the prototyping process covered about 30% of the acquired data (2 out of 7 tiles), it was essential to generate a single complete 3D system of the pulpit to ensure proper alignment of the scans (Figs. 4 and 5).

The post-production phases followed two different software packages. The data acquired by the Artec Eva instrument are managed and processed using Artec Studio Pro software developed by the same manufacturer. After import, each scan must be optimized through the registration command. In this way, a process of aligning the individual clouds within the scan is carried out, to reduce errors caused during the data acquisition phase. This is followed by the scan alignment phase, which is carried out by identifying homologous points between adjacent scans. Once the scans are aligned, a reverse modeling process takes place whereby a single mesh surface is

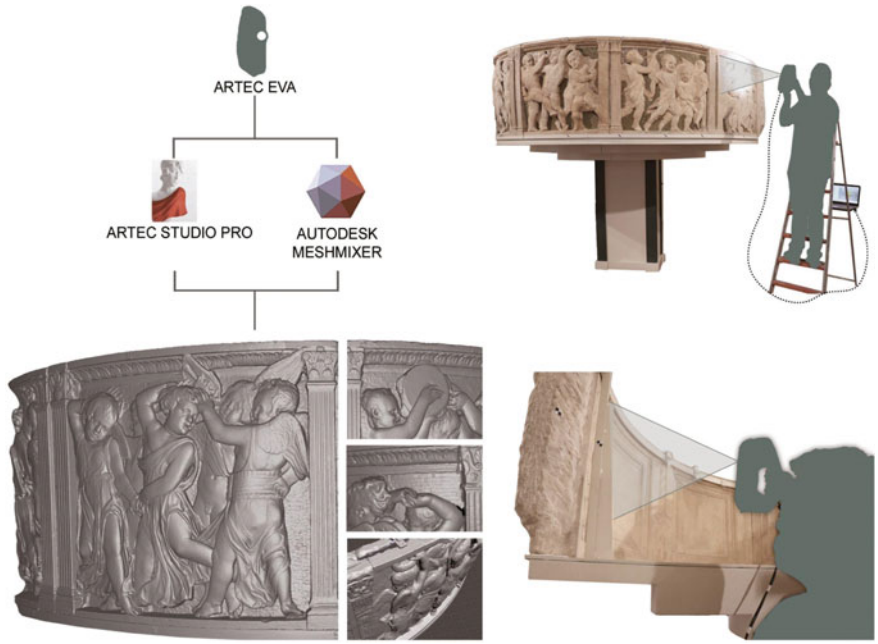

Fig. 4 Laser scanner data acquisition methodology (Modelling: H. Fu and C. Rivellino)

generated. The resulting mesh model of the two tiles (consisting of a triangular mesh of 58,820,300 polygons) was exported in.obj format.

With this amount of geometric information, it is possible to produce a model down to a scale of 5:1. For this reason, a significant decimation of the mesh was planned, reducing it by 50% (29,418,650 polygons). A second part of the model post-production phase takes place within the Autodesk Meshmixer software. This is where operations enabling optimization are carried out: removal of features caused by noise, removal of holes, reconstruction of small missing portions, etc., aimed at obtaining a closed solid model (manifold) (Fig. 6).

A number of 10 3D printers (Creality ender-5 Plus model)—part of the DAda-LAB and PLAY laboratories equipment—were used for the physical prototyping of the model. These are equipped with a 35 × 35 cm print bed and are among the largest desktop FDM 3D printers on the market. The maximum printable pattern size depends on the printing plate. It is—therefore—necessary to divide any model into several blocks of maximum 35 cm per side.

For the reproduction of 1:1 scale copy, a total of 18 blocks—9 for each tile—were provided.

Once the individual blocks have been set, the models are emptied to optimize printing time and costs. This procedure involves generating an offset surface, with the normal oriented towards the center of the block, thus transforming a solid into

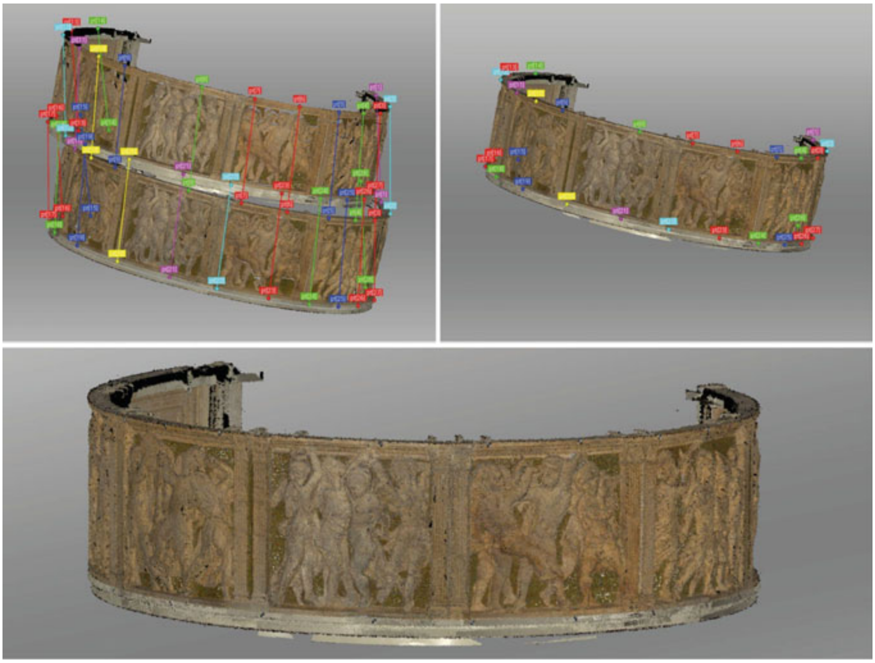

Fig. 5 Data alignment between scans considering target (Modelling: H. Fu)

a shell—without changing its external appearance—but reducing the filler material by around 60% (Fig. 7).

The shell thickness is determined by the set offset value (7 mm in this case), followed by different validation tests. To avoid any possible twisting or deformation, an internal reinforcement was inserted, a square-based joist connecting opposite surface walls. Finally, to avoid the automatic generation of the internal support, the upper wall was inclined by 15°. The optimized mesh model was exported in.obj format to be loaded into the 3D print management software (Cura Slicer). Codes were generated in.gcode format, and contains all the commands relating to the printing process (extruder position and speed, amount of filament injected, temperature of the print bed and nozzle).

Once the printing was finished, the automatically produced supports for the embossed parts were removed. The surfaces were cleaned of any imperfections due to residual material produced by the extruder. Finally, some surfaces were filed and grouted—removing any imperfections caused by the printing error—and then the parts were glued together (Fig. 8).

The use of white PLA filament, which makes the prints of the two tiles monochromatic, was a specific communicative choice. On a visual level, the objective was to emphasize the stiacciato technique, as the homogeneity of the color highlights the shadows and thus the depth of the bas-relief [11]. At a tactile level, it was planned

Fig. 6 Optimization procedures for features removal (e.g. noise, holes, reconstruction of small missing portions, etc.) (Modelling: H. Fu and C. Rivellino)

not to alter the height differences returned by the printer, which would have compromised the perception of roughness surfaces with even the slightest thickness. Furthermore, 3D prints can be made from materials that are more resistant to environmental conditions than traditional materials, making them more durable against changes in temperature or weather and thus increasing the longevity of artifacts [12] (Fig. 9).

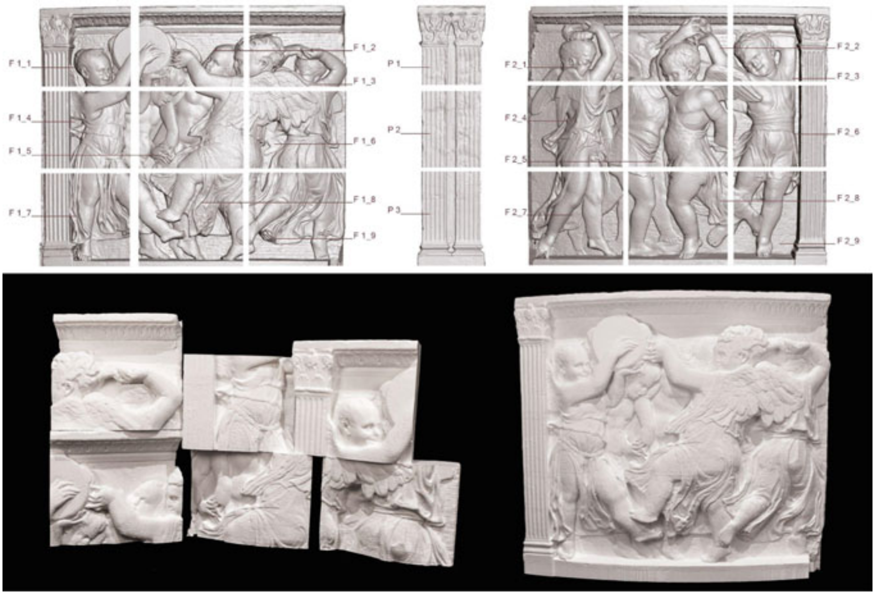

Fig. 7 Model segmentation in nine portions for each tile (Editing: C. Rivellino, photos: F. Picchio)

Fig. 8 The 3D printing process and the removal of any imperfection from the printed surface (Photos: F. Picchio)

Fig. 9 General image of the 1:1 scale 3D printing of the tiles. Below, detail of the surface roughness for the touch fruition (Photos: F. Picchio)

5 From Tactile Fruition to AR Applications

The 3D-printed model of the two tiles was displayed in the Museum's Sala del pulpito, with the possibility of being positioned in two different places in the room. An initial display was designed to insert the two printed panels in place of the two removed panels, creating a geometric continuity with the remaining panels of the pulpit but visually contrasting the uniform white coloring. However, the elevated position on the pedestal, although designed for direct real-digital viewing, does not allow tactile accessibility of all its parts. For this reason, a second fruition mode of the artwork has also been provided, to be used at the choice of the Museum's curators: the two printed panels are placed on a lower plinth, next to the original pulpit, to make them fully accessible. In the portion of the missing pulpit panels, the high-definition orthophoto of the two removed tiles has been inserted. This fact, in addition to facilitating the touch ability of the digitized and printed copy, also makes it easier to develop digital AR and VR applications to increase museum audience development [13]. In this way, it will be possible to enrich the visiting experience and spread knowledge of the work to a wider public [14].

A first Augmented Reality application of the interpretive mediation type was planned to restore the color component to the two PLA tiles: by using a smartphone and scanning a QR code in the proximity of the printed model, it is possible to virtually match the colorimetric information of the original tiles to the monochrome model. What appears on the display is a textured digital model of the two removed tiles, which aligns and overlaps with the 3D printed model. The communicative intention, in this case, was to achieve a visual effect that is anything but obvious: it is the user himself who, by choosing what to frame, gets to know the work through the discovery of certain specific chromatic aspects of the marble or polychrome tiles. The partial view of portions of textures, made possible by the AR application, prompts the observer to focus attention on details that are often missed in an overall view.

The alignment between the two models (the real monochrome printed one and the textured digital one) is ensured by the software developed. This automatically traces the image of the printed real model and, depending on the position and movement of the visitor, the application installed on the mobile device is able to dynamically correct the position of the digital model in real-time in relation to the static model positioned in space (Fig. 10).

The application for AR visualization of the textured component of Donatello's pulpit was developed using Unreal Engine 4 software, and prepared in apk format for Android devices. The function is activated via a QR code placed in the physical space or a touch button placed on the display of the mobile device. After the input signal, the model is loaded and automatically shown on the display [15].

A second application, of the type Outdoor guides and explorers, provided for the accessibility of the model outside the museum walls. Using the Sketchfab platform, it is possible to use the full-scale model (1:1) from one's mobile device within any space in which the user is located, via a link and in markerless mode. The activation of the AR function is followed by a time (about ten seconds) for the recognition of

Fig. 10 Augmented reality on-site and hall museum exposition with different digital outputs (Photos: H. Fu and F. Picchio)

the physical space and to establish a support plane on which the model is virtually placed. Once viewed, the user can move around the 3D model of the two tiles or freely approach them with a smartphone to enjoy the sculptural artwork from each angle (Fig. 11).

An advantage of augmented reality in such contexts is that it can provide augmented information at any point of a hypothetical museum tour or route, as well as in the comfort of one's own home or in places dedicated to education, thus promoting visitor learning in a more entertaining way (edutainment).

In this sense, augmented reality, as well as virtual reality, can play a relevant role from many points of view in heritage valorization and education, as they foster knowledge, re-elaboration and participation [16].

Not only the scenarios—real or virtual—in which the user is surrounded, allow the artwork to go beyond the physical limit of tangible matter. It is above all with the evolution of the museum user, who is no longer a mere spectator—in terms of perceptual mode and fruition sensitivity [17]—that the digitized artwork itself acquires new meanings and modes of interaction. In the user—artwork interaction, it can also be the user himself who configures his visit and which elements to interact with, as in the case of digital scenario reconstructions for serious games from accurate reproductions of the works [18]. In this sense, the contents of a artwork are constantly renewed, generating new forms of communication and allowing digital reproduction to change, preserving itself over time and becoming a artwork with its own identity.

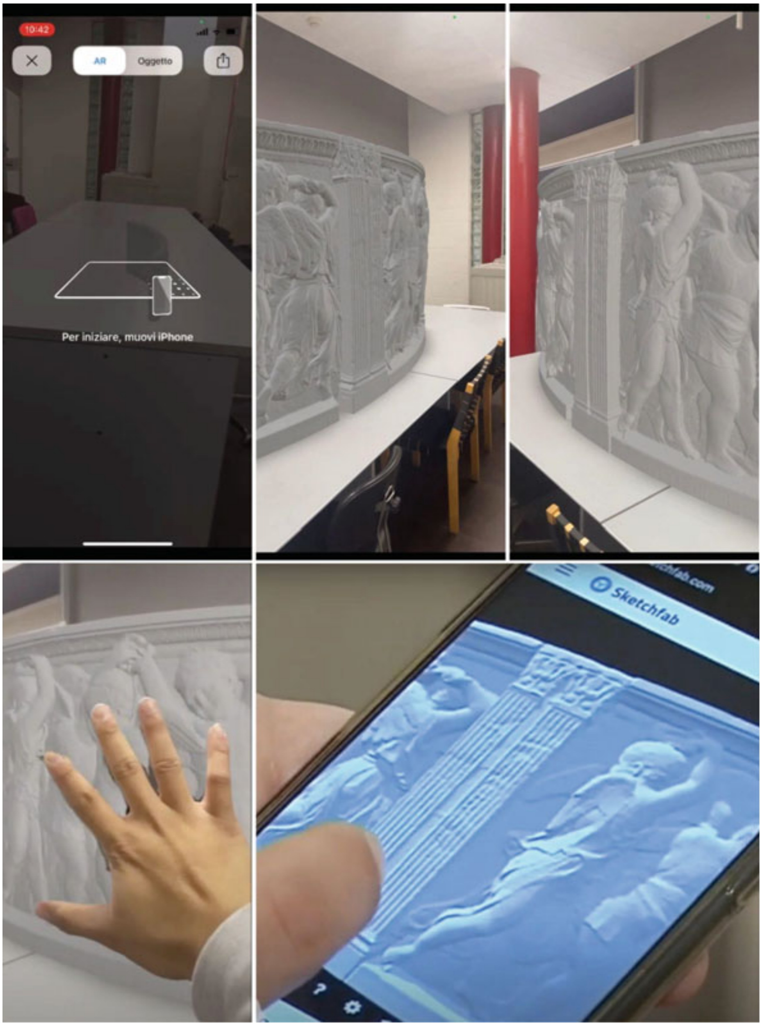

Fig. 11 Augmented reality for outdoor guides and explorers, using a device from which it can be uploaded a sketchfab model (Modelling: H. Fu, photos: H. Fu)

6 Conclusions

The relationship between digital technologies and museums, which has grown exponentially over the past decades, is now a phenomenon that current exhibition routes are unlikely to renounce. From websites to mobile apps, from touch installations to 3D printing, to augmented and virtual reality applications, the exhibition route is transformed by fully integrating technologies into the museum system, establishing a crucial shift from exhibition to heritage education.

Any operator can successfully reproduce the features of an artwork in a virtual duplicate that can be experienced by an electronic device. In addition to the faithful geometric reproduction of the model, a requirement that any duplicate must certainly possess, the technological museum layout aims to offer the visitor something more of the content and values of the artwork itself. In order for the work and the digital exhibition of which it is a part to communicate these values, it is necessary to effectively develop a specific and unambiguous museum narrative (a storytelling) [19]. This must involve the public to become an active part of an exhibition itinerary, so that each user can build his or her own visit path to know the artwork [20].

The exhibition proposal conceived for the pulpit room in the Museo dell'Opera del Duomo in Prato aimed at structuring a path of knowledge of the morphological and chromatic components of the pulpit panels, which could also be experienced through the use of digital tools and products. For this reason, different types of digital products and access to them have been envisaged. On the one hand, the touch reproduction of 3D printing makes them suitable for various educational purposes and attractive, interactive and inclusive forms of musealization [21, 22].

The copies realized become new representative models, which interpret the original work and increase its accessibility and knowledge, structuring an innovative narrative and exhibition route. Using augmented reality applications, an approach was undertaken to recreate the feeling of the presence of the two removed tiles, as if they were actually present and integrated into the real world, either in the room from which they were taken, or in an external environment, to be conveniently viewed at a time and manner chosen by the user.

In order to illustrate the digitization process undertaken and to encourage visitors to use the digital products on display, the exhibition design was accompanied by several information panels and a video trailer, designed and produced to describe the entire methodological process undertaken by the digitisation project (Fig. 12). The temporary exhibition the digital documentation of Donatello's pulpit, a journey of knowledge between Art, Architecture and Faith opened on 11 June 2022 in the pulpit room of the Museo dell'Opera del Duomo.

In the temporary installation project, the original pulpit work remains in the center of the room, while part of it houses the panels, video and 3D print. The intention was to integrate the new products into the environment and not make them perceived as disconnected or disturbing elements in relation to the original work. The basic idea is that technology can enhance its communicative aspect and user-friendly interface [23], without constituting—in any case—a cognitive, physical or economic barrier for the end user and the artwork, whether original or digital copy.

Fig. 12 Main informative panels that describe the digital research and the obtained products (Editing: F. Picchio and H. Fu)

Acknowledgements The documentation activities of Donatello's pulpit, promoted by the Director of the Museo dell'Opera del Duomo di Prato and the Ufficio Beni Culturali Musei Diocesani, in synergy between the University of Pavia and the University of Florence, and thanks to the funding of the Fondazione Cassa di Risparmio di Prato. Coordinating the research activities, which lasted almost a year and were directed by Professor Stefano Bertocci of the University of Florence, were Dr. Marco Ricciarini of the University of Florence and Dr. Francesca Picchio of the University of Pavia. A working group of PhD students, young researchers and students from the two universities was involved in the realization of the different digital products for the exhibition.

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AR&AI and Heritage Routes

Imagining Roman Port Cities: From Iconographic Evidence to 3D Reconstruction

Stéphanie Mailleur and Renato Saleri

1 Introduction

In the Roman imperial period, the control of the *Mare Nostrum* and the connection between Rome and its provinces were ensured thanks to an important port network that allowed to maintain an economic and commercial influence all around the Empire. More than a simple interface between the sea and the land, the ports are the object of particular attention and formed a real urban landscape, made up of utilitarian buildings and monuments organised around the port space in a scenographic and programmatic way. In recent decades, studies on ancient port infrastructures have multiplied. Despite recent archaeological excavations, our knowledge of port architecture under the Roman Empire remains very unclear. For the majority of ancient Mediterranean ports, the waterfront infrastructures are relatively poorly preserved due to the constraints of marine decay, the sea level variations or the modern construction projects. Archaeologists are able to reconstruct, most of the time, a plan but the third dimension is difficult to imagine.

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2 Context of the Research

In order to virtually reconstruct the urbanised spaces of port cities, archaeologists massively use a wide range of techniques enabling them to amplify their capacity to observe and analyse the remains of the past: the digital tools devoted, for example, to the analysis and interpretation of the data collected have benefited from technological contributions and innovations enriched in-situ and ex-situ for several decades now. On the other hand, this capacity to amplify the gaze of scientists still comes up against the difficulty of fully positioning the modelling, simulation and 3D geometric visualisation tools at the heart of the study. Indeed, the synthesis process involved in the final restitution of the anthropic space, often mobilising complex and highly specialised technical devices, almost always comes into play at the end of the line when the harmonisation of scientific contributions from the disciplines related to the context of the study have already in some way frozen the panorama of the hypotheses, particularly in the restitution of urban morphology or the representation of vernacular architecture.

This paper presents the research carried out within the framework of the project Modelling the morphology and dynamics of port cities in the Roman Mediterranean, funded by the LabEx IMU (Intelligences des Mondes Urbains) since December 2021. In a resolutely multidisciplinary and innovative approach, it follows the research undertaken in a doctoral thesis [1] which proposes an original reflection on the documentary potential of ancient iconographic sources to better understand the architectural aspect of Roman ports, by inevitably confronting them with data from the field and texts. It will also be based on the experiment conducted by the MAP around the 3D restitution of Portus, made possible thanks to the work of the Ecole Française de Rome and the participation of the Musée des Beaux-Arts de Lyon and Lugdunum, musée et théâtres romains de Fourvière.

3 The Ancient Iconographic Sources

3.1 Overview of the Corpus

Since the Augustan period, the Romans showed a certain enthusiasm for depicting maritime landscapes, which Vitruvius (*De Architectura*, VII 5, 2) and Pliny the Elder (*Natural History*, XXXV, 116) classed as *topia* (from the Greek *topos*, meaning geographical place). Port scenes thus became part of the iconographic repertoire of landscape painting and became widely popular, especially in the *pinakes* (from the Greek *pinax* meaning small pictures) of the domestic decorations of the second Pompeian style. The painting of Stabies (Fig. 1), shown below, like the series of Campanian paintings exceptionally preserved thanks to the eruption of Vesuvius in 79 AD, illustrates identifiable elements of port architecture without representing a specific port as many may have imagined. The painting decorates a private space, the

Fig. 1 Painting of Stabies (Villa San Marco). National Archaeological Museum of Naples, no 9514. 26 × 24.5 cm. first century (Photo S. Mailleur. Courtesy of the National Archaeological Museum of Naples)

cubiculum (bedroom) of the Villa San Marco in Stabies. It emphasises the aesthetic character of the natural and monumental seascape of the anthropised space.

The vast corpus of more than 260 documents collected during the doctoral research illustrates the extent of port iconography in the culture of the Roman Empire. It bears witness to the importance of ports in Roman society. This phenomenon seems to be closely linked to the historical context under the Imperial period, marked by an intensive port development policy. The most significant was carried out in Portus, the new seaport of imperial Rome. This major event, which made it possible to remedy the frequent shortages of wheat in winter, is commemorated by the sesterces of Nero (Fig. 2) dating from 64 AD. This coin depicts an identifiable port by its legend AVGVSTI POR(TVS) OST(IENSIS) S(ENATVS) C(ONSVLTV) indicating the Ostian Port of Augustus, by senatorial decree. It is a synthetic but very evocative view of Portus through the accumulation of recognisable symbols [2]. The left-hand side of the coin depicts the southern part of Claudius' harbour with monumental colonnaded structures arranged in a semi-circular shape. These are most probably storage buildings. Their position on the mole not only facilitated the transport, loading/unloading and storage of grain, but they also occupied a prominent place in the urban morphology of the harbour landscape. These storage warehouses also had a propaganda purpose as they advertised the wealth of the Empire. Porticoes adorned the facades of the warehouses to highlight their architecture and monumentalise the urban space. The right-hand side of the coin represents the north pier on *pilae*. This is a common symbol in port iconography, symbolising the knowledge of Roman engineers and the technical prowess of building into the sea thanks to the pozzolanic hydraulic mortar (this technique is described by Vitruvius in *De Architectura*, Chap. 5, 12). The *pilae* patterns seem to be more than utilitarian structures,

Fig. 2 Sestertius of Nero minted in AD 64 in Rome (in https://commons.wikimedia.org/wiki/File:NERONE-RIC_I_178-87000967_PORTUS.jpg)

as they became one of the major symbols of the Roman port. This motif has been used in a number of port representations.

Derived from a pictorial genre that appeared in the first century and marked by the influence of the Portus model, inaugurated in AD 64, port motifs were multiplied and declined on different artistic supports throughout the Roman imperial period. They are, in fact, as well represented on small portable artefacts, such as coins (3 cm), engraved stones (1.5 cm), oil lamp medallions (approx. 7–10 cm in diameter) and glass flasks, as on non-portable artefacts such as mosaics (between 41 cm and 11 m), reliefs and frescoes, offering larger fields for decoration.

The so-called Vase of Prague (Fig. 3), shown below, is one of a series of glass flasks most probably produced in Campania at the end of the 3rd and beginning of the fourth century. It constitutes a real documentary treasure since it represents a port city identifiable by the inscription PVTIOLI (Puteoli, modern Pozzuoli) and provides precious topographical indications. Once again, the accumulation of recognisable symbols highlights the monumental character of the urban landscape and attests to the existence of infrastructures that could be verified by archaeological research (example of the pier on *pilae*). This image certainly corresponds to the standard of an urban model that can be compared with the painting of Stabies, but also to a certain proven reality insofar as certain elements of the landscape of Puteoli are still visible today (e.g., the amphitheater) or attested by other sources. For example, the existence of SACOMA (RIUM), a weighing place, is confirmed by epigraphy [3].

Fig. 3 Drawing of the decor representing the portscape of Puteoli on a glass flask. National Museum in Prague, no. 137. End of the 3rd-beginning of the fourth century AD (In: Gianfrotta, P.A. 2011. *La topografia sulle bottiglie di Baia*. Rivista di Archeologia 35: 13–40, p. 17, Fig. 4a)

3.2 The Documentary Potential of Ancient Images

The examination of the iconographic corpus shows the impossibility of treating highly codified images as snapshots of reality and highlights the stereotypes of an ideal port landscape in its monumental and human components. It provides the basis for an analysis of the codes of representation and stereotypes attached to the image of the port, which creates a prerequisite for using this corpus for documentary purposes of a historical nature. Considering images as historical sources is a fairly recent concept, since art, long considered to be merely illustrative, occupied only a marginal place in ancient history studies. Images can indeed make an important contribution to the study of the architectural and urban aspect of the main Mediterranean ports as they show elevations of port buildings that have now disappeared.

However, the main challenge of this work is related to the interpretation of these images. It is necessary to remember that they do not faithfully transcribe reality. They sometimes come from the imagination or are subject to the interpretation of the craftsman, artistic conventions, trends or even the requirements of the sponsor [4]. The type of representation also depends on the constraints of the support and the craftsman must therefore adapt his iconographic language [5]. For example, on coins, where the space to be decorated is relatively limited, the craftsman must use a recognizable symbol referring to an idea rather than representing details as on frescoes or mosaics where the surface to be decorated is much larger ambitious.

In general, Roman art is subject to a standardization of forms and we can see a certain repetition of symbols. As Roman art is a communication system, to be usable, it is necessary to stereotype the symbols [6]. This explains the rather static character of Roman art and why the visual language corresponds to a standardization of the visual message often resulting from already known iconographic repertoires (example of the sacro-idyllic landscapes, Nilotic landscapes etc.).

As we have just seen and in order to overcome the issues related to the credibility of the images, it is essential to cross the iconographic sources and to establish correlations with the texts and the recent archaeological data which will make it possible to contribute to hypotheses of restitutions scientifically and historically credible.

4 Digital Approaches for Archaeology

This project benefits from a well consolidated technological maturation: for many years, digital tools have found their place within the design process. Biomimetic formalisms, genetic algorithms (Fig. 5) or rule-based systems are all fields of exploration able not only to produce unexpected forms but also to respond to environmental constraints with more variety and maybe more un-expectancy, strongly aware of potentialities and possibilities offered by a rapidly changing environment [7, 8].

We are now witnessing a shift from a transformational instrumentation model to a generative instrumentation model, which can overcome contextual and cognitive limits that were previously not easily accessible to digital environments. These new modalities of assistance of the creation process based on digital generative mechanisms have opened the way in which digital tools become a proposal partner, a support of perpetually renewed mental representations of the object of study [9]. This dynamic, deeply inscribed in the MAP laboratory's problematics since its birth, finds today new synergies with new scientific communities, many of which only lend digital tools the capacity of producing beautiful images when asked.

In this project, specific heuristics are used to build virtual simulacra on demand according to the needs of the restitution. Archaeologists are able to describe with great precision the built archetypes that populate the urban spaces of antiquity: the representations that have come down to us are multiple and the architectural characteristics of these subjects present morphological and decorative characteristics that can be analyzed, decomposed and recombined by using digital heuristics that are now well identified. These software environments exploit software bricks that help the designer to find formal and/or functional solutions with the help of sometimes bio-inspired mechanisms, able to adapt to a given environment by optimizing a set of intrinsic characteristics, which in the case of architecture can be morphological [10, 11] or structural [12, 13].

In the field of archaeology, the creation of multi-scale urban simulacra responds to the need to represent vanished urban realities of which only traces can be found today: on the ground, there are numerous buried remains, remains of built systems eroded by the incessant succession of urban transformations responding to the changing uses of individual and collective practices.

The ensuing sedimentation, often borrowing from the past the available materials already shaped for a different use, stirs up the urban fabric in depth, whose analysis and interpretation is permanently subject to caution. Some tools that are extremely complete from a descriptive point of view (City engine, GML or CGA) have the disadvantage of being difficult to use for non-specialist users. The mobilization of dedicated operators for the formalization of hypotheses (3D computer graphics artists, computer scientists, developers, etc.) de facto postpones the clean-up of the design and removes any critical possibility of questioning it. There is therefore a real need to bring back the instruments allowing the shared arbitration of the restitution hypotheses to the very place of the study field, whether it is an archaeological site or an exchange space.

4.1 Parametric and Generative Design Applied to Architecture

The parametric construction of architectural objects does not necessarily follow a constructive logic, at least not in its operational expression. Rather, in order not to overload the geometry, it must follow a preliminary decomposition of semantically identifiable architectural entities, naturally responding to the lexical scope of the expressed term, and classifiable by constructive groups: these groups gather homogeneous elements from the descriptive point of view but may incorporate topological descriptors that will allow to modify some characteristics. The difficulty consists in defining a conceptual model whose ergodicity would allow the description of the most disparate architectural morphological varieties but respecting the overall compactness of the descriptor in order to speed up the description process.

Importance is given to the research of the smallest morphological polytope, a study of which has already been carried out and presented in more detail below. It is thus considered that any architectural form can be decomposed, or factorized, to a very simple set of primitives which can be, by simple geometric transformations (translation, scale or rotation) be used to produce complex formal combinations [14–16]. As an example, this has made quite difficult to parametrically model the historic district of Lyon, France, (Fig. 4) in that we are witnessing a radicalization of a very localized building system: where the span was carried out between two wall slits perpendicular to the street, with consequently a greater freedom of arrangement of the windows of the street front, from the sixteenth century onwards the load-bearing walls became the walls facing the street, with the need to respect the constraints linked to the lowering of loads materialized by a strict superposition of the openings made in the façade. This effect will need some very specific descriptors as almost all the façades are unique.

When based on rules, the underlying description model will also try to include a reasonably limited set of descriptors, sufficient to discriminate against most formal disparities for a given family of objects. In this way, when faced with a historically coherent fabric, it is relatively easy to produce a credible disparity through a limited screen of parameters: for this banal architecture, often representing most of the architectural corpus of an historical city, less than a dozen of simple rules will suffice.

Fig. 4 Parametric design of the buildings of the Vieux Lyon district, France (untextured). The Maison du Chamarier (textured), because of an excessive amount of descriptive parameters, had to be designed manually (3D modelling and rendering: R. Saleri 2008–2009)

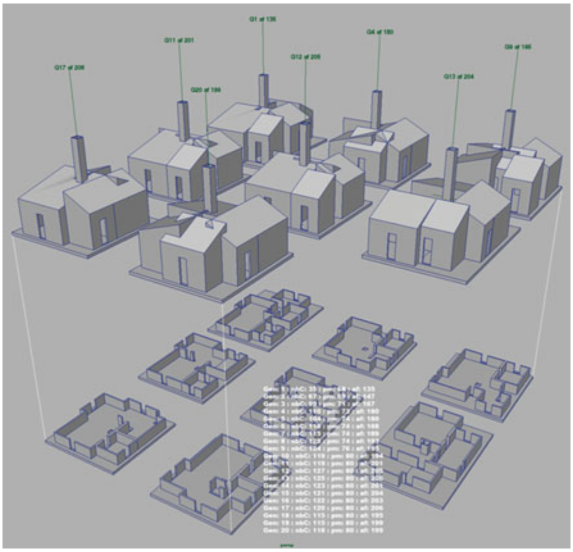

Fig. 5 Genetic algorithm applied to generative design (Programming and editing: R. Saleri 2012)

With wide or unique monumental or religious buildings, such a descriptor would need an enormous number of specific parameters necessary to describe a single constructed object and require a single set of specific rules, which would of course be counterproductive. Former works explored the way to express in a more structured way the geometry of historic buildings through a recursive enumeration of its constituent elements: for example, they use L-system formalisms that make it possible to model in space and time less linear growth phenomena that are closer, we believe, to the growth dynamics that we encounter in real life. Their recursive and auto-similar properties can e.g., introduce incremental levels of detail that can simulate the growth or the transformation of a built ensemble over time. For instance, L-systems, which are usually involved in modeling plant growth, are based on axioms and rules whose structural expression is applicable to architectural parametrization: redundant and self-mimetic characteristic applied in real life for manufacturing processes simplification can match fractal recursive dynamics: when applied to architecture, an infinite number of credible architectural or urban alternatives can be obtained.

Several formal heuristics have been explored during preliminary investigations on extremely disparate urban examples. The latest user-friendly urban modeler developed introduces a new GUI (Fig. 6), rewritten from an older release implemented and tested in the case of the Portus study mentioned above, extensively redesigned in terms of ergonomy and descriptive variety (Fig. 7). Three dimensional scale accuracy and the redefinition of vertical spatial distribution has been completely redefined: starting from the ground floor and the entresol, we describe each of the floors in a distinct way, (with the possibility of adding elements projecting or recessed), the attic level, the acroterium, a crown and the roof, which can be declined according to all the typological variants encountered at the time, straight or hipped roof, flat terrace or with acroterium monumental roof with lapidary or statuary elements.

The texture is applied floor by floor and allows to cover a large number of typological varieties of possible bays: blind facade, windows arranged in staggered rows, mullioned windows or with several lights, loggias or colonnades but also facades with bays distributed in a regular way favoring the descent of loads on load-bearing facades in particular or large bays with a low arch or a central arch (often present on gables or high parts of monumental buildings).

Fig. 6 A simulated urban fabric of Pompei, modeled with the bespoke tool developed within the project (Programming, editing and rendering: R. Saleri 2022)

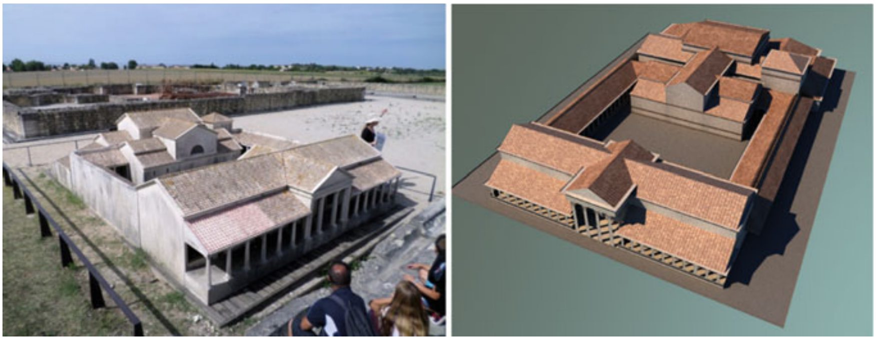

Fig. 7 Thermal baths of Barzan, simulated within the modeler and compared to the scale restitution (Programming, editing and rendering: R. Saleri 2022)

4.2 Gathering Collaborative Strategies

The project focuses on trans-disciplinary connections within a network of disparate scientific communities involved in a broad scientific perimeter. So far, we organized several events, both online and offline (launch days, University of Lyon thematic presentations, European Archaeology Days 2022, Roman Ports seminar but also direct confrontations with the various actors involved, Caen, Ostia …) that led us to identify shareable methodologies driven by new digital approaches (VR and AR public presentations…).

Generative design aroused the interest of many participants from different disciplinary fields: roman ports but also the transformation of coastal landscapes and the peculiar connections between harbors activities and the development of local and distant urbanism. The Roman ports seminars permitted to share the most recent research fields and to promote significant advances with expert and non-expert audiences. Finally, the assiduous dissemination on social media (announcements and transcriptions of major events, methodological achievements, thematic videos…) as well as the maintenance of mediation and dissemination supports (presence on the IMU and MAP portals) guarantee an increased visibility of the actions in progress within the project and feed its scientific influence that will be developed in its duration and in its academic and institutional outreach.

5 Perspectives

We are convinced of the preponderant role that generative approaches will have in the future—in the light of the most recent advances in the field of artificial intelligence—not so that they replace the creativity process but, on the contrary, to allow the discover of new paradigms able to consider the increasingly pressing environmental and technical constraints [17]. It will also be the occasion to develop new strategies allowing to ease architectural or urban design [18], to instrument and to stimulate the inventiveness in situation of project by producing rather objects to think than objects to build, and by accompanying what Donald Shön calls the reflexive conversation with the materials of the situation not only with the aim of arousing creativity but in order to enlighten, in a more global way, the paths of innovation [9].

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Virtual Archaeology. Reconstruction of a Hellenistic Furnace at the Duomo Metro Construction Sites in Naples

Luigi Fregonese, Mara Gallo, Margherita Pulcrano, and Franca Del Vecchio

1 Introduction

The 3-D modeling of an archaeological site is presented as part of an integrated methodology that originates from a documentation and indirect survey phase and arrives at defining a three-dimensional model only after studying, analyzing and verifying every piece of data derived from the excavation campaign and associated written sources.

The three-dimensional reconstruction, subsequently inserted within a virtual scenario, aims to offer a visual translation of a set of interdisciplinary research that aims at different objectives, including documentation, conservation and enhancement of the property. In addition, the production of the three-dimensional models goes to support analysis and interpretation for the development of reconstructive hypotheses, enabling the creation of information tools and Virtual Reality models for the promotion and narration of archaeological heritage especially that which is not accessible, reconstructing the historical memory of a place within the digital environment.

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With the arrival of new Virtual Reality and Augmented Reality technologies, the communication of data regarding archaeological excavations has progressed from the simple creation of informative databases to that o true containers of images and interactive three-dimensional representations.

Virtual Archaeology, using representational methodologies involving the use of interactive 3-D models, makes it possible to understand not only the development and phases of an archaeological excavation, but also to simulate three-dimensional reconstructions of an environment in a configuration different from the actual one. Based on an accurate historical analysis of the elements and structures of the excavation, it is possible to create a visual knowledge model, populated with information and multimedia content that allows for in-depth exploration and narration of archaeological contexts not otherwise accessible [1].

The goal of creating 3D virtual environments is not only for outreach and education, but also for analyzing and comprehending the archaeological site.

2 Indirect Survey and 3D Models: New Frontiers for the Management and Reading of the Archaeological Heritage

2.1 The Indirect Survey in the Archaeological Context

New technologies have found powerful applications in the field of archaeology and Cultural Heritage by enabling a new reading of the past. Indirect surveying (range-based/image-based or their integration) offers much potential for managing, reading, and interpreting the site under investigation; in fact, remote sensing technologies can be used to monitor changes in archaeological site conditions and to identify any damage or destruction.

Information gathered through indirect surveying can provide a deeper understanding of the historical and cultural context of the object under consideration and offer a comprehensive view of the archaeological site and its relationship to its surroundings [2].

This type of survey provides important metric information, and the resulting point cloud and mesh become a rich source for subsequent in-depth readings and analysis. Working in a three-dimensional space allows one to tell the story of the complexity of the site and artifacts and to understand their relationships, overlaps, relationships, and connections at multiple levels.

Therefore, in order to compare these models, they need to be geo-referenced in space; in fact, their superposition is useful for the analysis of the most millimeter displacements or changes and for studying their history or statics. In this way, it is possible to continue with the archaeological study even at a distance of time, always having a measurable point cloud or mesh at hand. In addition, the photorealism of digital surveys, allows in-depth documentation of the surface characteristics of the materials, such that their stratifications and the different interventions that have occurred over time can be identified, without contact with the object and, therefore, avoiding any direct interference.

However, for a better understanding and preservation of the heritage, the point cloud and textured mesh may be considered necessary but not sufficient because the surveyed structures are often not complete in their entirety and their interpretation is not straightforward. For this reason, the construction of a 3D model of the asset, thanks to the disciplinary input of expertise from different fields, allows digital proposal of solutions to recompose the findings, revealing and making usable the lost heritage that would otherwise be impossible to know.

2.2 The Construction of the 3D Model

Parallel to the field of restoration, the application of digital technologies and the use of tools to generate three-dimensional study environments has also expanded into the field of archaeology.

Virtual archaeology has an educational and popular role in the reconstruction of monuments, cities and territories to communicate ancient cultural heritage in an efficient, rapid and repeatable manner. It allows a correct and immediate understanding of the past, even of elements that are not accessible or even disappeared, through easy-to-use fruition tools for every user. The basis of virtual fruition is obviously the construction of a complex model with dimensional and colorimetric information of the analyzed area.

The process of acquiring 3-D data using passive sensors is an established practice in the documentation of cultural heritage, however, it gains more importance in the field of archaeology because of its ability to produce extremely realistic images of surfaces, which are essential for a detailed understanding of layering and decoration. Three-dimensional models built from these surveys can be a valuable tool for communicating and conveying a great deal of information without neglecting qualitative and methodological aspects.

3D models provide data on the size and condition of the surfaces examined and, in some cases, can improve the understanding of some details that are not easily visible or not immediately understood. Obviously, it is necessary that these 3Ds use the point cloud or textured mesh resulting from a scaled and color-accurate photogrammetric survey as a starting point.

The use of computer technology in Virtual Archaeology is characterized by a high communicative and learning impact, both for the high quality of scientific and cultural content. The purpose of 3D is the reconstructive study of artifacts according to specific principles, methods and techniques, and it mainly integrates methods of dissemination and communication with the help of virtual and/or augmented reality systems. These systems use all available media and in turn employ immersive and semi-immersive viewing systems that allow user access both online and offline, on mobile devices or computers. However, there are also critical issues in the adoption and implementation of three-dimensional reconstructions.

The field operator faces the first practical difficulty, because the activities may involve large areas, masonry structures but also detailed elements. For this reason, he must each time calibrate the acquisition of the photographic dataset with respect to the tool used and the degree of detail required. He has to integrate nadiral acquisitions with inclined and convergent ones in order to return a complete cloud, faithful to the original and responsive to the needs of the model and to the irregularities of the built environment.

Another difficulty is the technical aspect, as the archaeologist often lacks the necessary knowledge for advanced use of new technologies and must delegate the implementation of a reconstruction project to 3D experts who in turn have limited knowledge of the historical value of the object they are building. Obviously, precise understanding of the object one wants to represent is essential to achieve a faithful and accurate representation. And this can only be achieved through traditional archaeological research, which includes thorough bibliographic analysis, timely iconographic investigation, accurate survey of the artifact, and constructive comparison between different scientific professionals.

Therefore, the three-dimensional representation necessitates and fosters the chance of creating a collaborative study environment among diverse professionals, enabling them to generate digital models for research, representation, and teaching purposes. In summary, faithful 3D model building is a good way for sharing and publishing research results in an easier and more immediate way for anyone and offers many opportunities for the understanding, preservation, and enjoyment of cultural heritage, but it requires an integrated and multidisciplinary approach to achieve the best results.

2.3 Use of the 3D Model Through Virtual Reality

The creation of a true-to-life 3D model requires the synergy of different professionals in order to ensure not only a photorealistic rendering but also accuracy from a historical, archaeological and technical point of view. This 3D model can be used to create videos and animations to explain the site and its historical context in an easier and more engaging way, but most importantly, it can be enjoyed through virtual reality creating an effective immersive experience for all.

The enjoyment of the 3D model through virtual reality in archaeology represents a significant step forward in the understanding and enhancement of archaeological sites. The use of advanced technology to create three-dimensional models, from an accurate point cloud or mesh, allows for the involvement of an increasingly broad audience in the understanding and appreciation of archaeological heritage.

The technology used to create VR experiences was originally created for real-time rendering in video games, and as video games have grown in popularity, research has also become interested in their educational value. For this reason, virtual reality is a technology that can transform the study of archaeology into immersive educational or research experiences. Players in VR are not just playing a video game, but can move within the model, explore spaces and observe details from different perspectives, making the study experience more engaging, interactive and immersive.

Virtual reality is a technology that stimulates a user's senses and places them within a digital environment, the greater the photorealistic rendering of the model the greater the user's involvement.

This makes virtual reality particularly suitable for experiential inclination in virtual environments because it can be as effective as learning in the real world outside of virtual reality; in fact, when players feel that their experience is personal, they can more effectively absorb the learned content.

VR is unique in the way it transports players inside virtual environments and provides a sense of presence in that environment, in this way it allows them to overcome the physical limitations of the archaeological site, making even the most remote and hard-to-reach parts accessible.

It also makes it possible to visualize the site as it was in the past, reconstructing the original buildings and structures that may no longer be present or visible today. It enables greater information sharing and accessibility to archaeological sites, in fact, it is possible to share the 3D model with colleagues and students around the world, allowing them to explore the site without physically traveling to the place.

The ability to place the model in a device such as Oculus Quest allows for a fully immersive tour of the archaeological site, allowing the details of the model to be explored naturally and intuitively. With these devices, archaeologists can walk around the site, set up a bird's-eye view above the excavation, or collaborate across large distances with other professionals in the same-shared space. This could potentially open up archaeological sites to multiple researchers who cannot personally travel to a site.

The same concept applies to individual artifacts: museums could digitize their collections, and researchers, or anyone interested, could enter virtual reality and see 3D models of artifacts.

Through VR, it is possible to see objects from different angles, and this could be an advantage if the original artifact is very valuable or delicate and cannot be handled. In addition, it is possible to make the artifacts appear larger than they actually are in order to see details better. For these reasons, the combination of virtual reality technology with 3-D models is an important step toward greater accessibility and understanding of archaeological sites and artifacts because it makes it possible to overcome the physical limitations of a site or object, to study it interactively, and to share the information with an increasingly broad audience.

3 Technological Evolution in the Documentation of an Archaeological Excavation: The Application Case

3.1 The Duomo Station of the Naples Metro

The archaeological site of the Duomo Station of the Naples Metro Line 1 located in Piazza Nicola Amore in the heart of the city's historic center is chosen as the application case (Fig. 1).

The archaeological excavation, which began in 2003 and is still ongoing, covers an area of 2,000 square meters and involves an area adjacent to the plateau on which the ancient *Neapolis* stood and the southern side of the walls of the Greek, Byzantine and medieval periods. In 2012, the HE.SU.TECH laboratory took over the documentation of the excavation, using laser scanner survey and photogrammetric acquisition methodologies, both from SAPR and ground-based, to generate 3D models and digital orthophotos. This type of documentation, which has evolved over the years, has allowed and still allows for the identification and study of stratigraphic excavation phases and contextualization of temporal overlays of anthropological artifacts, even at a distance of time.

Obviously, constant research and close cooperation between management bodies and superintendencies have led to the continuous experimentation of solutions that can meet both site and documentation and knowledge needs while always taking into account the complex needs of an infrastructural site and the procedures for the recovery of important historical artifacts. Thanks to the use of advanced technologies and tools by the HE.SU.TECH laboratory, archaeological surveys within the construction site have become increasingly faster and more accurate.

Thus, the methodologies used have facilitated the evolution of the site, whose activities have continued in an expeditious manner, but without damaging the documentation of the site and favoring the preservation of the material found, which is

Fig. 1 Location of the archaeological site (*Photo* Google Earth)

partly demolished and partly disassembled into blocks and catalogued in order to be reassembled on site in later stages. For this reason, it is important to survey the precise location of the find and that all surveys are georeferenced.

3.2 Advanced Documentation of the Archaeological Excavation Phases Through Photogrammetric Survey

A series of photogrammetric surveys were necessary to document the different stages of excavation in the area under investigation. Most of the surveys are carried out using aerial or terrestrial photogrammetry because it provides a high photorealistic rendering. In fact, image-based surveys allow a more in-depth reading of frescoes or wall faces, and are more suitable in built heritage communication projects [3].

These surveys were carried out by hand or with a telescopic pole with SLR cameras such as the Canon EOS 5D Mark II and Mark III, using fixed 24 mm, 35 mm or macro 50 mm lenses (to capture the detail elements) that allowed a photo resolution of about 13 MP. However, given the vastness of the area to be documented, aerial surveying by drone has been chosen in recent years. At first with the Dji Spark and Dji Mavic Mini and since 2022 with the Dji Mavic 2 and Dji Mavic 3.

The latter drones allowed for a maximum photo resolution of up to 20 MP. The choice of instrumentation depends on several factors: the size of the investigated area, the size of the finds, and the archaeological significance of each layer. While the quantity of the surveys is related to the documentation needs of the archaeologists working in the field.

The area under investigation in this research is the Mezzanine area, which has a surface area of about 300 m^2 and a depth of about 12.5 m from road level. This area was investigated from January 2018 until April 2019, and 248 surveys were conducted. For each survey, the photogrammetric pipeline was followed on photo datasets consisting of at least 10 photos/sq m, processed in SfM Agisoft Metashape software. Dense point clouds were then constructed with about 250,000 points/sq m complete with position and orientation information and georeferenced using a total station. From these, mesh models were reconstructed and, subsequently, orthophotos were extracted at variable resolution according to the required graphic scale.

3.3 Georeferencing for Viewing on Multiple Levels

In archaeology, indirect surveying carried out with active or passive optical systems is a well-established but essential methodology for documenting sites and artifacts. The integration of reality-based methodologies with topographic ones, which as it is well known allow to determine the exact position of points with respect to a predefined system, allows to geo-reference the models through landmarks of known coordinates and reference points. In this way, the point cloud, whether acquired by laser scanner or processed photogrammetrically, is correctly oriented and scaled. For the Mezzanine area, also considering the type of excavation to come, nine targets were placed in the area taking into consideration both the morphology of the site and the elevation change due to the gradual decrease in land elevation (Fig. 2).

A polygon was then constructed around the area so that at least three targets were visible from different angles. Nevertheless, for some surveys, in individual rooms or in more cramped parts of the excavation, it was necessary to augment the network of polygonal vertices with secondary targets. From the orientation of the instrument—a Leica TCRM1203 total station was used for the specific research—on at least three targets, position information of notable points present in the excavation, materialized with nails, labels and markers, was recorded by radiation. The point clouds were then reported in the same absolute or geodetic coordinate reference system and important in Recap Pro visualization and editing software.

This software allows rotating, section, turning on and turning off the layers related to the different archaeological phases, allowing studying the evolution of the excavation and getting a clear and immediate perception of it (Fig. 3).

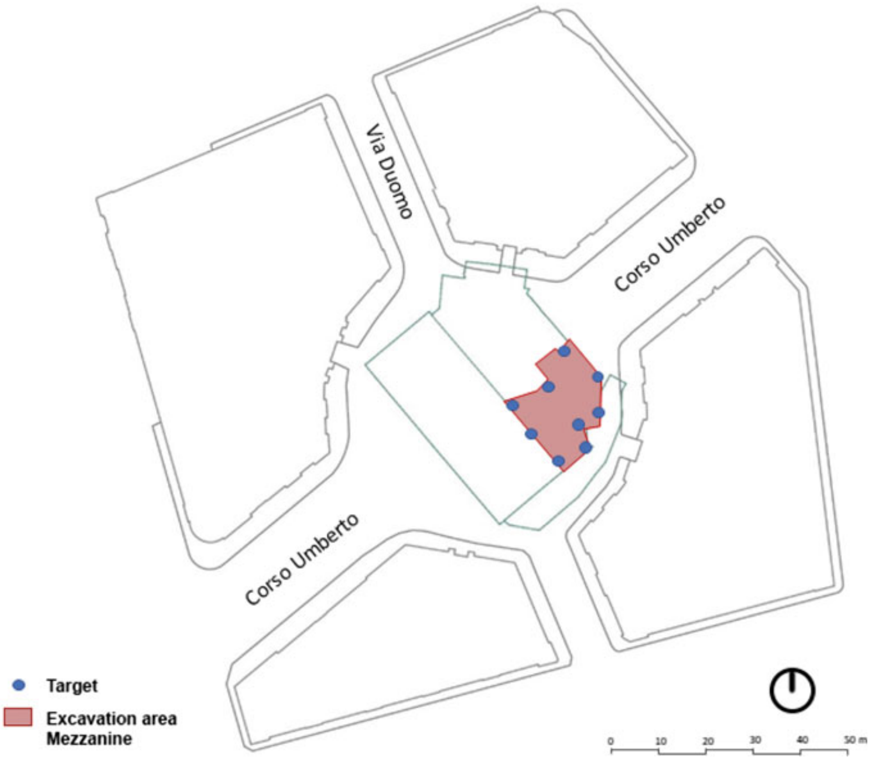

Fig. 2 Targets for topographical survey (Editing: M. Gallo)

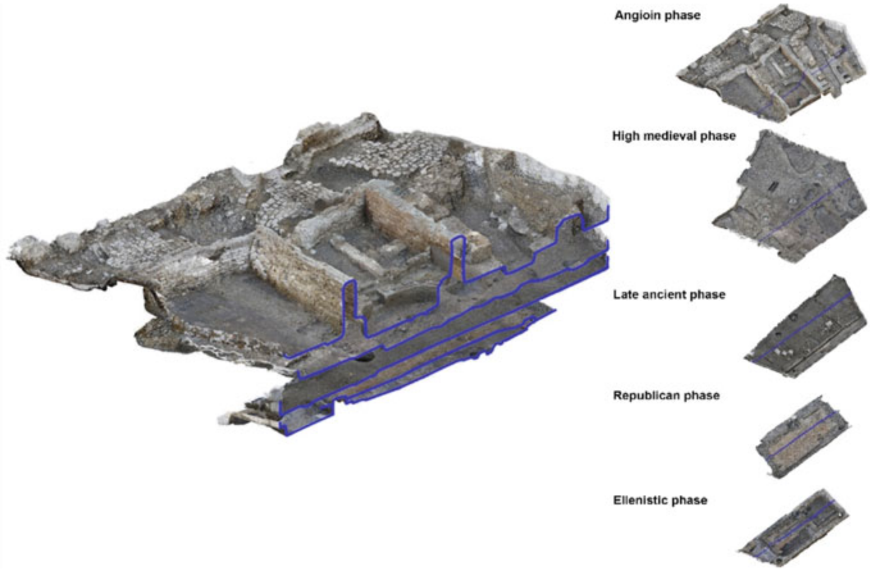

Fig. 3 Overlay of point clouds belonging to the most significant phases of the archaeological excavation in Recap pro software (Editing: L. Fregonese, M. Gallo and M. Pulcrano)

By inserting the different layers corresponding to the most significant phases of the excavation, it is possible to observe that there are no constant phases, but they vary according to the building evolutions and construction needs of the period, emphasizing the complexity of the fabric of the city of Naples over the centuries. In addition, by synchronizing and aligning the different point clouds acquired in different sessions, it is possible to identify any deformations and movements of the ground or structural elements, analyze the evolution of the construction site over the years, and becomes an essential support even for elements that are no longer in situ.

Thanks to Recap Pro, it was possible to grasp the operational sequence of the excavation, to look at the different layers in superposition and section, and to study differences in elevation or the evolution of the phases. Being able to place the studied site in a coordinate system facilitates its future research and consultation, and improves understanding of the context and spatial relationships between the different elements of the excavation (Fig. 4). Critically comparing these clouds has added important information about the excavation and has led to a greater knowledge of the site that can be the first step in setting up a restoration project or, as in this case, in building accurate 3D models of a specific phase.

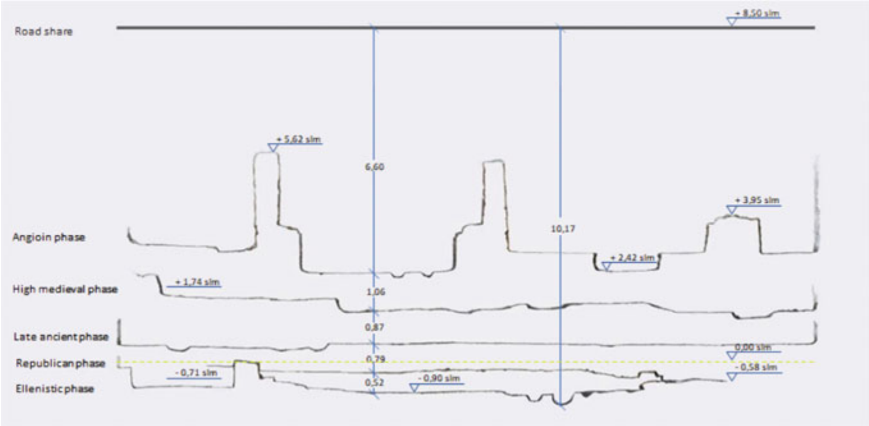

Fig. 4 Cross-section of overlapping point clouds with evidence of different phase heights (Editing: L. Fregonese M. Gallo and M. Pulcrano)

3.4 The Hellenistic Furnace

This research aims to focus on the last phase detected during the 2019 archaeological excavation. This particularly interesting phase is the Hellenistic phase and culminated in the discovery of a large kiln.

The Hellenistic extra-urban sanctuary, identified in the area under investigation, of a public character and cultic purpose was an articulated compound connected to the surrounding road network and served by internal routes. Here probably connected but independent apparatuses fulfilled different functions: worship, meeting and banquet halls, service rooms and artifacts for the production of pottery and building materials. Near the outlet into the road, the western boundary of the sanctuary, between the late 4th and early third centuries B.C., was represented by a large kiln intended for the production of amphorae, loutheria, bricks and loom weights [4]. Rectangular in plan, elongated for 12.00 m on the east–west axis and 4.75 m wide, the structure, half-buried, consists of a combustion chamber ascribable to the type with central corridor support whose *praefurnium* opens to the east onto a quadrangular forepart intended for loading and cleaning the firing area.

The perimeter structures of the kiln partly elevated and partly against the ground, consist of tuff blocks mounted transversely to the axis of the walls (diatoms) to give greater thickness to the walls and make them more solid, compact and resistant to high internal temperatures. Instead, tiles, roofing tiles and pieces of clay artifacts make up the linings that sew up sections of the interior facings altered by exposure to fire, the corridor and combustion chamber boundary piers, the sashes that in the initial phase define the entrance to the *praefurnium* and the supports of the perforated top on which the cooking vessels were stacked.

The combustion chamber, in its most complete arrangement shaped like a horse-shoe on the short west side, has a solid base foundation composed of tall slabs of yellow tufa lined with repeatedly renewed finishes. A fine mixture of clay and sand is spread on the floor, evenly carried over the walls of banks, supports and inner faces of the perimeter walls and covered with brick pavers in the central corridor.

4 From Reading the Elements to 3D Construction

4.1 Multidisciplinary Study from Photogrammetry to 3D Modeling

To date, multidisciplinary studies of an asset are done at multiple levels and by multiple skills in order to adapt conservation, restoration and maintenance strategies. In this research, in synergy with superintendence official Giuliana Boenzi and archaeologists Beatrice Roncella, Franca del Vecchio, and Riccardo Laurenza, we were able to advance reconstructive hypotheses of its various most significant phases. The first hypotheses were made from on-site observation and comparison with the reference bibliography.

However, we have to remember that currently that area of the excavation is totally used for the civil works of the subway, and the furnace is no longer on site. For this reason, high-resolution photogrammetric surveys become essential in order to ensure subsequent verifications, both dimensional but also colorimetric and structural, of details that may have initially gone unnoticed and to maintain historical memory of the find. From reading the surveys of the different layers related to the kiln, it was possible to understand and analyze the structural parts that have come down to us and to hypothesize other elements that composed it.

The survey selected as most significant and complete of the kiln was used as the basis for 3D modeling and reconstruction. Using metashape software, a dense cloud with a pitch of 3 mm consisting of about 22 million points and a low-resolution mesh composed of nearly 9 million faces and more than 4 million vertices was constructed for this area of about 60 m^2 (Fig. 5).

As is well known, models resulting from photogrammetry are models with a large number of polygons, which are suitable for the study of artifacts because of the high number of details, but not suitable for use in other applications such as in computer graphics render or similar [5].

For this reason it was necessary to lighten and decimate the model of at least 90% of the faces using the collapse command on Blender. In Blender software it is in fact possible to create a new mesh of the object with fewer polygons, and with a more regular structure, easy to animate and suitable for importing into programs for creating 3D animations, such as After Effects, Unreal 3D or Unity.

Of the original model, textures are retained, which can be projected onto the new lightened mesh for a more photorealistic rendering. At this point, we moved on to building all the elements, both the ones that are partially present and all the hypothetical ones.

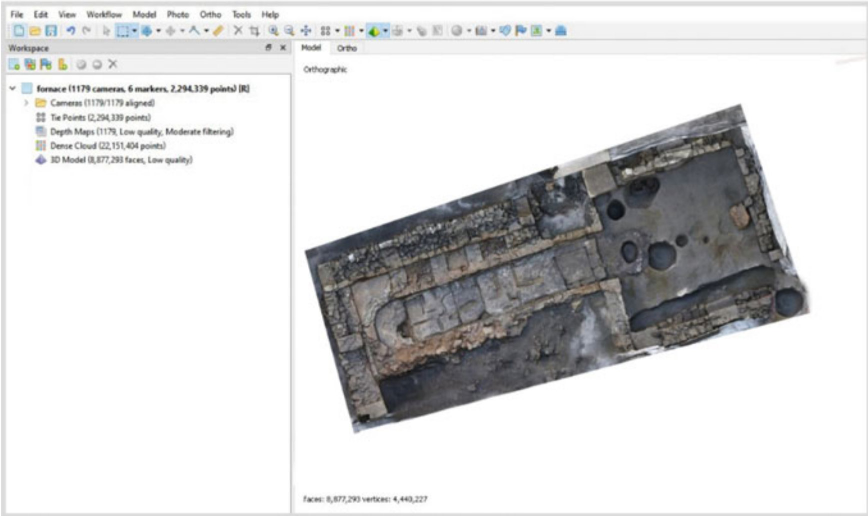

Fig. 5 Mesh model of the furnace in SfM Agisoft Metashape software (Editing: L. Fregonese, M. Gallo and M. Pulcrano)

Further investigations into this archaeological layer are currently underway to acquire a more comprehensive knowledge of this dynamic and interconnected system. In light of the current limitations of understanding the surrounding environment, the reconstruction of the furnace was made and studied independently of the complex context in which it is placed.

4.2 Reconstructive Hypothesis of the Furnace

The furnace was rectangular, elongated for 12.00 m on the east–west axis and 4.75 m wide. (Fig. 6a) The basement structure consisted of a horseshoe-shaped combustion chamber, which can be ascribed to the type with central corridor support. Here the fuel burned during the thermal cycle and developed the heat necessary to fire the artifacts stacked in the firing chamber above. From the survey, it is also possible to read the traces of the pillars supporting the perforated floor.

These are the essential structural element for the purposes of the load-bearing capacity of the kiln and must be as thin as possible so as not to take away space from the fuel and facilitate its exit but also resistant to high temperatures. The pillars allowed good circulation of air from the *prefurnium* and meanwhile supported the perforated floor and all the elements to be fired.

The *prefurnium* was a vaulted corridor that connected the combustion chamber. This was where the preheating phase took place and the function of drawing air in from the outside to feed combustion and aid draft (Fig. 6b) [6].

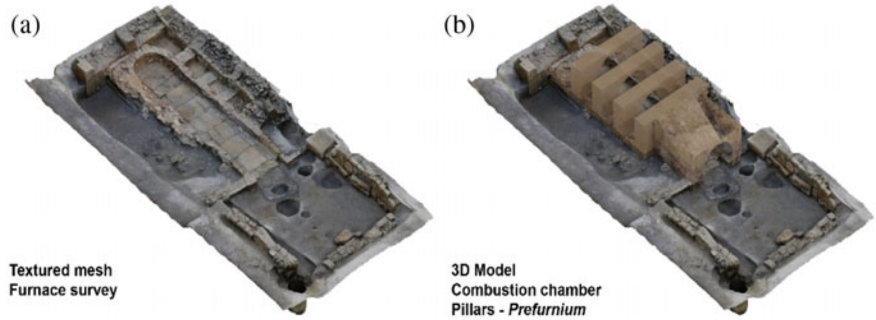

Fig. 6 a–b Textured mesh model of the furnace survey imported into Blender software; construction of the combustion chamber, pillars and *prefurnium* on the textured mesh of the furnace in Blender software (Modelling: M. Gallo)

Obviously, each furnace in order to support the artifacts and dissipate heat evenly needed a perforated top that acted as a barrier to the products of combustion and directed them in various directions, forcing them to divide evenly in the firing chamber above. This plane rested on support pillars and was enclosed within the outer perimeter walls. As can be deduced from the findings, the outer walls followed the size of the firing chamber to facilitate its construction.

They are made of tuff blocks, which makes them solid, compact and resistant to high internal temperatures. (Fig. 7a) From reading the external traces, it is also possible to deduce the presence of a forepart, that is, a room used for laying the elements to be fired or freshly cooked. It is not known whether this room was covered by a light covering or left uncovered. Furnace covers, on the other hand, could be stable or temporary.

In this case, the fixed tubular one was chosen for the reconstructive hypothesis. The vault rests on the perimeter walls where it discharges its own weight and is

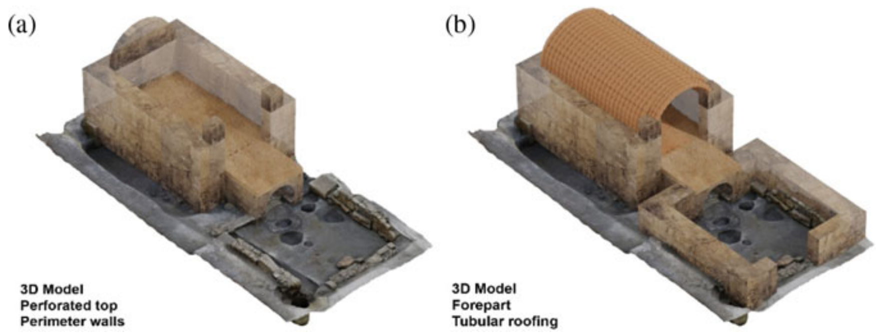

Fig. 7 a–b Construction of the perforated top and the perimetral walls; construction of the forepart and the tubular roofing on the textured mesh of the furnace in Blender software (Modelling: M. Gallo)

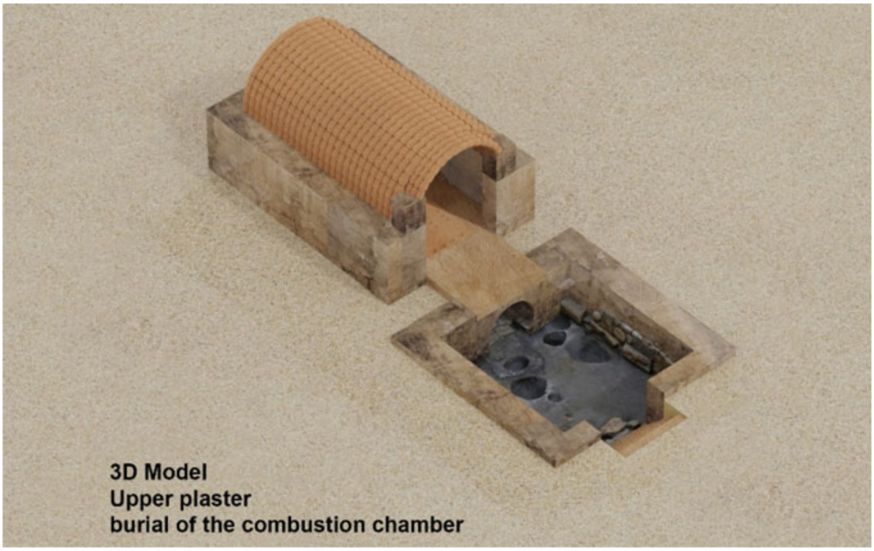

Fig. 8 Construction of the upper plaster on the roof and burying of the combustion chamber on the textured mesh of the furnace in Blender software (Modelling: M. Gallo)

composed of tubules embedded one inside the other and arranged in such a way as to create arches that placed side by side in series next to each other could create a light but also solid framework (Fig. 7b). A protective layer of uniform plaster with small holes to allow smoke to escape probably covered the tubular vault.

When the furnace was in operation, provision must obviously also be made for the chamber to be sealed with waste material that would buffer and completely enclose the firing chamber; the holes in the vault thus remained the only exit routes. In this way, there was less dispersion of heat, which was retained as long as possible inside. Finally, the burying of the combustion chamber was proposed for this reconstruction, which provided solidity to the system and created better thermal insulation (Fig. 8).

4.3 The Fruition of the 3D Model: An Application of Virtual Reality in Archaeology

The last part of the research involved the construction of the experience of fruition of the 3D model. Through the Unity application, a virtual tour of the kiln was built both in the state in which it was surveyed and in its reconstructive hypothesis, according to a dual level of fruition.

Unity is a cross-platform graphics engine that enables the development of video games and other interactive content, such as architectural visualizations or real-time 3D animations. After importing the 3D model and setting up the scenes, minor changes in the script were sufficient to be able to structure the fruition for both desktop VR and visor-based fruition. With desktop-type virtual reality, the user has the ability to freely navigate through the computer within the furnace and click on different elements placed within the model. This visualization needed some programming work at the base that would allow the user to navigate within the space and move in all directions. It also gives the ability to jump and teleport to some notable points and to click and move objects placed in the furnace.

Alongside this first experience, a second application involved the construction of an immersive VR by making the same project usable through visors. In particular, it was chosen to use an Oculus Quest 2 that, thanks to the associated controllers, allows interaction with the detailed elements of the scene. In this way, it is possible to walk, jump, grasp and rotate objects as if one were actually on the spot. For both of these types of fruitions, artifacts found in the Nicola Amore Square excavation that are hypothesized to have been made in the very kiln under consideration have been placed inside the kiln.

These are part of the main production of the site: stamped handles of Greco-Italic amphorae and different types of supports that were used for the proper stacking of the artifacts inside the firing chamber, but also bricks, loom weights or other fictile material. Their cataloguing was taken care of by archaeologist del Vecchio F., and for some they were also surveyed by laser scanner Scan in a box by engineer Fassi F. and architects Fregonese L., Gallo M., Pulcrano M., Scandurra S. [7]. Obviously, even these models before being imported into Unity were simplified using the Blender software. The faces were decimated by 90% using the collapse command and then the high resolution texture was associated with color information (Fig. 9).

In the final stage of this research, we tried to make the transition from the detected model to the reconstructed model quick and easy. To do this, we added a button at the bottom of the scene in both the desktop and Oculus applications. This button, when clicked, makes it easy to switch from the excavation view to the reconstructed furnace view, vice versa, making the experience more intuitive, and engaging for the user (Fig. 10).

5 Conclusions

In conclusion, 3D technology and Virtual Reality represent a huge advantage for archeology, providing an intuitive and easy to understand visual language to present the users with an overall view of the sites.

Their immediacy, simplicity and dynamism make them indispensable tools for communication and have profoundly influenced the way of acquiring and disseminating knowledge on the historical and archaeological heritage. Furthermore, in some cases, these technologies represent the only means of dissemination for assets that are no longer viable or visible to the public. Virtual reality is certainly a precious tool with rich potential, but it is essential that it is used with full awareness of its limits and risks.

Fig. 9 Stamp inserted in the furnace and usable via Oculus Quest 2 in the Unity application (Editing: M. Gallo and M. Pulcrano)

Fig. 10 Button for switching from the survey scene to the reconstruction scene in desktop mode (Editing: M. Gallo and M. Pulcrano)

The two poles of tension must be kept closely connected: virtuality and reality. One without the other they risk either the fable or the opacity of incomprehension. A close relationship between the two can instead be extremely fertile both for research and for teaching [8]. It should also always be remembered that archeology remains a field in continuous evolution, where new discoveries and new acquisitions follow one another constantly, contributing to keep our relationship with the past alive and changing. Our project therefore remains open to new and potential interpretations that could emerge from the excavation campaigns in the adjacent areas and from the study of the finds found in the neighboring urban areas.

The possibility of finding remains of the cooking elements or of the furnace itself, provides us with further information to confirm or deny our current interpretations. Since the knowledge of historical and archaeological heritage is a field in constant evolution and learning, the application of 3D technologies and Virtual Reality will vary according to the case, and we are always ready to adapt our approach accordingly, ensuring maximum completeness and accuracy as possible.

Acknowledgements We would like to thank the superintendent for the City of Naples, archaeologist Luigi La Rocca, and officials Drs. Daniela Giampaola and Giuliana Boenzi for facilitating and encouraging the study and publication of the contexts presented. In addition, our thanks go to the entire team, coordinated by Dr. Beatrice Roncella, working on the analysis of the complex and extraordinary archaeological evidence, from which the data analyzed emerge. The archaeological research is in fact related to the works for the construction of the Duomo Station of the Naples Metro, in Nicola Amore Square. Archaeologists M. Ascione, M. De Filippo, F. Del Vecchio, A. Esposito, R. Laurenza, architects from the Entasis studio and the Milan Polytechnic University collaborated on the excavation activities.

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Castello di Mirafiori: Reconstructive Modelling and WebAR

Roberta Spallone, Marco Vitali, Valerio Palma, Laura Ribotta, and Enrico Pupi

1 Introduction

The project results from a research agreement between the Department of Architecture and Design of the Politecnico di Torino and the Municipality of Turin to realise an augmented reality simulation of Castello di Mirafiori and cultural accompaniment for citizens funded by the European project proGIreg (productive Green Infrastructure for post-industrial urban regeneration). The building and the gardens are documented by archival and bibliographical sources (texts, technical drawings, views) whose intertwined information has made it possible to digitally reconstruct their morphology in the period of most extraordinary splendour and hypothesise their location. The digital model reconstructs the external structure, including the decorative apparatus and the complex of the gardens, schematised according to the findings of the documentary analysis.

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The project included the realisation of an installation incorporating augmented reality (AR) features aimed at making the results of documentary research and digital reconstruction accessible to a broad audience. The software was developed that interacts with an information panel installed at the castle ruins. The result is a web app made with the free and open-source software (FOSS) AR.js, which allows users to access AR directly from a web browser without downloading applications. It uses as the experience repository a web page of MuseoTorino, the virtual museum of the city.

Moreover, the creation of physical reproduction to scale through digital fabrication processes, as a function of inclusive fruition, with which to associate the AR experience, foreshadows future research developments.

2 Documentary Analysis, Selection and Interweaving of Sources for Modelling

All that remains today of the ancient Castello di Mirafiori, one of the out-of-town residences of the Savoy family, are a few arches of the cryptoporticus and a few sections of masonry toward the Sangone stream. The building was part of the so-called Corona di Delizie (Crown of Delices), that is, the system of Royal Residences, historically desired by the Savoy family to surround themselves with sumptuous *maisons de plaisance*, which arose between the sixteenth and seventeenth centuries around the city of Turin.

The history of the castle and gardens, reconstructed through documentary analysis, are described in Vittorio De Fabiani's [1, 2] and Chiara Devoti's [3] essays.

The construction of the original building began in 1583, when Giacomo di Savoia-Nemours (1531–1585), who in 1581 had purchased from Filiberto Pingone the Spinetta estate located between Moncalieri and Turin, undertook the building of a large palace equipped with gardens, according to a French taste model, probably completed around 1585. A few years later, in 1587, Carlo Emanuele I (1562–1630), who had purchased the palace, undertook two interventions on a territorial scale: the first to the north of the castle, with the tracing of a road, Contrada Nuova (coinciding with today's Via Roma) in a straight line from the Royal Palace to Castello di Mirafiori; the second to the south with the detour of the waters of the Sangone to define the design of the green. The following year, 1588, the Infanta Caterina (1567–1597), whom Carlo Emanuele had married in 1585, made the castle her summer residence and recognised its role as a *Delizia*. In 1618 Carlo Emanuele assigned the Mirafiori residence to his eldest son and future ruler, Vittorio Amedeo I (1587–1637). The plan for the palace's expansion for Vittorio Amedeo's wedding to Cristina of France (1606–1663) was preserved at the National Library in Turin and attributed to Carlo di Castellamonte; it can be dated between 1619 and 1620 (Fig. 1).

In the drawing, the main building with the two pavilions, the double system of staircases to the garden, the fence of the large courtyard of honour, and the gateway

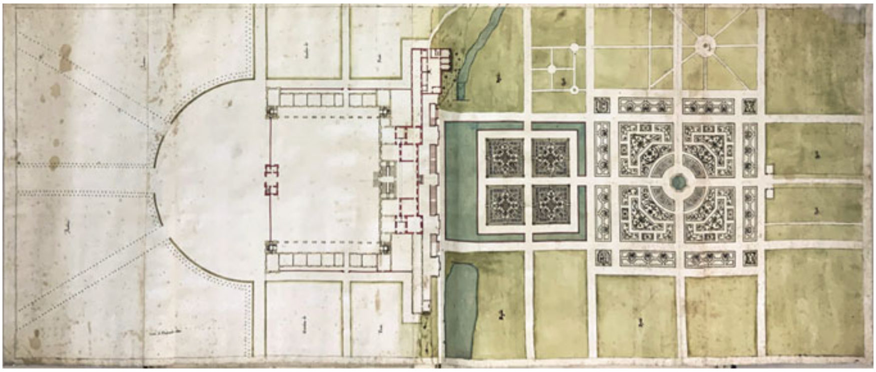

Fig. 1 Carlo di Castellamonte, Palace expansion project for the wedding of Vittorio Amedeo to Maria Cristina of France, 1619–1620 (BNT, Fondo Valperga, q I 64, n. 19)

on the axis of the palace to the main avenue on the opposite side appear to have been built (filled in red), while the expansions with the doubling of the main building and pavilions, the construction of the symmetrical wing and the low buildings flanking the courtyard to the north do not appear to have been documented. The 1655 view by Giovanni Tommaso Borgonio (Fig. 2), showing the castle as seen from the gardens, is consistent with Castellamonte's drawing.

Fig. 2 G. T. Borgonio, Castello di Mirafiori, da I Baccanali antichi e moderni […] (1655), View from the garden of the castle with two-pavilion and French-roofed, before the 18th-century elevation (BRT, St. P. 953, c. 49)

A 1715 *cabreo*, a sort of cadastre map representing what existed at that date, also confirms that the symmetrical wing featured in Castellamonte's drawing was never built and that the gardens had lost their elaborate chisel-like features over the years. Indeed, since Vittorio Amedeo died in 1637 and the subsequent difficulties of Cristina's regency, interest in the palace had been waning. It experienced a definitive decline after the duchess's death in 1663. The State Registers of 1740 describe the new organisation of the building, whose possession would officially pass to the Mauritian Order in 1753. Since 1726 the castle had undergone a transformation of its roofs and interior, aimed at its new function as a tobacco factory. The 1741 plates demonstrate the changes made to the palace; in particular, the longitudinal section accurately documents the interposition of floors to create as many as seven levels and the new roof conformation. On a smaller scale, the so-called Carta della Caccia (pre-1762) depicts the territory's layout with the palace's outline at that time. In 1779 the building was reported to be used for agricultural functions and in 1800 it was confiscated by the French government. Ownership passed first to the National List and later to Giovanni Battista Gambarotta. The estate valuation report described a complex that had undergone profound transformations but was not yet fully compromised. The flooding of the Sangone and the disinterest of farm owners, especially agricultural ones, which followed during the nineteenth century, caused the gradual disappearance of Castello di Mirafiori.

The location of the castle in the territory, of which the few remaining vestiges give some clues, was aided by the overlapping of the Carta della Caccia with the current numerical cartography (Fig. 3). This superimposition, carried out taking into account the changed flow of the Sangone, made it possible to assess the correct positioning of the castle with the principal axes of development of the seventeenth- and eighteenth-century suburban fabric and with the rural building, once in service of the castle, surveyed in the cadastre as a rectangular-plan building consisting of a rustic house, courtyard and garden (Fig. 4).

The digital reconstruction of the castle and gardens, taking into account the textual descriptions, began with selecting iconographic sources, which describe the morphological, geometric and architectural features of the artefact and the design of the gardens through technical drawings, paintings and views. Among the latter, two well-known plates from the *Theatrum Sabaudiae* (1682) [4] offer images that are certainly impressive for the monumentality attributed to the castle, doubled in its consistencies and made symmetrical, and the invention of a large architectural exedra towards the city, but they are not helpful for reconstruction. It was, therefore, crucial to identify, among the few technical drawings to scale, those helpful in crystallising the morphology of the building in a defined time range.

The graphical analysis, interwoven with the reading of bibliographical sources, made it possible to hypothesise the configuration of the complex in the period of its most extraordinary splendour, the one in which, between the late sixteenth and mid-seventeenth centuries, the two ducal couples -Carlo Emanuele I with the Infanta Caterina and Vittorio Amedeo I with Cristina of France- had elected the residence as a place of loisir for them and the court. Fundamental in this regard is, as we have seen, the drawing by Carlo di Castellamonte equipped with a graphic scale of *trabucchi*

Fig. 3 Superimposition of the Carta della Caccia, ante 1762. (AST, Carte Topografiche Segrete, 13 A VI rosso) to the digital map of the city (https://www.geoportale.piemonte.it/visregpigo/) (Editing: M. Vitali)

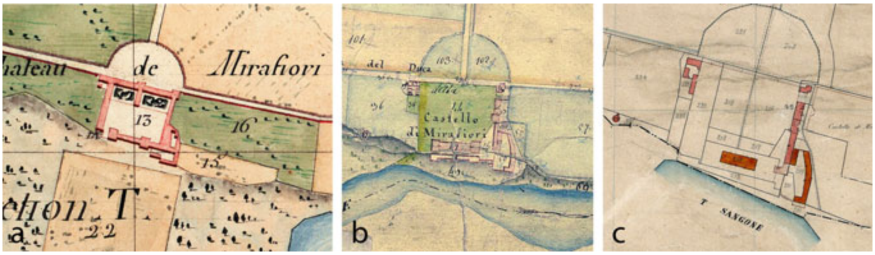

Fig. 4 Comparison between three nineteenth-century cadastres: **a** Catasto Napoleonico, 1805; **b** Catasto Gatti, 1820–1830; **c** Catasto Rabbini, 1866 (**a** AST, Sezioni Riunite, Catasti, Catasto Francese, Allegato A, Mappe del Catasto Francese, Circondario di Torino, Mandamento di Torino, Torino; **b** ASCT, CAG, Sezioni 18–19; **c** ASCT, Sezioni Riunite, Catasti, Catasto Rabbini, Circondario di Torino, Mappe, distribuzione dei fogli di mappa e linea territoriale, Torino)

(20 *trabucchi* ≈12.7 cm) and *piedi liprandi* (the Piedmontese measure unities of the time). Recall that the Piedmontese *trabucco* is ≈3.0825 m and its submultiples are the *piede liprando* (1/6 of *trabucco* ≈51.375 cm) and the ounce (1/12 of *piede liprando* ≈4.28125 cm).

This document, described in detail above, placed in projective correspondence with Borgonio's view (Fig. 5), allowed for a 3D reconstruction of the palace and made it possible to trace the layout of the gardens at the time of the marriage between

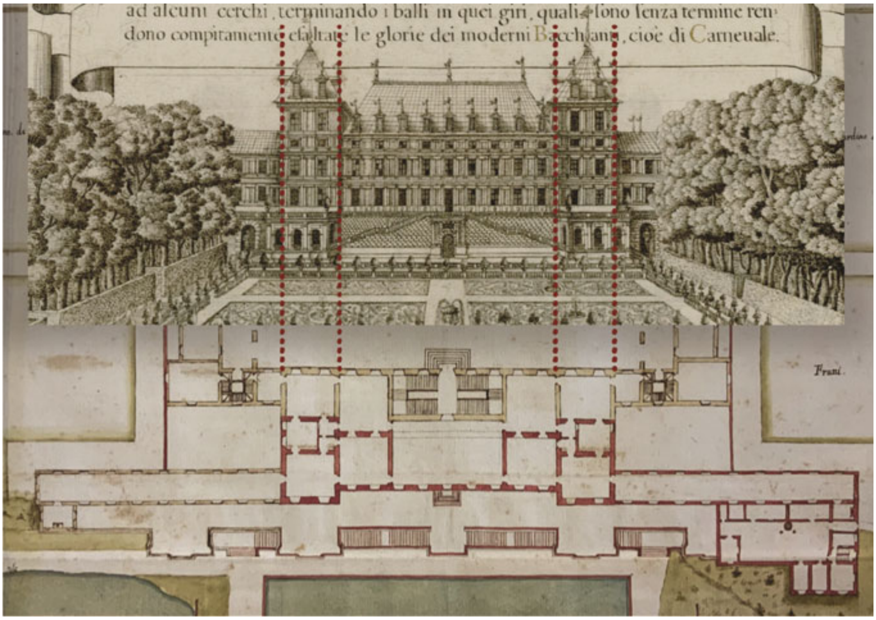

Fig. 5 Projective correspondence between the plan by Carlo di Castellamonte and the view by Borgonio (Editing: M. Vitali)

Vittorio Amedeo and Cristina. The validation of the informative, geometric and metric content of the view, drawn up in one vanishing point perspective, made use not only of the verification of the projective correspondence with the Castellamonte plan but also of the comparison with the longitudinal section that represents the 1741 survey, described above. The correspondence of the openings and floors, in the view and the survey, made it possible to consider Borgonio's engraving a reliable source.

The built consistencies were redrawn, and subsequent modelling in *piedi liprandi* was to verify integer and submultiple values.

The overall footprint of the castle results in 135 $\times$ 49.5 *piedi liprandi*, with an increase to 55 *piedi liprandi* in depth at the side pavilions. The height from the terrace towards the stream to the eaves is 31 *piedi liprandi* for the central body and 42 *piedi liprandi* for the two side pavilions.

3 Documentary Analysis, Selection and Interweaving of Sources for Modelling

The activity of digital reconstruction always constitutes a complex and delicate step of the work, especially when dealing with objects that, in part or in full, as in this case, no longer exist.

Even with the difficulty represented by the need to reconstruct the entire castle and its appurtenances from a series of graphic documents lacking certain information, the work set out to respect the criteria of scientificity and transparency described in the London Charter [5], aiming to make explicit assessments of the reliability of the sources, criteria for comparing them, methods of realisation and choices for the integration of missing data, to obtain a durable virtual reconstruction, easily accessible and updatable over time.

The goal, in terms more specifically related to the topic of investigation, is to build a digital modelling pathway that succeeds in returning a narrative that makes explicit the choices made in terms of re-construction (primarily related to missing information and the resulting reconstructive hypotheses), the reasons that guided them, and the value of the resulting digital model as a communication tool as well as a support for the AR applications for which it was designed.

In the case of the Castello di Mirafiori, the work is quite challenging since, as seen in the previous paragraph, the 3D reconstruction takes its starting point from a series of graphic documents that do not restore the complex. Carlo di Castellamonte's drawing consists of a single plan plate, in which a de facto state, fielded in red, and a design state, only partially realised, fielded in yellow, are superimposed. Assessments of how the project was realised and what remained only in intentions are deduced from the historical studies previously cited and comforted by the analysis and comparison of historical cartographies after the moment taken into consideration for the reconstruction. In particular, we refer to the topographical Carta della Caccia (ante 1762) and the nineteenth-century cadasters: the Catasto Napoleonico (1805), the Catasto Gatti (1820–1830), and the Catasto Rabbini (1866).

Regarding the 3D description of the complex, particularly the height of its elements, reference, as said, was made to Borgonio's view of 1655.

The qualitative and dimensional correspondences between this document and Carlo di Castellamonte's plan were assessed, verifying how the general layout of the complex (number of openings in the main façade towards the courtyard and the side pavilions, arrangement of the main entrances), the spatial organisation of the descending staircase towards the garden (with the two symmetrical ramps, the terraces supported by the two cryptoporticus and the central opening), as well as the planimetric distribution of the gardens (including the fishpond, fountains and accessory spaces such as the fruit gardens and the woods in Castellamonte's drawing), turn out to be perfectly consistent with each other, and as mentioned in the previous paragraph, with the 1741 survey drawings.

The modelling work started with the punctual redrawing of Carlo di Castellamonte's plate through a direct survey. From Borgonio's perspective representation, through simple projection operations on the picture plane, it was possible to derive the heights of the main body of the castle (cornices, openings), of the vertical articulation of the terrace overlooking the garden and of the main decorative elements (balustrades and fountains) and of the closing features of the Italian garden space (the walls separating it from the surrounding *boschi*).

Secondly, from the engraving, it was possible to identify and model the main elements constituting the decorative language in overlapping orders of the façade on the garden, the articulated composition of the staircase with ashlar front and high plinth defining the impost plane of the cryptoporticus, the side niches in axis with the paths outside the fishpond.

In the view, the representation of the roofing of the main body leaves some space for uncertainty in 3D reconstruction, as it could appear to be conformed to a hipped roof but also a two-pitched roof, taking into account the perspective view. The choice fell on the two-pitch shape, also considering the similarity with Sebastiano Serlio's Château d'Ancy-le-Franc, one of the sources of inspiration for the Castello di Mirafiori.

Thus, the level of detail was set concerning the purposes of the model, designed first and foremost for AR visualisation, which dictates the realisation of a lightweight model to allow for rapid downloading and smooth visualisation. Secondly, the same model, net of some simplifications necessary for the AR experience, was designed to understand and communicate the complex, providing for the realisation of a physical model, as below described.

Regarding the arrangement of the flowerbeds and the decorative motifs that characterise them, Borgonio's engraving summarily represents only a part of them (the one relating to the flowerbeds included in the fishpond enclosure), in solid perspective foreshortening, which is why it was preferred to refer, for the modelling of these elements, to Castellamonte's drawing, which represents them in a very punctual way.

The elements on which interpretation work has been necessary are mainly those that do not appear in Borgonio's representation, such as:

- The northern façade of the castle (the one facing the city).
- The organisation and arrangement of the court of honour and the gateway to the complex accurately represented in Castellamonte's plan but for which no elevation information is available (if one does not consider the fancy reconstruction presented in one of the two views of the castle in the Theatrum Sabaudiae).
- The building adjacent to the castle, partly represented by Borgonio, given the relevant presence in the engraving of vegetation, a compact backdrop framing the façade towards the gardens of the main building body.

The final result of the 3D modelling is the reconstruction of the external envelope of the castle, the system of gardens and water features on the front facing the Sangone, the enclosure with the tree-lined exedra, and the monumental gate toward the city (Figs. 6 and 7). The visualisation of the model uses a conceptual style, which enhances the geometric and plastic features of the complex.

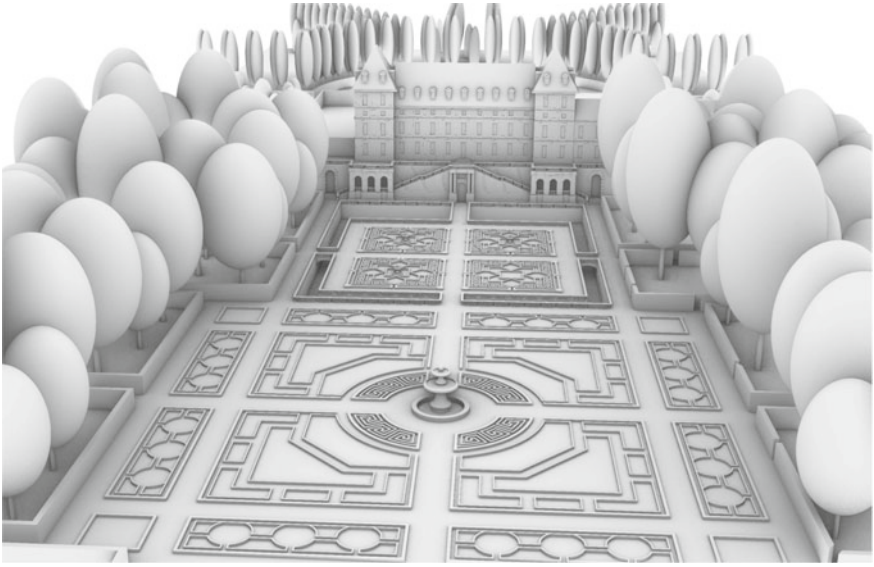

Fig. 6 Perspective view of the reconstructive model from the gardens (Modelling: R. Spallone, M. Vitali)

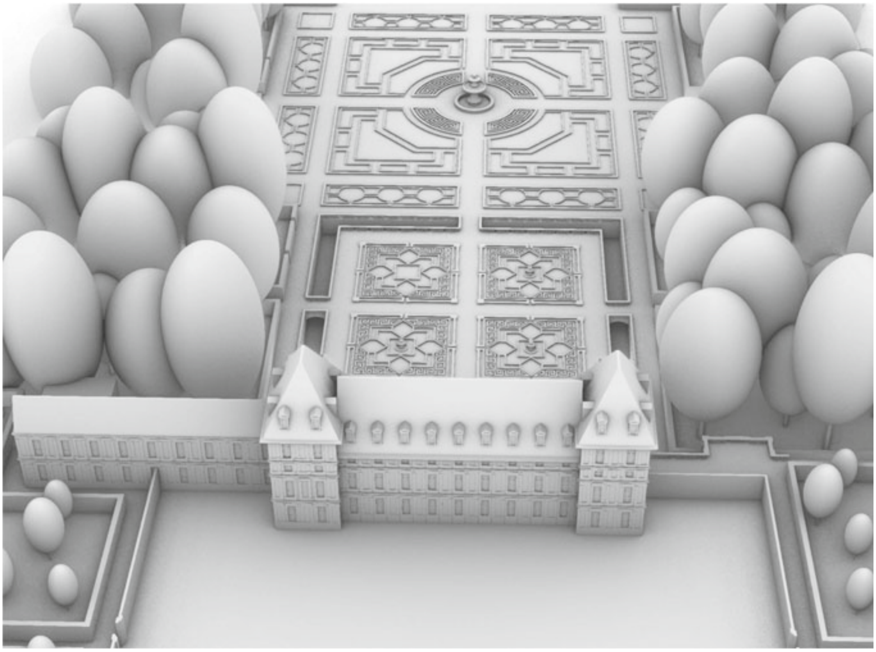

Fig. 7 Perspective view of the reconstructive model from the back courtyard (Modelling: R. Spallone, M. Vitali)

4 Augmented Reality Experience

4.1 Augmented Reality: Background

AR allows superimposing computer-generated elements into images of the physical world, captured, for example, through a camera [6, 7]. The digital layers can be processed through information about the user's position—that is, from his/her point of view or the position of the image capture tool—to simulate their positioning in real space. AR traces the position of relevant points—i.e., highly recognisable points—in the user's environment. This information can combine with data from other sensors, such as the inertial platforms of mobile devices. The alignment between the physical space and the digital component can occur through a target object to be recognised, of which the application has a priori knowledge (e.g., an image, a schematic marker, or a more complex object registered as a 3D representation). Alternatively, alignment can be achieved through sole markerless tracking techniques, based on the detection of natural features without prior knowledge, when these are compatible with the alignment accuracy to be obtained [7, 8].

The availability of these technologies on a large share of mobile devices has been supported by the advancement of computer graphics technologies and by a strong commercial interest, mainly developed during the last decade. This trend, as well as the wide accessibility achieved, has drawn the attention of managers, users, and other stakeholders of cultural sites for AR installations and mixed reality (MR) more generally. In these environments, digital content can integrate with physical spaces, artefacts, and artworks, without replacing or interrupting the live experience [9]. Furthermore, forecasts of the spreading of these technologies through head-mounted devices (HMD) indicate that the field is fertile for research and development [10, 11]. Currently, AR technologies provide various tools for interacting with large environments. Among these, the functions for extended tracking can be highlighted. These use various sensors available on AR devices (head-mounted displays, tablets, smartphones) to keep the digital layers consistent with the user's movements, even when the target elements leave the field of view of the visualisation tools [12]. Furthermore, several technical solutions allow the tracking of physical objects and the alignment of the digital layer, resulting in applications that are no longer limited to the tabletop scale [8].

However, the most advanced AR functions are mainly available through commercial software, which offers higher-quality tracking techniques. In contrast, free and open-source software (FOSS) solutions are still limited in choice and capabilities [13]. Nevertheless, open-source tools have some fundamental characteristics to overcome frequent issues related to AR systems. The use of widely shared languages and formats and the compatibility with different devices favour the development of scalable applications with dynamic functions and contents, unlike proprietary development environments [14].

The experience described in this contribution adopts a webAR system [15] based on an already established anchoring system—a small two-dimensional element—but meets economic and accessibility-related constraints, as described below.

4.2 Application Concept and Development

The project carried on the creation of an installation based on AR functions to make the results of documentary research and digital reconstruction accessible to a vast audience (Fig. 8). The developed concept is a web app capable of supporting intuitive navigation of the castle model. The app integrates a more usual information panel installed on the site where the remains of the castle are located. The site does not allow an inexperienced user to easily traced back the few remaining structures (a limited portion of substructures) to the original building.

The visualisation of the model superimposed on the site on a 1:1 scale was considered not viable, as the current appearance of the site would not allow for a substantial overlap to add information to the physical environment through AR. Furthermore, the extended tracking functions, aimed at enabling greater freedom of movement during the experience, would have required commercial software to be more suitable for the project budget.

We then designed the superimposition of the 1:1500 scale model over the images printed on the panel, specifically on a map of the area at the same scale. The choice of a web app has allowed us to use FOSS and to create a tool accessible via a URL or a QR code without the permanent download software.

The chosen AR framework is the AR.js technology [16, 17]. The software supports the goal of a low-cost project, both regarding development and maintenance, and is

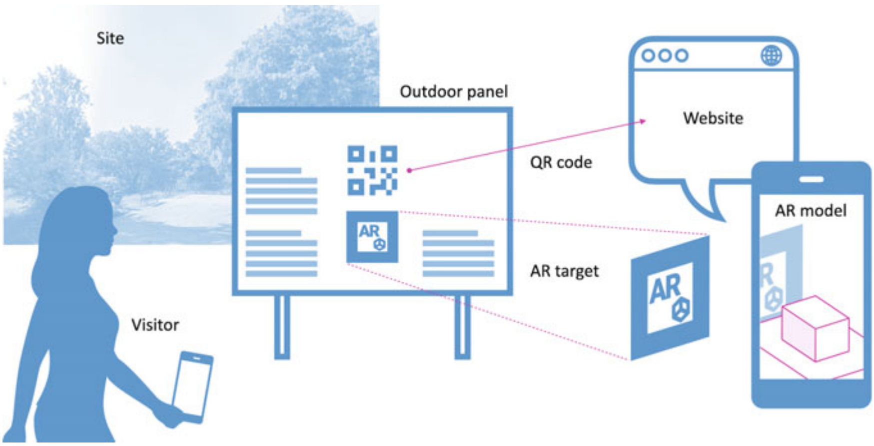

Fig. 8 Scheme of the application concept (Editing: V. Palma)

very accessible regarding the diffusion of compatible devices. AR.js is a JavaScript language library that needs a web page to work. The project is open-source and downloadable from GitHub, and the first experiments can be performed very quickly and with just a few lines of code in commonly used web languages (HTML, CSS and JS). Furthermore, publishing an AR.js project requires only a website hosting service, limiting publication and update times compared to the distribution of a mobile app.

In general, AR.js allows developers to build AR functions with different anchoring and tracking systems, including marker-tracking, natural-feature-based image tracking, and GPS-based techniques. In our case, we adopted a pattern marker, i.e., a simple image interpreted as a small array of values. For this kind of marker to be effective, high contrast and symmetry-free design are required. In addition, the marker includes a thick black frame that facilitates tracking even when printed in a small size (at least 2.5 × 2.5 cm is recommended).

The AR marker has been integrated into the area's map, which shows the site's current state and the castle's layout. The panel also indicates instructions to easily guide different types of enjoyers using the app and the QR code for accessing the website that hosts the application (Fig. 9).

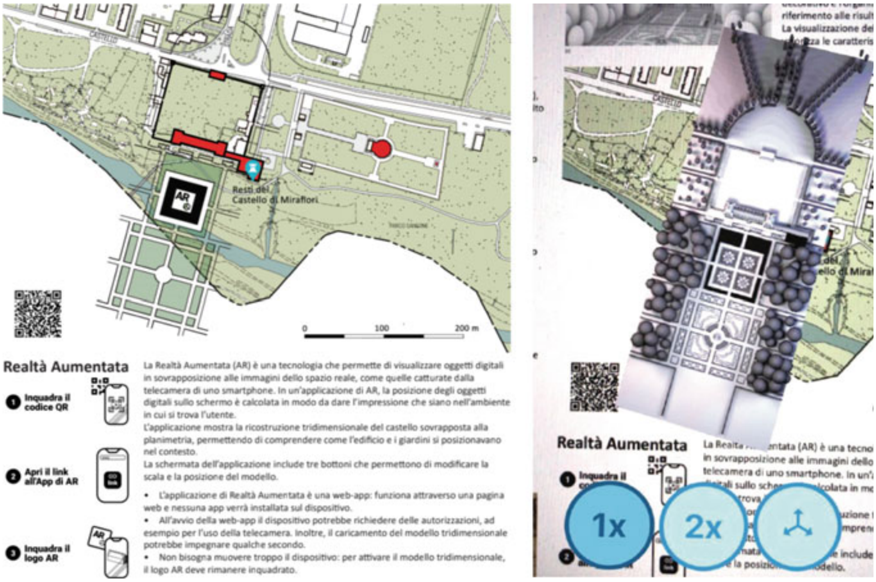

Fig. 9 Left: detail of the physical panel, showing the map of the area, the AR target, a QR code to access the web app, and a guide for the user (bottom). Right: screenshot of the web app showing the AR function and the buttons to activate different visualisation modes (Editing: V. Palma)

4.3 Model Optimisation and Visualisation Functions

Compared to the study model, the app's available model has been simplified to be lighter and quicker to load. The most influential meshes, especially in the case of repeating elements such as balusters, have been radically reduced, taking into account the effects on the final resolution of the model view. The operation reduced the model from an initial size of more than 200 MB to approximately 26.4 MB.

Another optimisation procedure was the creation of a texture starting from a clay render of the model (texture baking). This allowed the materials to occupy little storage space and lower real-time computational effort. Indeed, in this case, dynamic lighting was not considered necessary. The five textures produced, ranging between the 2048 × 2048 px and 4096 × 4096 px formats, converted into JPG format and compressed compatibly with the model display scale, occupy about 8 MB of disk space. The model optimisation actions were performed in Blender, exporting a final OBJ model (Fig. 10).

Since the initial dimensions of the model shown in the app are bound to the scale of the site plan, we set up different display modes. These are activated via buttons and provide a better sight of the details. Since the panel has been installed in vertical panel orientation, a button allows horizontal viewing of the model. This display mode is more appropriately called VR, as it is disconnected from the images of the panel by activating a dark digital background that hides the panel isolating the castle. The model, detached from the map, is displayed on a 1:750 scale. The same scale is shown in a second zoomed display mode, coplanar to the planimetry, featuring an obscured background in this case too.

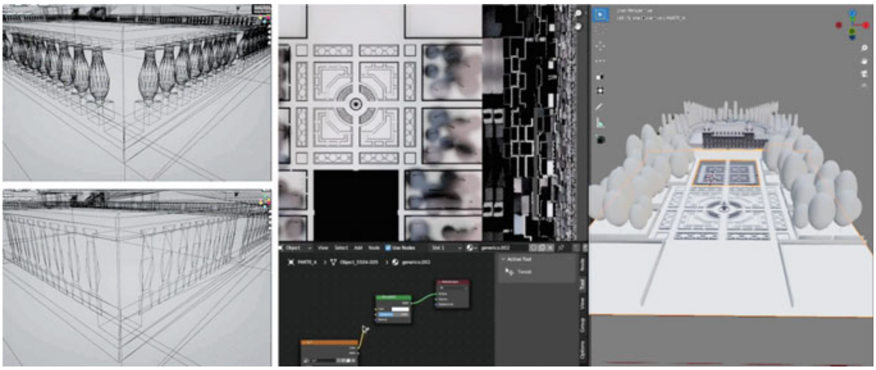

Fig. 10 Left: example of mesh simplification showing unmodified balusters (top) and the replacement meshes (bottom). Right: screenshot from the process of texture baking from the clay render of the model, performed in Blender (Editing: V. Palma)

4.4 Results and Limitations

The advantages associated with the use of a webAR tool concern:

- The possibility of distributing an app that can be accessed simply from a link and without the need for installation on the device.
- Ease of development, since the use of widespread web languages (HTML, CSS, JS) is expected.
- Ease of publication provided that a hosting facility is available.
- The ability to quickly develop and publish new versions of the tool.
- Seamless integration of other online information.

There are, of course, some noteworthy limits, which, however, we have found compatible with our specific project:

- It is necessary to account for download times of the multimedia resources (the model and the textures in our case) and also for potential network problems in the sites where the application will be used.
- The AR library lacks extended tracking functionalities, i.e., the ability to keep the AR running when the target leaves the field of view.
- Compared to other AR tools, there are limits to the stability and fluidity of the final experience and limited access to other more complex interaction functions (which can more easily be developed for a mobile app).

More generally, the choice of FOSS and webAR was particularly suitable for a project with a restricted budget oriented towards broad accessibility. Furthermore, adopting open-source software for building AR experiences supports the development of flexible and accessible solutions, tackling the critical issues of AR interoperability and scalability.

5 Digital Fabrication

The realisation of the physical model of the Castello di Mirafiori primarily uses the digital reconstructive modelling already completed, implying the adjustment of some essential aspects: on the one hand, involves a qualitative reshaping of the elements (necessary simplifications), and on the other hand, require a quantitative discretisation of the components through which design the assembly of the model.

First of all, it is necessary to convert the unit of measurement of the digital model from *piedi liprandi* to metres; after, it is essential to choose the scale of representation of the model, paying attention both to the macro-dimension of the model and consequently to the needs arising from its future location and transportation, and to the micro-dimensioning of the compositional elements, to avoid an excessive need about the adjustment of the thin shells. In this regard, after carrying out a series of evaluations, it was decided to proceed by adopting the scale of 1:250, resulting in a total footprint of 80 × 174 × 22 cm; this scale of representation also constitutes a compromise solution regarding the thinner elements, whose thickness does not decrease below one millimetre. The two-sided analysis of these aspects allows to make a conscious choice, to proceed to a subsequent engineering phase with the relative safety of not encountering critical inconsistencies. In this delicate step, modelling of the elements in series by instances of blocks reveals itself to be of fundamental importance; this practice allows rapid adjustment of thin parts, such as balustrades, where stereometric geometry was unavoidable to be applied.

It becomes necessary at this stage to prefigure the output of the physical model, depending on the materials' availability and dimensions in Raw format and the possible processing operations they will undergo. The approach, in this case, is the combination of vegetal cardboard panels, subjected to a process of engraving and cutting by laser machine, and 3D printing of the components characterised by a greater degree of detail, like the planimetric layout of the gardens, the basement part and the central body of the castle (Fig. 11).

The process of file preparation proceeds in parallel for both production techniques: in the first case, it is advisable to calculate the use of vegetal cardboard panels both in the function of the adaptation to the geometry in the object and about the adequate amount of panels and their subsequent processing by laser cutting machine, in this case, it is considered appropriate to use panels with a thickness of 0.3 cm (the correction in defect carried out in the digital model was 0.01 cm); at the same time it is essential to operate cleaning of the geometries that the 3D printing process will produce.

This operation allows a digital model to export 3D files where fixing processes will not be necessary or, at most, reduced to a minimum. During the systematic application of this methodology, it is also helpful to calculate the error that will inevitably

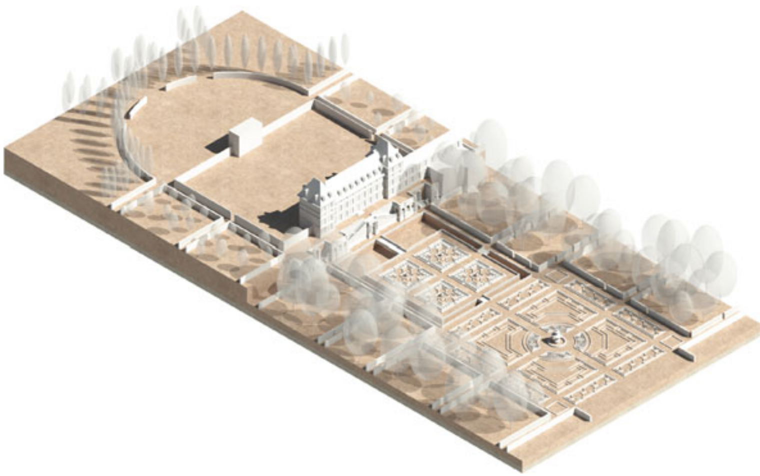

Fig. 11 Digital preview of the physical model (Modelling: E. Pupi)

be encountered during 3D printing to avoid inconsistencies during assembly. It is opportune to provide an interstitial space between the 3D printed components and the components derived from laser cutting, equal to half of the extrusion width.

The separation of the elements is of equal importance according to the working volumes available (in this case: laser cutting 90 × 60 × 1 cm; 3D printing 33 × 24 × 30 cm), thus originating a perfect digital copy of the physical model that is produced. To unify and give firmness to the model, it was also chosen to introduce a base panel where assemble the components, using a 1.5 cm-thick plywood panel; the size coincides with the overall dimensions of the model (80 × 174 cm). It is also planned to drill holes with a diameter of 0.1 cm corresponding to the trees in the digital model to facilitate their later assembly.

Concerning the parts never built, although they constituted the extension project of the castle, regarding Carlo di Castellamonte's drawing, only the engraving of the plan, appropriately vectorised through digital recalculation, is contemplated. This conceptual approach results in a possible AR experience about the physical model: it is possible to prefigure the physical realisation of the portions of the castle that were effectively built, and thanks to the application of AR, digitally insert the philological reconstruction of the extension project that wasn't physically realised.

6 The Castello di Mirafiori and Augmented Reality

The experimentation of AR on the ruins of the Mirafiori Castle is part of the proGIreg European Project, funded under the European Horizon 2020 Program.

The main objective of the project is urban regeneration based upon the experimentation of Nature-based solutions (so-called NBS) in the area of the Mirafiori Sud district (southern region of the city).

The castle, although no longer existing today, gave its name to the entire district and is particularly significant now, as its term refers exclusively to the more recent industrial past, as Mirafiori was in the past seat of the FIAT plants.

Starting from a dialogue with the actors of the territory, within the project, a demonstrative action has been carried out by planting a bush with a geometric design to recall the garden of the castle and the positioning of historical signposts, which briefly told the story of the castle in three languages.

The Borgata Mirafiori committee, which for years has been telling the story of the neighbourhood starting from the castle ruins, takes care of the green hedge thanks to its volunteers (Fig. 12). At the same time, the social enterprise Orti Generali carries out the work.

However, the Borgata Mirafiori committee wanted to tell the monument's story in a more detailed way, as it had been almost destroyed.

Starting from this need, and thanks to the experience conducted by the City of Turin with the 5GEVE project (in collaboration with the Politecnico di Torino), aimed at reconstructing the cultural heritage of the city in AR, the idea of creating AR on the Castello di Mirafiori was immediately born. The project also produced a

Fig. 12 Left: historical reenactment in period costumes in front of the remains of Castello di Mirafiori Castle. Right: the panel on-site (Photos: L. Ribotta)

short video (3 min) describing how the AR app works and the development process. The video, shown in conjunction with the project presentation and promotion events, was conceived as an inclusion tool to convey the proposal of integrating a digital and interactive component into the more traditional information device. In particular, this step was relevant in fostering support for the project from the local community, which is very active in promoting and protecting the site.

The realisation has been accompanied by a continuous story on the territory, starting from the comparison with the Committee, which appreciated the detailed historical research and provided even more thorough and complete information collected over the years by the citizens.

The first public demonstration event took place in May 2022, involving some students from Primo Levi School in Turin, who illustrated how the AR model works to the many citizens who attended the event. Subsequently, in June, with the Open House Torino event repeated yearly, a specific stage was added to illustrate the castle and the AR model; around 70 people attended the event. During the European Network of Living Labs (ENoLL) days, held in Turin at the end of September 2022, a visit to the Mirafiori district was proposed, and around thirty urban regeneration experts from all over Europe had the opportunity to hear the history of the castle and try out the AR model. Some of them suggested that a visit of this type should be included in the official tourist itineraries of the city, given the high environmental, social and cultural content. Finally, the city presented the experimentation at the Major Cities of Europe conference, held in Larissa in November 2022 as an example of how nature and technology can integrate to respond to the needs of citizens, trigger urban regeneration and involvement, and generate new ideas and possibilities for the territory.

7 Conclusion

This contribution presents a work in which the digital level permeates every stage establishing, through augmented reality, a link with physical, territorial, and architectural reality up to the dimension of scale reproduction through the plastic model.

The experience, inspired by the logic of cost containment, durability over time, and ease of use by diverse users, is fully scalable to other widespread cases in urban and territorial reality. It also fosters digital education and inclusion goals.

Acknowledgements This paper is the result of the research on reconstructive modelling and WebAR of Castello di Mirafiori carried out by the authors. The authors wrote together paragraphs 1 and 7; R. Spallone wrote par. 2; M. Vitali par. 3; V. Palma par. 4; E. Pupi par. 5; L. Ribotta par. 6.

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Digital Modelling, Immersive Fruition and Divulgation of Pre-nuragic Altar of Monte d'Accoddi

Enrico Cicalò, Michele Valentino, Andrea Sias, Marta Pileri, and Amedeo Ganciu

1 Introduction

In a region such as Sardinia, rich in monuments and archaeological evidence, and at the centre of some of the most important tourist flows at the national level, the issue of the use of cultural heritage sites is central to both regional and local policies. The spread and role that digital technologies are assuming in this sphere are producing a vertiginous acceleration of planning at all levels, driven by the exponential growth of small and large companies operating both within and outside the region. We are witnessing a race to digitise the cultural heritage that, besides being supported by national and European policies, responds more to the logic of an increasingly competitive market than to the demand for quality and scientific rigour of the products made available to the public. In this scenario, it becomes urgent to experiment with methods of knowledge transmission that are rigorous but at the same time capable of intercepting the demand for involvement and fruition coming from the market, local authorities, sector operators, and citizens.

This race towards digitisation and virtualisation of cultural heritage also runs the risk of raising the technological level of the proposal of products supporting fruition, paradoxically ending up by becoming exclusionary rather than inclusive. Not all target audiences have the digital literacy and confidence with digital tools necessary to easily enjoy products and experiences that bring the cultural heritage experience more and more into the virtual sphere, distancing it from the materiality of reality.

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2 The Virtualisation of Archaeological Heritage Communication

The relationship between the real and virtual dimensions is complex and constantly evolving. This apparently dichotomous relationship has been strongly influenced by technological advances and the information technology revolution, which have made it possible to experiment with and realise simulated realities, weakening the dividing line between these two dimensions and raising important questions about the nature of reality itself. As Jean Baudrillard [1] argues, the virtual tends to replace the real today, creating a world in which simulations and models take over, blurring the line between reality and representation and creating a new reality in its own right; a generation of virtual models with no genesis in reality: a hyperreal.

Although far from this dystopian and alarmist conception, in which simulations and models take the place of reality, the new digital tools have nonetheless conquered a fundamental role in various spheres of our society, such as the protection and enjoyment of historical and cultural heritage. Indeed, new technologies have significantly contributed to the research, dissemination, and preservation of cultural heritage to the extent that several international bodies working in this field have developed specific guidelines for the responsible use of these technologies. *UNESCO Charter on the Preservation of Digital Heritage* [2], first, and the *London Charter* [3] later, were the first documents to recognise the potential and role of new digital tools by setting out the principles that can guarantee the quality of digital visualisations of cultural heritage, prescribing a scientific approach and directing it towards the most appropriate methods for their dissemination. The guidelines proposed in *The Principles of the Seville Charter* [4] then incorporated the principles of the previous documents. They implemented their contents with particular reference to the application of digital visualisations in the field of archaeological and architectural heritage. Among the themes explored in the document, of particular importance is the role that digital methods and technologies are taking on in the conservation and, above all, the dissemination of archaeological and architectural heritage to a broader and less specialised public. The wide dissemination of and easy access to these technologies nowadays calls for reflection on the use of these tools, especially concerning the ability of end users to use these techniques to meet their needs and fulfil their expectations. While the dissemination of digital technologies for the creation of visualisations of cultural heritage assets and sites is increasing, the digital literacy of the public that must use them is only sometimes adequate. Thus, communicating cultural heritage today also takes on an ethical value and requires using the most advanced technologies to make available communication supports built through scientific and rigorous methods, capable of engaging and reaching different audiences.

3 Virtualising Sardinia's Archaeological Heritage

Although Sardinia is an island that boasts a rich archaeological heritage, with testimonies dating back to different epochs and cultures, research in the field of the application of immersive strategies for their fruition has yet to succeed in covering the vast array of monument types. In recent years, however, there has been a great ferment in planning in this area linked to the increasingly widespread use of these technologies, the growth in the number of companies operating in the sector, and the strong attractiveness of these technologies to younger audiences. While many projects in the region are now at an embryonic stage, others are more mature and have become consolidated tools for disseminating the region's archaeological heritage resources. In 2014, CRS4's Digital Mont'e Prama [5] project was launched to document, archive, and present to the public the collection of prehistoric statues of the Mont'e Prama complex through three-dimensional digital copies obtained by 3D scanning. In the same year, CRS4 published the NURNET portal that collects an open data mapping of the locations of all regional archaeological monuments such as nuraghi, domus de janas (house of the fairies), menhirs and sacred wells on a GIS basis. In 2018, the Sardinia Virtual Archaeology [6] portal, financed by the Autonomous Region of Sardinia, was inaugurated, making available to the user immersive visits to some types of archaeological sites and the most well-known and significant monuments in the region. Another relevant example is the Nora Virtual Tour [7] project (2019), aimed at creating a web portal for digital access to the archaeological site of Nora in the province of Cagliari, which also includes virtual tours and interactive 3D reconstructions. Finally, in the field of museum virtualisation, the 2020 project of the virtual tour of the Museo Archeologico Nazionale di Cagliari [8] allows the virtual fruition of the museum's four exhibition floors through five high-resolution spherical images.

4 The Case Study: The Pre-nuragic Altar of Monte d'Accoddi

Despite the wide range of case studies found in literature and the history of the digitisation of the island's archaeological heritage, there are still some significant gaps related to the wide variety of evidence on the island, from prehistoric sites to the Punic and Roman ones. The former, in particular, constitute a peculiarity of Sardinia's archaeological heritage. Several thousand prehistoric sites have been registered in the regional catalogue of archaeological heritage (Fig. 1), ranging from the 540 stone funerary monuments dating back some 3000 years, known as Tombs of the Giants, to the 5170 nuraghi dating back to the Bronze Age. The latter constitute only the best-known part of Sardinia's prehistoric archaeological sites. In fact, the only Sardinian site on the UNESCO World Heritage List is the nuragic village of Su Nuraxi in Barumini.

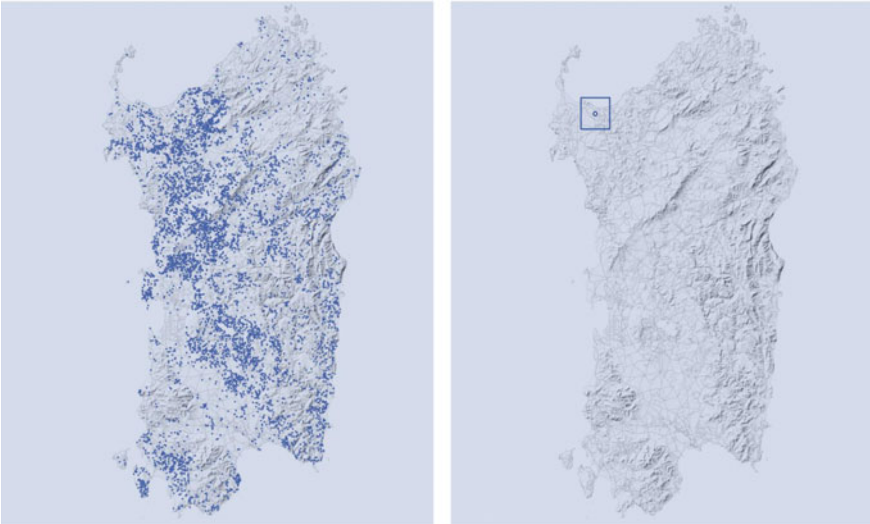

Fig. 1 Left: archaeological sites in Sardinia. Right: Site of Pre-Nuragic altar of Monte d'Accoddi. *Editing* A. Sias

Sardinia also has numerous testimonies ranging from the Middle Neolithic to the Copper Age, up to the dawn of the Bronze Age, the last phase of the pre-Nuragic period. Studies in this regard, as testified by various archaeologists [9–11], have yielded a complex and articulated cultural and settlement system of prehistoric Sardinia, which, although characterised by a relevant cultural continuity, manifests itself in a multitude of very different testimonies.

Among these testimonies, the archaeological site of Monte d'Accoddi (Fig. 2), located in northern Sardinia near the city of Sassari, is of particular interest. Besides being one of the oldest and most fascinating megalithic monuments on the island, it constitutes a unicum in the archaeological landscape of Europe and the entire Mediterranean. The site, chosen as a case study for the research presented in this article, is characterised by the presence of a stepped altar that is often mistakenly associated, due to an apparent morphological similarity, with the multi-storey horizontal superimposed structures (ziggurat) of Mesopotamia. This conformation places the monument in a period prior to the Nuragic Age, particularly between the Neolithic and the Bronze Age, as testified by the numerous archaeological finds.

The reference dates in the chronology of the site are essentially eight (Fig. 3): the San Ciriaco culture (4400–4000 BC); the Ozieri culture (4100–3500 BC); the Sub-Ozieri culture (3600–2900 BC.); the Filigosa culture (3000–2500 BC); the Abealzu culture (2600–2400 BC); the Monte Claro culture (2900–2300 BC); the Vaso Campaniforme culture (2400–2200 BC); and finally, the Bonnanaro culture (2200–1900 B.C.).

The earliest documented occupation of the site dates back to an interval between 3500 and 3200 B.C., at the beginning of the Recent Neolithic. On this settlement,

Fig. 2 Pre-Nuragic altar of Monte d'Accoddi. *Source* Wikipedia, Ángel M. Felicísimo

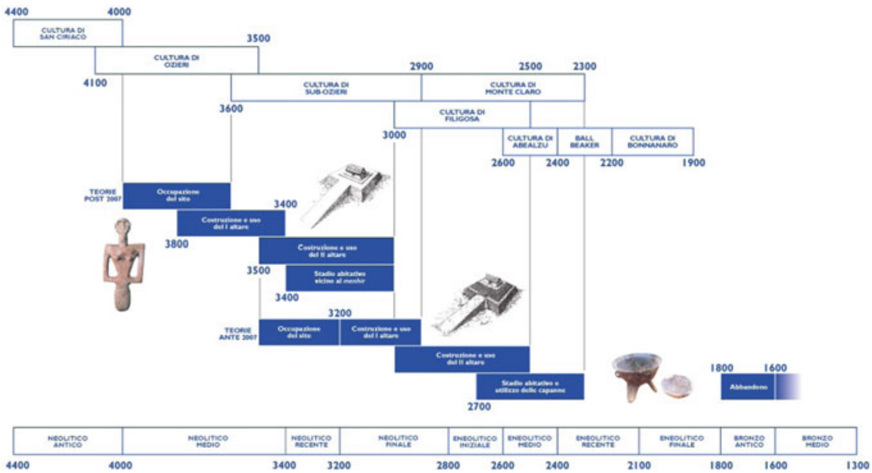

Fig. 3 Phases of occupation of the archaeological site. *Editing* M. Pileri

between 3200 and 2900 B.C., during the Final Neolithic and Early Neolithic periods, a newly settled community dedicated to agriculture was stratified, which is also attributed to the construction and installation of a menhir in a ritual area later occupied by the construction of the first terraced altars: the red temple and the stepped temple [12].

During the first excavation, in addition to the altar, some critical evidence emerged, such as a menhir, two offering tables, a spheroidal stone called omphalos, an elliptical stone with sepulchral value, and some remains of a village where the Sorcerer's Hut is located. Later, the remains of a dolmen and five other menhirs were found not far from where the omphalos came from.

During the second excavation campaign, the remains of an older temple were found, similar in shape to the recent sanctuary but smaller in size. On top of the older monument was a temple cell, similar to the huts in the surrounding village but with a masonry plinth. Although some scholars leaned towards a wall configuration with two different slopes, like the red pyramid of Dahshur in Egypt, the restoration that defines the shape of the monument today was carried out on the hypothesis of a stepped pyramid. It is assumed that this red temple was destroyed around 3000 B.C. and, from what remained of it, the later stepped temple, still visible today, was built.

Despite scholars' different theories and interpretations, the architectural uniqueness of Monte d'Accoddi in the European and Mediterranean context remains undisputed. The exact temporal location of the site still needs to be debated among archaeologists, who still point to numerous doubts about the original shape of the most recent terraced altar.

The only possible comparisons are with the step pyramid of the Geser burial monument at Sakkara. More fascinating, however, is the reference to the sacred towers with ramps and steps in Mesopotamia, such as the ziggurats of Ur, Assur, Korsabad, and Aqar Quf. However, the comparison that seems most indicative is with the ziggurat of Anu in Uruk, built at a similar time to the site of Monte d'Accoddi [13].

5 The Survey and Model for the Virtual Fruition of the Altar of Monte d'Accoddi

As stated in the Principles of the *Seville Charter* (2017), computer visualisation in the field of archaeological heritage, which involves the use of new technologies, requires an interdisciplinary approach. Proper bibliographic research allows for a multiplicity of scientifically founded reconstructive hypotheses. In contrast, the survey allows for the elaboration of the necessary knowledge base on which to base the visualisations of the reconstructive hypotheses, in line with the consolidated methods of Virtual Archaeology. In the case study analysed in this research, the continuous comparison between the archaeological sources and the actions aimed at surveying and representing the monument was fundamental.

The peculiar conformation of the archaeological site described above has made it necessary to base the representation on an in-depth bibliographic study and an accurate aerial-photogrammetric survey divided into the following phases:

- Planning of the flight campaign.

- Processing of the frames taken by the drone aimed at obtaining the point cloud and the mesh model.
- Processing of the results obtained and relative comparison with the bibliographic references.

The outcome of the process made it possible to construct a helpful basis for the proposal of different types of digital representation and visualisation to favour the cultural accessibility of the site and graphically restore the information related to the different construction phases of the monument.

Due to the need for precision in the survey, the limitations imposed by the instrumentation, and the regulations in force regarding overflight, the survey of the archaeological area was based on careful flight planning. The site, which covers approximately two hectares, is, located near the built-up area of Sassari. Consequently, the maximum flight height was set at 60 m above ground level, in compliance with Article 793 of the Navigation Code issued by ENAC. The decision was also made to resort to the automatic flight of the aircraft, opting for a smaller drone (DJI Mini 2), which allowed for greater control but entailed a severe limitation in flight duration, imposing an operating time of only twenty minutes.

Two flights were therefore carried out: one with the camera set perpendicularly to the ground, over the entire extent of the archaeological site, in order to survey the entire horizontal surface, and one with a 30° inclination to acquire data on the vertical surfaces of the site. The route planning was carried out after calculating the Ground Sample Distance (GSD) to set the overlap constraint between the frames with the camera in 4:3 format. The height and GSD constraint outcome imposed a distance between swipes of 21.4 m. Flight planning for the nadiral take was performed by measuring the distance between parallel swipes and a 70% frame overlap setting. These parameters generated a flight plan lasting 18 min, which resulted in a mosaic with a detail of 0.2 cm/inch.

Having acquired the constraint information, the flight plan was studied in the CAD environment, and the geometry was optimised concerning the distance between the swipes and the available flight time. By importing the data into the GIS environment, it was then possible to geolocalise the geometry by attaching metadata relating to latitude, longitude, and height above ground to the path. This last parameter was set so that the aircraft would follow the course of the terrain at the height of 50 m above the ground, based on the Digital Terrain Model (DTM) taken from the database of the Autonomous Region of Sardinia's Geoportal. In order to be consistent with the data that the GPS inside the Remotely Piloted Aircraft (APR) would have detected, the metadata assigned to the flight plan was imported according to the WGS84 geographical reference system (EPSG: 4326).

Operationally, the flight campaign consisted of three phases: a first phase of positioning and surveying the targets on the ground using the Topcon HiPer Pro GPS; a second that involved flying over the area for the nadiral sights and that allowed 160 frames to be acquired (Fig. 4); and finally, a third phase that involved the vertical sights of the altar through a perimeter flight with the camera facing the asset and set at an inclination of 30° to the ground, obtaining 47 frames (Fig. 5).

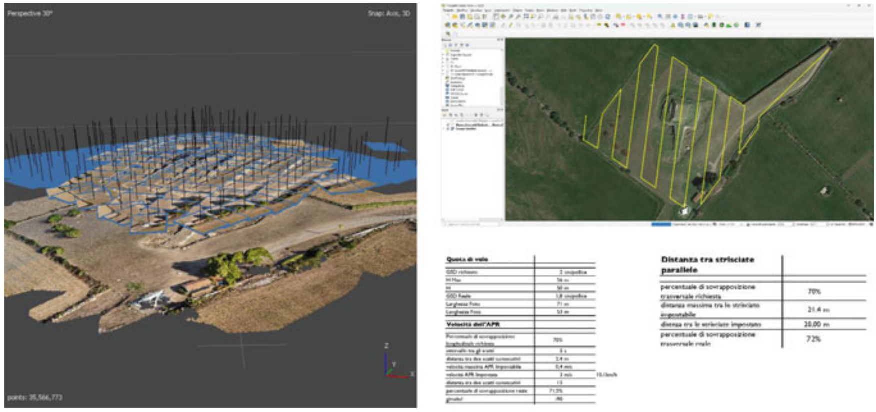

Fig. 4 Stages of nadiral flight planning for drone photogrammetric survey taking into account constraints. *Editing* A. Sias

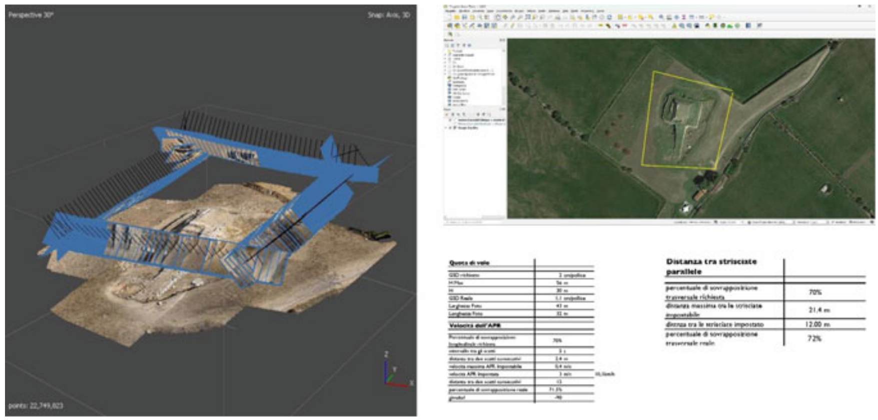

Fig. 5 Flight planning stages with inclined camera for drone photogrammetric survey taking into account constraints. *Editing* A. Sias

Subsequently, the 207 frames obtained were aligned, and the outcome of the nadiral flight campaign was merged with the oblique flight campaign thanks to the targets placed on the ground and detected during the campaign. The first result of the processing was a cloud of 276,350 scattered points. Its analysis enabled the elimination of the most approximate points. The software automatically generates these during the processing of the scattered cloud. Through the calculation of the confidence index, it was possible to identify the fidelity of the point generation. The point cloud obtained after the confidence analysis produced a dense cloud of 10,060,409 points. In addition, the mesh was generated, which allowed importing the data into three-dimensional modelling environments to process the model and propose different representations for site communication (Fig. 6).

Fig. 6 Mesh processed from the point cloud of the photogrammetric survey. *Editing* A. Sias

Subsequently, by importing the mesh obtained from the processing of the survey frames into the application software for 3D surface modelling (Rhinoceros), it was possible to experiment with different types of visualisation. The processing of the model through Visual Programming language (VPL) made it possible to obtain accurate topographical representations of the site, from isometric curves to consequential vertical sections (Fig. 7).

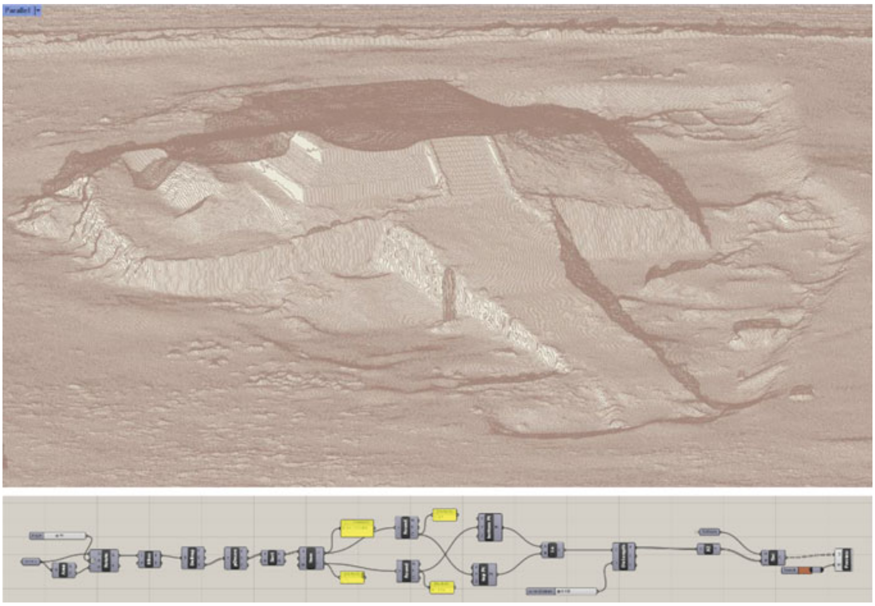

Fig. 7 Topographical representations of the site, from isometric curves to consequential ver-tical sections. *Graphic elaboration* A. Sias

The first result of the survey and modelling process of the site was the graphic tables that accurately render the monument and its state of preservation (Fig. 8). Subsequently, the model was used as the basis for the virtual use of the site and the different reconstructive hypotheses for educational and recreational purposes. To this end, a possible way of using the site through Virtual Reality (VR) was tested. In order to ensure the navigability of the site and the superimposition of the different information states, further processing of the mesh and model was necessary using the three-dimensional image rendering and texturing software Blender. The model, thus optimised, making it possible to structure remotely accessible guided tours in VR.

The virtual tour was designed for informative focuses, from the stratification and evolution of the site to the textual description of the objects. In addition to rendering the three evolutionary phases of the altar described above—the red temple,

Fig. 8 Graphic panels showing the monument and its state of conservation. *Editing* M. Valentino and A. Sias

Fig. 9 Digital representation of the historical phases that affected the altar of Monte d'Accoddi, through the coincidental visualisation of the current state with the stepped temple and the previous red temple. *Editing* M. Valentino and A. Sias

the stepped temple and the current state—the model provides more detailed information on the various singular elements that make up the settlement system, such as the Sorcerer's Hut, the omphalos (from the Greek $\grave{o}\mu\varphi\breve{\alpha}\lambda\acute{o}\varsigma$ that meaning navel) and the menhir (Fig. 9).

At the same time, an attempt was made to use the models of the construction phases for a virtual fruition to be experienced on-site through Augmented Reality (AR). The design of the more traditional information panels can be implemented for this purpose with targets that enable the visualisation of ancillary information and the reconstructive models themselves with the help of mobile devices. In order to achieve this further development, it was necessary to use the Unity graphics engine for AR visualisation, which simulates a three-dimensional virtual model and enables detailed information about the object.

The last phase of the project involves the implementation of the model with the different construction hypotheses in physical reality with an Extended Tracking process that disregards the presence of the targets in the field of view of the device and its camera. This would allow the different reconstructive hypotheses of the altar to be visualised in actual size. Due to the irregularity and size of the monument and the few anchoring points, the first attempts in this direction have shown criticalities in locating and scaling the model correctly. This implies the need to involve further expertise involving computer experts capable of implementing machine learning systems to optimise anchorage recognition. This further development would guarantee an integration between direct and virtual experience, allowing for the enrichment of learning processes, the involvement of new users who are more attracted to technology, as well as the provision of compensatory measures to facilitate accessibility to the site for users with forms of disability that prevent regular use.

6 From Model to Visual Journalism for the Dissemination of Monte d'Accoddi

The data, information, models, and graphic renderings used to support immersive use in VR and high-tech AR were then used to produce a low-tech graphic product that can also be used analogically. Applying the methods and strategies of Visual

Journalism—an approach to the communication of cultural heritage based on the most advanced 3D modelling technologies, but which renders the information in the form of an illustration that is easily readable by a non-expert audience [14]—a graphic table has produced a user can also use that with a low level of digital literacy, and that can be disseminated through paper media or interpretive panels within site (Fig. 9).

Today's emphasis on communication modes and digital tools often does not consider the different digital skills and competences of different audiences and their need for digital and visual literacy. According to the OECD [15], only 21% of Italians have a sufficient level of digital literacy. However, despite the problematic nature of this figure, the contemporary tendency is to entrust the entire organisation of society to the digital with apparent problems of social inclusion and equal access to services [16]. In fact, the production of images for Visual Journalism requires the construction of three-dimensional supports on which to base the illustration of content. Three-dimensional digital modelling allows the creation of models to base post-production aimed at the illustration for the communication of cultural heritage, particularly architectural heritage. Even behind the production of low-tech communication media, such as illustrations on printed publishing products intended to be enjoyed and understood by the general public, there is, therefore, the use of three-dimensional models that can also be produced using the most advanced digital modelling technologies (Fig. 10).

7 Conclusion

Through the exploration of the case study presented in this article, an answer was sought to the new questions of accessibility and fruition of cultural heritage sites, particularly archaeological sites. The research also seeks to adopt an inclusive approach by proposing different ways of using a site using the same information base and operational path of information construction.

The research presented in this article presents some innovative and original aspects in the field of graphic representation and communication of cultural heritage, such as:

- The experimentation of an operational method for the survey, modelling, graphic restitution, and virtualisation of an archaeological monument that has not yet been investigated from this point of view and which, due to its dimensional, morphological, and historical-archaeological characteristics, requires the definition and experimentation of a method calibrated to its peculiarities.
- The development of an operational method capable of putting into a system the entire chain of methods and tools for the representation and communication of cultural heritage that, starting from the photogrammetric survey, go through 3D modelling, graphic restitution, VR, AR up to illustration and Visual Journalism.

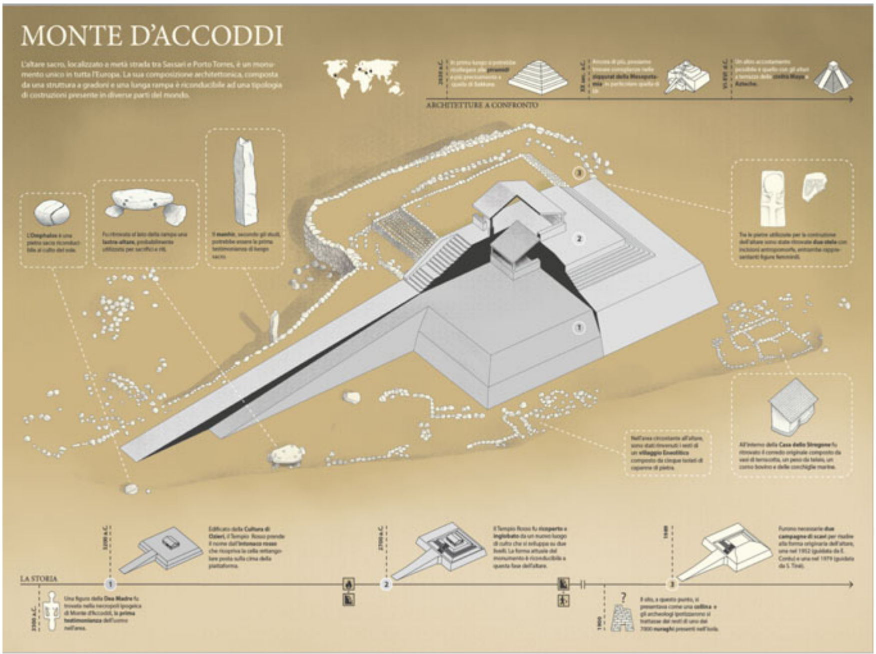

Fig. 10 Visual Journalism panel proposal elaborated to provide alternatives to users with different digital skills and competencies in order to meet their need for digital and visual literacy. *Editing* C. Zuddas

- The development of different graphic-visual products starting from the same model concerning the need to make the site being researched accessible to multiple audiences with different skills, abilities, and literacy levels.

Real and virtual, digital, and analogue, high tech and low tech find through the proposed method a form of balance in which within each dichotomy, each element does not compete with or replace its antagonist, but on the contrary, supports and strengthens it. Only through collaboration between all the different components involved in the process is it possible to adopt an inclusive approach and truly foster the accessibility and enjoyment of cultural heritage and the transmission of knowledge related to it in a democratic and universal perspective.

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Digital Technologies to the Enhancement of the Cultural Heritage: A Virtual Tour for the Church of San Giacomo Apostolo Maggiore

Sabrina Acquaviva, Margherita Pulcrano, Simona Scandurra, Daniela Palomba, and Antonella di Luggo

1 Introduction

There have been numerous initiatives over the past few years to spread aware-ness of cultural heritage through the web. These initiatives have made it possible for users of all types to access information more quickly thanks to digital technologies. The new high-performance digital technologies have produced new ways to accomplish the pre-established goals of information exchange pertaining to cultural settings, facilitating and speeding up the reading and processing of that information. In addition, the expansion and diversification of digital representation and communication formats, such as maps, images, videos, virtual tours, and 3D models, have made them more accessible through the development of specific apps that can be easily shared, contributing to create new forms of enhancement.

Therefore, the scientific field is dotted with various examples of experiences of use of Cultural Heritage—virtual, augmented and mixed—that put the users at the centre

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of the learning process, sometimes by transporting them virtually into new environments, other times by involving them directly in the virtual experience and thereby deepening their understanding of the good [1, 2]. These approaches required a shift in the way that data was often represented, more closely tying it to the third dimension. The evocative and communicative power of the figurations is exploited, which combine the technical restitution of data and photorealistic rendering, constituting to date the most accurate representation system in order to manage and disseminate information about cultural contexts and increase knowledge, all set in a digital space. The type of data utilised to create these virtual paths is what determines the various operational approaches in this area because it is the central process around which the entire virtual structure rotates and without which it is impossible for it to exist. The development of these procedures has been significantly aided by the three-dimensional digitization, carried out using reality-based technology, which has introduced new approaches to reading and recording reality. Its use now makes it feasible to gather data that replicates real circumstances in a digital environment, facilitating and enhancing dissemination initiatives. The three-dimensional models and the data derived from them, close to the perceived reality, inserted in the fruitive contexts have implemented and helped to satisfy the increasing implicit demand of the users to be involved and active in the visit paths transforming them from passive and linear to interactive [3, 4]. These approaches have undoubtedly grown significantly over the years in relation to the propagation of the pandemic from Covid-19 [5]. The inability to enter or live in complete freedom in some locations has heavily influenced the use of such devices. Museums and historical sites have started to produce digital content to be included on their platforms and social networks able to reach every person. User-friendly programmes have been employed to make these experiences accessible and inclusive, mostly based on the creation of virtual tours using 360-degree panoramic photos, beneficial to generate a virtual trail that can be utilised by any user [6].

Therefore, this research is part of digital communication proposing the creation of a network of virtual use for the dissemination of the religious heritage of the Neapolitan province, starting from the construction of a web-based map that contains all the information collected about it. From a methodological perspective, the key locations that define the digital map have been hierarchized according to a typological and topological classification using graphical and tabular tables of the constituent elements and sections. The research into the Church of San Giacomo Apostolo Maggiore in the community of Casalnuovo di Napoli as a test site for the building of the virtual tour broadened the experimentation in order to put the framework into practise. The church is incorporated into a curtain building that draws the Corso Umberto I, the traditional axis of connection between Naples and Caserta and the city's principal thoroughfare. The façade and the tall bell tower on the broad expanse that serves as the churchyard are distinguished by a spartan and linear design that hides the opulence of the inner space and the wealth of its ornamental apparatus. Due to the unique characteristics of the artefact, the working group enhanced its investigation through bibliographical research, archive and digital surveys for the acquisition of spatial data and all the information necessary for the construction of a project

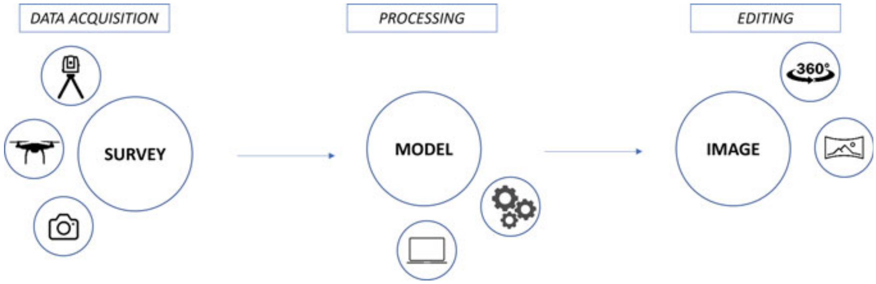

Fig. 1 Workflow for creating the fruition application. *Editing* authors

of use, planning a virtual tour as part of an integrated and coherent process with the acquisition phases. According to this viewpoint, the reality-based instrumental survey that had an impact on the church were planned and executed in anticipation of the outcome to be obtained, both in terms of the type of data required by the research's objectives and the accuracy required for the site's proper documentation.

Finally, the open Marzipano application, which enables you to create virtual tours using the data collected and/or processed by the earlier phases of survey and documentation, has been chosen to be used in the structuring of the project of fruition, executable on site via app and remotely via web browser. As a result, a tour was created, allowing visitors to experience the virtual environment and engage with infospots that provide more information than is immediately visible to the visitor, so boosting awareness of the artefact (Figs. 1 and 2).

2 The Web-Map for the Knowledge of the Religious Heritage

Cultural heritage has always needed to be recorded and catalogued in order to be known about and protected, particularly in areas that are aesthetically rich but difficult to access. Particularly in the current research, the analysis of the religious cultural heritage has led to the knowledge of not only the geometric features of position and shape, which can vary depending on the good, but especially of all those recurring and exceptional elements that are a part of the Neapolitan religious architecture.

The priority of the study's first phase was to collect and archive historical, morphological, physical, and descriptive data regarding the religious buildings in the suburbs of Naples, whose installations are closely related to urban surroundings. In addition to the general information and localization was completed a filing of all those qualitative aspects that describe the religious buildings: the structure of the church; the presence or not of the side chapels; the shape of the dome; until then to arrive in detail to analyse the presence of decorations and frescoes. In order to create the digital map, it was decided to merge all this data into a specific database that was

Fig. 2 Operational phases realized for the structuring of the virtual application. *Editing* authors

always implementable and that would also allow cross-research among the elements and that it was able to keep close the link among the data and their geographical location. Therefore, it was chosen to use the open-source software QGIS that provides an orderly and sequential structuring of the data entered in it (Fig. 3).

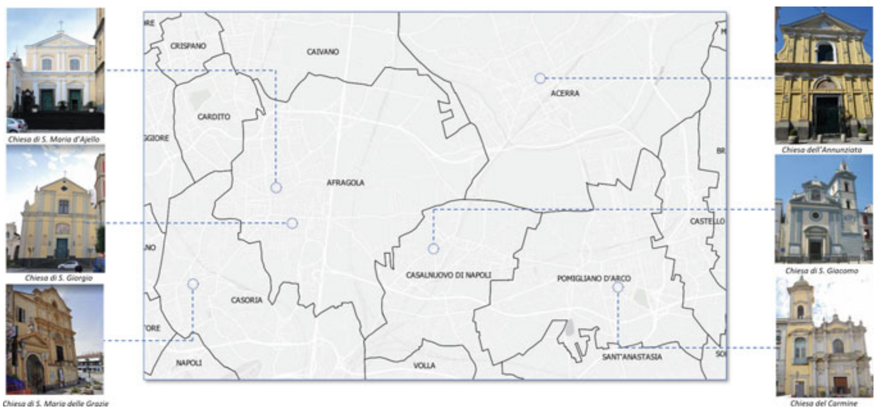

Fig. 3 Geographical identification of different architectural emergencies. *Editing* authors

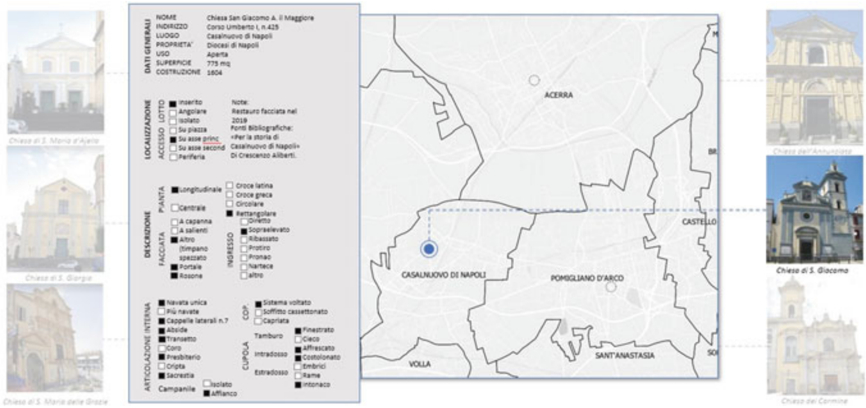

Fig. 4 Linking alphanumeric data of religious sites to their geographical location. *Editing* authors

This phase's purpose was to transform the previously assembled tables into vector and visual information as well as apply geographic information, returning them in the form of a map, a powerful visual communication piece. The maps' immediate visual impact and capacity to depict even the most difficult-to-perceive things have led to their widespread application in the study of cultural heritage. Because of the intimate relationship between graphic representation and visual perception, which serves as the foundation for effective communication, these visual artefacts enable us to observe and comprehend the dynamics behind some occurrences. Therefore, the representation of an architectural phenomenon and the connection to its relative information need a priori choice related to which type of vector element can best tell it. The preference fell on the type of punctual geometry that, like the others, identifies the position of the religious good and has an easy-to-read structure for its inclusion within the web-map (Fig. 4).

The map's organisational structure, however, is still tied to the desktop programme and cannot be fully utilised there. It was crucial to use the Java Script open-source library Leaflet, which allowed for the creation of an interactive map for mobile devices (WebGIS), in order to generate a map that could be shared [7]. In particular, this tool needs a basic map (for example, Google satellite) to merge the geometric, position and information data within an HTML element connected to the web. The interaction between the stored data and the basic cartography is granted thanks to the export of structured data in GIS in the Geojson interchange format able to represent simple geographic features and their non-space attributes and to read them on the web using scripts js. For a better and simpler identification of the locations and to increase knowledge, this map has been paired with additional helpful information about the context in which the buildings are positioned. Due to the editing of scritp.css, which controls the graphic design of web pages, the map was later modified by widgets and other tools. Evidently, in order to provide more fluidity in the usage of the web-map,

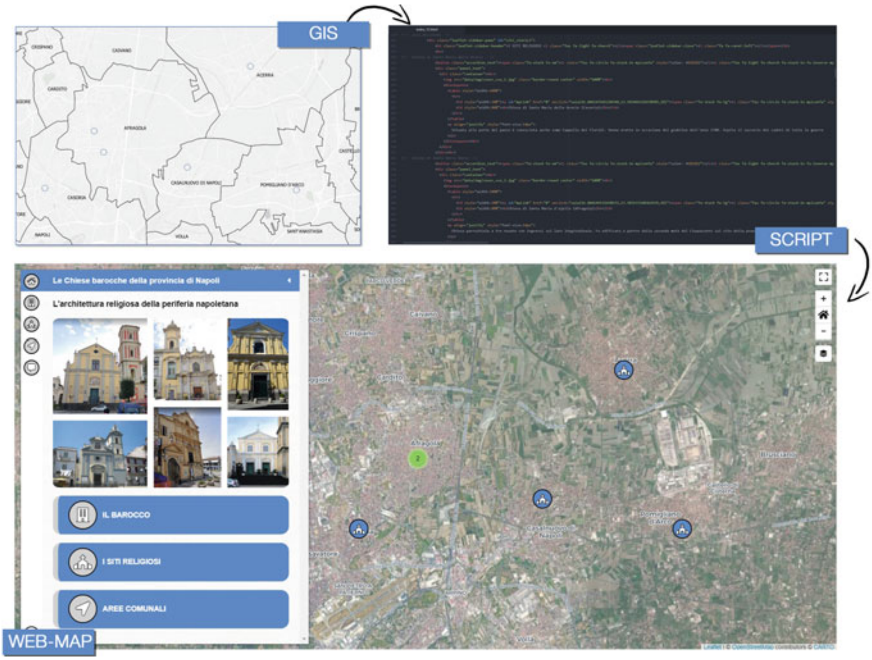

Fig. 5 Web-map construction. *Editing*: authors

consideration has to be given to the ability and manageability of data in the web environment (Fig. 5).

3 Technologies for the Digitization of Religious Heritage

The successive steps of the research have had the objective to identify a case study for the creation of the virtual tour connected to the web-map. Among the different religious sites analyzed was chosen the Church of San Giacomo Apostolo Maggiore located in the historic center of the town of Casalnuovo di Napoli. This building dates back to the second half of the sixteenth century and over time has undergone a series of alterations and restorations that have modified the structure and have given it the current architectural conformation (Fig. 6). In particular, the exterior of the church consists of a main facade characterized by a linear and symmetrical style underlined by decorative elements such as Ionic pilasters and molded cornices. The entrance is framed by a system of columns surmounted by a broken tympanum. On the right is the bell tower that is leaning against the side elevation and stands on three levels culminating with a bell tower. The remaining facades are not visible as the church is inserted in the building fabric. The sober and linear exterior decoration contrasts with the richness of the interior. In detail, the structure of the church consists of a single nave on the sides of which there are chapels characterized by the presence of small altars with polychrome marble decorations. The sumptuousness of the decorated apparatus can be seen in every element that shapes the church. The vault, which covers the nave and conceals the wooden structural elements of the roof, is characterized by medallions and frescoed lunettes. This vaulted structure engages on a powerful entablature that frames it. Below it open round arches that serve as an opening for the side chapels, in conjunction with the opening of the lunettes. A round triumphal arch separates the nave from the presbytery. The latter is elegantly finished with stuccoes of clear classic taste and covered by an ellipsoidal dome illuminated by mullioned windows, which is grafted on four plumes also frescoed with religious images. The whole decorative pattern culminates in the altar area at a raised level and separated from the rest by a marble balustrade dating from the eighteenth century (Fig. 7) [8, 9].

Following the historical and documentary analysis, it was necessary to carry out survey operations to fully understand the articulation of the spaces and the different environments in order to provide not only an updated documentation of the site but at the same time form the basis spatial and theoretical for the subsequent construction of the virtual fruition project. It was therefore necessary to assess which was the most suitable relevant methodology for recording the metric and geometric characteristics of the Church. The site, in fact, is characterized by different environments for morphology and size. This has imposed accurate reflections on the planning of the acquisition of the data and on the instruments to use. In particular, it has chosen to use the well-established reality-based technologies. They are able to acquire and

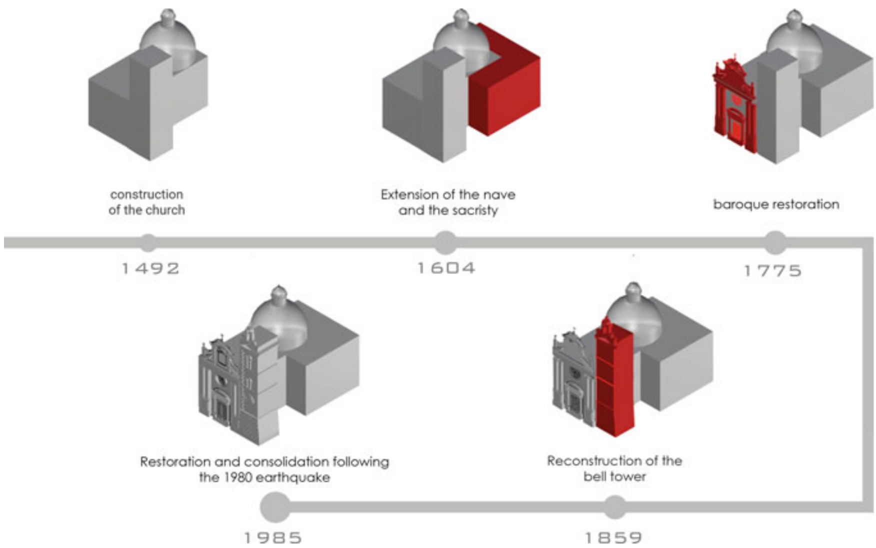

Fig. 6 Architectural evolution of the church of San Giacomo Apostolo Maggiore. *Modelling and editing* F. Equestre

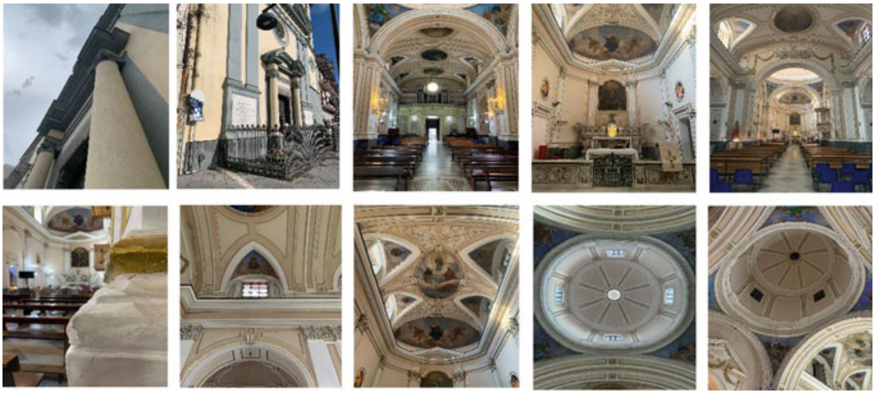

Fig. 7 Photographic survey of the interior and exterior of the Church. *Photos* authors

return accurate documentation in the form of three-dimensional models—point cloud and polygonal model -and overcome certain critical issues inherent in the documentation of the complexity of the historical building [10]. The survey campaign was divided into two different phases. The first saw the use of range-based and image-based survey technologies to acquire the morphometric information of the entire site, while a second measure of photogrammetric survey of detail concerned the survey of polychrome marbles that constitute the different altars of the side chapels.

The constitution of the project of general survey was dictated not only by the desire to have an accurate and as complete as possible data but was guided above all by the main purpose of this study: the construction of the virtual tour. In particular, strategic points were chosen for the laser scanner stations (Faro Focus s120) in order to correctly capture the geometries and curvilinear coverings of the different environments. For each laser scan, it was decided to also record the colorimetric parameter through the acquisition of photographs at the same time as the laser shooting. In order to generate the complete point cloud, such as a digital cast of the real object, the various scans were aligned in the process and oriented according to a common local reference system, work facilitated by the presence of flat and spherical targets present in the scene, visible from multiple locations. In this way and following the affixing of the colorimetric data a point cloud was generated. It digitally recreates and visually tells the continuum of matter returning it according to a discrete set of points (Fig. 8).

This acquisition, however, is limited only to the internal space and to the main facade of the building because the intrados and extrados of the roofs were not easily accessible. To overcome this criticality, it was decided to carry out an image-based survey with the help of UAV (Husban Zino), creating video recordings in manual mode, alternating shots with the camera axis orthogonal to those with inclined axis with respect to the surfaces (Fig. 9). The frames that were used to continue with the classical photogrammetric processing pipeline were subsequently extracted from the resulting video [11]. The image-based point cloud, from which the church's pitched

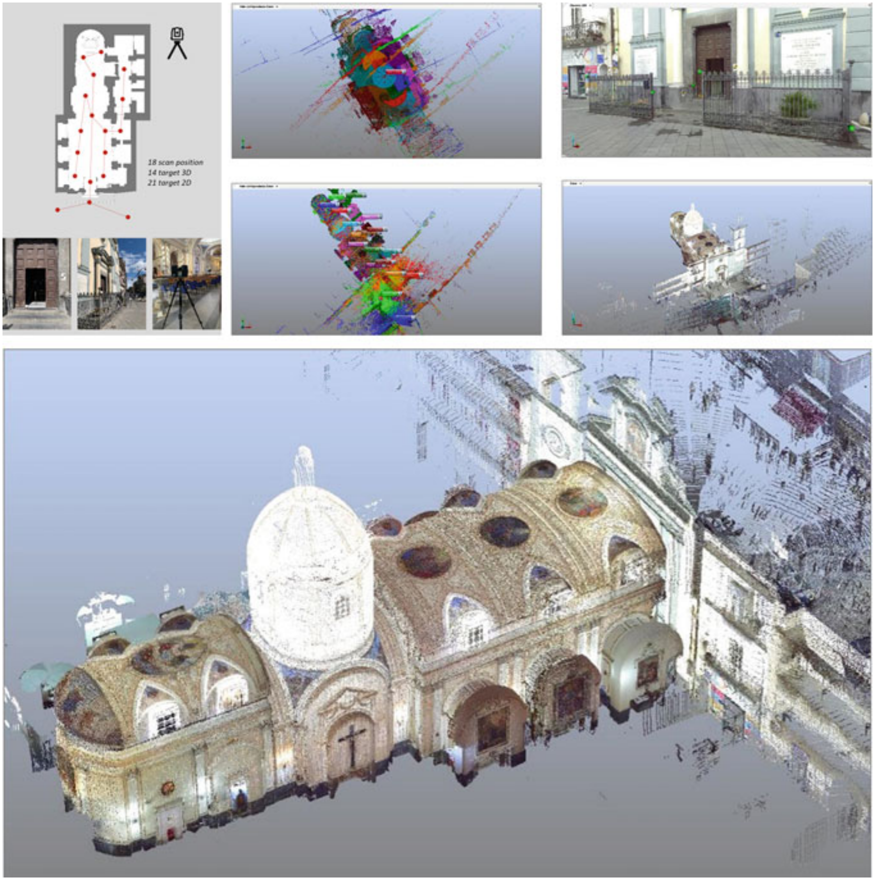

Fig. 8 Range-based survey with laser scanner phase shift. Route scheme (above); alignment of point clouds (right); point cloud (below). *Survey and editing* authors

roof and dome conformation can be inferred, was roto-shifted and integrated into the laser cloud by natural control points in the scene, obtaining a complete cloud of the entire morphology of the site [12, 13].

A terrestrial photogrammetric survey of detail has interested instead the altars of the side chapels. This is due to the fact that although accurate from a geometric point of view, the laser scanner survey is partially lacking on the photorealistic one, and not able to describe the richness of the polychrome marble of the altars. The integrated model obtained was fundamental in order to describe and represent the architecture of the site through two-dimensional representations that allowed to fully understand the articulation of the spaces and the connections between the different elements (Fig. 10).

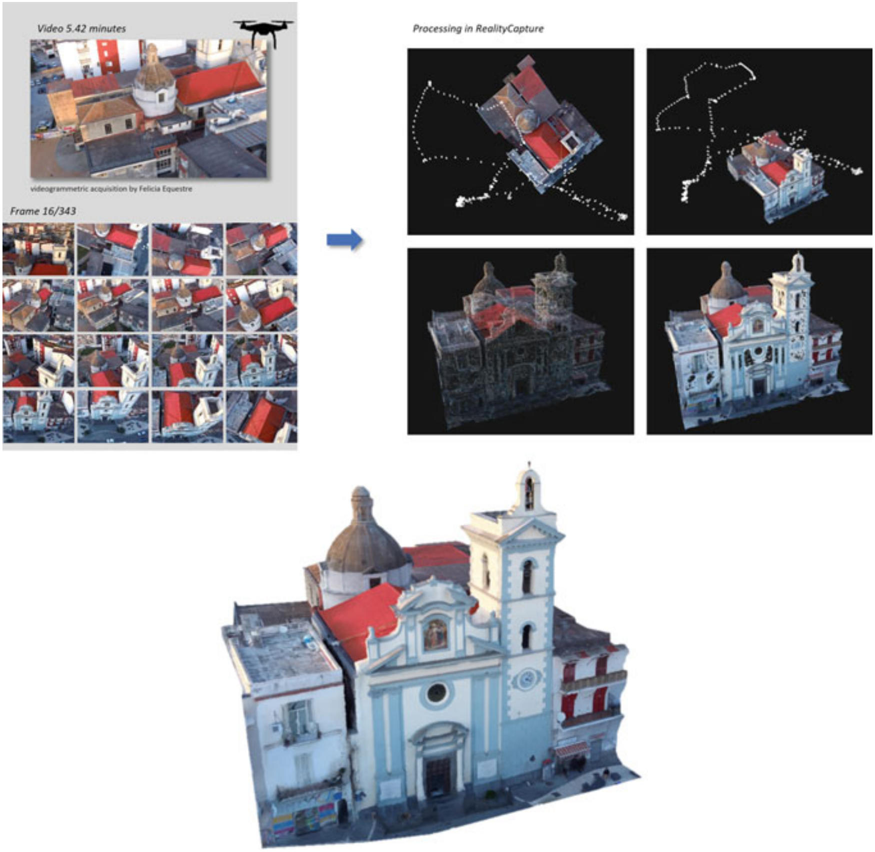

Fig. 9 Image-based point cloud processed by Husband Zino dataset. *Graphic elaboration* authors

4 A Virtual Tour for Expanding Knowledge

Finally, in the last phase of the research, the dissemination objectives of the site have raised questions about the modalities of fruition. As is well known, today there are many methodologies and tools that allow to structure different communication projects both in the way they are used and in the objectives they pursue and in the tools they use. In this specific case, the objectives related to the construction of a user friendly application that does not require special support devices, but accessible both through mobile devices and through remote desktop fruitions have pushed towards the construction of a virtual tour that does not end in the simple digital transposition of the cultural heritage, but it takes as input the results of the research and then build an alternative communication channel in the fruition of the church [14].

In order to create the tour, equirectangular photos extrapolated from the processing of laser survey data were used. In particular, in the first phases of the survey planning,

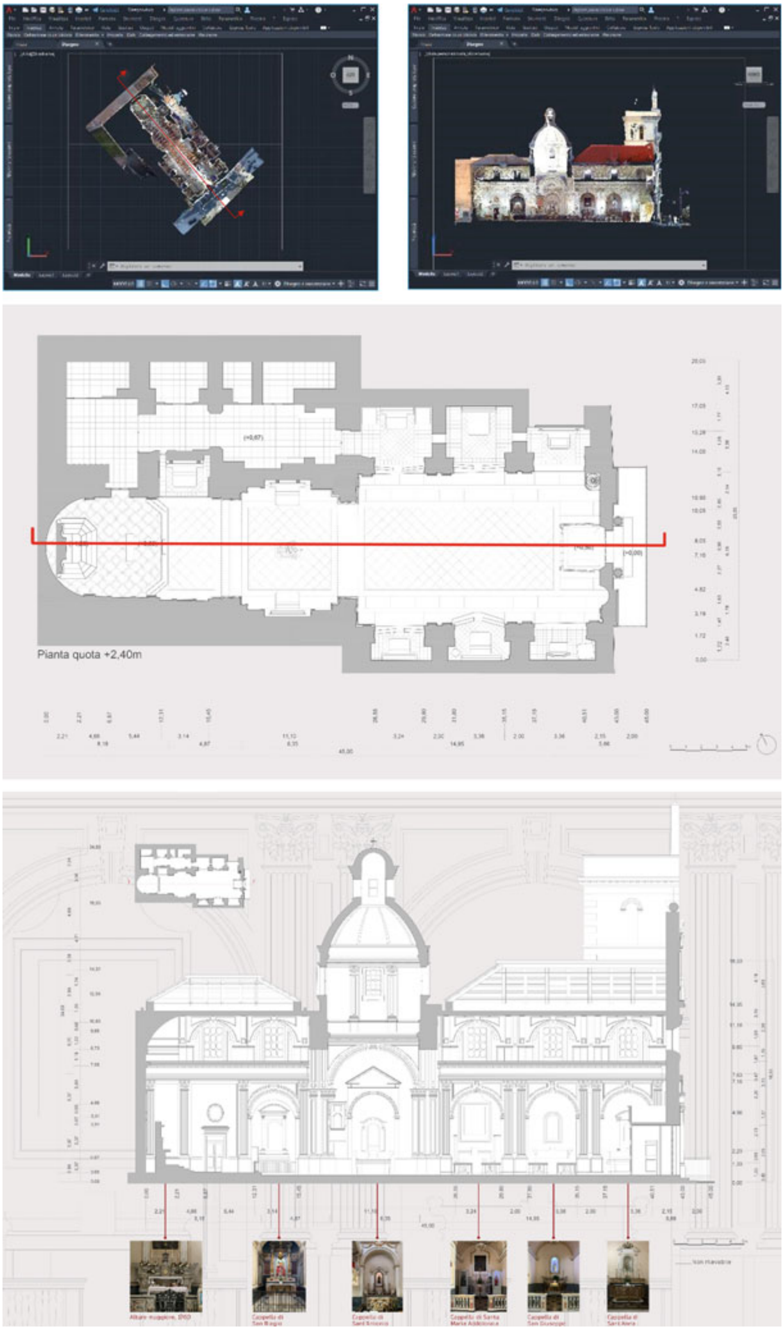

Fig. 10 Two-dimensional and three-dimensional representations of the church of San Giacomo Apostolo Maggiore. *Graphic elaboration* F. Equestre

Fig. 11 Post-processing of equirectangular produced by laser scanner. *Editing* authors

specific points of acquisition were chosen, useful not only for a correct data recording but also for points representing the ideal path of the virtual visit within the church. An equirectangular image is a projection on a (rectangular) plane of the surface of a sphere. Those extracted from laser acquisitions, however, are characterized by an optimal quality and photographic resolution, but have greater distortions because they do not fully comply with the proportionality parameters of spherical photos, i.e. the ratio of 1:2 which makes the perception of environments more realistic. This is clearly due to the limitation of the acquisition field of the instrument that to exclude the support tripod from shooting limits the acquisition to 300 in the vertical plane. Consequently, in order to allow an adequate reading of the image, to correct this relationship preparatory to the actual creation of the tour was the structuring of the image in photoediting software Gimp, where it has been possible to recreate the right proportions (Fig. 11).

The creation of an equirectangular using the integrated polygonal model, especially for the roofing area, was also tested. Through the open source software Blender it was possible to import the model into the work environment and through the preparation of a panoramic chamber was rendered a view in the form of an equirectangular image characterized by the correct proportion parameters. This procedure allows you to choose a custom point of view by taking advantage of the previously recorded reality-based models, not limited to the scanner scan position.

Therefore, all changes to the images have been made to the tour. The experience was programmed through the use of the software—also open source—Marzipano [15, 16] through different phases. The first allowed to define the general structure by setting the different images as predefined positions of an ideal path that leads to the discovery of the different environments that form the church. Several hotspot links and informative popups were inserted to implement the photo content brought by the 360 images. In order to customize the tour and make it responsive to goals, through the editing of the programming codes that manage the execution as well

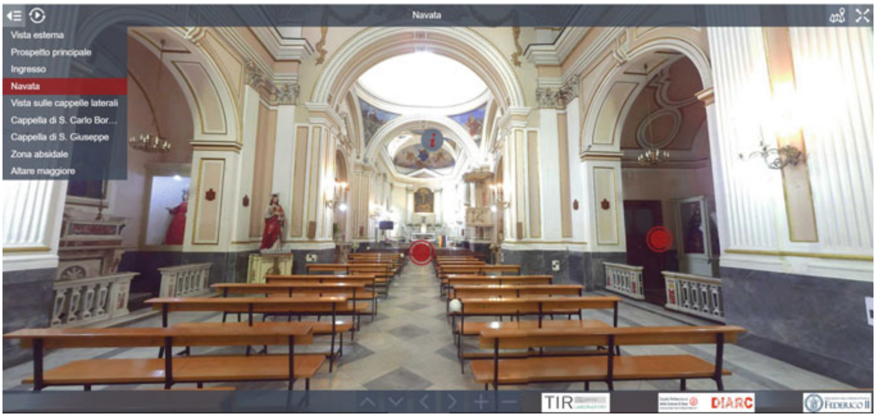

Fig. 12 Creation of the Virtual Tour by Marzipano software. *Editing* authors

as the graphic design was possible to add links to the various graphic elements to make the experience more effective and direct. Thanks to these codes have been imported within the tour also the two-dimensional representations in such a way as to allow an overall reading of the articulation of the complex that is not perceived by the 360 images because limited to a specific position, and to offer technical and informative information. In addition, each position has been renamed according to the corresponding environment of the church, and displayed in the navigation menu that is updated dynamically in relation to the changes of views chosen by the user. Each element, each command respects the graphic encodings chosen initially and that recall those of the web-map. Therefore, all the elements are characterized by a precise sign/ graphic language that is reflected on the entire web application, trying to limit the possible confusion that can be generated by the use of such tools (Fig. 12).

The photogrammetric models of the altars were also included in the process. The obj file is linked to the tour on the web using sketchfab site. This element has been subjected to a first operation of decimation and editing that has returned a model certainly lighter in terms of polygons but no less responsive in the graphics thanks to a further phase of texturization with high quality.

The created virtual tour has been added to the web-map by linking with the GIS application. The path of the tour becomes one of the values of attributes table of the point element of the Church of San Giacomo Apostolo Maggiore and inserted in the web-map by conversion to geojson interchange files. In this way the web-map is implemented by a virtual fruition of the sites investigated creating a structure that can be enjoyed both remotely and in situ and at the same time being able to take advantage of special tools to make the visit immersive. Therefore, the built map expands knowledge through information points and allow management and navigation in full autonomy involving not only emotional and sensory involvement, but a new way of knowing and making known such religious site (Fig. 13).

Fig. 13 Fruition mode of the web-map and the virtual tour. *Editing* authors

5 Discussion and Conclusion

The study of this research shows how the representation and dissemination of cultural heritage are influenced by the possibilities offered by digital technologies also in relation to the protection of the asset. The multidisciplinary approach assisted by the use of the various techniques used for the survey and representation were fundamental points for the documentation, verification and updating of the knowledge of the case study. The first stages of the research were permeated by the characteristic of systematic nature. In fact, they were carried out according to an orderly system in order to create an open documentation that can be continuously updated. All the information acquired in the various phases was represented graphically through thematic maps and analysis with the support of the QGIS platform. Therefore, taking advantage of the storage environment and the possibility to view the data also in web-GIS applications it is possible to query these databases, either by specialized users or simple citizens/tourists, with the ultimate aim of enhancing those architectural emergencies that very often are hidden by the continuous change of the urban context or difficult accessibility. Following the examination of the various archival documents (metric-estimative calculations, municipal resolutions, historical maps, ancient survey, project hypotheses, news and descriptions) we proceeded with several inspections to verify the current state, identify and validate in situ architectural emergencies and properly plan the next phase of survey on the individual case study. The different data acquisition operations carried out on the church of San Giacomo Apostolo Maggiore, have been integrated with each other in order to obtain a more detailed representation of the facades and not only of the floor plan.

The critical analysis in the use of different survey tools and outputs led to identify which of them was the most useful to create a path of use that did not require large technological equipment for its use. This has led to the use of equirectangular images more manageable by web environments than a cloud of points or a polygonal model that need further editing to be easily usable. Therefore, despite the continuous and frenetic technological development that leads to always prefer the most performing technology, it is necessary to evaluate which of them best suits the goal.

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Semantic 3D Models and Virtual Environments for Narrating and Learning the Heritage's Cultural Contents

Anna Lisa Pecora

1 Introduction

In recent years, the development of Information and Communication Technologies (ICT) systems has increased new research frontiers in the study of spatial cognition. This phenomenon depends on the subject of our attention: seeing architecture is different from seeing an image of architecture; in this case, the visual message is further deciphered by a double synthesis and interpretation; first by the designer and then by the user, who should decode the graphic signs as physical space's elements.

Moreover, a multitude of individual and unconscious mental processes complicate the understanding of the space that, so, can differ from individual to individual. For this reason, graphic signs should be managed with full awareness in order to empower communication and spatial knowledge. The virtual environments, in fact, if well designed, can constitute a barrier-free learning space that can guide spatial interpretation by adapting itself to the user's cognitive needs and, therefore, implementing the pedagogical potential of the in vivo visit experience.

The present study uses an innovative VR/AR design to communicate the heritage with a human-centered approach, to narrate not only the visible contents but also the theoretical and semantic characteristics of the architecture. The main objective is to shift attention from the technological tool to the user, in order to enhance the potential of 3D models as educational tools to improve architectural heritage communication and learning for all.

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2 Background

2.1 ICT for Heritage Communication

Virtual and augmented reality systems hide huge potential to tell and reveal the complexity of the architectural heritage. The fragility of the cultural heritage, often not fully available, can be supported by digital technologies capable of removing physical and cognitive barriers, activating new processes of dissemination and knowledge of the heritage. However, the use of such technologies is not enough to widely convey the heritage cultural contents and their semantic efficacy. In fact, what we observe in an AR/VR digital environment are not physical objects, but expressive codes, which must be appropriately selected and designed to effectively convey their communicative content.

If the drawing has in itself the potential of a language, or metalanguage [1], which can be universal at the same time, but also accurate in decoding the message, ICTs represent a multifaceted operational tool, capable of simultaneously managing multiple media levels and adapt to the user's needs [2]. In particular, in the important relationship between man and environment, technologies today assume a dominant role, due to the incredible digital instruments' flexibility and the ever-greater definition of graphic rendering. Virtual Reality (VR) and Augmented Reality (AR) are just some of the new frontiers that technology offers allowing us to mediate the experience with space through simulated reconstructions. In this sense, the drawing of the virtual environment is not only the description of a physical reference but becomes a cognitive medium of the space and its characteristic elements. For this reason, edutainment for cultural heritage is one of the rapidly developing fields where emotional involvement plays a key role in the learning process of the heritage's cultural contents. In particular, ICTs differ from traditional communication methods in wide aspects: the learning process focused on the user, the introduction of the temporal dimension, the potential of modifying logical, graphic and environmental structures, the interaction with the digital environment, a broad sensory involvement that goes beyond visual communication and that is also crucial in special teaching dedicated to an increasingly large share of new generation learners.

From a cognitive point of view, it is remarkable progress toward the definition of a human-centered experience of the built environment. Modifying the scene's morphological and figurative setting, managing frame and movement methods in a virtual model with the same modality of physical space and highlighting of hidden details and information, allow full virtualization of reality in both VR and AR.

This way the ICTs provide a direct experience, giving back the sensation of total autonomy but, at the same time, supported and customized to the users' abilities. The final result is an increase in the communication potential and effectiveness of the educational process. Even if there is always a filter between the user and the digital environment, whether it's a screen, an optical viewer, a helmet or gloves with feedback mechanisms, the primary role of interactivity is to make the user filling at the center of the scene, to experience the space firsthand.

2.2 Augmenting Reality

In detail, augmented reality allows the visitor in situ to overlap the digital architecture (3D model) on the physical object. Using open-source apps such as Agument, virtual data are visually overlapped and integrated into the real world, in the physical space framed by the mobile device camera [3]. The digital content automatically becomes visible on the screen when a specifically created marker is framed since the link with the model has been uniquely assigned during the 3D design phase. This process is provided through the correct identification of an insertion point of the 3D model of the existing architecture in the physical space. Thus, spaces of hybrid and multimodal coexistence are generated; this way, the direct, physical and indispensable experience of visiting the site becomes an interactive path of knowledge assisted and implemented by experience through information, graphic signs and digital objects integrated into the real ones, achieving a mixed reality. For this purpose, it is necessary to delete the dichotomy between physical space and digital space during the design phase of the communication path: "la nostra vita dell'ultimo decennio testimonia la nostra capacità di vivere in entrambi, spesso anche contemporaneamente" [3].

2.3 Virtual Reality

Regarding VR systems, however, they isolate the observer from the surrounding space to totally immerse him in a new digital space that can be observed through VR headsets [3]. These computer-generated settings imitate reality and can be enjoyed through multiple devices with different levels of immersion and presence.

To have an immersive effect, VR systems reproduce particular types of images called panoramic, spherical or 360°, which give the sensation of being at the center of the scene and observing the context in any direction. The final perceptual result is total immersion and it provides a totally different sensation compared to observing a film through a monitor thanks to the totally absence of frame contours.

The panoramic images are created using an equidistant cylindrical projection or equirectangular, so that once an observation center has been established in space, the content of the image is projected onto an ideal spherical surface and developed flat, according to a mapping that has the center of projection or nodal point as its x/y coordinate center in order to obtain a single panoramic photo or the frames for a video montage. This flat development has a ratio between width and height equal to 2:1, since the upper and lower edges, obtained by dilation of the respective poles they represent. The panoramic images can be photographic or rendered from a 3D model and generated directly by the modeling software, using a panoramic camera or starting from a multitude of partially overlapping shots (Fig. 1). In this case, the shots must all take place from the same nodal point, until reaching a FOV angle of 360° horizontally and 180° vertically. The photographic acquisition software processes the

Fig. 1 Example of photo merge. *Author* A.L. Pecora

shots to realize the uninterrupted stitching or photo merge by recognizing, among the contiguous images, pairs of homologous points or control points.

3 Perception, Cognition and Learning in VR Systems

Having the sensation of being in a physical space is one of the most important aspects of virtual reality, as high levels of presence allow many of the visuo-spatial characteristics involved when interacting with a real environment. No other media surrounds the person in such an enveloping way as to make him feel like the protagonist of the action, giving him the opportunity to look around him in any direction and at any time. For this reason, the design must be user-centered, considering in depth the response to the system inputs. It is necessary to take into account the whole rich system of relationships that builds the link between space and perception, as well as between men and technology.

Therefore, I conducted a thorough investigation of the cognitive-sensory relationships supporting the vision of an environment, starting from the assumption that the well-ordered management of spatial information flow can increase the potential of ICT as a valid learning tool. First, I analyzed the physical context, where the space directly conveys its morphological characteristics, then the pictorial space where, in addition the perceptive and cognitive system's filter, there is the interpretation of the designer who had to make multiple choices (choice of framing, point of observation, elements to highlight and those to blur, lighting, chromatic choices and much more) to reach the final layout. The virtual environment, although it is the result of graphic actions, implies different perceptive dynamics in itself; in this case, a complex relationship between the image and the observer comes into play. In summary, we pass from an observed space to a lived space where the narration cannot take place without the observer's action. When the perceptive experience requires a movement, also simulated, integrated cognitive processes are triggered, in which not only the sense of sight is involved, but also the vestibular and haptic system. We don't need to move the whole body to involve the movement receptors; just rotating the head, we can catch the wholeness of a scene that extends its limits beyond the human visual field.

As Stephan Günzel says “There is a central medial difference between simulation pictures and classical forms of pictures, namely that while conventional pictures were constituted by pictorial space or an image-space, interactive pictures on the contrary present a space-image” [4]. In traditional media, even passing from a static image to a dynamic video, the user has a passive role that neither interferes nor can influence the action. On the contrary, in VR the narration cannot take place without the observer’s active involvement.

It is a physiological issue; the body and not only the sight becomes the way to experience three-dimensional environments. We then move from observation to navigation, during which the visual framing is not delimited by borders and the space becomes a place to be actively explored in the first person. Another fundamental difference between traditional images and VR representations concerns the possibility of interaction; actions and reactions that occur in near real-time, similar to what happens in the physical world. The interaction drives the user in an active condition with respect to the surrounding space, starting from the simple choice to change the point of view and therefore to observe the environment from a different position; an unfeasible condition, both when observing any static image, and when watching actions in a movie, where the frame is definitively chosen by the director during shooting.

However, VR is still a simulation and, therefore, as in any graphic representation, the designer’s choices have a priority role in conveying, hindering or promoting the cognitive process that leads to the understanding of space and the decoding of its figurative codes. In most cases, everything in a computer graphic (CG) environment has been placed there for a purpose and therefore its morphological and aesthetic characteristics are the result of targeted choices [5]. When this happens, virtual reality can be considered a communication tool. According to Jason Jerald, in fact, the dialogue does not necessarily have to take place between two or more people, but also between man and technology and, in the particular case of virtual reality, if this is well designed, a collaboration between man and machine is established in which both software and hardware work in harmony to enable intuitive communication with humans [6]. In particular, the user acts in the simulated space by interacting with the stimuli conveyed by the technological system as if he were in the real world, therefore, the communication between the virtual setting and the observer is defined as direct [6].

Since learning conveyed through ICT is related to the possibility of operating, discovering, and observing without apparent mediations, it is more natural when compared to symbolic-reconstructive educational methods, such as those mediated by writing. Therefore, a path of knowledge in an immersive environment can be more immediate than traditional learning methods, not only because more friendly, but also because some steps of this cognitive process reflect those implemented in everyday life. In the field of scientific research, these similarities have, in part, eased the understanding of the factors that most affect the communicative and pedagogical effectiveness of the experience. In this regard, Morganti and Riva report research born from the collaboration between the Faculty of Communication Sciences of Italian Switzerland University and the Department of Psychology of the Turin University, on the effectiveness of virtual environments for understanding space. The researchers start from the same assumptions of in vivo pedagogical experiences, i.e., from the study of the perception, movement and synesthesia process [7]. The study assumes, in fact, that spatial knowledge is not the result of an aggregating sequence of information from the outside world, but rather a situated process, during which mind and environment compare each other according to the perception–action system. According to the research group, the analysis of spatial knowledge in VR can be based on the same principles, since in such cases, the information coming from the virtual environments allows the user the same interaction modalities that are possible even in a non-simulated context. For example, the navigation modality with an egocentric perspective allows orienting by building an effective mind map, therefore, the visual approach is the same as we observe and build our experiential baggage on a daily basis.

The observer thus becomes the reference center of a polar coordinates system which allows the decoding of spatial values. In relation to this subject Di Tore states that: “Nel sistema di riferimento allocentrico (oggetto-oggetto), le informazioni sulla posizione di un oggetto sono codificate in base alla posizione di altri oggetti. La posizione di un oggetto è relativa alla posizione degli altri oggetti. Nel sistema di riferimento egocentrico (soggetto-oggetto), le informazioni sulla posizione di un oggetto vengono codificate in base agli assi corporei del soggetto. La posizione di un oggetto è relativa alla posizione del soggetto. È possibile rappresentare il sistema egocentrico utilizzando il piano cartesiano ricavato dagli incroci del piano frontale e del piano sagittale” [8] (Fig. 2). Despite, in fact, we interact with the world in multisensory mode, it is through sight that we are able to have more accurate and rapid information on our spatial location and direction of movement, since it embraces an extremely wider field of action than the others senses [6].

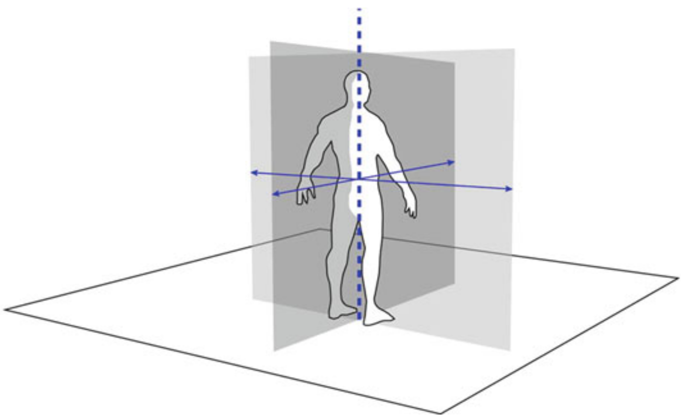

Fig. 2 Scheme based on Di Tore’s description about egocentric coordinates. *Author* A. L. Pecora

4 The Human-Centered Design

4.1 The Design Process

Referring to the observations developed during the analytical phase of the present research, I built an innovative digital twin to enhance its physical twin, with the aim of emotionally involving visitors in the knowledge process. The digital twin is not simply a 3D model, an exact copy of the physical reference model, but a dynamic and semantic representation of space allowed by the incredible versatility of digital technologies such as virtual and augmented reality. They allow several settings, for example, the selection of morphological space details, the managing of the light, saturation and vividness levels, the choice of chromatic characteristics and much more, providing new ways of using the information about the heritage with communication goals. An important aspect, from an educational point of view, concerns the potential of stimulating the users' attention and interest conveying information through an attractive tool that increases their emotional involvement and consequently gives new strength to the learning process. Furthermore, since the stimulus can travel on figurative rather than verbal contents, the cognitive dynamics change improving the heritage knowledge. The reading of visual patterns affects what Berlyne calls collative properties of the stimulus, (that are attributes depending on the relationships between objects) and, therefore, if properly managed, they can stimulate an exploratory behavior that raises the levels of arousal and consequently promote the process of knowledge and learning. The arousal indicates a momentary degree of alertness, vigilance, attention to which correspond physiological manifestations of acceleration of the heartbeat, pupillary dilation, increase in blood pressure, muscle contractions, electrical response of the skin, which are measurable and which integrate other, less direct, measurement methods of this type of behavior, such as the analysis of verbal responses and the observation of the subject's motor activity. The positive hedonic value qualifies those processes, connected to the stimulation of certain areas of the brain, which preside over the experience of gratifying events, usually defined by the human being as pleasant or attractive [9].

Therefore, a prototype was developed, that's a VR tour aimed at guiding the visitor to understand the complex relationships within architecture: between architecture and its geometry, architecture and its decoration, the architecture and its history, thus giving a specific semantic role to visuo-spatial signs. The virtual tour does not substitute the experience of the physical space but overlaps with it, increasing the value of museum communication. The potentials offered by this operative method are several:

- using different levels of representation to connect the physical space to non-visible information regarding different issues such as history, architecture, geometry, good's construction phases.
- using the universal language of images to allow inclusive access to the cultural contents of the heritage.

- emotionally involving the user by placing him at the center of the learning process, increasing the effectiveness of museum communication.
- eliminating physical barriers, linked not only to the different abilities of each user but also to the fragility of goods that may be inaccessible.
- adapting the communication, the representation of the space and the narrative contents to the user's needs.
- recording the user's perceptive responses in real time through eye fixation detection systems in order to improve the initial project.

The design choices, in each stage of the tour, take into account multiple factors: the themes of the narration, the space qualities to be highlighted and those to be summarized, the pedagogical goals to be achieved.

For this purpose, I've achieved various types of surveys and drawings. For the visualization of the indoor environments, I've developed digital photogrammetric surveys in Structure from motion_Sfm to build point clouds and textured meshes of each environment (Fig. 3), while the survey of the external spaces has been performed through a photographic stitching process, which allowed to produce panoramic photos by joining several shots (Fig. 1). Both types of surveys, aimed to obtain realistic images of space, have focused on a gradual transition from the visualization of the physical space to the virtual one and vice versa and for a static exploration of the environment. I've also realized a 3D model of the building with its indoor and outdoor spaces to produce panoramic renderings of the virtual environment (Fig. 4).

In particular, when a frame is used individually, the viewer has the sensation of being at the center of the scene and observing it in different directions, but always from the same position, thus with a static exploration of space. Instead, to provide the illusion of movement between different spots in space, numerous frames have been assembled in sequence in such a way as to generate a continuous navigation modality, without visual jumps. Continuous navigation differs from teleport or discontinuous navigation because it builds visual connections between different spatial positions. Therefore, continuous navigation has been chosen in order to facilitate spatial knowledge even in inexperienced people as it supports orientation and the construction of mental maps by relating different spots in space.

The digital twin is characterized by simple geometries and a reduction of decorations in order to facilitate the reading of the architectural space through a selection of essential spatial information, schematization and conceptualization of the architectural apparatus, mainly reproducing the historical-stylistic essential qualities. In this way, the information is introduced gradually and one at a time on a schematic background through graphic animations which highlight the theme of the narration step by step.

Fig. 3 Photogrammetric survey of the Monumental Staircase. **a** Point cloud. **b** Dense cloud. **c** Textured mesh. *Modelling* A.L. Pecora

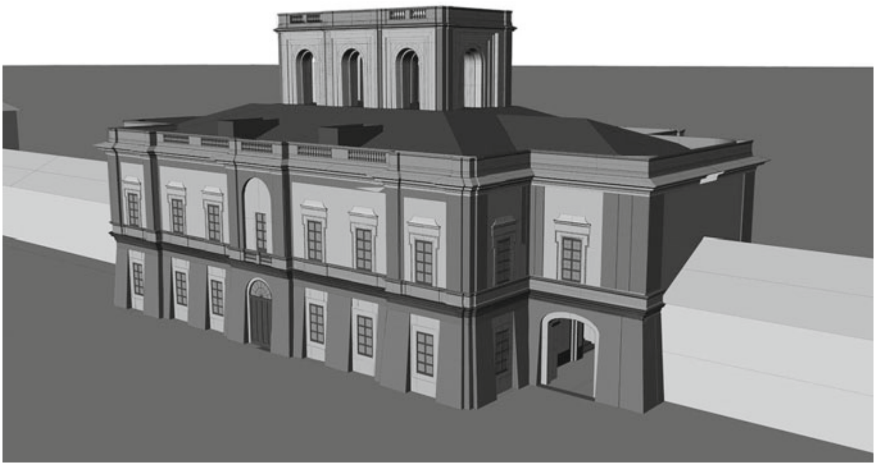

Fig. 4. 3D model of the Royal Palace of Carditello. *Modelling* A.L. Pecora

4.2 *The Case Study: The Royal Palace of Carditello*

The case study focuses on the Royal Palace of Carditello in San Tammaro (CE) since the variety of its architectural structure and the richness of cultural contents allow to experiment with different drawing methods depending on the themes of narration and of the space morphological characteristics. The Royal Site of Carditello was born as a farm acquired by Carlo III of Bourbon in 1744. The estate of Carditello, like other royal sites built in those years, combines the king's passion for hunting and the enjoyment of rural life. This project can still be read today in the particular relationship between the building and the surrounding environment reflected in the simplicity of the decoration, all aimed at evoking the ancient world and nature. Carditello seems to lay the foundations for a new style, in line with the renewed Illuminist sentiment. The gentle look at the rural world results in elegant examples of mural painting and stucco well blended with the rural and hunting vocation of the places and referring to the naturalistic representations of Augustan age imperial residences. In Carditello the natural landscape became not only the residence's backdrop but also the decoration of its interiors. Hackert and his staff transferred to the rooms' walls, almost as if they were windows open to the outside, images, scenes, representations of a bucolic and real-world expressing the *raison d'être* of this royal delight to which Ferdinando IV was so deeply linked [10] (Fig. 5). Here we read the aspiration towards new neoclassical ideals of rediscovered harmony with nature and of an aesthetic that traces its elegance in the compositional balance of shapes and imitation of ancient models. Carditello, therefore, is conceived as a model royal site in contrast to feudal backwardness through an enlightened example of agricultural economy that can also lift the social fabric.

Here, the architecture and its aesthetic confirm and express this innovative impulse to combine the beautiful and the useful in agreement with the eighteenth-century Illuminist sentiment.

In particular, the main purpose of the site was to start a royal purebred equine breeding with the aim of training a cavalry suitable for the war. In 1787, Ferdinando IV of Bourbon transformed the hunting lodge into a modern farm, extended over approximately 2000 ha, for the cultivation of cereals, legumes and fodder, the latter to support the breeding of the prized breeds of horses and caw. In the same period, Francesco Collecini was commissioned to build the Royal Palace, located in the center of the lodge and inaugurated on 9th May 1793. After the unification of Italy, the Royal Palace of Carditello was owned by King Vittorio Emanuele II of Savoy, as shown by the royal coat of arms of the Savoy family placed outside on the highest point of the main facade (Fig. 6). Starting with the Savoy dynasty and following, the lodge went through a long and slow period of disregard and spoliation continued almost to the present day when the Fondazione Real Sito di Carditello took on the management of the site through the MIBACT. Thus began a period of recovery and enhancement so that today the Palace is open to visitors through diversified educational and leisure activities. After the death of King Ferdinando I of Naples in 1825, the kingdom passed for a short time to his son Francesco I and, after only five

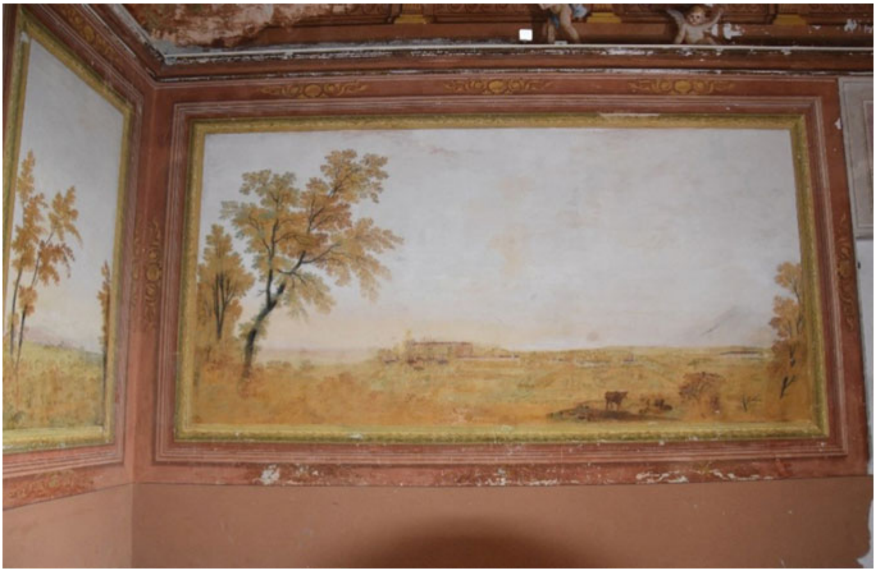

Fig. 5 Jakob Philipp Hackert: room of Agresti paintings; detail of the painting with a view of the Royal Palace of Caserta. *Photo* A.L. Pecora

years, to Ferdinando II due to the premature death of his father Francesco. Ferdinando II had married Maria Cristina of Savoy who influenced the administration of the kingdom towards a regime of puritanical austerity. After the glories of Ferdinand I's kingdom and with the death, in 1859, of Ferdinand II: "la monarchia borbonica era ormai al suo drammatico epilogo; e la sorte riservava proprio al re Francesco, successore di Ferdinando II e figlio di una Savoia, di lasciare al re Vittorio Emanuele II il regno delle Due Sicilie […]. Con l'avvento dei Savoia la tenuta di Carditello tornò ad essere principalmente una riserva di caccia e gli edifici, e tra questi particolarmente la palazzina centrale sempre meno abitata e più incustodita, andarono lentamente ma progressivamente logorandosi" [11].

Fig. 6 The Savoy's coat of arms placed on the Royal Palace's main façade. *Photo* A.L. Pecora

Simplicity and linearity also characterize the interiors, both in the floor plan, which respects the symmetrical façade layout and in the decorations which, here in Carditello, completely leave the decorative richness of the rococo style still widespread in Naples [12].

4.3 The Royal Palace

The Royal Palace (Fig. 7a), where part of the visit experience takes place, is characterized by architectural solutions of neoclassical inspiration, with a clear symmetry both in the iconographic profile and in the facades. Here the vertical axis is underlined by deep arches and by a forwarded external curtain wall, furthermore, a Savoy's coat of arms stands out in the center of the summit balustrade. After the death of King Ferdinando I of Naples in 1825, the kingdom passed for a short time to his son Francesco I and, after only 5 years, to Ferdinando II due to the premature death of his father Francesco. Ferdinando II had married Maria Cristina of Savoy who influenced the administration of the kingdom towards a regime of puritanical austerity. After the glories of Ferdinand I's kingdom and with the death, in 1859, of Ferdinand I "Ila monarchia borbonica era ormai al suo drammatico epilogo; e la sorte riservava proprio al re Francesco, successore di Ferdinando II e figlio di una Savoia, di lasciare al re Vittorio Emanuele II il regno delle Due Sicilie […]".

The Monumental Staircase (Fig. 7b), located on the central building's corners, lead to the noble floor. Each staircase, with three stretches, is covered by a pavilion vault decorated with phytomorphic festoons and thistle flowers. The floral shoots

Fig. 7 **a** The Royal Palace (Photo: A.L. Pecora). **b** The Monumental Staircase (Photo: A.L. Pecora)

are surrounded by relief frames that trace the diagonal lines of the vault and highlight its geometries (Fig. 8a). This scheme continues along the walls which, thus, are marked by rectangular fields. The central one houses stucco high-reliefs with evocative hunting triumphs (by the sculptor Angelo Brunelli) where the venison appears alongside the weapons (Fig. 8b). This environment is one of the main stages of the virtual and in vivo visit itinerary. In the virtual tour appropriate drawing choices connected to a gradual sensory stimulation aim at the narration of the cultural contents that underlie architecture in its many aspects: the spatial value, the geometric configuration of the vaulted surfaces and decorative details. The close bond between the decorative apparatus and the architectural spatiality constitutes a typological example on which to evaluate the communicative potential of the prototype and, in particular, of its figurative language.

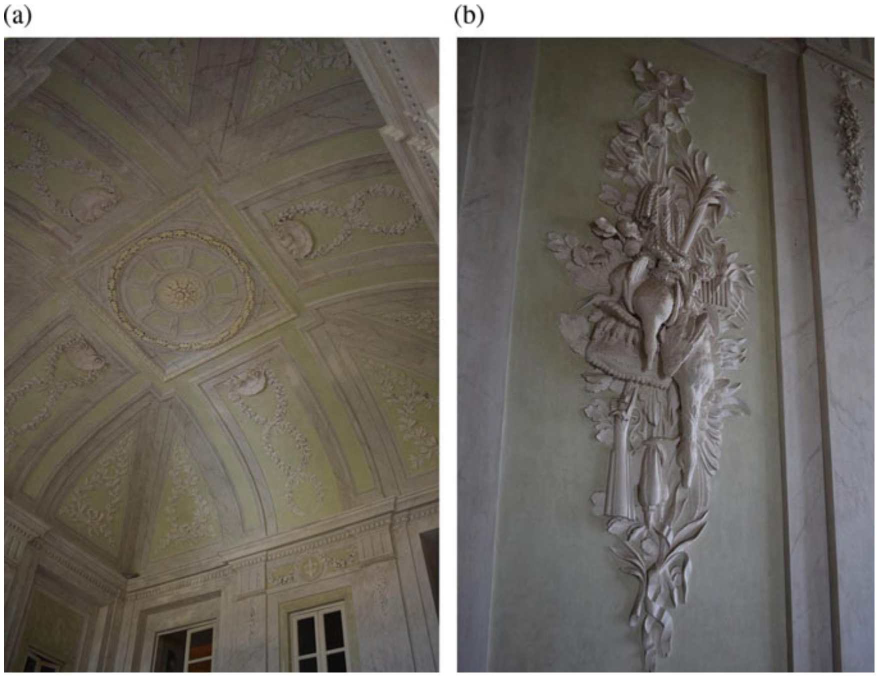

Fig. 8 **a** The detail of the pavilion vault (Photo: A.L. Pecora). **b** The Angelo Brunelli's stucco high-reliefs (Photo: A.L. Pecora).

4.4 A Stage of the Tour: The Monumental Staircase

In this room, the aim was first to communicate the geometry of the pavilion vault and its particular relationship with the decorations, then to reveal the relationship between the decorative reliefs on the walls and the history of the building.

A virtual assistant has been included along the route and, in particular, characterizes the main stages of the tour. In this way, the avatar's presence is associated with the narrative content, arousing the user's curiosity and attention and, consequently, facilitating memorization. The objectives more specifically inherent to the drawing discipline are transversal and, therefore, also functional to the achievement of the pedagogical and ergonomic objectives but, at the same time, play the specific role of supporting orientation in space, providing visual and movement guidelines in the virtual environment. For this purpose, and with the further objective of providing the essential information in a well-ordered and clear manner, the backdrop where the user is invited to stop is schematically drawn, without decorations and in grayscale without, however, losing its stylistic recognizability (Fig. 9). The virtual environment thus designed offers a suitable background in which to gradually introduce the visual focuses and details conveying the narrative contents.

The main subject of this room is the vault and its decorations, which recall the themes of the thistle and hunting, recurring in the frescoes and decorations throughout the architectural complex. The first step in this phase of the tour, is to guide the gaze upwards, to facilitate the reading of the vault and its compositional elements. Therefore, for perceptive purposes, I managed the lighting conditions leaving the room in dim light and obtaining a spot of light on the ceiling, in order to place the vault as the center of attention. The difference between the illuminated area and the shaded area has the purpose of isolating and making the target visible, thus the objective

Fig. 9 A panoramic image, developed flat, of the virtual environment before introducing visual focuses. *Modelling* A.L. Pecora

towards which the route aims to attract attention. Therefore, for a few moments, the vault remains the only lighted part of the room, to then gradually bring the entire space back to a condition of total brightness. The following animations focus on the geometry of the vault by underlying its diagonals, and subsequently, highlighting its decorations; a further representative trick, in this regard, is a temporary enlargement of the decorative detail (in this case the central relief of the vault, representing the thistle flower) in order to make the visually distant detail more visible, and therefore appreciable and recognizable in physical space (Fig. 10). This phase is followed by the gradual insertion, in the virtual environment, of the high-reliefs on the walls (Fig. 11). Gradually the simplified image of the decorations is replaced by the same subjects in realistic full colors to highlight the plastic, material and sculptural qualities which will then have to be recognized in the subsequent phase of the in vivo tour. This stage accompanies the user, little by little, towards the visualization of the final frame of this narrative step, where the space is entirely represented with its realistic spatial qualities of lights and colors (Fig. 12). In order to simulate a movement and a physical path of the observer in these spaces, it was not possible to use a spherical image linked to a fixed central point of view and, therefore, the entire environment was photogrammetrically surveyed in order to have a three-dimensional point cloud and mesh surfaces with high-definition textures. This image is obtained by developing a panoramic rendering of a point cloud, acquired with a photogrammetric survey. All details later inserted into the virtual environment are obtained by clipping from this same image. In order to make the details consistent with the environment in which they are inserted, during the rendering phase the same settings are assigned to the two models, the 3D vector model and the point cloud: height and position of the point of view, camera's direction, lighting values, etc.

5 Conclusion

By setting the level of detail, the chromatic and luminous qualities, the quantity and value of the graphic signs in a digital environment, ICTs reveal the complex theoretical and morphological relationships between the different elements of the space, enhancing their semantic value and facilitating their understanding and learning. The architecture must be able to transmit, through adequate drawing choices, its typological and spatial characteristics (of perspective depth, dimensions and directionality) without perceptually overloading the user with visual information that is not strictly necessary. In this way, not only the potential of museum fruition is increased, free from physical and cognitive barriers, but new relationships develop between the narrated space, its cultural contents and the visitor thanks to a user-centered design.

Furthermore, the added value of this methodology lies in the incredible flexibility and potential of being developed with different technologies; in addition to the VR presented in the case study, augmented reality also offers the same operational potential, which can be used in different contexts; not only in the museum field but also in

Fig. 10 Some stages of the video showing the animations aimed to put in evidence geometries and decorations of the vault. *Modelling* A.L. Pecora

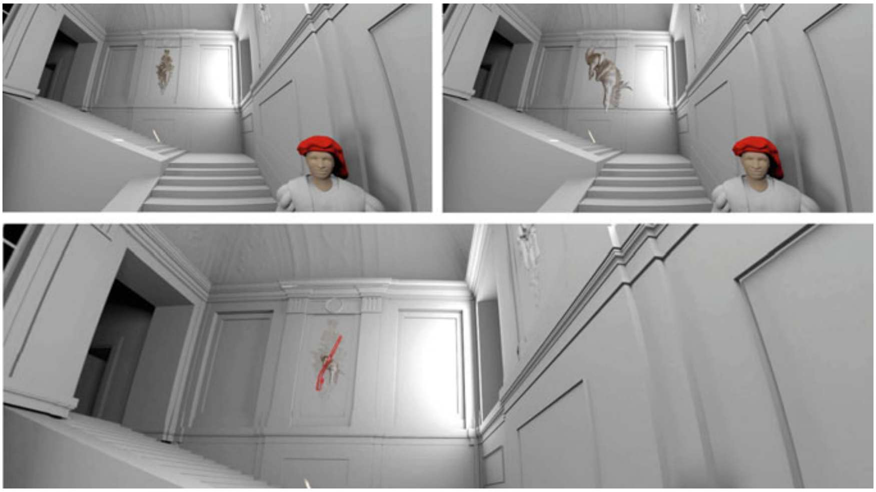

Fig. 11 Some stages of the video showing the animations aimed to put in evidence the decorations on the walls. *Modelling* A.L. Pecora

Fig. 12 A panoramic image, developed flat, of the virtual environment obtained from photogrammetric surveys. *Modelling* A.L. Pecora

pedagogical, tourist, experiential contexts and always with an inclusive perspective that allows anyone the full autonomous access to culture.

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VR and Holographic Information System for the Conservation Project

Fausta Fiorillo, Simone Teruggi, Sonia Pistidda, and Francesco Fassi

1 Introduction

3D digitization of cultural heritage is a necessary process; it makes it possible to create a detailed, complete, and accurate 3D digital representation of a building or structure primarily used for the documentation, preservation, and fruition of CH. Photogrammetry and laser scanning are two surveying methods often used to digitize cultural heritage. These methods have been used for a long time in the 3D digital surveying of historical monuments, and particular laser scanners and UAV photogrammetry have become a standard in the professional praxis.

For this reason, for some time now, within several master's degree courses at the Polytechnic University of Milan, integrated classes in Survey and Built Heritage Preservation have been programmed that precisely encourage the learning and use of digital techniques for the knowledge and understanding of the existing built environment and as support for conservation, maintenance and reuse operations.

One of the main unsolved issues in the digitalization pipeline regards the use by the practitioner of 3D data effectively and helpfully by making the most of the data completeness, immersivity of the tridimensional geometry, richness of detail, and accurate color.

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The aspect of data fruition is still unresolved nowadays, both from the more technical and practical point of view of the use of 3D data in daily practice, but also from the point of view of the potential that this type of data brings. The most common use of this data in professional practice is to extract 2D representations, that is, the classic architectural graphics that are synthetic and abstract representations of reality. This happens because it is the most common data in use and hence the easiest to understand and work with. The research question is how to use the complete, realistic, detailed 3D data directly within pre-planning and decision-making practices without going through lengthy data processing and transformation operations that lead to extreme simplifications, loss of information, and the metric characteristic of the collected data.

Thus, the idea is to exploit educational activities where students test themselves with advanced surveying techniques aimed at designing conservation or reuse activities using virtual-type techniques for the shared use of data in the design phase and the final communication of the results obtained. This innovative approach for examining, studying, and designing using a digital 3D representation involves two essential steps:

(1) The first is the direct use of digitalization-derived 3D point clouds. The direct use of the point cloud refers to the use of the final point cloud produced by the surveying process, which includes instrumental acquisition, the registration of various point clouds, creation of the overall cloud, cleaning of the cloud, and potential decimation to decrease its weight and equalizes its resolution. The idea is to avoid any other subsequent modeling process.

(2) The second is the creation of a data-enriched point cloud. It is nothing more than the final point cloud with information docked to both the cloud's constituent parts and individual point hotspots. These information sheets can concern intrinsic and extrinsic characteristics (e.g., state of the art, the form of use, state of conservation, main building features, etc.) of the architectural elements referenced in a 3D information system.

This can be done using existing stand-alone or web/cloud-based platforms, certainly a tried-and-true method, albeit one that is still rarely employed inside the realm of professional practice. Another more advanced way is to use VR techniques to allow immersive first-person exploration of the digital model. The user is inside the virtual scene, which facilitates the reading and interpreting of the data (virtual representation + connected sheets) more realistically. This experience can enable the comprehension of the characteristics and conservation problems of the building in a systemic way. Another approach is to use a holographic table device that allows to analyze and observe the same data (Point clouds with associated info) in a 3D environment shared by multiple users (currently, the maximum number of users is 4 for the hologram table), thus favoring a collaborative approach. One method does not exclude the other; on the contrary, they can be complementary in favor of a pipeline for an advanced and informative representation of the heritage that can be useful for conservation activities.

The Meta Quest 2 and the Euclideon Hologram Table are the instruments used to prove the validity of the approach. The first is a last-generation VR headset with 6 degrees of freedom. It allows total immersion in visualizing and navigating 3D models and their context. The second consists of a flat screen equipped with four projectors that allow displaying of virtual models in holograms. Moving the experience beyond the simple visualization of the 3D models, a specifically designed system has been created using the Unity game engine connected to a PostgreSQL database.

The goal is to create an ad hoc system that allows all the actors involved in the conservation project to collect, archive, and update information relating to the inspection activity carried out directly on the detailed and accurate VR and/or holographic representation of the object. Collaborative consultation and data queries can be made during the VR or holographic visualization, enhancing communication and sharing between all involved professionals.

1.1 State of the Art

Virtual [1] and Holographic [2] representations proved successful in different industrial and medical scenarios for training, education, maintenance, design purposes, or feasibility studies [3–5]. Virtual Reality (VR) has been mainly used for virtual tourism in the Cultural Heritage field, especially during the recent pandemic, enabling virtual access to remote areas and museums [6]. A current research topic concerns the applications of Augmented Reality (AR), particularly the possibility of defining a BIM-AR workflow for built heritage monitoring and a collaborative approach [7–9].

Few examples devoted to the professional practice of architectural heritage became available only recently thanks to the adoption of virtual and holographic headsets (e.g., Microsoft HoloLens 2 [10], Meta Quest 2 [11]), which are more oriented to the knowledge and immersive exploration of the architectural heritage [12] or of hazardous sites as in the Giovelli's mines in the project presented by [13]. In general, all VR projects look to this technique as an attractive, interactive, realistic, and close-to-the-student medium that improves the reworking and acquisition of new knowledge [14]. Still, these applications now allow posing a new research question: how can new survey techniques and VR and holographic representation contribute significantly to the design phase in the conservation field?

One solution is to use the 3D model as an information system [15–17]. One of the first examples in this regard was carried out for the Veneranda Fabbrica del Duomo di Milano with the aim of immersive navigation of the model of the Main Spire of Milan's Cathedral hooked to a cloud-based DB [18]. The technically successful experience involved the creation of the 3D model of the spire and a major semi-automatic operation of decimation that, in fact, significantly extended the time to use the data from the time of the survey. In addition, the extreme simplification of the non-textured 3D datum made virtual navigation unrealistic.

2 Case of Study: Cornello Del Tasso

Cornello dei Tasso is a charming little municipality in the Lombardy region of northern Italy, specifically in the province of Bergamo and in Valle Brembana. The settlement is on a hill and looks out over the valley and the stunning alpine mountains, making it a strategic hub for trade and business in the past through the famous Via Mercatorum, one of the oldest historical paths for commercial purposes. The village's history can be traced back to the Middle Ages, and it has maintained much of its medieval character over the years (Fig. 1). Its presence played a crucial role until the end of the sixteenth century when the new Priula road was built down the valley. Following these events, the village remained isolated, losing its ancient function but allowing the preservation of its unique architectural fabric.

In addition to its natural beauty, Cornello dei Tasso is renowned for its well-preserved medieval architecture made by stone winding laes, a monumental porch where the Via Marcatorum passed, and a 14th-century Santa Maria Assunta church, one of the rare examples of the Romanesque architecture in Valle Brembana.

Fig. 1 Two views of Cornello dei Tasso. On the left is the arcade, and on the right is the group of buildings overlooking the Brembo river's valley. *Photos* S. Pistidda

Although significantly transformed over the centuries, the church's gorgeous architecture and stunning frescoes have made it a popular stop for worshippers worldwide. Formerly Cornello links its name to the influential Tasso family, the inventories of the postal system who lived there. The ruins of the ancient, fortified palace of the family remain as evidence, today reduced to an archaeological area.

The course aimed to investigate the entire urban structure from an interdisciplinary perspective: the understanding and restitution of its conformation through advanced survey techniques; the reading of the construction system and of the complex structural morphology and the investigation of the construction techniques, building materials and their mechanism of degradation. The entire knowledge project and all the information acquired then allowed the development of design ideas to regenerate the place. The territorial analysis and all the data collected made it possible to understand the potentialities and critical aspects of the site, extending the reflections to the surrounding environments. The collaboration between the disciplines involved and the continuous comparison with all the tools used have proved to be an interesting technical and methodological challenge.

2.1 The 3D Survey

The survey activities of the village were carried out for two years by photogrammetric and scanner techniques. Considering the complexity of the site and the extension of the village but also the degree of detail required by the diagnostic investigations (less than 1 cm), it was chosen to use the Leica RTC360 scanner that allows both a high-speed (<3 min) acquisition of 360 panoramic scans at very high definition (3 m@10 m) with a declared noise of less than 1 mm. The color acquisition, the density of the acquired data, and the possibility to pre-register the scans on the ground directly during the survey allowed us to obtain a final point cloud from which it is possible to extract metric information at the maximum scale of 1:20.

The model was then completed with a drone photogrammetric acquisition to realize the DTM (Digital Terrain Model) of the area and the 3D of the roofs (Fig. 2).

At the educational level, dedicated photogrammetric campaigns were then conducted to map material and degradation of the exterior surfaces.

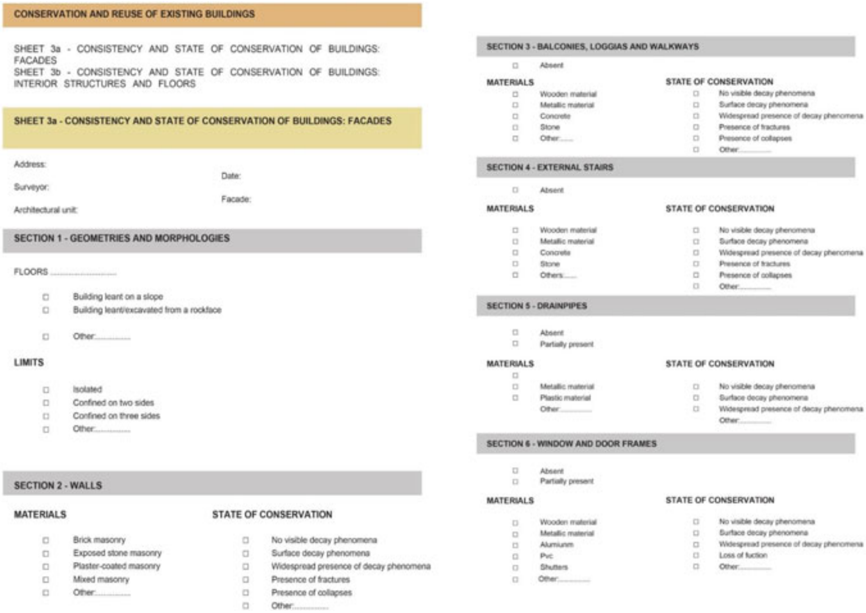
2.2 The Conservation Investigation

Investigations of different materials and decay conditions of structures are also conducted at various degrees of detail and depth, either after or simultaneously with the geometric acquisition of spaces and shapes. Students must complete field sheets and collect images reporting buildings' preservation level, structural details, and materials while imitating the typical working environment. The intervention and conservation planning activities associated with the conservation project begin with

Fig. 2 The complete point cloud of Cornello dei Tasso produced by combining laser scanning and photogrammetric point cloud. *Modelling* F. Fassi

this information that is usually gathered on-site and must then be converted into digital form in a subsequent step. The importance of studying together a significant quantity of information and systematically collecting data allows us to develop cross-reflections already in the survey phase on the field. This represents an important step in reading the characteristics of materials, the construction techniques, and identifying the possible causes of deterioration. Especially for this last step, the possibility of collecting and managing all the data together allows interlinking different hypotheses and assumptions.

Commercially there are applications that enable real-time digital data collection in the field, like the Leica GeoTags feature of Leica Cyclone Field 360 [19] that provides tools for creating Cyclone annotations that become TruView Hotlinks when the user runs Cyclone PUBLISHER, or cloud-based platforms, like FLYVAST [20] or AUTODESK ReCap [21] that allow adding labels or hotspots directly on the cloud. These applications were not used for two reasons: first, due to logistical considerations related to the busy teaching schedule, and second, because the data



CONSERVATION AND REUSE OF EXISTING BUILDINGS

SHEET 3a - CONSISTENCY AND STATE OF CONSERVATION OF BUILDINGS: FACADES
SHEET 3b - CONSISTENCY AND STATE OF CONSERVATION OF BUILDINGS: INTERIOR STRUCTURES AND FLOORS

SHEET 3a - CONSISTENCY AND STATE OF CONSERVATION OF BUILDINGS: FACADES

Address:
Date:
Surveyor:
Facade:
Architectural unit:

SECTION 1 - GEOMETRIES AND MORPHOLOGIES

FLOORS ....

- ☐ Building leant on a slope
- ☐ Building leant/excavated from a rockface
- ☐ Other:..............

LIMITS

- ☐ Isolated
- ☐ Confined on two sides
- ☐ Confined on three sides
- ☐ Other:..............

SECTION 2 - WALLS

MATERIALS
- ☐ Brick masonry
- ☐ Exposed stone masonry
- ☐ Plaster-coated masonry
- ☐ Mixed masonry
- ☐ Other:..............

STATE OF CONSERVATION
- ☐ No visible decay phenomena
- ☐ Surface decay phenomena
- ☐ Widespread presence of decay phenomena
- ☐ Presence of fractures
- ☐ Presence of collapses
- ☐ Other:..............

SECTION 3 - BALCONIES, LOGGIAS AND WALKWAYS

- ☐ Absent

MATERIALS
- ☐ Wooden material
- ☐ Metallic material
- ☐ Concrete
- ☐ Stone
- ☐ Other:......

STATE OF CONSERVATION
- ☐ No visible decay phenomena
- ☐ Surface decay phenomena
- ☐ Widespread presence of decay phenomena
- ☐ Presence of fractures
- ☐ Presence of collapses
- ☐ Other:..............

SECTION 4 - EXTERNAL STAIRS

- ☐ Absent

MATERIALS
- ☐ Wooden material
- ☐ Metallic material
- ☐ Concrete
- ☐ Stone
- ☐ Others:......

STATE OF CONSERVATION
- ☐ No visible decay phenomena
- ☐ Surface decay phenomena
- ☐ Widespread presence of decay phenomena
- ☐ Presence of fractures
- ☐ Presence of collapses
- ☐ Other:..............

SECTION 5 - DRAINPIPES

- ☐ Absent
- ☐ Partially present

MATERIALS
- ☐
- ☐ Metallic material
- ☐ Plastic material
- Other:..............

STATE OF CONSERVATION
- ☐ No visible decay phenomena
- ☐ Surface decay phenomena
- ☐ Widespread presence of decay phenomena
- Other:..............

SECTION 6 - WINDOW AND DOOR FRAMES

- ☐ Absent
- ☐ Partially present

MATERIALS
- ☐ Wooden material
- ☐ Metallic material
- ☐ Aluminum
- ☐ Pvc
- ☐ Shutters
- ☐ Other:..............

STATE OF CONSERVATION
- ☐ No visible decay phenomena
- ☐ Surface decay phenomena
- ☐ Widespread presence of decay phenomena
- ☐ Loss of function
- ☐ Other:..............

Fig. 3 One example of the factsheet that students must fill during the investigation on the field. *Editing*: S. Pistidda

collected with commercial systems are typically closed and not exportable, making it inaccessible and useless for use in the VR-Holographic system developed later.

Figure 3 shows some examples of tables that should be filled out. The factsheets help to collect information following different levels of detail, starting from the territorial analysis to the open spaces and to the building characters. The compilation of the forms can be done on-site and updated, and implemented in virtual mode, directly connecting the sheets with the spatial data. The sheets are conceived to guide the surveyor to collect data in a systematic way, from the general to the detail. The collected data allow for creating thematic maps according to specific themes: quality of the open spaces, materials, type of structures, state of conservation, etc.

3 The System Setup

3.1 The VR Device Description and Setup

The Meta Quest 2 VR headset has been accepted as the used VR device. One eyewear and two controllers make up its construction. The 6 DoF capabilities of the visor allow it to monitor head and body motions and convert them into movement within the virtual environment. It can map its surroundings using four cameras (two front-facing and two side-facing), generating a 3D representation of the world in real time and providing a mixed reality and greyscale see-through experience.

The Qualcomm Snapdragon XR2 CPU and 6 GB RAM memory enable onboard signal processing. It may be used with glasses and renders the picture on two LCD panels with an 1832 × 1920 resolution that refreshes up to 90 times per second. Depending on the headset version, its archive space is restricted to 128 GB or 256 GB.

The apparatus may function in one of two ways: (1) independently operating; and (2) linked to a computer. As with other mobile devices, the first scenario's device uses the Android operating system and has a finite amount of processing power and battery life.

By using a USB-C connection to connect to a computer, it can render more complicated material by making use of the computer's processing power and overcoming battery life and computational issues. It is attached to the machine; however, thus the range of experience will be limited since the cable's length directly affects it.

3.2 The Holotable Description and Setup

The Euclideon Hologram Business Table is a device that performs a Stereo view-dependent rendering able to simulate a 3D experience for visualizing data above-screen as a holographic display. The apparatus comprises an integrated projection system and a horizontal flat screen measuring 1.2 m × 1.2 m. The latter allows 3D models to show in a hemispherical volume in the center of the table screen up to a height of about 70 cm. A workstation (5820 Dell Precision Tower) with two graphics cards controls the holographic device (AMD Radeon Pro WX5100). Through four projectors, one person simultaneously gets the pictures that will be shown on the glass surface in the middle of the table (Vivitek D757WT with a maximum resolution of 1920 × 1200 at 60 Hz).

The holograms may be fully interacted with using specially made wands and glasses, and both employ an infrared tracking system to determine their location and orientation in space, controlling what the operators want to see. Four tracking domes are placed in each of the table's four corners, and controllers, a Sync Emitter, and a Radio Frequency Dongle are linked to the PC through USB. Their accurate location can be determined thanks to some spheres on the wand and the glasses.

The operation of the table is a very straightforward process. The table is large enough (2.1 m × 2.1 m × 0.6 m) for two people to stand around it, and it can monitor where each person's wand and stereo glasses are at all times. When the location and orientation of the glasses and wand devices are known, four distinct pictures, two images for each participant, are sent onto the table, one for each eye. These images are for the left eye and the right eye. Therefore, the technology can produce all four pictures in real time, making it possible for two separate operators to move freely about the table while maintaining their stereo vision.

It is a unique device in that it enables a group of people to examine the same 3D digital item simultaneously from a variety of viewpoints, all without the need for cumbersome VR hardware.

3.3 Software Development and 3D Model Setup

Hologram table software setup. The envisioned holographic experience was created using the Unity 3D program. It is a gaming engine that enables developers to produce 3D content for mobile devices, computers, VR devices, and augmented reality (AR) devices. Software capabilities are only limited by the availability of libraries to communicate with the intended device, which might range from desktops to apps for virtual and augmented reality. To connect to the holographic table's hardware, the newest Unity Toolkit libraries (V0.5.62790) released by Euclideon must be imported.

They include all required tools and procedures for gaining access to and using sensor streams emanating from the device (e.g., wand position, button trigger, wand ray).

On the Holographic Table workstation, which is in charge of all the background operations required for a proper holographic projection, the most recent HoloTray software must be installed.

VR integration set up. It has been done using the Oculus Integration SDK v44. For example, device posture, controller interactions, and head and body motions are just a few examples of the libraries and functions it offers to connect with Quest 2 hardware within Unity 3D.

3D point cloud model preparation. The FBX (FilmBoX) format is the default format in which Unity 3D software can operate and import tridimensional objects. However, point cloud models are incompatible with this file type. Therefore, to import and visualize point cloud data in PLY (Polygonal File Format), the PCX [22] libraries must be used. As a result, the Unity game engine can read every point that makes up the model and consider it as a distinctive 3D mesh model made up exclusively of vertexes (with no faces). Each vertex brings the RGB data associated with the corresponding point.

Point clouds must undergo several pre-processing procedures in order to be utilized inside Unity. These steps must be performed to appropriately decimate the point cloud in order to show the required detail while considering the graphics performance of the systems that will be used.

The Unity software, like most game engines, also has a left-handed reference system; for this reason, it is required to flip the Y axis with the Z when saving to the PLY file. Inside the game engine, just (R, G, and B) data can be read. Other information that may be included in survey data and that you want to preserve (e.g., reflectance value when color is not included) must be previously manually transformed into the (R, G, B) data type associated with each point, considering that this technique will replace a pre-existing radiometric data. It is necessary to create a different version of the same model in order to display different types of stored data.

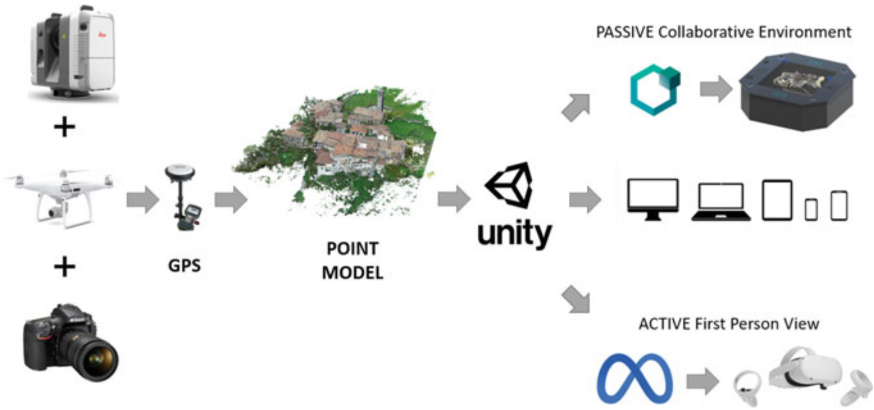


Fig. 4 Unity development pipelines. *Editing* F. Fiorillo

Here Cloud-Compare software was utilized to carry out these procedures, and only data with real (R, G, and B) colors have been considered for this study.

The work pipeline (Fig. 4) that permits utilizing the survey data in the Unity environment includes, in brief, the following processes:

The following steps were then implemented:

(1) Scan alignments and editing of the point cloud (the output file format is typically E57).
(2) Processing of the UAV point cloud and referring to the same coordinate system as the TLS survey.
(3) Point cloud setup for holographic display (model decimation and orientation).
(4) Model export in a PLY file format compatible with PCX libraries to finally arrive at using Unity Toolkits for the Hologram Table.

A unique point model data was developed with a final resolution of 10 cm for the whole hamlet and a total of 2.700.000 c.ca of points, considering purposes and device performances. It includes several interior rooms as well as all of the outside spaces assessed using TLS and UAV photogrammetric models of the roof and the surrounding environs (DTM).

In order to detect collisions and interactions between the model, user avatar, and pointers in Unity, a low poly mesh has also been produced from a lower-resolution version of the point cloud model. Because the mesh model is only intended to be used as a concealed volume and should not be rendered and shown, the procedure is quick and was carried out within the Agisoft Metashape program with no additional post-elaborations.

DB development. The database that lies behind the experience and the collaboration between the Holographic table and VR headset has been developed using PostgreSQL.

There is a Unity integration available that allows Unity3D to interact, upload and download content from PostgreSQL (it is called UnityNpgsql, and it is based on Npgsql v2.2.7. It is necessary to solve namespace conflicts with Unity standard libraries).

The database faithfully reproduces the information schema compiled during the field surveys.

4 Sharing Content Through VR and Holographic Table

4.1 VR System

The goal is to explore the model virtually as if we were there, with the ability to see the previously added data referenced on the surfaces in the proper 3D location and ultimately change or add more. It is intended to create hotspots linked to the PostgreSQL database where the table structure has been developed to replicate the conservation table sheet in order to include all possible entries (Fig. 5).

The data input window may be made by building a variety of precise-structured objects inside Unity. A backdrop of a planar frame is used to hold a set of hardcoded text fields.

Drop-down lists and checkboxes allow the selection of different options for each entry to avoid the use of text fields for free-descriptive purposes where each user might submit their own unique and subjective information. This expedites data input and ensures that coding remains consistent throughout time, favoring future data querying and comparison.

At this stage of development, the database structure and the infrastructure for viewing and editing cannot be modified after the app has been installed on the device;

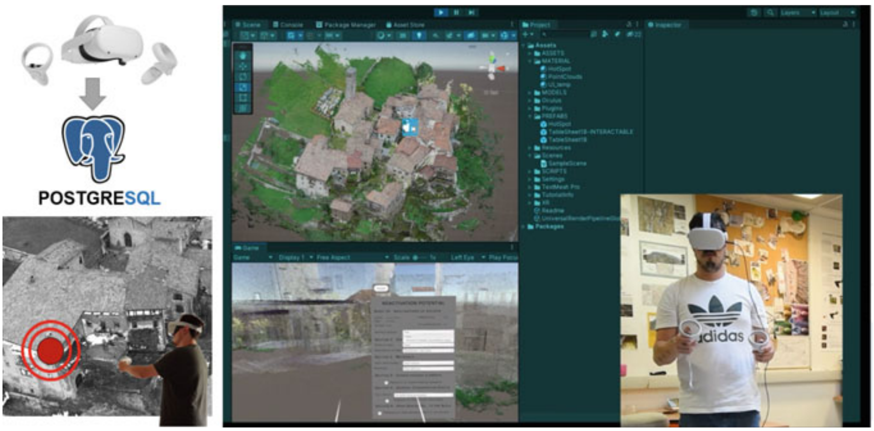


Fig. 5 VR environment for the first-person immersive exploration, the hotspot creation referenced on the point cloud, and the factsheet filling. *Editing* S. Teruggi

instead, a new version of the application must be created in order to modify the table format. Another drawback is the need for an internet connection in order to load and upload data to the cloud-based database. These are undoubtedly restrictions, especially in comparison to other projects that enable dynamic interface changing and temporary local caching in connection failure scenarios. The limitations are a direct result of the instructional character of the project.

The VR Head-mounted display (HMD) user may now browse the point cloud in First Person View (FPV). While the right controller stick enables view rotation adjustment, the left one allows for full movement in all directions (that is usually controlled by the user's head direction). The user may point to a saved informational hotspot and then click it by pressing a button controller on the right. Following the user's confirmation of the point, a table containing blank fields, including checkboxes and drop-down menus, is shown. The user may either click on the checkbox to pick an option or on the drop-down list to see the possibilities and select the one they want.

The coordinates of the chosen point are recorded together with the ID of the newly entered spot when a new one is entered. A red hotspot is left on the creation point as a placeholder after confirming the record (Fig. 5).

4.2 Holographic System

Using the features of the Unity Toolkits, every component of the holographic experience must be created. Uploading the point cloud model and the Hologram Table assets that are included in the toolkits is the first operational first procedure to be carried out within Unity. This makes it possible to (1) include the device's 3D virtual model and all its sensors in the Unity environment and (2) have the required background scripts for streaming holograms via the table's four projectors. All virtual models that must be displayed on the surface of the Hologram Table must be positioned with respect to the asset model of the table from the Unity Toolkits, which may be resized and shifted as needed. It is important to keep in mind that any item that does not fit on the device's flat display in the unity application will not appear while the program is running. The point model positioning can be aided by simulating the user's first point of view (FPV); it gives a rough idea of how holograms will result on the physical device. Alternatively, it is possible to connect the developer's computer to the same network of the Hologram Table through an Ethernet cable. In this way, it is possible to live test the application before final deployment making all necessary adjustments.

For each 3D model shown in the scene to respond to various user actions, specific toolkit scripts must be attached to the objects to establish interactions. The toolkits, for instance, provide access to the wand controller ray cast, which is a ray that is projected from the virtual model of the wand and shows the direction in which the controller is oriented. Additionally, when a particular button is pressed, some functions may access wand signals. This makes it possible to create a conditional system where, when a specific button is touched, and a 3D object is pointed at with the wand, a particular job is carried out.

Four separate elements make up the scene according to the experience's fundamental setup (Fig. 6):

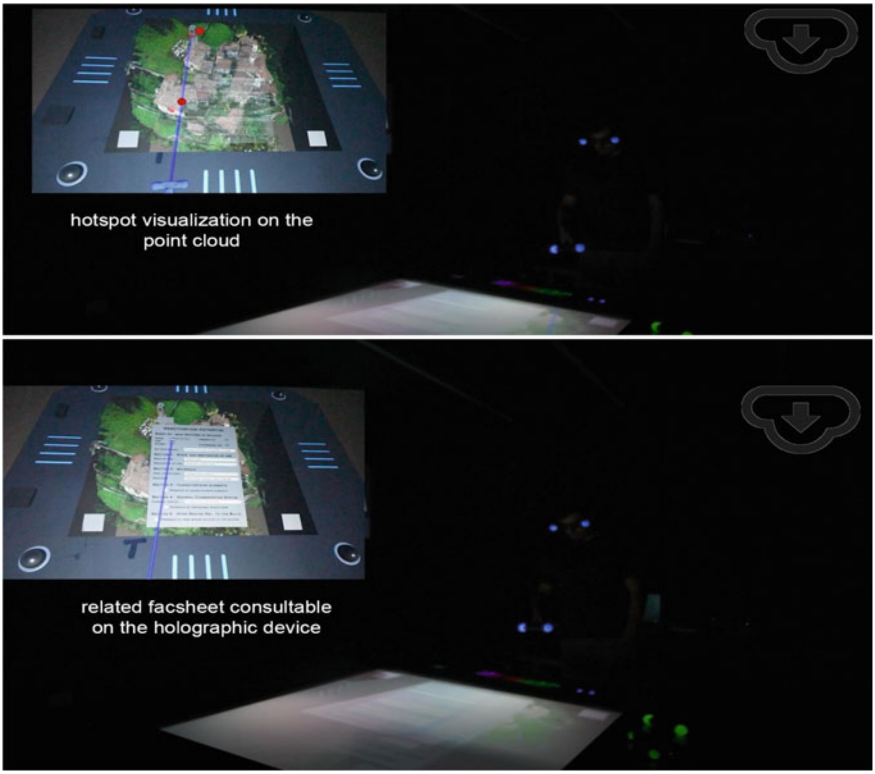


Fig. 6 Holographic table data consultation. *Editing* F. Fiorillo and S. Teruggi

Fig. 7 Students navigating the point cloud during the classroom activity. *Photos* F. Fassi

- The Cornello dei Tasso point cloud model.
- 3D red sphere corresponding to materialize hotspot on the scene.
- Floating frames and text objects that represent the informative table (and its relative information).
- Buttons that allow hiding/showing the hotspots and resetting the view.

The tables must be positioned almost parallel to the device display area, as should any relevant user interface components. With this alignment, the content that can be displayed inside the rendering sections of the 70 cm dome above the hologram table can be more easily read.

Fig. 8 Students presenting the final project on the Holographic table. *Photos* F. Fiorillo

5 Conclusions

The primary goal of this educational project is to impart various methods for utilizing 3D data obtained using cutting-edge three-dimensional surveying techniques for the conservation project to students.

There are three goals. The first goal is to help them understand how a survey conducted at a large scale (1:50–1:20) for professional purposes can be employed to quickly and easily create decimated models that are suitable for cataloging, organizing, and referencing additional data and information, as well as for more mainstream and enjoyable uses. And although what would seem evident, the contrary is not valid!

The second objective is to start teaching younger generations to think specifically in three dimensions by employing digital data as a tool for measurement, research, and even as a database of knowledge. The intention is to specifically accustom students to using point clouds as the primary reference model from which to begin all further processing.

The third goal is to help them recognize the distinctions among the various 3D fruition systems that are frequently grouped together behind a variety of acronyms that are frequently given the same weight and meaning but are different systems that can be used for very different purposes despite using the same data and coming from the same development environment. A crucial overall challenge is to train the students from the beginning to approach the knowledge phase as a project, collecting information and data in a conscious way, bearing in mind that the final goal of this step is to develop a deep understanding for implementing the best design choices.

Several considerations and lessons learned can be gathered at the conclusion of this educational experience.

Nowadays, VR apps can almost entirely replace a genuine visit to a real location, enabling even remote operators to see and study the site. The lack of ad hoc applications, which is still a problem, the need to prepare ad hoc, very light, geometrically simplified data enhanced with high-quality textures, and finally, the difficulty of using these systems combined with the requirement for powerful computers were the three main factors that slowed down or even prevented the use of VR visualization in professional practice up to this point. Most of the issue is resolved by the ability to use a point cloud model directly in a VR environment. Ad hoc textured models are not required, which significantly cuts down on waiting time—almost entirely eliminating it—and improves the process's speed and data availability. Additionally, the process is made simpler by the lack of modeling expertise needed. Furthermore, the process's decimated point clouds actually maintain their original metric quality, driving them valid data. Moreover, one can view data in high quality without the requirement for costly graphics workstations by connecting the device to fixed PCs.

The tasks that have been put to the test the most during the instruction process include navigation, visual inspection, and information referencing for conservation diagnostic research (Fig. 7). These are the fundamental and introductory knowledge requirements for any project involving the preservation, and reuse of Cultural

Heritage sites. The teaching exercise with students really demonstrated the viability and applicability of the VR procedure for business goals in terms of time, money, and ease of use.

The goal of the Holographic Table experiment was to evaluate the use of a cutting-edge, 3D sharing tool to help intervention project planning and, afterward, the presentation of the work and results obtained—activities that are challenging to do with other virtual or immersive technologies [23]. The 3D data shown is identical to that utilized for the VR system. However, in this instance, it may also be high-definition due to the technology's exceptionally high definition capabilities [24]. Since it originates from the same cloud DB, the information is the same; in this context, it can only be accessed and displayed and not modified. Therefore, it is a system that has reached its last stage in the cognitive process (Fig. 8). Although impressive, the 3D technology is not immersive; thus, it is suitable for all users in a participatory manner. The system has several limitations, including the small number of users who can interact in person and the high cost of the equipment, but on the plus side, operators don't require any special training to utilize it. This is a critically significant aspect. The fact that it is challenging to use, exchange, and engage in 3D among various professionals is another explanation for the limited use of 3D in professional activities. Even today, there are typically no suitable instruments to facilitate information sharing and collaborative work. The information must be condensed into 2D summary tables for professional use before being printed. Although intended for a large audience and not well suited for professional work, the usage of 3D data with 3D viewers (web or otherwise) or video animations, or classical VR navigation [25] still necessitates processing that is frequently unsustainable in terms of time and expense. Although it is only available to a select group of users, the usage of a technology like the holographic table enables simple, quick, and participatory use of data without the need for intermediary processes.

6 Future Works

There are currently very few commercial applications that enable tracking of the entire pipeline, from information acquisition in the field to its 3D referencing and sophisticated management on a dedicated DB to its eventual use in digital consultative systems like web platforms or VR or holographic viewers. Leica's Cyclone software suite appears to close this gap the best of these. In fact, it enables the addition of referenced information hotspots to the 3D during the acquisition process as well as their maintenance throughout the processing pipeline and their availability on a unique TruView VR viewer that enables point cloud navigation and visualization of the inserted information with immersive sensors like HP Reverb.

The advantage of homemade systems like the one here is that you can quickly change the code to various output systems. Connecting it to web platforms that are now being developed [17] and that can assist in data collection on the field and easy management of them is one of the first enhancements. Additionally, the plan is

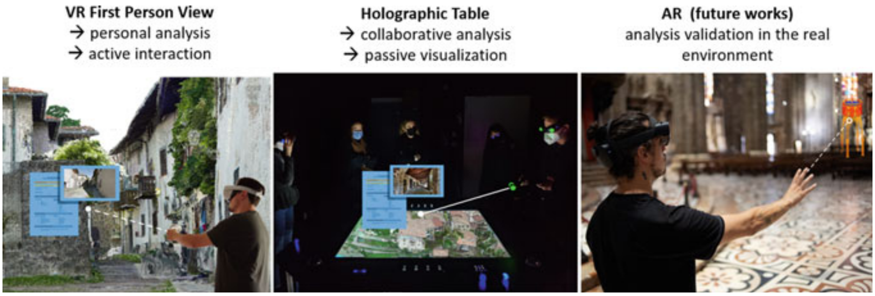


Fig. 9 VR, hologram and AR key aspects. *Editing* F. Fiorillo and S. Teruggi

to expand the program to augmented reality (AR) devices (HoloLens, tablets, and smartphones) in order to digitize the interventions right away (Fig. 9).

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REWIND: Interactive Cognitive Artefacts for Lost Landmarks Rediscovery

Mara Capone and Angela Cicala

1 Introduction

Experimentation of geolocated interactive communication artefacts allows you the simulation of a journey through time, thanks to 3D digital models contextualization within the real geographical and urban context. These simulations promote the construction of web-based interactive communication artefacts, usable in situ and/or remotely, able to spread cultural content and stimulate a shared use of heritage, also through gamification processes [1].

The methodological approach and defined procedures are the basis of testing activity that, starting from an emblematic case study aims to define an implementable and replicable system.

Majolica domes in Naples are the case study. This type of cladding spread from the end of the XV century throughout the city landscape, defining an identity character of historical landscape. In the past, majolica tiles were one of the least expensive solutions and therefore frequently used to waterproof the extrados after structural consolidation works. In recent times, however, the original coverings have often been replaced or removed during restoration works [2, 3]. Furthermore, urban transformations in the historic centre have deeply reshaped the landscape, by incorporating many domes into urban structure that has become increasingly compact over time.

The research aim is to spread knowledge and rediscover these lost landmarks through web-based interactive cognitive artefacts, usable in situ or remotely, able to spread cultural content and stimulating participatory use of heritage, also with pseudo-ludic methods (gamification).

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The main research goals are:

- Experimenting strategies that can engage users by stimulating active behaviors by developing web-based interactive cognitive artefacts.
- Defining a methodological path for 3D navigable model generation to represent transformations.
- Evaluating the iconographic code to be used, to represent the urban transformation.

2 Methodological Approach and Framework

From a methodological point of view, the main phases of research are:

- Mapping majolica domes in Naples (Fig.1) [4].
- Case studies definition.
- Digital Twins to represent the transformations.
- Interactive cognitive artefacts to spread knowledge (experimental activity) (Fig. 2).

The majolica domes, created to waterproof and protect domes from atmospheric agents, have become elements connoting historical centers and natural contexts [5].

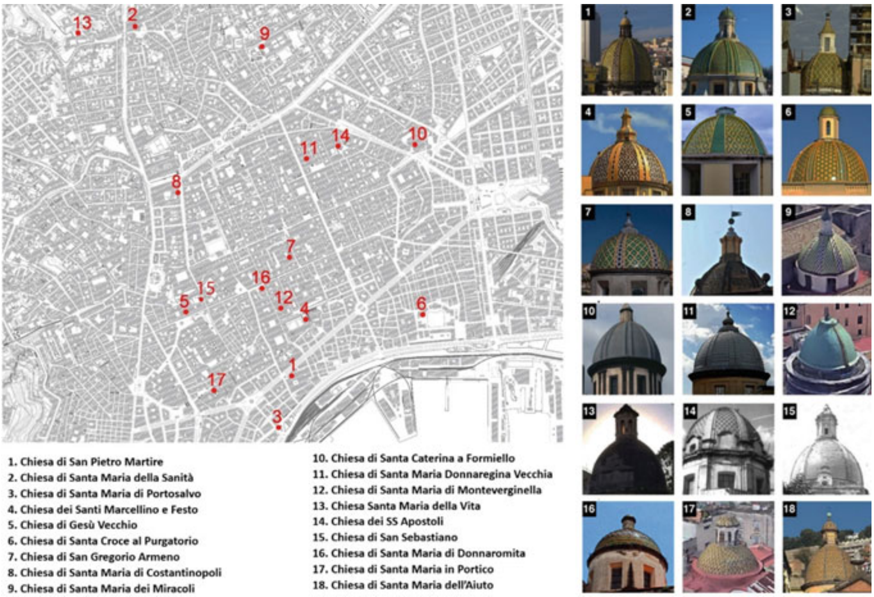

Fig. 1 Mapping majolica domes in Naples: existing, transformed and demolished. (immages 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 16, 17,18 Bing Maps. Immage 14 D. Nicolella, *Le cupole di Napoli, Napoli 1997*, immages 7 and 15, Archivio Soprintendenza Beni Architettonici di Napoli). *Editing* M. Capone

Fig. 2 Workflow: from 3D modelling to interactive cognitive artefacts. *Editing* M. Capone

There are many materials and techniques used to protect the domes that stand out in the Neapolitan urban context, to mark the presence of a religious community [6, 7]. The coatings with majolica tiles, dry mounted with nails on a wooden board are the interface between dome and its context, connoting it in the landscape in which it stands out [8, 9].

Earthquakes have left many buildings in ruins or sometime generated many gaps and structural damage. In the religious context, bequests and charities made it possible to quickly repair the damage caused by the tremors. Sometimes it was an opportunity for architectural renewal that found its specific field of experimentation in domes and their extrados coatings [10, 11].

The choice of the type of cladding was generally made by the architect when the dome was built, but over the centuries there have been cases in which the need to repair or consolidate the structure damaged due to construction defects or earthquake damage, required the removal or disassembly of the extrados protection structures.

The majolica tiles could be removed, catalogued and reassembled, partially or totally replaced with new tiles or replaced with other easier waterproofing techniques, in relation to the level of commitment required to consolidate the dome. Of course, the level of recoverability of the roof covering following disassembly depends on the method of installation. Additionally, structural reinforcement often offered an occasion for adapting the figurative design. This included the later addition of majolica tiles that were initially absent from the original dome. In recent history, unconscious consolidation interventions of the domes have totally removed their extrados coatings, delating these particular testimony of constructive technique. In this framework, majolica domes mapping in Naples is the research starting point. The majolica domes have been grouped into three groups: existing, transformed, destroyed.

For each group a case study has been identified (Fig. 3):

- 1: S. Maria di Portosalvo—existing.
- 2: SS. Apostoli—trasformed.
- 3: S. Sebastiano—demolished [12].

Fig. 3 Case studies. Different groups of Maiolica domes: existing, transformed and demolished. (1. Photo by A. Cicala; 2. D. Nicolella, *Le cupole di Napoli, Napoli 1997*; 3. Archivio Soprintendenza Beni Architettonici di Napoli). *Editing* M. Capone

The first step of the research is the timeline definition (Fig. 4). The main phases have been identified to represent the urban context and church transformation, especially in relation to the dome.

The urban context transformations have often denied the perceptive dimension of these identity elements; therefore, a mapping of the majolica domes in Naples will be carried out. Based on the analysis of archival, bibliographic and iconographic sources, it will be identified majolica domes that still exist and those that have been

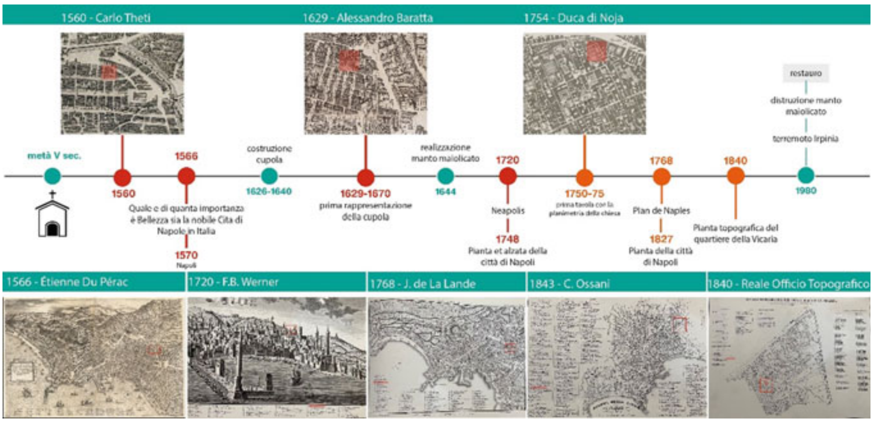

Fig. 4 Case study: Church of SS. Apostoli. Sources analysis and interpretation for timeline definition. *Editing* A. Cicala

demolished or transformed ones, whose majolica cladding has been removed. Moreover, a number of panoramic points have been identified, from which it will be possible to use these communicative artefacts, in order to test them.

3 Case Study: The Church of SS. Apostoli in Naples

This paper shows the case of a transformed majolica dome: the dome of the Church of SS. Apostoli. It is one of the four oldest churches in Naples. It was built in the fifth century, and it has been transformed over time. Now, the church can be considered a beautiful example of Naples-Baroque style. Located in the historic center of the city, along the upper *decumanus*, it was built by Bishop Sotero on the ruins of a Temple dedicated to Mercury. Through the documentation and historical cartography analysis, the transformations of the Church and the urban context over time have been traced [13].

The view of the city of Naples, drawn by Carlo Theti and engraved by Sebastiano del Re, is the first document in which it is possible to identify the SS Apostoli Church, dates to 1560 (Fig. 5). The dome is visible without majolica tiles covering in Alessandro Baratta view, dated 1629, but it is known, from archival documentation, that it was decorated only a few years later, in 1644. Moreover, there was a lantern on the original dome, which can be visible by observing Baratta view. Later the lantern collapsed; no documents have been found to date this event, but it certainly happened before 1980 (Figs. 6 and 7).

Some photos have been found in which you can see the dome with majolica tiles and without lantern dates to 1980. The current appearance of the dome is the outcome of the restoration works required after the serious damage caused by the 1980 earthquake, that involved the replacement of the original majolica cladding with a bituminous coat. Today you can see the dome without majolica tiles and without the lantern.

The historic cartography interpretation plays a key role in defining urban context transformation (Figs. 6 and 7). The first historical map of Naples can be considered the Duke of Noja plan, 1754, you can see in this map how the church has been incorporated in the urban fabric during the time. This process is clearer if you look at the cartography drawn by Federico Schiavone for the Municipality of Naples, starting from 1872.

Currently the church is surrounded by many buildings, therefore the dome is clearly visible only from some panoramic points.

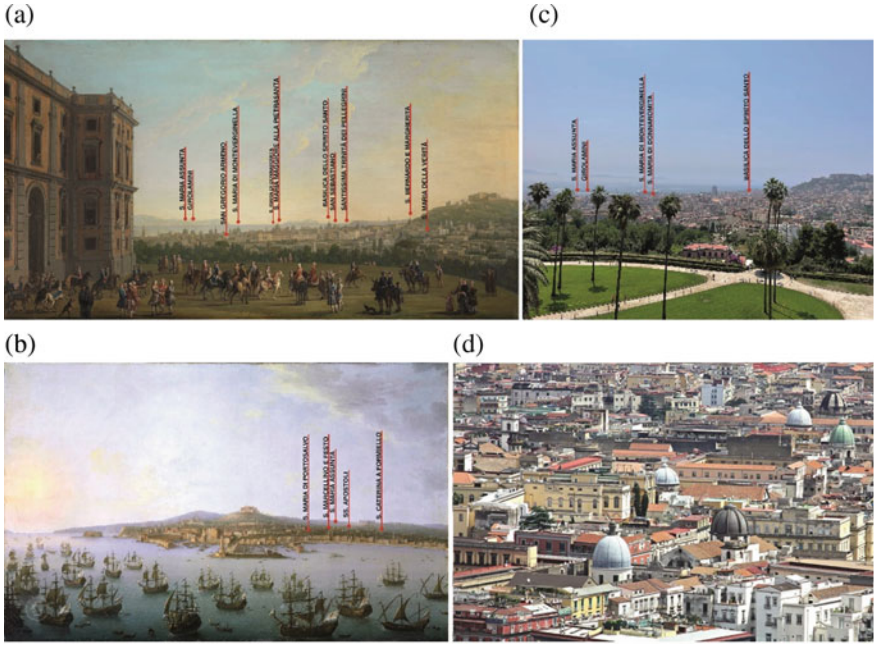

Fig. 5 Case studies: landscape transformation iconographic sources analysis. Comparison between Antonio Jolì's paintings and contemporary views. (Image a and image b Wikipedia. Image c photo by author, Angela Cicala. Image d Bing Map). *Editing* A. Cicala

3.1 3D Digital Models

Starting from the critical interpretation of sources, it was possible to define everything needed for 3D digital models generation. First, the 2D drawings based on sources were defined for the urban context modelling and especially for the dome.

Then, starting from the current map, it was possible to overlap the reconstruction hypothesis formulated by studying and comparing the views and the maps with the written and iconographic sources (Figs. 6 and 7).

In detail, the stages for the urban context and the dome transformation defined are:

- A: Urban context transformation (Figs. 6 and 7)
  STAGE 1: 1560—Lafrery—church without dome
  STAGE 2: 1629—Baratta—church with dome
  STAGE 3: 1754—Duca di Noja dome with tiles without lantern
  STAGE 4: 2022—current.
- B: Dome transformation (Fig. 8)
  STAGE 1: 1640—dome with lantern without tiles
  STAGE 2: 1644—dome with lantern and tiles
  STAGE 3: 1979—dome with tiles without lantern

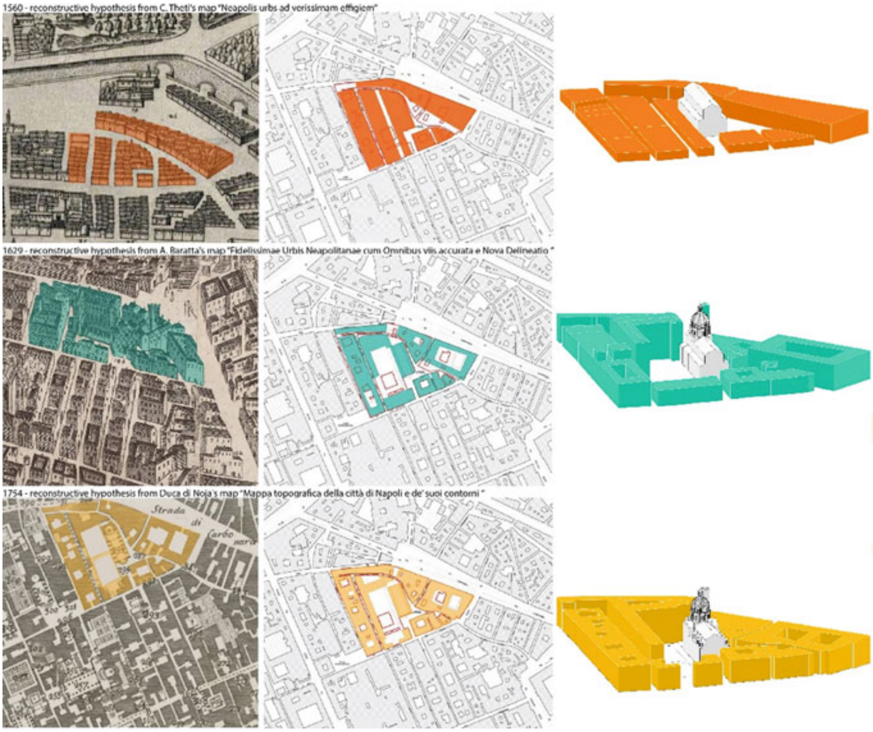

Fig. 6 Reconstructive hypotheses: from critical analysis of sources to 3D model of urban context. *Modelling* A. Cicala

STAGE 4: 1981—dome without lantern and tiles.

Therefore, the current state of the dome and the current urban context are the starting point. The Digital Twin of the church of SS. Apostoli was generated using the survey drawings provided by Soprintendenza Archeologica Belle Arti e Paesaggio of Naples.

Heritage Digitalization process is usually based on Digital Twins that you can generate by using well-established technologies for data acquisition (laser scanner and digital photogrammetry), merging set of data from historical sources and by using parametric tools for construction of 3D LOIN (Level Of Information Need) oriented models. A Digital Twin is generally considered a perfect copy of a physical object in digital format where all data and information from the real world is faithfully reproduced in the virtual one [14]. Digital Twin is a useful tool not only for cultural Heritage Enhancement, but for its protection and preservation. Digital Twin can be also considered a knowledge model obtained by merging qualitative and quantitative information, bibliographic and iconographic data, in order to represent place transformation. Digital twins can become 3D Interfaces for data management that could be used not only by experts (historians, art historians, restorers, virtual visitors, etc.).

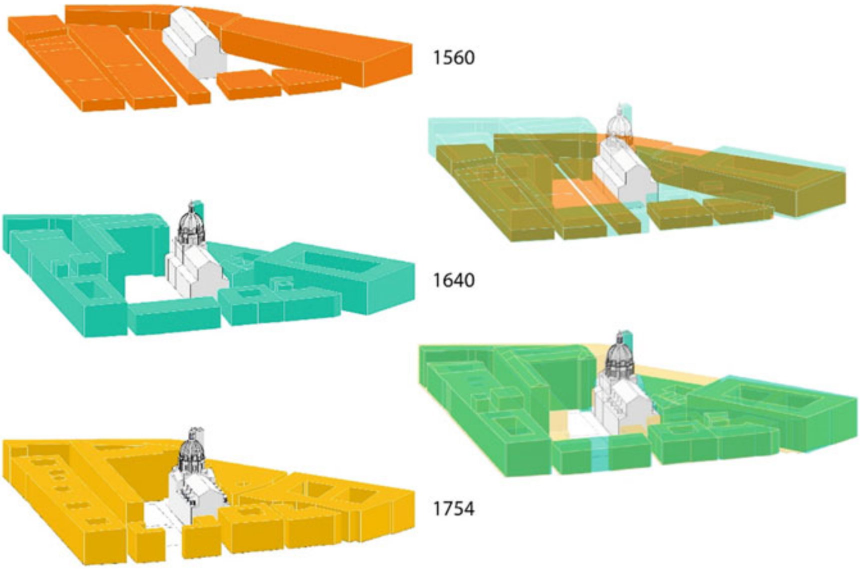

Fig. 7 Urban Contest transformation: interpretation of sources and visualization tests. *Modelling* A. Cicala

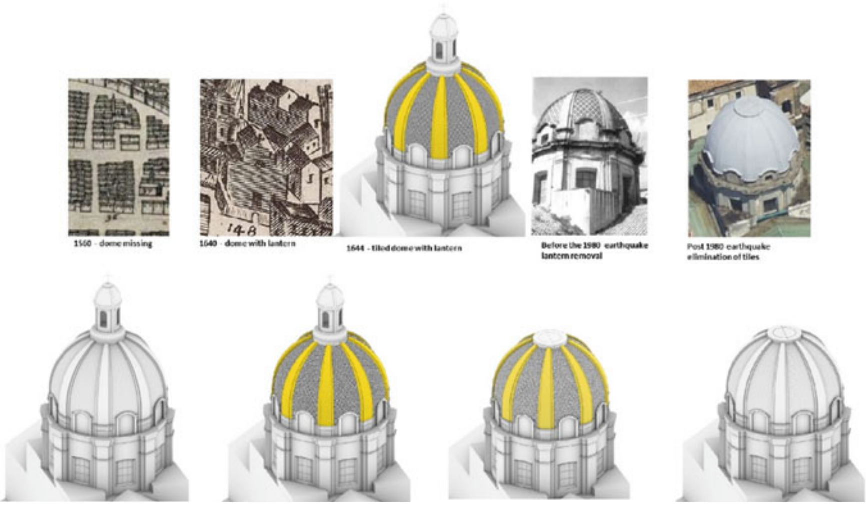

Fig. 8 Church of SS. Apostoli: 3D models to represent dome transformation during the time. *Modelling* M. Capone

Therefore, Cultural Heritage Digital Twins makes it possible to achieve the goals of their valorization and knowledge and their safeguard which can also be achieved by means of continuous monitoring with IoT (Internet of Things) technologies.

If the Digital Twin is a theoretically identical twin to reality, 3D LOIN—oriented Model—is a model in which the level of detail can be defined as you need. The use of procedural modelling techniques, based on sets of geometric rules, is supporting the construction of 3D LOIN—oriented Model.

For example, a Scan to HBIM process based on LOIN oriented logic simplifies and improves the digitalization process of complex historical-architectural systems, preserving its recognizability. In this case the main goal is to obtain an ideal 3D model that best fits the look of the real building. Furthermore, interoperability between processes (e.g., VPL, Visual Programming Language and BIM, Building Information Modelling) and related software (e.g., Grasshopper, Rhino for VPL and Edifcius, ACCA software, for BIM/HBIM) can support and improve the digitization process and the generation of Cultural Heritage Artifacts also suitable in communication project for dissemination and sharing [15]. MaTiDo (Majolica Tiles on Dome) was the tool used to distribute majolica tiles on the dome surface of the Church of SS Apostoli in Naples. The goal is to generate a smart 3D model suitable for different uses and to represent the dome appearance in different stages. MaTiDo is a generative algorithmic defined in our previous research that allows users to place tiles fish scale on revolution domes and oval or elliptical ones, on domes with ribs and domes without ribs, the input data is the extrados surface of the dome (Fig. 9). MaTiDo tool has been tested to reproduce the appearance of existing domes and virtually reconstruct modified or destroyed domes [15].

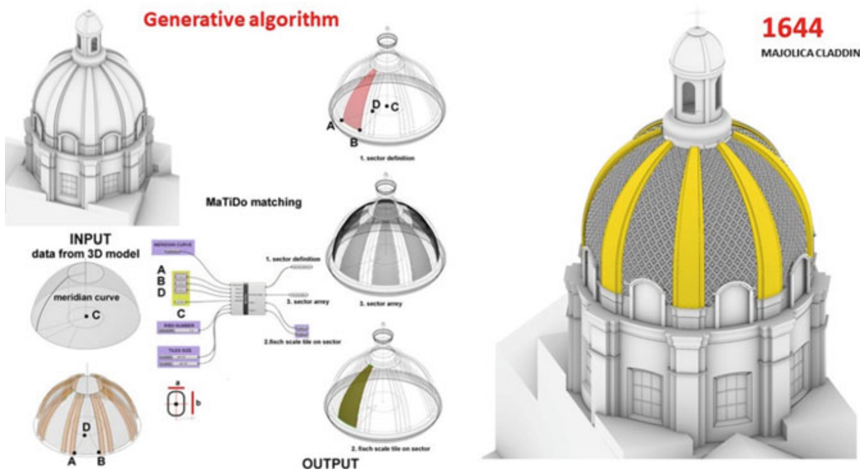

Fig. 9 Case study: MaTiDo workflow for tiles distribution on the SS. Apostoli dome. *Modelling* M. Capone

3.2 Interactive Communicative Artefacts

The application fields of 3D digital models (digital twins and/or Model 3D LOIN-oriented) can therefore be various: from the management processes of restoration and consolidation works, to systems aimed at knowledge and dissemination, to information systems where different kind of data can be linked to 3D digital model.

Two different types of processes have been tested in this research: the first is based on use of 3D datasets of urban contexts by adding our 3D models with different LODs (Level of Detail) (Fig. 10), the second is based on integrate use of online mapping tools, such as Google Platform and Tourmake\Viewmaker, that allow you to share customized interactive images using Street View involving users who can actively interact with the environment also through VR visors in real-time experiences. Advanced research must monitor the continuous evolution of tools and representation methods and opportunities to design different ways to visualizing reconstructive hypothesis. The virtual reconstructions have been used to address different issues and to target different users. One of the main challenges is linked to use of 3D urban data in order to generate systems that allow users to interact with urban context to understand place transformations through a real time experience with the urban digital twin.

The first step consists in generating the urban digital twin using 3D urban data. There are some tools that can be used to create detailed models of terrain and urban areas that, if available, allow users to add customised 3D model with different LODs. These tools make it possible to simulate different scenarios that can be explored thought still images, fly through animations and stereo panoramas. In order to increase knowledge about the relationship between 3D models generated and the urban context, several existing tools have been tested. These tools, by managing

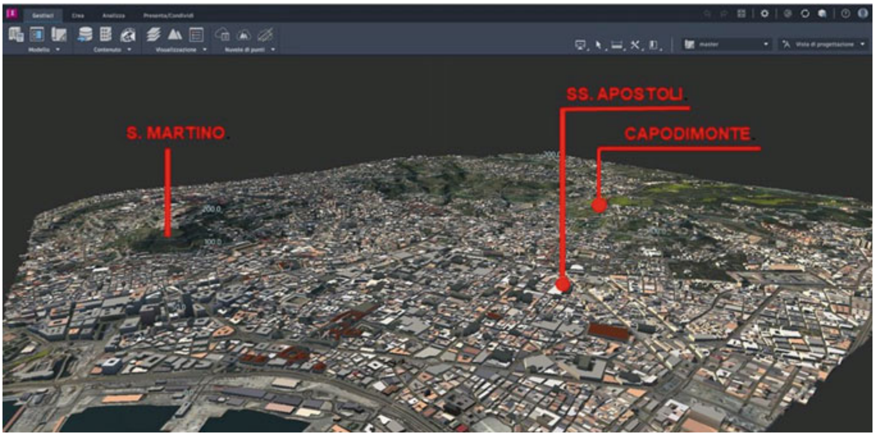

Fig. 10 Autodesk Infraworks testing activity: add 3D data to urban context in order to landscape representation. *Modelling* A. Cicala

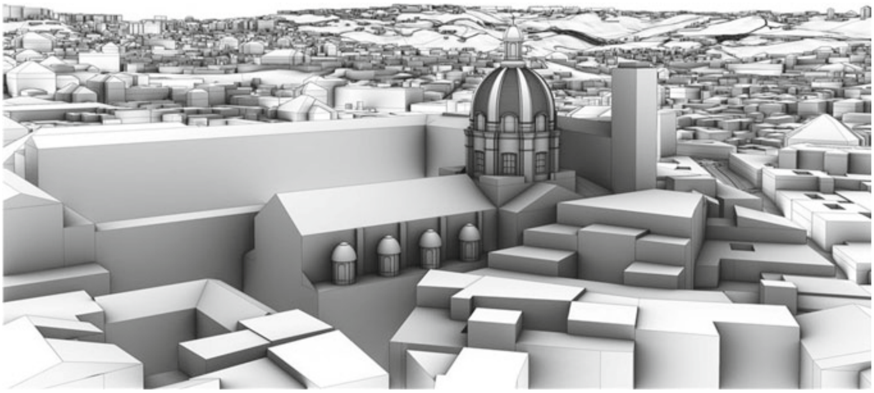

Fig. 11 Overview of the church of SS. Apostoli (with tiles and lantern) in the current urban context. Testing activity by merging large landscapes and small 3D objects of a high detail. CAD Mapper \Rhino—image by data merging process. *Modelling* A. Cicala

quantities of urban data, allow you to obtain an integrated and georeferenced model in the landscape (Fig. 11).

The first step allows you to obtain a topographic CAD file of the area surrounding the Church of SS. Apostoli, using CAD MAPPER, that is an opensource tool. It transforms data from public sources such as OpenStreetMap, NASA, and USGS into neatly organized CAD files by network of points and curves, which return the orography of the area (Fig. 12). In the second phase, BIM software, Autodesk Infraworks, was used. It allows the restitution of visually realistic models complete in every detail with available GIS data: terrain models, orthophotos, survey data, environmental and anthropogenic data. Aiming to provide a visual and panoramic experience of the area, which could communicate the differences between the past and present, through Infraworks, data about the surrounding infrastructure and buildings, such as dimensions, heights, materials, were collected [16] (Fig. 13).

Within this framework, the inclusion of the Church of SS. Apostoli in the urban context was tested.

A very important topic to deal with is the relationship between LODs of the urban context and visualization purposes. However, for visualization purposes, a greater area described with lower detail is required. The parts of the model that are more distant from the point of interest (POI) may be progressively simplified and it could be a solution. You have to try to harmonize highly heterogeneous sources to provide different models for different needs [17, 18]. The solution includes the fusion of referential terrain models of different LODs as well as the fusion of different 3D data sources for the reconstruction of the built heritage. Several methods have been tested in which different LODs can be used for large landscapes and small high detail 3D objects.

One of the research aims is to evaluate the tools trought testing activities. The tools for landscape tour generation tested in this part of research are CAD MAPPER and Autodesk Infraworks, both are optimal in terms of interoperability with different types of software and allow you for a wide range of locations due to rich databases.

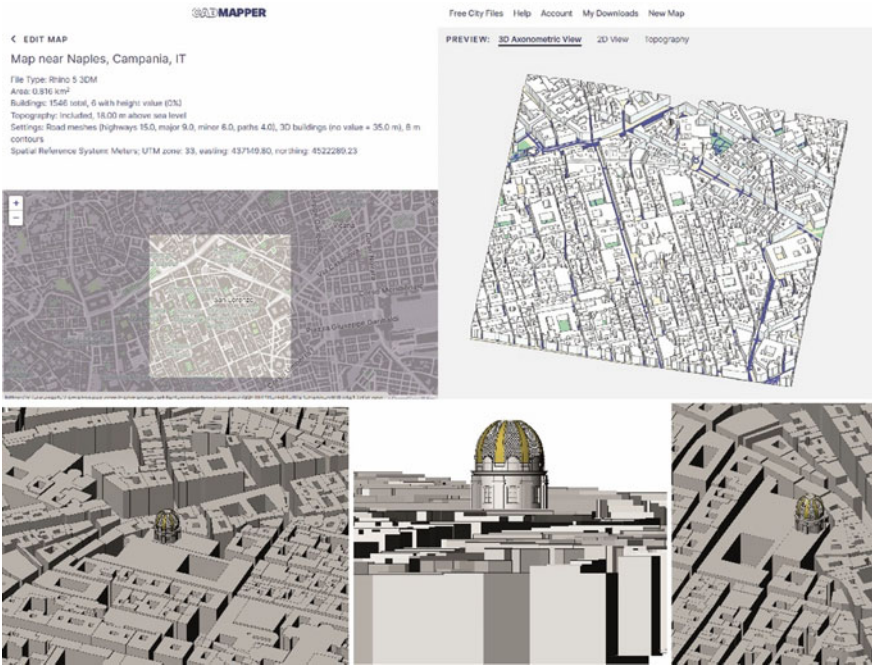

Fig. 12 Testing activity: adding 3D custom model to CAD Mapper urban context. *Editing and Modelling*: A. Cicala

The CAD MAPPER tool shows limitations about the configuration of buildings. In many cases, there seems to be a flattening of the entire context to a uniform height due to the absence of height information related to infrastructure and buildings; in addition, the buildings do not appear to be detailed in either construction or materials. On the contrary, Infraworks allows us to obtain a detailed context on the construction, land, geographic level. It allows you to make changes within a defined context, to detail the area according to your requirements, but also to import design elements. The second process being tested concerns experimenting with the options given by tools such as Google Platform to define web based interactive interfaces. They show the contextualization of the church model within the landscape, and mainly its evolution over time. In particular, the creation of the project using Google platform was experimented with after identifying the area, markers were placed each corresponding to a phase of change affecting the church (1640–1644–1979) with respective images of the 3D model. The project was shared in such a way as to make it accessible to users through a reference link. In this framework, the use of Viewmake has been tested, it is a free App, that allows the creation of customized tours starting from imported panoramas. It is possible to enrich the virtual tour by using action points to share some additional information, navigate within the tour quickly and intuitively, include photos and customized contents in any area of interest, such as drawings, texts, iconographic sources. A few simple steps to connect the panoramas with the

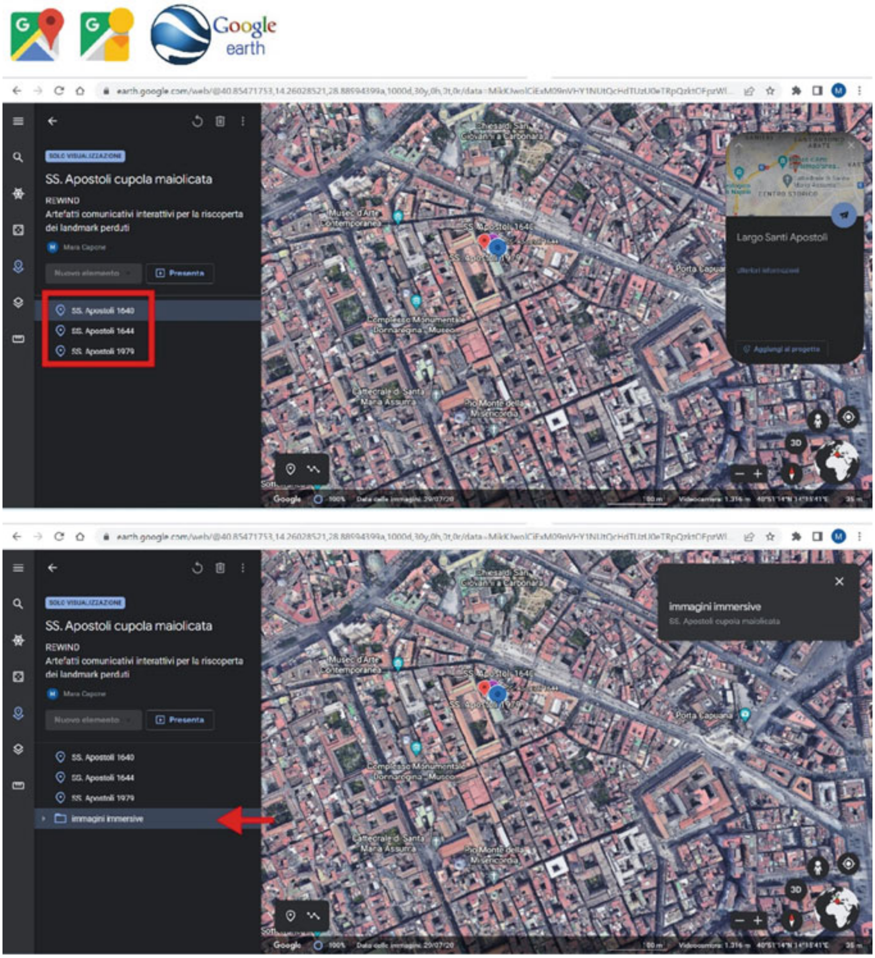

Fig. 13 Visualization of the reconstructive hypothesis about the church of SS. Apostoli, within the current urban context. *Editing* A. Cicala

navigation arrows, to create real virtual paths that are walkable. Once realized, the tours can be displayed even offline, an important function that will allow users to look at every time and every place. This technology actively involves users and makes them protagonists of the scene, it allows you to view environments through VR visors by stimulating the perception of an effective virtual reality. It is also possible to test the visor use that allows you to live a unique and totally immersive experience, capable of transforming a smartphone into a useful lens to navigate into the virtual path. It would provide user involvement in every aspect, enhancing interaction with the model and its context. The use of platforms such as Tourmake, would allow you the realization of an interactive tour customized within the reconstructed reality. The user could understand the meaning of the lost elements by comparing them with the current reality, through images, hotspots, markers, significant 3D elements.

In order to enrich user perception through images and historical information, the work in progress allows you to lead back to a virtual reality corresponding to the period of reference through some specific placemarks. Through the placemarks, user will be able to locate the domes of the Neapolitan landscape and immerse themselves in ancient contexts by comparing them with reality (Figs. 13 and 14). Moreover, thanks to the reconstruction of the context starting from the orography to the buildings surrounding the church, it will be possible to have a perception of territorial and constructive differences. Through an appropriate application starting from the current image, it will be possible to view the correspondent image of the chosen period and, in the case study, to see the substantial differences that characterize the dome of the Church SS Apostoli.

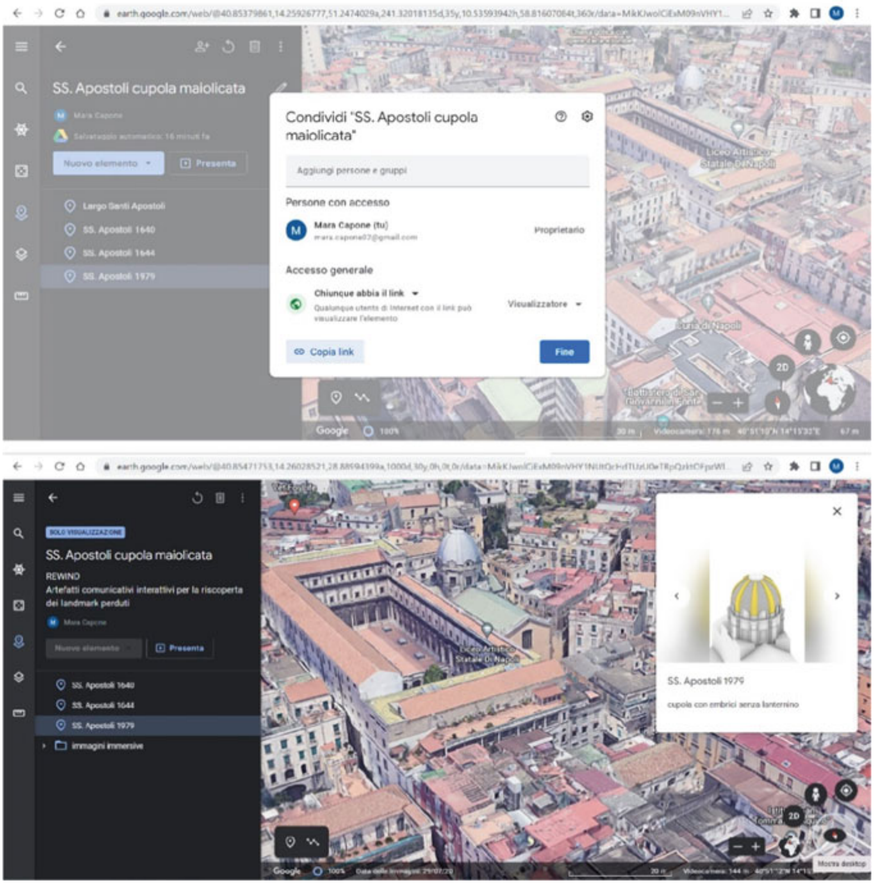

Fig. 14 Testing activity: sharing with users with Google platform. *Editing* A. Cicala

4 Conclusions and Future Works

One of the main goals of our research activity is to test a methodological path to virtual reconstruct Historical Heritage to REWIND, virtually travel during time to recover place identity, by testing the use of advanced technologies and free tools able to allow users engaging in an interactive experience.

It is possible to define the communication systems that allow you to represent the evolution of the urban context and monument, in different phases of its history, interactively overlapping through fading the 3D reconstruction on the current conditions of the site. In accordance with the experiments performed [19], the research will be implemented in relation to AR and VR applications, especially by developing a specific App that allows users to understand the city identity by decoding landscape from panoramic points using AR options (Fig. 15). The goal is to turn a view of Naples from a panoramic point into an interface of knowledge tour that can highlight specific identity values of the Neapolitan landscape: the majolica domes as lost landmark.

Fig. 15 VR/AR—Concept—App for rediscovery lost landmarks. Case study: Majolica dome of the Church of SS. Apostoli in Naples. Panoramic point view from App use: S. Martino hill. *Editing* M. Capone

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AR&AI and Classification/3D Analysis

Automatic Virtual Reconstruction of Historic Buildings Through Deep Learning. A Critical Analysis of a Paradigm Shift

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1 Introduction

For several centuries, the reconstruction and preservation of historic buildings has been a topic of interest that has defined conservation policies and the enhancement of Architectural Heritage in all countries. Since nineteenth century, the importance of the built heritage has been emphasized for its potential as a repository of the historical and cultural memory of any region [1]. In this sense, many of the current European policies are aimed at enhancing the value of these heritage elements [2].

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One of the key aspects determining the reconstruction and conservation of these buildings is the knowledge of their historical evolution. This has consolidated a specific area of knowledge, namely restoration, which is essential to establish a methodology for approaching their original state. However, the study of the original state of historic buildings has become a controversial and changing subject due to the different discoveries that have been made over the years. Meanwhile, in many places there are remains of catalogued historic buildings in a state of ruin, whose restoration and conservation requires significant investment and whose future is compromised by socio-economic circumstances.

Virtual reconstruction is a way of intervening in this type of historical locations for several reasons. First, it allows the Architectural Heritage to be interpreted and musealized. In this way, the architectural remain becomes an object of contemplation as well as an object of learning and dissemination of culture. On the other hand, thanks to digital media, the dissemination of heritage can be extended through remote channels and integrated into virtual immersion experiences.

Therefore, virtual reconstruction is nowadays an affordable and safe solution to approach a strategy of conservation and preservation of historical heritage, and it is also a very suitable channel to maintain the scientific discussion on the original state of the buildings.

Virtual reconstruction is not a novelty. Many authors—artists and historians—have speculated for many centuries about the original state of the architectural remains. Although it was not until the eighteenth century that a scientific method for systematizing virtual reconstruction began to be organized, we have the paintings and engravings of many earlier artists that have provided evidence of the original state of many buildings. The progressive incorporation of new representation systems and technology, especially digital media, has boosted this field of knowledge.

In the context of this research, the technological advances that have taken place in the last decade in the field of artificial intelligence have propitiated a paradigm shift in virtual reconstruction [3, 4]. Analyzing previous reconstruction methods, we have been able to identify a certain linearity in the way representation systems and technology have been incorporated and accommodated. However, the prediction systems proposed by AI (Artificial Intelligence) suggests a turning point that may change in the coming years the way we approach, from a scientific point of view, the question of virtual reconstruction.

To confirm this paradigm shift, it is necessary to delve into the methodology currently used to train neural networks in the Deep Learning environment, specifically in the methodology of image analysis using GAN (Generative Adversarial Networks) technology. Our experience in the field of virtual reconstruction has also led us to incorporate analysis technology using NLP (Natural Language Processing) techniques.

Both the results and the conclusions suggest a new way of approaching this science, which now inevitably integrates historical, representational, and also the technological aspects.

2 Linear Evolution of Virtual Building Reconstruction Methods

The virtual reconstruction of a historic building consists in predicting, using an eminently graphic representation, what its original appearance could be, or its intermediate states, based on the observation of its remains. The term virtual refers to the fact that there is no physical intervention on the building, but an assumption of how it could have been. The representation systems can be multiple, being a perspective or isometric image, a planimetric document or orthogonal projection—plan, elevation, or section—or a three-dimensional model. The observation of the architectural remains not only refers to the physical presence of some ruins, but can also integrate written sources, which may come from scientific literature or other literary references of various kinds. Therefore, the virtual reconstruction of this type of buildings has been affected by a multitude of variables ranging from the origin of the data to the representation system used to display the results of the research.

To delimit more precisely the scope of the virtual reconstruction to which we refer, we will take as a reference those studies that have tried to investigate what a building could have been, and therefore have made a theoretical assumption about the architectural style and constructive logic that could have promoted the design. This is necessary because throughout history we can find numerous representations of buildings and urban spaces that respond to a speculative interest with an aesthetic conditioned to the worldview of the epoch. Therefore, some idealizations or illusory representations of architectures that have existed or could have existed have been avoided. The rise of archaeological science between the eighteenth and nineteenth centuries and its development since the twentieth century helps to place in parallel the science of restoration and, therefore, the virtual reconstruction of heritage elements [5–7]. This may help to understand the scope of the chronological delimitation proposed for this study.

As we will see below, the historical analysis of the methodologies, used for the virtual reconstruction of the buildings of the past, evidences the additive and linear nature of the integrated processes (Fig. 1). This means that the methodology for approaching the problem of reconstructing a building from its remains has progressively incorporated new discoveries in terms of (a) data collection and (b) systems of representation. In several cases, some of the procedures have been replaced by more elaborate and precise ones, but without changing the essence of the general methodology.

Another important characteristic of virtual reconstruction is the intermediation of a theoretical assumption between the two phases mentioned above. This theoretical assumption, which we could also call theoretical presumption or theoretical speculation, means that in the process of virtual reconstruction there is a critical moment in which a decision is made regarding the appearance and configuration of the object of study. This decision implies taking a specific path and discarding others, based on a scientific argument from the various sources available. The choice of the architect, the historian, the art specialist, or the researcher will be decisive for the final result.

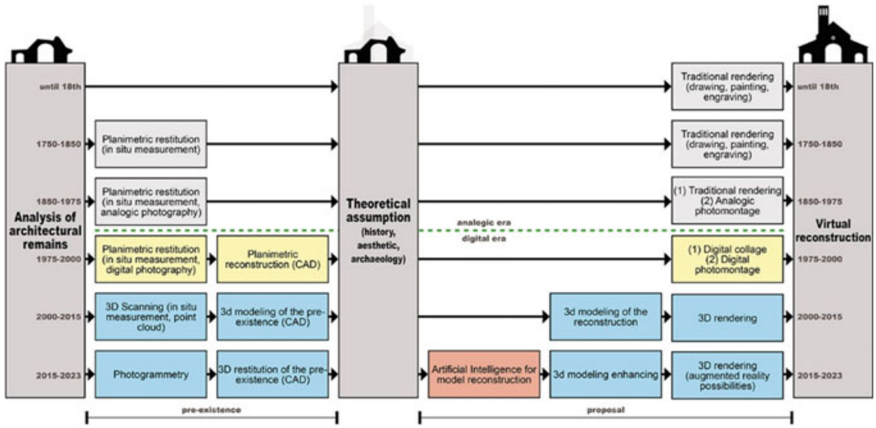

Fig. 1 Diagram of the linear evolution of virtual building reconstruction methods. *Authors* E. Delgado-Martos, G. Intra Sidola

2.1 Virtual Reconstruction Until the 18th Century

We cannot speak precisely of virtual reconstruction of buildings as an area of knowledge until the middle of the eighteenth century. However, we cannot discard the importance and interest of artistic works—drawings, paintings and engravings—pre-dating that epoch, which represent buildings that are now in ruins or have lost an important part of their original configuration.

As mentioned above, some of these representations show an idealized or invented vision of the object of study, while others tried to capture with relative fidelity the state of the building as the artist experienced it. The Renaissance awakened the interest of architects and artists to reveal the appearance of the forms of the past, which appeared to them as unfinished vestiges. Classical order became a first systematic response in the search for an architectural language that would connect with the forms of the past. Thus, the various architectural treatises—those by Leon Battista Alberti, Sebastiano Serlio, Jacopo Barozzi da Vignola, Andrea Palladio, among others—tried to identify some patterns that could be found in the Roman ruins, not so much to reconstruct them, but rather to create new proposals.

From a methodological point of view, the architectural treatise became a way of configuring a theoretical assumption that, although not intentionally applied for real reconstruction, was used as a guide for the representation of the idealized scenarios of the past. In relationship to the two phases mentioned above, it can be pointed out that the phase related to data collection depended fundamentally on observation and, occasionally, on the measurement of the vestiges of the classical order—measurements and proportions. The phase related to the system of representation had a great impulse especially thanks to the appearance of the science of perspective, which managed to systematize and rationalize the presence and coherence of the represented object.

2.2 Virtual Reconstruction Between 1750 and 2000

In the middle of the eighteenth century, historians became interested in investigating architectural remains from a scientific perspective. Partly thanks to archaeology, the interest in rigorously studying the architectural remains involved an analysis and cataloguing workflow entailed the task of intuiting the representation of the original state of the buildings [8]. From this moment, the architectural remains were the source for the collection of data because, on the one hand, they evidenced the specific elements that composed the original building; on the other hand, they made it possible to establish relationships with other similar architectural structures and, therefore, opened the door to the historiography of architecture.

Between the second half of the eighteenth century and the beginning of the nineteenth century we find numerous examples of virtual reconstructions of buildings and cities—see, for instance, the works by Giovanni Battista Piranesi—that reveal the interest in discovering the original appearance of incomplete structures. During this period, in addition to the use of perspective, planimetry was developed to control the geometry of the object of study. Much of this work was carried out in situ, taking data directly from the site and converting it into a repository that could be shared with other researchers. Therefore, the study of the architectural remains could be carried out from the data obtained and converted into plans. This interest was accentuated during the nineteenth century in the period that, especially in Europe, we know as Eclecticism. Historical styles became the leitmotiv of many of the great constructions, being necessary to analyze and understand them to replicate their appearance. It was also at this time, thanks to the work of John Ruskin, Eugène Viollet-le-Duc and Gottfried Semper, among others, when society began to be aware of the value of a historic building and how to intervene in it.

From 1830 onwards, the invention of photography made an important contribution to the data collection phase, incorporating objectivity in the verification of the state of the architectural remains under analysis. In addition, the element presented in the photograph could be edited and modified through the technique of collage and photomontage. These modern techniques were added to the existing ones, expanding the range of possibilities for the representation of the virtual reconstruction.

The dawn of the digital era brought an apparent change in the approach to virtual analysis and reconstruction work, but the course of time has shown that this was only a simple replacement of tools. Thanks to digital technology, the analog data was transformed into computerized data. The analysis phase of the architectural remains incorporated CAD (Computer-Aided Design) tools, improving the accuracy and consistency of the planimetry. Digital photography also replaced analog photography, incorporating advanced editing systems that made it possible to intervene on the representation of the ruin in a photorealistic way. The digital era made possible to accelerate the processes of data analysis and virtual representation.

Until the end of the twentieth century, technological advances have not been substantial in the methodology of virtual reconstruction of historic buildings. Although the new tools have allowed accelerating processes and sharing advances, the reconstruction methodology has remained intact, being necessary to intermediate the data collection phase and the creative phase of representation by the conjecture of the specialist in the field.

2.3 Virtual Reconstruction Between 2000 and 2015

Although 3D computer graphics has been known since the 1970s, its development has been closely associated with the more general term CAD. By the year 2000, 3D digital models were already widely used in many areas of design, engineering, and architecture, including the generation of images using this type of environment. Although originally the technique of virtual rendering with 3D models is not very novel compared to earlier techniques, the acquisition of 3D scanner data using point clouds and the photogrammetry have produced a significant advance in reconstruction methodology.

The importance of new technological advances in the acquisition of on-site data lies in the possibility of obtaining a digital twin of the architectural remains almost automatically. This means the possibility of being able to operate with it in a more precise way, being able to foresee and quantify with much more precision the decisions regarding many aspects, such as virtual reconstruction [9]. BIM (Building Information Modeling) technology has made it possible to parameterize the parts of the three-dimensional model to integrate different layers of information, making it a valuable object for predicting the useful life of a building from the design phase. These parametric models, also called digital twins, allow to obtain images of the virtual reconstruction.

In the twenty-first century, the advance of 3D technology from new rendering engines has allowed the processing of a greater quantity of images to propose new experiences in the virtual representation of architectural environments. AR (Augmented Reality) and VR (Virtual Reality) are now presented as two important complements to traditional representation systems.

Some applications in the field of artificial intelligence have been used to automate some processes in the field of virtual reconstruction of historic buildings. Unlike the predictive models that we will see later, these AI applications have collaborated in the management of processes in the data collection phase or in the phase of elaboration of the virtual representation [10].

Despite the great technological advances made in recent years, reconstruction methodologies have continued to require an intermediary phase to convert data collection into a proposal.

2.4 Conclusions on the Linear Evolution of Virtual Reconstruction Techniques

As seen above, the history of the virtual reconstruction of buildings has not undergone a significant change from its initial configuration until approximately 2015. In this sense, we can state that there has been a linear evolution in which elements have been added and processes have been replaced by more efficient ones. In addition, the need to guide decision-making on how to reconstruct a building in ruins has persisted.

3 Automatic Virtual Reconstruction Using AI

The traditional methodology for virtual reconstruction of historical buildings described above coexists with the latest advances developed within AI, specifically in relation to Machine Learning and Deep Learning. In relation to the field of image analysis, GANs have revolutionized the process of obtaining results, automating the entire process [11, 12]. On the other hand, NPL (Natural Language Processing) algorithms are making possible to obtain amazing images from huge databases. Both systems propose new ways of dealing with traditional problems and promote substantial changes in many of the established procedures.

3.1 Analysis of the Methodology for Virtual Reconstruction Using Deep Learning

Our experience in this field [13] has allowed us to describe the methodology used for the realization of a virtual reconstruction of a historical building, which is mainly divided into two phases. The first phase is the training of the neural network. The second is the phase of debugging and improvement of the response.

The training phase of the neural network (GAN network) is characterized by the elaboration of an image dataset to be integrated into the computational algorithm. The GAN network has generative models that use two deep neural networks that compete to present an optimal prediction. Both generative models are coordinated, with the generative model creating reconstruction proposals and the discriminative model trying to verify the veracity or falsifiability of the result. The two neural networks improve as learning progresses, making the prediction more and more accurate [14].

To perform this iterative training, a large number of images are needed. These images come from a pairwise composition, which consists in an image of a previous state in which the ruins of a building are observed, and an image of a reconstructed state of the same building. The more images in the training dataset, the more likely the GAN will be able to identify the areas to be reconstructed and thus identify the patterns that determine the reconstruction.

The difficulty we encountered when planning the construction of the dataset was the impossibility of having in reality a set of photographs of destroyed architectural examples and another set of identical reconstructed buildings, all of the same style. This led us to better understand the relevance of patterns in neural network learning. To solve this question, we decided to build the dataset with synthetic 3D models and using a systematic architectural language to be able to elaborate ruined states and reconstructed states. Following this premise, we got a couple of images for the two neural networks to play with. We chose to work on Greek temples. In addition, to improve learning, we decided to implement a set of segmented images that represented in colors the different parts of the building. In this way, the generative network learned how the ruined state was through a rendering and a segmented image, in which the incomplete architectural elements were pointed out, and on the other hand, a rendering of the reconstructed state was incorporated in the learning process together with the segmented image including all the missing architectural elements.

To enlarge the image dataset, we determined three states of ruin (Fig. 2) with all the associated segmented images. The case study was also deeply analyzed by adapting the synthetic modeling to real, or at least plausible, cases. The different building possibilities together with the three associated ruin states, as well as the linked segmented images, provided tens of thousands of images [13].

Fig. 2 States of destruction of one of the synthetic models representing an octastyle Greek peripteral temple. From the original state, the 3 states of ruin of the four facades of the building are shown. *Modelling and rendering* E. Delgado-Martos

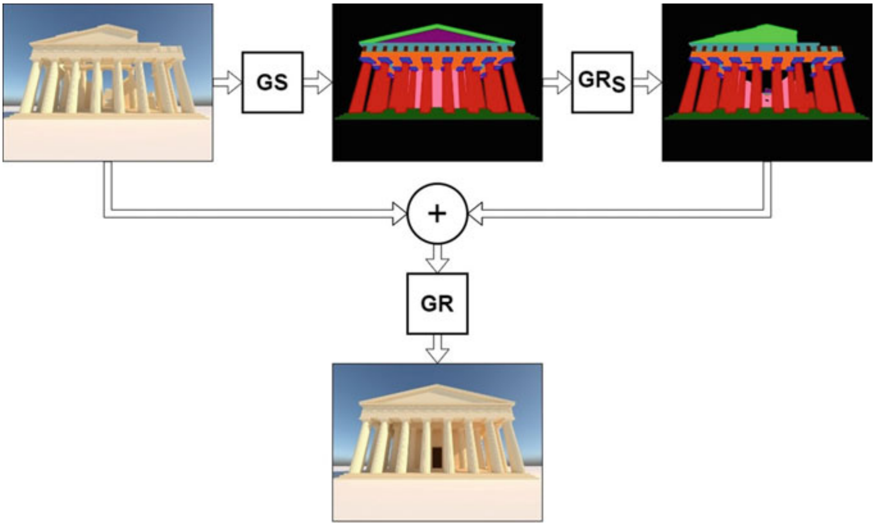

Fig. 3 GAN network composition used for virtual reconstruction. *Diagram* A. Nogales, A.M. Maitín, A.J. García-Tejedor

We designed a GAN network (GR) that was a composition of two other GAN subnetworks (Fig. 3). The first subnetwork (GS) matched the image of a ruin (input) with a segmented image of the reconstructed state; the second subnetwork (GRs) matched the segmented image of the reconstructed state with a segmented image of the initial ruin. The compositing result (GR) was able to present the reconstructed image (output) automatically. We call this procedure automatic virtual in painting restoration [13].

The second phase announced at the beginning of this section refers to the evaluation of the neural network response. Using surveys with specialists the responses are evaluated and the necessary adjustments are made, to improve the algorithm with the objective of restarting the training.

From this point of view, it has been considered methodologically opportune to integrate the training work of the GAN network with an NPL subprocess. In general, this type of tools is giving surprising results in terms of image generation from text. Applications such as DALL-E provide images of great effect and apparently great realism, even in the architectural domain. However, to an experienced eye, the result is often insufficient because of its lack of coherence, both structurally and in terms of architectural language.

The integration of an NPL tool in the training process of the GAN network therefore required a rigorous definition of the specific purpose and of the sub-process in which to apply it, as well as a specific study for the drafting of the text to be used for its operation and a careful and constant control of the results progressively obtained.

In this way, the NPL Transformer has proved its usefulness in the generation of the segmented images (Fig. 4), through activation functions, increasing the degree

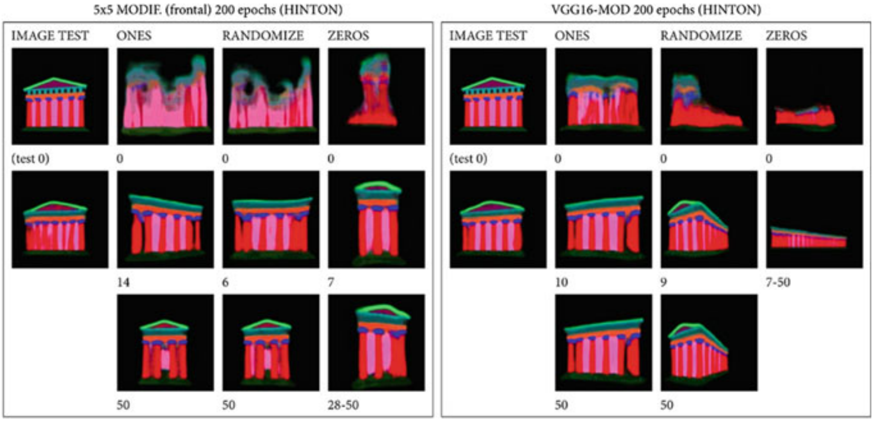

Fig. 4 NPL Transformer algorithm using different activation functions to obtain segmented images. *Images* A.M. Maitín

of automation of the process as a whole, and also increasing accuracy of the results. The details of this application are the subject of an article currently being published.

4 Results and Discussion

In this paper we present two methodologies for the virtual reconstruction of historic buildings. The first methodology, which we have called traditional, analyzes the pre-existence, and determines a reconstruction result from a theoretical assumption. Obviously, we cannot claim that the theoretical assumption is completely true. In fact, successive discoveries throughout history have changed the assumptions of the original states of ruined buildings, as for example when it was discovered that Greek temples were polychrome. This means that (a) the choice of a result is decisive for the elaboration of a virtual reconstruction and may vary according to the specialist and the epoch. On the other hand, the analysis of each case study (b) determines an independent decision, even when analyzing different buildings of the same period and of the same architectural style. Finally, the theoretical assumption (c) is sensitive to the multiplicity of circumstances surrounding the construction of a building, as well as to the different changes that may have occurred over time, such as alterations or the integration of new architectural styles.

The second methodology, which we have called automatic virtual reconstruction, trains a neural network in a specific architectural language. This line presents several aspects, some of them problematic, like the previous one. On the one hand, (a) it predetermines the characteristics of an architectural style in a generalized way, without assuming the multiplicity of circumstances surrounding its construction, the architectural style in which it is framed and its evolution. The training of the neural network would require many different examples to produce an optimal prediction about the reconstructed state. On the other hand, this difficulty becomes a strength because the neural network (b) can learn a constructive and an aesthetic logic that is present in the repetition of a pattern. The problem with this methodology lies in building families that do not have enough fully reconstructed elements and do not infer patterns for reconstruction. This implies that for some architectural styles (c) it is necessary to make a theoretical assumption of the original state, incurring the difficulties of the first methodology.

5 Conclusion and Perspectives

As noted in the introduction, the scenario presented in the field of virtual reconstruction using AI is very suggestive. The dissertation has pointed out that traditional reconstruction methods can address complex problems from individualized case studies. New technologies are increasing the accuracy in the analysis of architectural remains, and new virtual reconstruction rendering systems have opened a range of possibilities in the heritage experience. However, the process of presuming the original state still depends on the expertise and knowledge of the specialist, as well as the existing data on the object of study.

On the other hand, the incipient methods of reconstruction using AI present a vast horizon to be explored. First, (a) there is the possibility of training a neural network to learn an architectural language in order to identify patterns. This aspect is not trivial, because this methodology is suggesting that there may be hidden relationships not perceptible in the observation of isolated examples, which could determine constructive logics, aesthetic tendencies, or other design patterns that, perhaps, are unknown. Second, (b) the answer understood as prediction allows us to have not only one result, but several among which we can decide with more criteria. Finally, (c) the ingenuity of the neural network response allows us to explore the unexpected, and also the unexplored. Without intending to personify AI, the neural network response is relatively creative because it computes a large amount of data.

We believe that both methodologies will coexist. We sense that the paradigm shift will occur when the neural network trainings allow for fluent analysis of real images, both from online repositories and directly from reality. At that point, the virtual reconstruction work could consist of analyzing architectural remains from images and evaluating the neural network predictions.

There are many perspectives in this field. Image collection could allow the automatic acquisition of a parameterized 3D digital twin. This would allow monitoring the Architectural Heritage on a regional, national, and global scale. The integration of automatic virtual reconstruction technology into common apps could improve the user experience and interpretation of cultural heritage. Neural network training suggests a collaborative space in which historians, architects and other specialists could progressively improve reconstruction science.

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Digital Heritage Documentation. Mapping Features Through Automatic, Critical-Interpretative Procedures

Federica Maietti

1 Introduction

Facing today issues related to conservation, enhancement, fruition of Cultural Heritage, means facing connections between this domain and the domain of digitization and digital data management.

Cultural Heritage is increasingly represented and described through digital entities (3D models, digital collections, digital libraries and digital archives) and interactive interfaces [1].

The use of tools and procedures for digitizing Cultural Heritage is becoming increasingly widespread. The latest 3D survey technologies are able to produce very accurate models in a very short time, with clear advantages in terms of speed and metric precision during onsite acquisition, while the processing of the acquired data can be very time-consuming and complex, according to different purposes.

These 3D models with a high information density allow a heritage understanding in its metric, morphological, structural, material and conservation features, but proper digital data management processes are needed to segment and discretize data through semantic classifications [2] with a high critical-interpretive value.

The increasingly widespread use of technologies for digital data capturing of Heritage buildings and sites is therefore producing many 3D models, that very often are only partially exploited [3] for conservative purposes. In addition to get information about dimensions, shapes and geometries, current research avenues are indeed exploring different procedures to analyze surface features, as an additional tool to manage issues related to the state of conservation of heritage assets [4].

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While definitely metric-morphologic information and geometrical features are essential for the knowledge and documentation of Cultural Heritage—being a potential strategic support for different assessment, conservation and restoration work—data provided by 3D Heritage digitization contain additional layers of information to be assessed related to the state of conservation and surface features.

Today, in addition to Terrestrial Laser Scanning (TLS) technologies, photogrammetry is being used for several applications, by processing image data [5]. Current procedures mainly belong to the application of photo-based scanning or image-based 3D modelling software aimed at creating 3D models from photographic images. From the possibility to identifying homological points for orientation and key points for geometric and texturing process proper of the photomodelling, the evolution of algorithms led to Structure-from-Motion (SfM) systems [6–8].

Both of these procedures—TLS and photogrammetry (terrestrial or aerial)—are used, depending on the features of the building or site to be surveyed, having to carefully consider the aim of the 3D data capturing, heritage size and complexity, accuracy requirements, etc. However, the ease of use and functionality of Structure-from-Motion photogrammetry and 3D photomodelling techniques, together with the increasing optimization of algorithms of computer vision, are making this acquisition system widely used.

On the appropriateness of using different technologies to document—in their overall spatiality and complexity—heritage buildings or sites, considerations should be broad and in-depth, always considering, among the main selection criteria, the purpose of the three-dimensional documentation, and how the digital data will be used. Anyway, an essential insight is that, more and more, the integrated procedure, by combining different acquisition techniques and different software, is the best solution to address different documentation needs.

With regard to the computer-based management of the large amount of digital data that is generally obtained by surveying buildings that—being part of the Cultural Heritage—present complexities and irregularities, the direction being taken is towards optimizing and reducing processing times.

From a rapid evolution of the tools at our disposal to acquire—ever faster—and process knowledge data in a digital environment, follows the need to reduce the time it takes to use these data.

A central issue in the field of digitization is indeed the progressive speeding up of processes: the speed of execution of the survey is a feature on which instrument manufacturers are investing. Tools capable of quickly surveying complex buildings [9] can acquire terabytes and terabytes of data. All this information needs to be discretized in order to be used.

There is and there will be a huge amount of digital data to manage and this will lead to the production of more and more performing computers, servers and cloud-based solutions able to store data; and, most likely, more and more processes will be needed to simplify the data handling and filtering, as well as to classify information.

Moreover, the current demands in terms of technological advances and new skills are consistent with some strategic research directions (PNRR—the national Plan for

Recovery and Resilience, European Commission Work Programmes): digitization and innovation, ecological transition, social inclusion.

The possibility of increasing knowledge, procedures and innovative tools for heritage digitization and the advanced analysis of digital models responds to the expected acceleration of digitization as a support for restoration of tangible heritage and to increase knowledge, accessibility, use and dissemination.

The current funded research lines envisage an effort in the direction of increasing digitization of heritage and structured data organization within shared platforms, improving the accessibility of heritage, also by removing physical, cultural, perceptual and knowledge barriers in the interaction with Cultural Heritage. Moreover, a synergy between existing technologies and environmental systems for monitoring, surveillance and management of cultural sites is an additional need.

An advancement in the management of digital data at different scales (historical-architectural heritage, spread heritage, heritage stored in museums and cultural sites) is more and more required in line with the objective of accelerating digital transformation processes.

Furthermore, the use of applications implementing classification algorithms is foreseen as the solution to optimize the speeding up of processes of a large number of data, while improving the reliability for correct interpretations.

Hence the need to transfer and consolidate new innovative enabling technical and professional skills.

In this direction, several research is being conducted and are under development by applying Artificial Intelligence (AI) processes, such as Machine Learning (ML) and Deep Learning (DL) algorithms [10–12], in order to automate the hierarchization of data.

Concerning surface features analysis, the processing of data derived from different methodologies—mainly TLS and photogrammetry—have advantages and shortcomings, shortly discussed in the following sections.

2 Research Scenario

Features recognition, data segmentation and thematic management of heritage digital data are at the center of the present research. Mapping heritage surface features through automatic or semi-automatic procedures is a widely explored issue nowadays [13], while critical-interpretative possible outcomes and reliability still need to be furtherly explored.

The main focus is the concept of thematic analysis, a process very well known within the survey discipline when direct, onsite analysis are performed by assessing the state of conservation of an Heritage site by visually exploring and touching each surface, by applying traditional material and decay classification supported by reference documents (e.g. definition codified in the UNI 11182–2006 standard—*Cultural heritage—Natural and artificial stone materials—Description of the form of alteration—Terms and definitions*).

Usually a visual inspection and preliminary analysis of the state of conservation is performed during the survey campaign.

The current issue is in the post-processing step: how to transfer surface features for documentation, knowledge and restoration purposes to final users? Is still the bi-dimensional representation the most required support for heritage management procedures? How to meet the—often tight—deadlines in the delivery of digital documentation that combines suitable metric-morphological accuracy with an equally rigorous thematic assessment of the state of conservation? To what extent the delivery of 3D models—enriched by different layers of knowledge—are really usable by Heritage managers?

Coming back to the most commonly used surveying methodologies and to the use of digital outcomes for features analysis, geometries and point clouds (coordinates) and color-based data (radiometric features such as RGB and HSV) [14] are equally needed for assessment and data segmentation. Elements recognition [15] is essential not only for architectural documentation and analysis. Geometries and shapes segmentation to assess architectural features is the first step of an overall analysis, also related to the state of conservation. The way in which degradation affects surfaces also depends on the geometric characteristics (projections, recessed surfaces, moldings, presence of sculptural elements, flat surfaces, etc.) and, of course, on the materials.

Materials and construction techniques analysis is essential for the overall assessment and to analyze the state of conservation; different materials (bricks, plasters, stones) lead to different forms of degradation, or react in different ways to specific environmental threats.

Successful experimentations on segmentation and recognition of surface features such as materials and decay have been carried out mainly processing images orthophotos, and UV textures, by applying algorithms on two-dimensional data, to reproject outcomes on the three-dimensional model [16].

While radiometric parameters (color information) are mostly applied to historical surface assessment, the intensity value is hardly used for this kind of analysis.

2.1 Intensity Value Analysis

As an additional layer of knowledge captured by TLS—or generally LIDAR (Light Detection and Ranging or Light Imaging, Detection, And Ranging) since LIDAR more and more often is called 3D laser scanning (terrestrial, airborne, and mobile applications)—surveying methods [17] the intensity value is a measure, collected for every surveyed point. It is based, in part, on the reflectivity of the object reached by the laser pulse.

Reflectance is a function of the wavelength used. Basically, the term reflectance can be defined as the ratio of reflected radiant flux (optical power) to the incident flux at a reflecting object. It generally depends on the direction of incident light and on the optical frequency or wavelength. The intensity value differs depending on the composition and features of the surface of the object reflecting the laser.

All points corresponding to a particular material that has the same intensity value are represented in the point cloud model by the same color. According to the same principle, the state of conservation of the surveyed surfaces (biological patina, moisture, crusts, surface deposits, etc.) is represented with particular colors in the point cloud model since these surface conditions have different ranges of intensity value.

This means that it is possible to visualize in the point cloud homogeneous areas with the same features, as if—theoretically—a sort of mapping of the material and conservative condition was available not only for a visual analysis but also metrically very accurate, depending on the accuracy [18] features of the survey (Fig. 1).

Even if intensity can be used as an aid in feature detection and extraction and in LIDAR point classification in different field of research [19], for heritage features recognition purposes several issues are not solved.

The intensity value depends not only on surface specifications but also on different parameters (instrument calibration, laser angle of incidence, environmental conditions, distance between instrument and the object to be surveyed, etc.) so a careful assessment is needed to understand the reliability of the results. It is very well known that intensity values changes depending on the instrument used. And, generally it

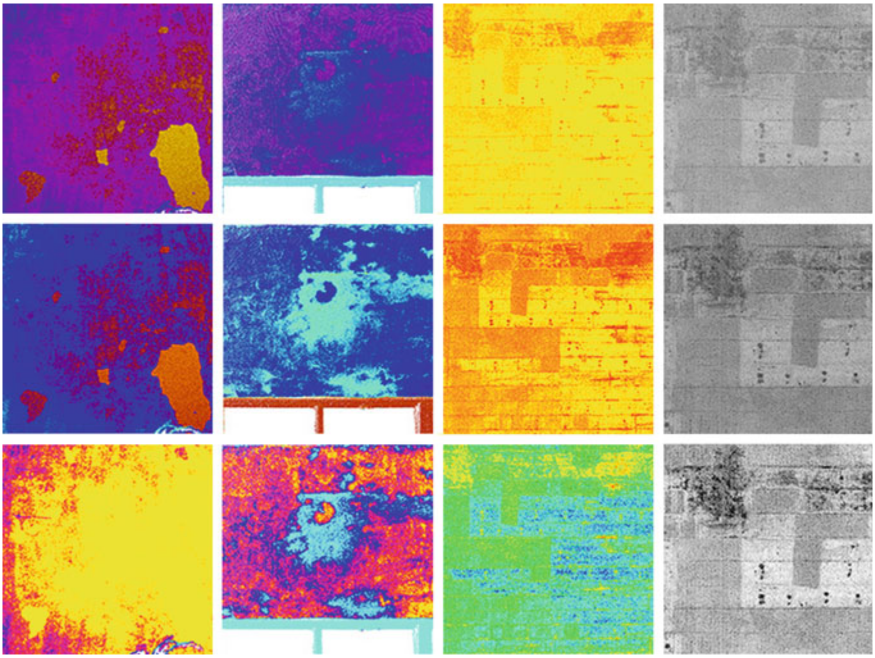

Fig. 1 Samples of dataset extractions from existing databases to find classification criteria to outline surface specifications, in this case through the analysis of the intensity values (Editing: F. Maietti)

cannot be considered reliable with an angle of incidence of the laser beam on the surface less than 45°.

The procedure could be very promising in outlining surface specifications but—due to the above mentioned limitations—the process can be just semiautomatic (and for some operations, manual) therefore it is very time consuming and needs a different and systematic approach by processing a large amount of data.

Some preliminary experimentations have been done [20] in outlining specific decay areas starting from 3D databases of surveyed historical buildings (Fig. 2).

Some of the most interesting results highlight how apparently homogenous surfaces show different intensity values, indicating that further investigations are needed in those areas. This aspect is relevant when integrated survey are aimed also at diagnostic purposes.

These tests have been done by comparing the real condition of the surveyed heritage (visually analyzed) with the range of intensity values in the 3D point cloud model but this procedure is mostly manual, and often is the support for 2D vector

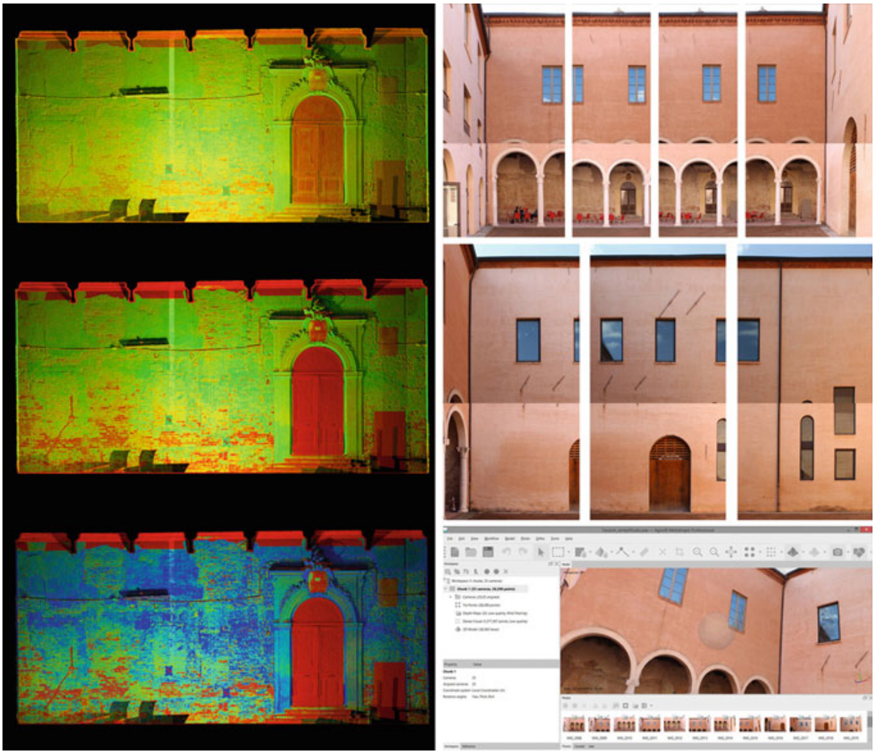

Fig. 2 Experimentations on surface data assessment by processing the intensity value from 3D laser scanner survey, and color-based data from Structure-from-Motion procedure. In this case, the assessment focused on the degradation on the inner surface of the arcade of the internal courtyard of Palazzo Tassoni Estense, Ferrara (Editing: F. Maietti)

graphic representation of pathologies. This is also because very often, requirements from clients (public administrations, heritage sites managers, etc.) needing graphic representations to manage the restoration site are still limited to two-dimensional drawings.

From these experiences, some research questions arose. Is it possible to use this laser-scanning feature to set up a procedure able to apply the intensity value for mapping the state of conservation of historical buildings?

Can the survey of historical architecture by means of 3D scanning be the basis for the use of 3D data for diagnostic purposes and for assessing historical surfaces?

Which is the degree of reliability of this data for diagnostic purposes? How reliable (and metrically accurate) can be the automatic mapping of surface specifications directly to the point cloud?

In heritage field, the automatic extraction of information is a process still presenting shortcomings (theoretical-critical and technical). Even though experimented workflow and advanced digital tools [21], the process is fragmented.

Despite current successful research in data segmentation and classification, further steps can be achieved to find procedures able to outline decay areas or features related to the Heritage state of conservation with the accuracy required for preservation and restoration purposes by exploiting current automatic tools.

3 Methodologies

The proposed methodology aims to investigate further possibilities for thematic classification of data related to surface features of cultural heritage starting from current results in processing color-based data and adding data achieved by laser scanning.

This procedure can be an added value in the critical-interpretative process of data thematization overcoming some limitations in the source data by photogrammetry when conditions are not optimal for capturing high quality colorimetric values, necessary for a detailed investigation of the state of preservation. Moreover, considering representation needs in delivering conservative information, this can open up new possibilities for advanced use of the point clouds.

The methodology is based on two preliminary assumptions.

To develop and apply a procedure or an algorithm that considers the intensity value, the input point cloud must be obtained from an integrated 3D survey carried out for this purpose.

To apply or set up an algorithm that considers both points' geometric features and their colorimetric data, the point clouds must contain both this information. Since acquiring the RGB data from laser scanners generally does not generate satisfactory results, there is a tendency not to acquire this feature [22]. Therefore, point clouds from photogrammetry are preferred for applying the algorithms. These, being derived and not measured could have lower accuracy if not controlled correctly, and lack the intensity value data as they are obtained by laser scanner acquisitions.

Regarding the first point, comparative diagrams on the different response in terms of intensity value of different materials/decays are needed. This is the first part of the research, and it's the more time consuming and crucial to set up further steps. The aim is to associate specific intensity value ranges with specific materials and states of conservation or a group of homogeneous materials. By coding specific ranges, some preliminary interpretative assumptions can be traced. This analysis also involves coding different intensity values (if any) of the same object/material surveyed through different sensors. Therefore several parameters must be included.

Some databases are under analysis. Datasets are selected to test the preliminary step (critical analysis) by processing:

- Dataset from TLS (intensity value).
- Dataset from SfM (RGB/HSV).
- Surfaces surveyed by both methodologies.
- Manual annotation, starting the segmentation step of point clouds according to the previous direct knowledge of the state of conservation.
- Examination of issues (indoor spaces, outdoor areas, location, environmental conditions, orientation, etc.) that can affect/influence the reliability of data for post-processing. Sometimes issues in using photogrammetry for decay mapping occur. The quality of the source data depends on the complexity of the site to be surveyed and on environmental conditions (exposure, shadows, dark areas, etc.).

Following the overall methodology and the main purposes of focusing on critical-interpretative assessment to foster conservation processes, preliminary analyses include additional data, such as historical information, diagnostic analysis (when available), archive sources to retrace previous interventions, etc.

The first assessment of the 3D point cloud of Casa Biagio Rossetti (Fig. 3) in Ferrara, Italy, by the renowned architect, for instance, is focusing on some decorative elements on the main façade. Biagio Rossetti, who is well-known for being the architect of the greatest planning adventure of Renaissance Europe, the Addizione Erculea, worked between 1466 and 1516 on the construction of buildings within the grid of mediaeval Ferrara and its expansion areas prior to the Addizione Erculea, the plans for which began in 1484, on the initiative of Duke Ercole I d'Este, and the work was carried out between 1492 and 1510.

Casa Biagio Rossetti was built for himself and his family between 1490 and 1498, in the south-eastern sector of the city, along Via della Ghiara (today Via XX Settembre).

Concerning the main façade, historical documentations report about the restoration in 1910–11 of the molded terracotta decorations of the doorway and upper floor windows, while the upper cornice was replaced with the currently visible terracotta one that replicates the design found in other Rossetti buildings.

The 3D survey of Casa Biagio Rossetti was accomplished with the objective of documenting the current state of the building, integrating the existing documentation with new knowledge data. This recent digital documentation work provided the opportunity for an analysis of the intensity value and an initial segmentation of the materials and sculptural elements.

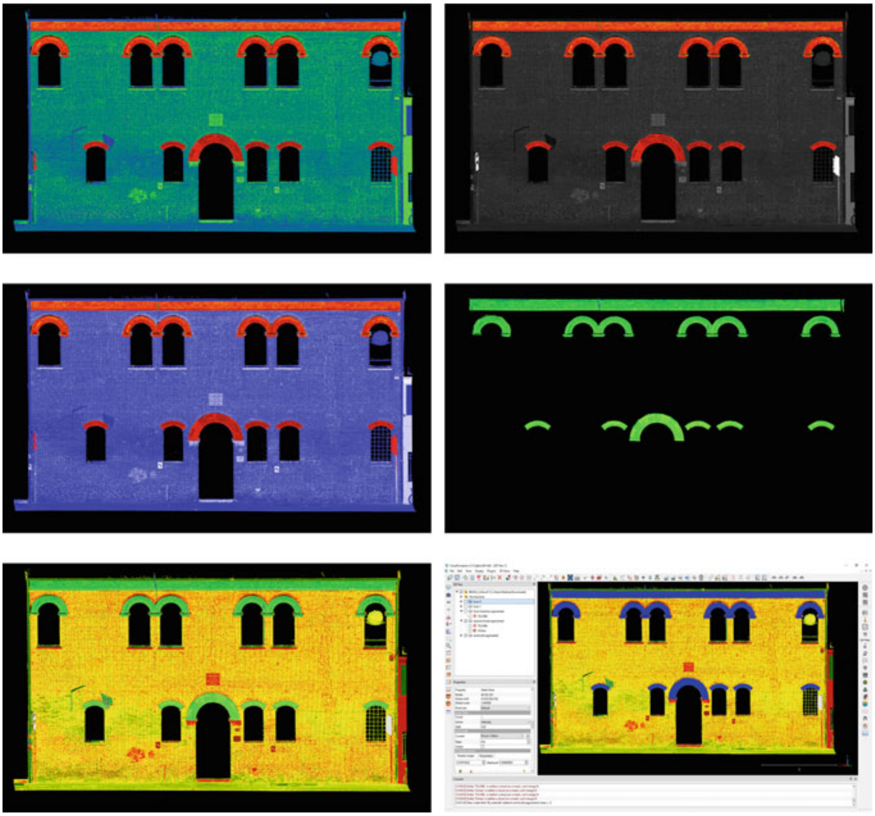

Fig. 3 Assessment of the 3D point cloud of Casa Biagio Rossetti in Ferrara, Italy, focused on the decorative elements on the main façade, some restored and some replaced. Analysis of the intensity value to highlight surface specifications (previous interventions and degradations), and initial segmentation of the materials and sculptural elements (Editing: F. Maietti)

This update becomes significant not only in order to monitor the state of conservation and the current use of the historical architecture, but also to propose a reinterpretation of the characteristic elements that still remain despite the building has undergone several alterations and changes over the centuries.

The research is part of an agreement between the Department of Architecture of the University of Ferrara and the Municipality of Ferrara, Monumental and Heritage Office, aimed at the study, analysis, conservation and enhancement of Casa Biagio Rossetti, through direct and three-dimensional digital surveys in order to increase studies and investigations on the architectural artefact, and to have data to support the identification of possible intervention strategies (Fig. 4).

An additional case study under analysis is the Social Theatre of Novi, Modena, Italy (Fig. 5). The building, built from 1923 to 1929, was documented within a specific and broader research focused on the optimization of survey procedures and

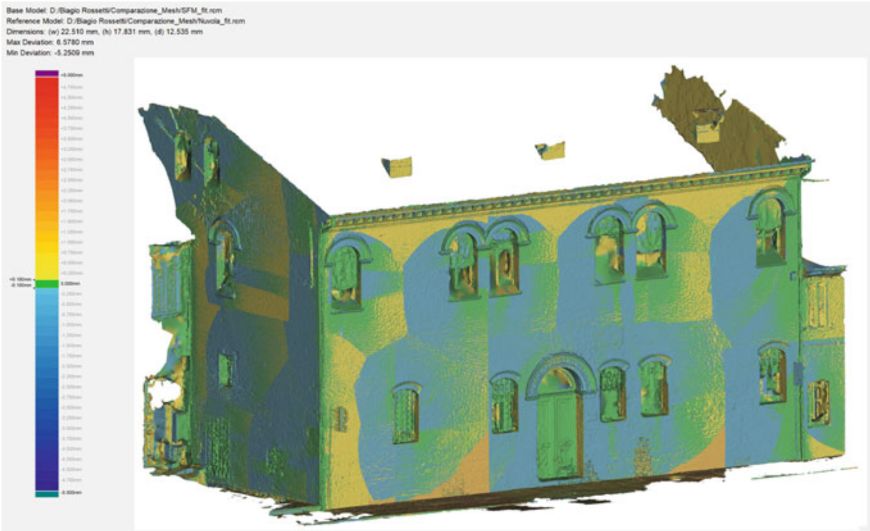

Fig. 4 Clash detection for comparison of meshes obtained from point clouds processed by time-of-flight scanning and point clouds processed by photomodelling (Editing: F. Maietti)

application of integrated digital tools for seismic risk mitigation of cultural heritage. As part of this research, the Theatre of Novi was surveyed by applying different methodologies, including 3D laser scanning and aerial photogrammetry, in addition to the direct and photographic survey of the state of conservation. The digital documentation was the basis for analyzing the intensity values of the main façade, and for a preliminary segmentation of some specific decays.

4 Workflow

The purpose is to explore AI processes in order to combine the irreplaceable cultural and interpretative skill with suitable tools useful to prioritizing data in a hierarchical way according to different levels of knowledge through automatic procedures.

The overall process foresees:

- Annotation of specific features for segmenting point clouds from different digital sources (both point clouds and photogrammetric data), including the intensity value after having defined comparative clusters of different responses for different materials/decays and using different technologies in different environmental conditions (scan positions, weather).
- Assessments from digital sources will be the basis to apply interpretive trained algorithms to classify data and describe specific features in datasets (construction techniques, surface features, state of conservation, morphologies, etc.).

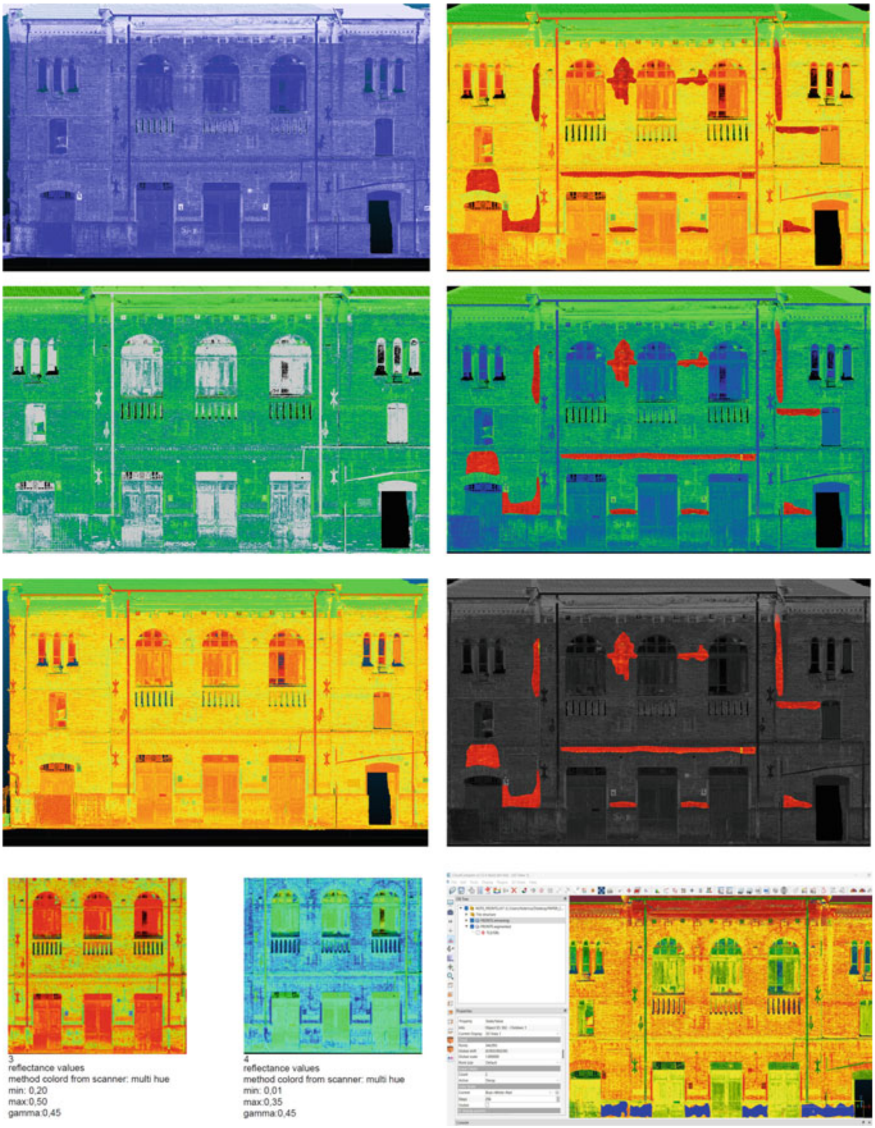

Fig. 5 Assessment of the 3D point cloud of Social Theatre of Novi, Modena, Italy. On the left, intensity values analysis to assess specific decays according to clusters of values. On the right, initial segmentation of specific decays (deposits and raising damp) (Editing: F. Maietti)

- As an additional step, the link of identified features (classification) to the H-BIM model is foreseen by integrating it with diagnostic data from sensors, towards an interdisciplinary BIM with parameters from semantic segmentation of the most relevant areas for documentation, knowledge, analysis, management [23, 24].
- The analysis of possible connections with existing open standard semantic web platforms for monitoring, maintenance and management of cultural heritage through semantically enriched HBIM models [25] is the last step of the research, in order to foster data accessibility and use through integrated H-BIM models and information querying and analysis through semantic web platform (Fig. 6).

Alongside a classification of the State of the Art, requirements and open issues in the main research domains, the selection of available 3D databases and existing point clouds of historical buildings is allowing the definition of suitable datasets (according to the criteria of complexity of historical surfaces in terms of materials and state of conservation/degradation issues, selecting surfaces where most of the degradation is localized). This step foresees the reuse of several databases, capitalizing unexploited data for the specific purposes of the research, and it's combined with specific data acquisition tailored to the research questions, in order to manage different data sets outlining intensity values ranges. The comparison among different sensors/different instruments is part of this research section.

The extraction of parts of the point clouds from selected databases to identify intensity value standard ranges for interpretation and segmentation is the base for finding homogeneous areas according to the selection of parameters/criteria for intensity value. This step is performed via manual annotation.

This step is crucial since it will allow defining standard intensity value ranges—now missing—in the point cloud that can be traced back to specific categories of degradation.

After the assessment of possible intensity value standard ranges, a supervised procedure (on selected point clouds and numerical ranges of intensity values) will be applied to classify subsets of data where the decay is located.

5 Conclusion

The research is in its very beginning, and is aimed at deepening the semantic interrogation of digital models of historic-architectural buildings, characterized by stratifications, complexities and often issues of vulnerability and state of conservation.

Methodology is currently being set up, and some comparative data sets are being explored. A set of existing point cloud databases are under processing, in order to point out classification criteria to outline specific features (construction techniques, materials, state of conservation, etc.). This will lead to a methodology that facilitates an increasingly structured organization of interpretative data, also within shared platforms.

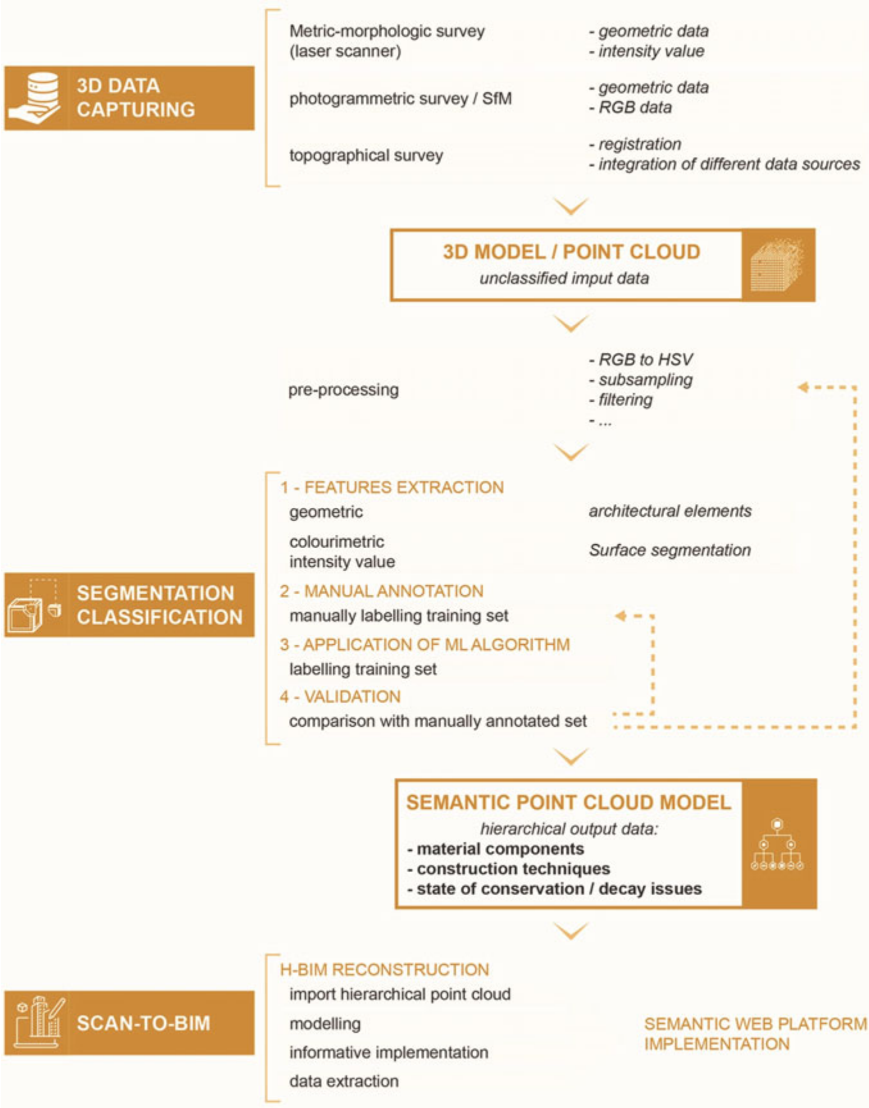

Fig. 6 Overall methodology/workflow schema. The steps related to 3D data capturing and selection of existing databases, the pre-processing for features extraction and the preliminary manual annotations on architectural elements and surface state of conservation are currently being processed, in order to have labelled training sets for classification (Editing: F. Maietti)

This advancement in the thematic management of digital data can contribute to solving the burden of direct and repeated extractions, transferring analytical skills to algorithms, improving the feasibility of diagnostics and the management time of processes.

The assessment, classification and effective usability of the intensity values for data thematization purposes is the most relevant open research question merging intensity value processing, segmentation and algorithms, but other issues are still open as well, such as the managing of decay superimpositions—mainly in data segmentation/features recognition; how to meet high accuracy levels in features mapping such as the ones required from the restoration field, and how to make thematic data in digital environments practically usable by heritage managers.

The vision is to highlight further possibilities offered by the intensity value assessment, highlighting features that are sometimes not visible to the naked eye, linked to decay or the presence of different materials, as an additional aid during the knowledge phases and opening up for new applications. Targeted experiments are needed to provide comparative data on both the different types of materials and the various forms of decay, finding classification criteria.

For the time being, the intensity value is an effective first warning that may lead to interpretative hypotheses, to be verified through other investigations and to be compared and read together with all the other available data (historical, diagnostic, etc.) so that its evaluation fits into a more general framework of knowledge of the Heritage building or site for the purposes of its conservation.

The state of the art today is very rich of new tools, methodologies and promising results, and new horizons open up almost daily in the field of AI.

Features and pattern recognition and AI is nowadays increasingly a topic of research within different fields of Cultural Heritage [26], making clear the need to manage information and data in a well-controlled, organized way.

The focus is how to better assess, analyze and use available data and information included in the digital representation of an heritage object, building or site. New assessment and analysis are required exploiting current technologies and tools for documenting and representing heritage, bringing together different expertise in heritage assessment and IT processes, so now more than ever different skills have to be combined [27].

In this scenario, however, it is nevertheless appropriate asking who will benefit from these procedures, considering the gap among high-skilled research environments and the daily work of those in charge to manage Heritage. So one of the main challenges will be being able to transfer this knowledge into a really applicable procedure.

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Image Segmentation and Emotional Analysis of Virtual and Augmented Reality Urban Scenes

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1 Introduction

The advancements in Augmented Reality (AR) and Virtual Reality (VR) technologies opened up new opportunities for engaging citizens in participatory processes in urban development projects [1–4]. Local authorities may benefit from using digital tools for collecting public input in collaborative processes towards a shared equitable urban development; indeed, web and mobile tools represent an affordable system to engage citizens and share public data supporting the management of the growing urban complexity [5, 6]. These technologies can favor an informed involvement in decision-making processes by supporting laypeople's understanding of urban transformations [2, 7]. Furthermore, these technologies can encourage an understanding of the complex relationship between various environmental factors and the experience of people living in a particular area [8, 9]. For instance, the direct exposition of natural elements in the urban setting is generally associated with beneficial restorative outcomes, favoring well-being, mental health, depression reduction, and stress relief [10–16]. These effects generally emerge also when such environments are presented through photographs, videos, or Virtual Reality [17–20]. To control the intervening variables, research in this field is often conducted in laboratories rather than outdoor (see [21] for a methodological summary).

In virtual scenarios, it is possible to reduce variables according to the experimental goals, e.g., previous studies focus on the influence of light or weather conditions on the emotional dimensions [22]. For instance, previous studies deepen the

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understanding of the relationship between vegetation observed and psychological effects using eye tracking techniques [23, 24]; these studies highlight that natural landscapes may be easier to visually explore and memorize due to the fewer object types than urban landscapes [25]. Analysis involving devices, such as eye trackers, is generally conducted in-vitro and involves a limited number of people in parallel, depending on the number of available devices. To pursue the same overall goal of analyzing the human/natural environment relationship with less sophisticated devices, we propose using image segmentation techniques coupled with the exp-EIA © (experiential—Environmental Impact Assessment) method to compare different conditions and assess the influence of urban greenery on the observer's emotions. Image segmentation divides an image into distinct regions or objects by classifying pixels with semantic labels [26]. By applying image segmentation algorithms to urban scenarios, it is possible to identify the area occupied by specific object categories by quantifying elements' size, shape, and texture [27, 28]. By matching these data with the observer reactions, it is possible to assess the correlation between the physical characteristics of a given urban environment and the emotions of the people who inhabit it [29, 30]. The exp-EIA © method allows us to collect and analyze users' psychological reactions to an existing or designed environment—via Augmented or Virtual Reality—by coupling architectural and psychological disciplines.

2 Methods and Materials

2.1 Case Studies

Data collection was carried out in two areas (later: Study 1 and 2) of the Porta-Romana district in south Milan, Italy. A recent process of renovation [31], still undergoing, is changing the district's identity from industrial and railway yards to business-oriented [32]. Study 1 uses VR StreetView™ pannable panoramas from four fixed points of view surrounding the recently renovated Fondazione Prada and piazza Olivetti. The four views are namely: the view of the Fondazione Prada tower from Isonzo Avenue; the Fondazione Prada golden building seen from Orobia Street; the Vitae project construction site seen from Serio Street; the Fastweb headquarter seen from Adriano Olivetti Square. Study 2 presented the photorealistic render of the VITAE design project by Covivio, Carlo Ratti Associati, and Partners superimposed on-site (Serio Street) to the actual environment through Augmented Reality (AR) using the CitySense™ app. The 3D photorealistic model of the urban transformation is geolocalized and anchored to the actual context by the app; the 3D model of the context is not visible to participants in AR mode, but it is used as an occlusion mask in the simulation software to correctly superimpose the new building to the existing ones.

2.2 Participants and Procedure

In Study 1, participants from Università degli Studi di Milano (48 students: age M = 26; s.d. = 12.12) navigated four spherical panoramas of the existing condition; these images were projected on a widescreen and panned by the moderator. After this short visual exploration, the virtual camera was set to the initial target point and, for each viewpoint, participants filled in a psychological questionnaire. In Study 2, a public participatory event (63 citizens: age M = 41; s.d. = 12.81) was held for the first public presentation of the VITAE design project (Experiencing VITAE—LABSIMURB; description and pictures available at: http://www.labsimurb.polimi.it/research/ar4cup/experiencing_vitae); the event was designed ad hoc to allow semi-guided explorative walk of the project area using the CitySense™ app in AR mode. Three relevant perspectives (two in front of the designed project and one on its back) were defined as most relevant for the assessment. In these points, participants looked around through the app visualizing the VITAE project and then answered a questionnaire embedded in the same app to assess the urban scenario. The same questionnaire, based on the exp-EIA © method, was used in both studies to enable the comparison of the experience in the two areas of the same district. Twenty items rated on a 5-point Likert scale, based on James Russell's circumplex model of emotions, were proposed to assess the participants' emotional reactions to the urban setting [33]. The outcomes of the questionnaire allowed us to describe the emotions through four main factors: Pleasantness, Unpleasantness, Arousal, and Sleepiness. These factors are conceived as two pairs of oppositional values on the Unpleasant-Pleasant continuum, indicating the level of pleasure perceived, and the Sleepy-Arousing continuum, indicating the level of emotional activation. This method, included in the broader exp-EIA © methodology, enables the detection and representation of the person's affective state related to a specific view, thus geolocated. The analysis always considered the cluster of near users looking in the same direction for assessing the average emotional reaction of the cluster rather than the individual one.

2.3 Analyses

In both conditions (VR, AR), participants' answers were clustered according to their locations (Study 1: StreetView™ camera location; Study 2: GPS observers' locations) using the DBSCAN method [34] with Scikit-learn 0.22 and Python 3.8 libraries. Recording spatial exploration data is crucial for analyzing results in a georeferenced form. The average value of the emotional appraisal has been computed for each cluster. The Streetview pictures of Study 1 and the screenshots collected in Study 2 have been segmented using the GluonCV library [35] with ADE20K pre-trained mode [27]; for each detected object category, our code recorded the covered percentage of the picture surface.

Among the 150 categories involving outdoor and indoor sets of objects available in the ADE20K model, we focused on the following: wall, building, floor, tree, road, sidewalk, earth, car, water, signboard, streetlight, pole, fountain, and traffic light. The sky percentage was not considered due to the different weather conditions. Data collected through the emotional appraisal questionnaire were treated in three ways. Firstly, descriptive statistics were used to locate the experiences from each point of view on Russell's circumplex model, i.e., the artesian plane of the emotional states, which locates pleasant emotions on the right and unpleasant emotions on the left, activating emotions on the top, and deactivating emotions on the bottom. The artesian plane is divided into triangular slices corresponding to basic emotions; the range of emotions is labeled, and different colors describe each emotional state. Secondly, the users' position and their visual target, together with the geolocated emotions enabled to map was actually visible from that perspective and which was the average emotional reaction to it; indeed, according to the exp-EIA © method, colors corresponding to the emotional experiences derived from the Russell circumplex model were applied to the corresponding partial isovist on the urban map; the partial isovist represents the portion of visible space from a specific vantage point of view and with a single target [36]. Thirdly, inferential statistics were used to detect significant correlations between the picture surface percentage occupied by each object category in the urban scenes and the emotional factors derived from the analysis.

Due to the different simulation solutions of the two studies (VR in Study 1, AR in Study 2) and the different fruition of the scenes (indoor in Study 1, and outdoor in Study 2), the correlation values between objects in the scenes and the assessed emotions in the two systems may differ. For this reason, we applied the Bland–Altman evaluation method [37, 38] to establish the agreement level between the correlations found in the two case studies. In the Bland–Altman's chart (Figs. 7, 8), the mean of the correlation pairs found in the two cases is shown on the abscissas, and the difference between the two correlation values is represented on the ordinates. According to this representation, the more the studies' correlation pair agree, the closer they are to the indifference line (represented as a dashed blue line on the charts) on the vertical axis; the closer they are to the indifference line, the closer they are to the probable real value independent of interfering factors. Furthermore, the more the correlation values converge, the higher the correlation mean value is (either negative or positive) and the more they are placed at the two extremes of the horizontal axis (higher correlation zone highlighted in green on the charts). To sum up, the highest agreements are represented inside the confidence area (azure stripe in the chart); the higher negative correlations (induced decreasing of the specific emotional effect) lay on the left side, and the higher positive correlations (induced increasing of the emotional effect) lay on the right side of the chart. We classified the agreement based on the following criteria: (i) High level: the correlations' difference is within the confidence range of the difference values (mean-t_test_confidence, points inside the azure stripe) and absolute value $|r_{dif}| \geq 0.75$ (highlighted in green); (ii) Medium level: the correlations' difference is within the confidence range of the difference values (points inside the azure stripe) but with an absolute value $|r_{dif}| < 0.75$; (iii) all the other correlations are classified as a Low level if they lay within the intermediate bands between the confidence area of the difference values, and the t-confidence boundaries (± 1.96 std) of the data (the charts' area outside the azure stripe and inside the red dashed lines).

3 Results

Point of Views (PoV) A and B of Study 1 were labeled as depressed. PoV C of Study 1 was labeled as alert-excited. PoV D of Study 1 was labeled as tense. PoVs 1 and 3 of Study 2 were labeled as fatigued. PoV 2 of Study 2 was labeled as calm. In Fig. 1, each white dot represents the average value of the emotional reaction from a single point of view (PoV). Figure 2 illustrates on a map the isovists corresponding to the different PoVs rated by participants. Each isovist's color corresponds to the PoV position on Russell's cartesian plane. Overall, 14 objects emerged from the image segmentation process as the most relevant to represent the views (Fig. 4). The percentage of the picture occupied by these categories is reported in Table 1. The first five columns represent the majority of the object identified in the scene: wall; building; floor; tree; road. In particular, in Fig. 4—PoV3 the visible portion of the façade, categorized as a wall, occupies 29.6% of the picture; PoV C is the picture with the higher portion of an entire building in the scene (31.5%), and is the one with the larger floor surface identified (22.5%); PoV A presents the larger tree surface among the image dataset (28.9%); PoV A, PoV B, PoV1 have similar road surface percentages (respectively 22.5%, 23.2%, 24.1%). In both studies, the correlation (Fig. 3) between tree covered area and arousal factor was negative (Study 1: − 0.70; Study 2: − 0.91); the correlation between tree covered area and unpleasant factor was negative as well (Study 1: − 0.83; Study 2: − 0.87). Hence, the presence of a tree decreases both factors. In both cases, the picture area covered by buildings results as positively correlated with unpleasantness (Study 1: 0.71; Study 2: 0.81). The area identified as the floor is positively correlated with the arousal factor (Study 1: 0.89; Study 2: 0.79).

The correlations between the object percentages and the emotional values assessed in the two areas diverge for most object categories (Fig. 3), but a few pairs emotion/object show a high level of agreement, as addressed later. The means (Table 2) of the two studies' correlations (horizontal axis in the Bland–Altman charts) are positively higher for the following pairs: building/unpleasant 0.76, and floor/arousal 0.84; at the same time, they result negatively higher for: tree/unpleasant − 0.85 (Figs. 5, 6), tree/arousal − 0.81. The correlations pairs differences encompassed by the related confidence interval (Table 3, highlighted in green) are: pleasant-building − 0.25; pleasant-signboard 0.72; pleasant-traffic light 0.67; unpleasant-building 0.1; unpleasant-tree − 0.04; unpleasant-signboard − 0.42; arousal-floor − 0.1; arousal-tree − 0.21; sleepiness-building − 0.17; sleepiness-earth − 0.28; sleepiness-signboard 0.75; sleepiness-traffic light 0.91. Considering both the averages and the differences, the highest agreement emerges in the following values (Table 4, Fig. 7): unpleasant-building positive correlation (increasing effect); unpleasant-tree negative

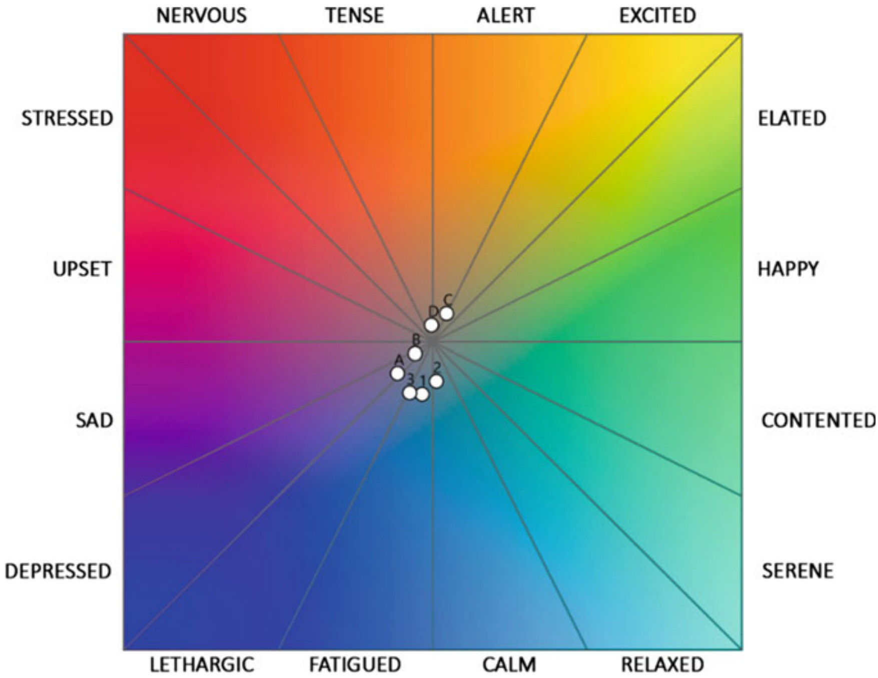

Fig. 1 Russel chart. Points A, B, C, D of Study 1 are seen as VR pannable panoramic pictures; points 1, 2, 3 of Study 2 are clustered from Experiencing Vitae event data collection. The slices represent fields of homogenous emotions labeled on the boundary. The point distance from the chart center represents the emotion mean intensity perceived by the participants (*Source* G. Stancato, B. Piga; image formerly published in [39])

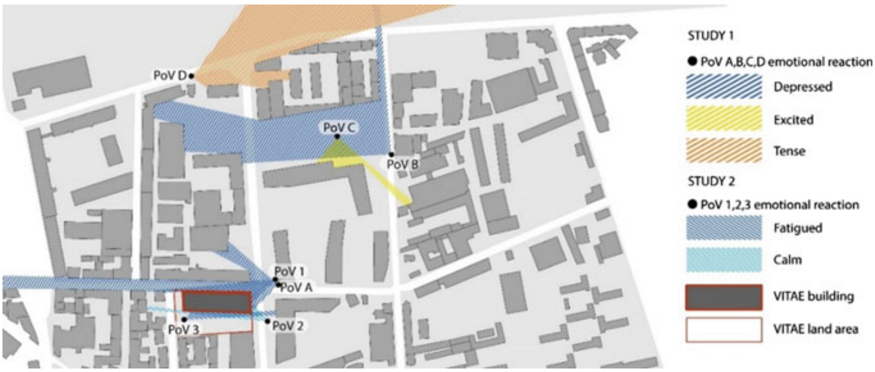

Fig. 2 Semantic Isovists. Points A, B, C, D of Study 1 are seen as VR pannable panoramic pictures; points 1, 2, 3 of Study 2 are clustered from Experiencing Vitae event data collection. Represented field of view is 60°, colors relate to the average emotion felt by the participants (*Source* G. Stancato, B. Piga; image formerly published in [39])

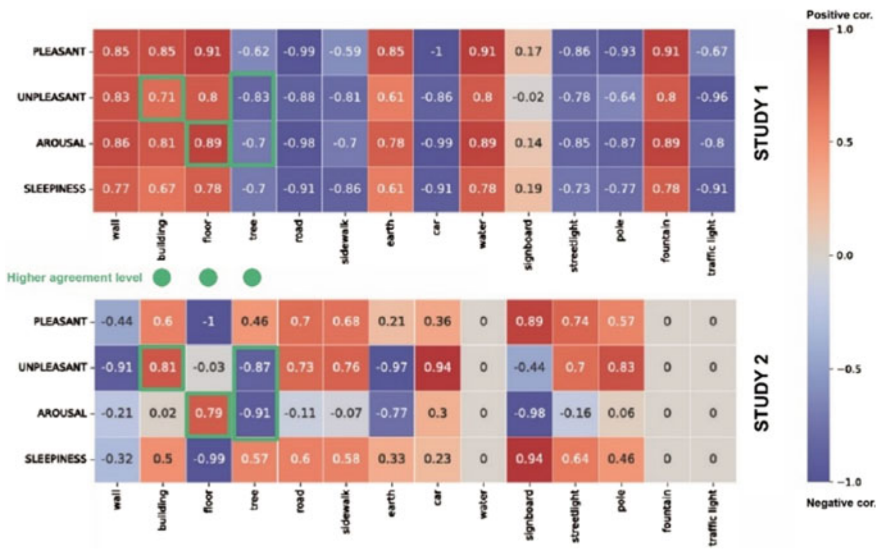

Fig. 3 Correlations matrix. On rows the emotional factor, on columns the object category. The color gradient represents the kind of correlation: Negative in blue; Positive in red; neutral in grey. Green rectangles, and green circles represent where higher agreement has been identified thanks to the Bland–Altman evaluation method (*Source* G. Stancato, B. Piga)

correlation (decreasing effect); arousal-tree negative correlation (decreasing effect); arousal-floor positive correlation (increasing effect) (Fig. 8).

4 Discussion

In this work, we have applied the Experiential Environmental Impact Assessment method (exp-EIA ©) in two conditions, different scenes fruition, and different samples: students indoors with VR in Study 1 and citizens outdoors with AR in Study 2. We applied the Bland–Altman evaluation method to find regular and stable correlations between the elements perceived in the urban environment and the emotions felt by the observers (collected through a psychological questionnaire), independently of the described variations. This method highlights the agreement in values collected with two different systems and devices evaluating similar phenomena.

To evaluate the influence of specific categories of objects in the scene on the observer's feelings, we applied the image segmentation technique, reporting the percentage of picture surfaces occupied by each urban object category. This method identified the higher and more stable correlations, regardless of the device, sample, and conditions, in the following emotion/object pairs: buildings which induce an increasing unpleasant effect; trees induce decreasing in the unpleasant effect and decreasing arousal effect; floors increasing arousal effect. The emotional effects

Fig. 4 Image Segmentation of the urban scenes related to the emotional data collection. POV 1,2,3 are screenshots centered on the clustered views emerging from the Experiencing VITAE event; POV A, B, C, D show the image segmentation of pre-selected views presented to the Study 1 participants (*Source* Background screenshots of PoV 1-2-3 captured by the CitySense app; background picture of PoV A-B-C-D by GoogleStreet; superimposed masks generated by the image segmentation process)

collected in the two areas show a common emotional pattern; the presence of trees induces the reduction of unpleasant and stressful conditions, as highlighted by previous studies. The presence of buildings induces an increase in the unpleasantness perceived by the observer. The described method can be applied to different conditions and urban contexts to find different emotional response patterns. An advantage of applying this methodology is the possibility of using affordable devices involving several people simultaneously in participatory processes.

Table 1 Percentage of picture surface calculated after the image segmentation

Figure/ Category	Wall (%)	Building (%)	Floor (%)	Tree (%)	Road (%)	Sidewalk (%)	Earth (%)	Car (%)	Water (%)	Signboard (%)	Streetlight (%)	Pole (%)	Fountain (%)	Traffic light (%)
POVA	1.7	16.6	0.0	28.9	22.5	4.7	0.1	0.9	0.0	3.3	0.2	0.6	0.0	0.2
POVB	5.8	14.9	0.0	2.3	23.2	3.0	0.0	1.1	0.0	2.6	0.2	1.8	0.0	0.0
POVC	14.9	31.5	22.5	1.0	6.7	2.8	0.2	0.0	4.2	3.0	0.0	0.0	0.1	0.0
POVD	2.3	11.8	0.0	21.7	15.5	1.6	0.0	0.4	0.0	3.9	0.2	0.0	0.0	0.0
POV1	0.2	28.9	1.2	14.2	24.1	0.0	0.2	1.4	0.0	3.5	0.1	0.5	0.0	0.0
POV2	21.1	7.7	7.0	5.4	0.0	0.1	0.0	0.5	0.0	3.2	0.0	0.1	0.0	0.0
POV3	29.6	5.8	2.7	33.1	1.7	0.0	9.0	0.0	0.0	3.5	0.0	0.1	0.0	0.0

The categories in columns relate to the ADE20K categorization

Table 2 Mean correlation (Study 1 + Study 2)/2, the higher positive or negative lay on the extremes of the corresponding Bland–Altman horizontal axis

Category/Emotion	Pleasant	Unpleasant	Arousal	Sleepiness
Wall	0.21	– 0.04	0.33	0.23
Building	0.73	**0.76**	0.42	0.59
Floor	– 0.05	0.39	**0.84**	– 0.11
Tree	– 0.08	**– 0.85**	**– 0.81**	– 0.07
Road	– 0.15	– 0.08	– 0.55	– 0.16
Sidewalk	0.05	– 0.03	– 0.39	– 0.14
Earth	0.53	– 0.18	0.01	0.47
Car	– 0.32	0.04	– 0.35	– 0.34
Water	0.46	0.40	0.45	0.39
Signboard	0.53	– 0.23	– 0.42	0.57
Streetlight	0.21	– 0.04	0.33	0.23
Pole	– 0.06	– 0.04	– 0.51	– 0.05
Fountain	– 0.18	0.10	– 0.41	– 0.16
Traffic light	0.46	0.40	0.45	0.39

Higher average values imply a higher correlation in both studies

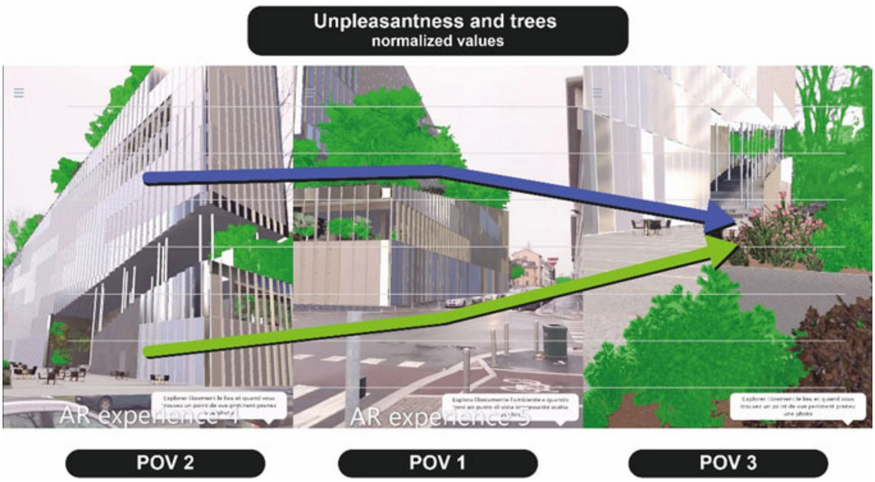

Fig. 5 The Unpleasantness values and picture percentage covered in trees for the POV 1-2-3. The blue arrow represents the unpleasantness decreasing, the green arrow represents the increasing of trees in the pictures. Both unpleasantness and trees values are normalized in the [0–1] range to make them comparable (*Source* Background screenshots catched by the CitySense app; superimposed masks and chart: G. Stancato, B. Piga)

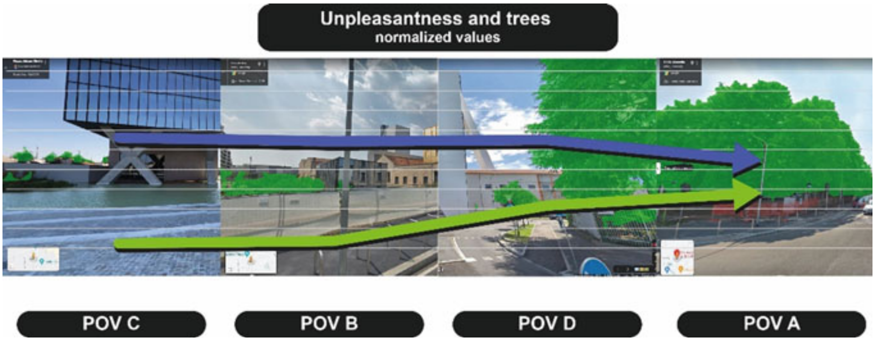

Fig. 6 The Unpleasantness values and picture percentage covered in trees for the POV A-B-C-D. The blue arrow represents the unpleasantness decreasing, the green arrow represents the increasing of trees in the pictures. Both unpleasantness and trees values are normalized in the [0–1] range to make them comparable (*Source* Background picture by GoogleStreet; superimposed masks and chart: G. Stancato, B. Piga)

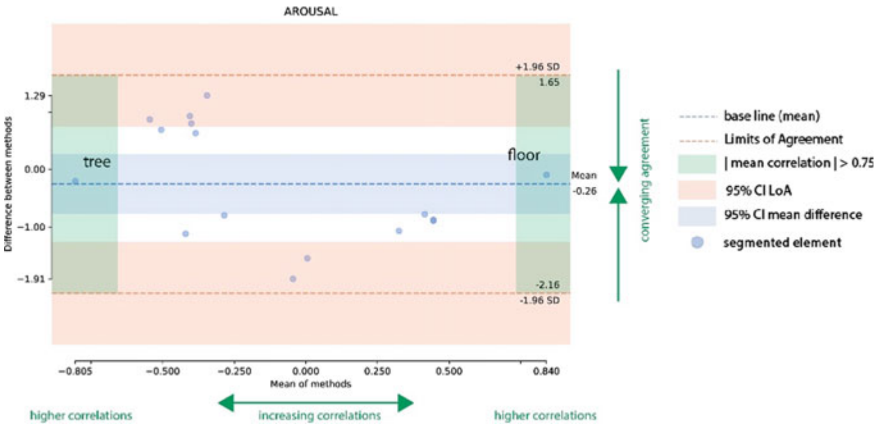

Fig. 7 Bland–Altman chart for the arousal variable. The presence of trees reduces the arousal effect with a consequent relief of the observer while the paved surface increases it (*Source* G. Stancato, B. Piga)

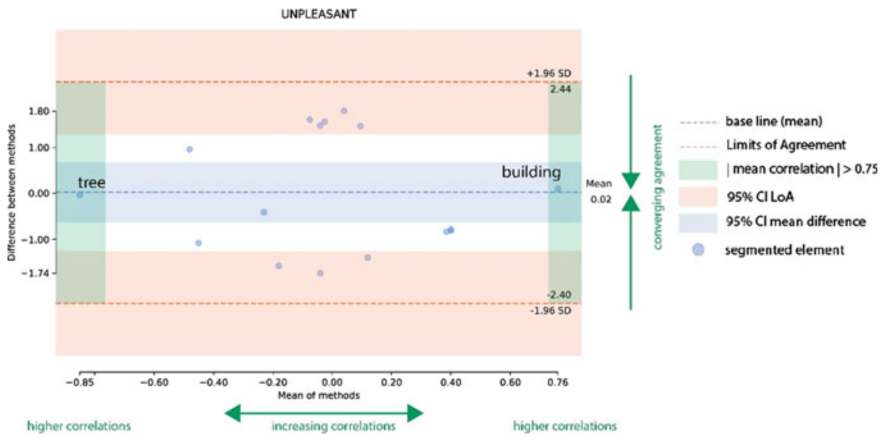

Fig. 8 Bland–Altman chart for the unpleasant variable. The presence of trees reduces the unpleasantness while the presence of buildings increases it (*Source* G. Stancato, B. Piga)

Table 3 Difference between the two studies (Study 1—Study 2), the closer to zero the better; Emphasized in bold the differences that lay within the confidence mean difference interval (azure area of the Bland–Altman charts)

Category/Emotion	Pleasant	Unpleasant	Arousal	Sleepiness
Wall	– 1.29	– 1.74	– 1.07	– 1.09
Building	**– 0.25**	**0.10**	– 0.79	**– 0.17**
Floor	– 1.91	– 0.83	**– 0.10**	– 1.77
Tree	1.08	**– 0.04**	**– 0.21**	1.27
Road	1.69	1.61	0.87	1.51
Sidewalk	1.27	1.57	0.63	1.44
Earth	– 0.64	– 1.58	– 1.55	**– 0.28**
Car	1.36	1.80	1.29	1.14
Water	– 0.91	– 0.80	– 0.89	– 0.78
Signboard	**0.72**	**– 0.42**	– 1.12	**0.75**
Streetlight	1.60	1.48	0.69	1.37
Pole	1.50	1.47	0.93	1.23
Fountain	– 0.91	– 0.80	– 0.89	– 0.78
Traffic light	**0.67**	0.96	0.80	**0.91**
Standard deviation	1.23	1.26	0.95	1.11
Mean (distance from equality)	0.28	0.20	– 0.10	0.34
Standard error	0.33	0.34	0.25	0.30
Confidence	0.71	0.73	0.55	0.64

(continued)

Table 3 (continued)

Category/Emotion	Pleasant	Unpleasant	Arousal	Sleepiness
Confidence—lower Limit mean	− 0.42	− 0.53	− 0.65	− 0.30
Confidence—upper Limit mean	0.99	0.93	0.45	0.98

These values correspond to the Bland–Altman vertical axis. Closer is the value to zero higher is the equivalence of the correlations in both studies

Table 4 Agreement level

Category/Emotion	Pleasant	Unpleasant	Arousal	Sleepiness
Wall	Low	Low	Low	Low
Building	*Medium*	**High**	Low	*Medium*
Floor	Low	Low	**High**	Low
Tree	Low	**High**	**High**	Low
Road	Low	Low	Low	Low
Sidewalk	Low	Low	Low	Low
Earth	Low	Low	Low	*Medium*
Car	Low	Low	Low	Low
Water	Low	Low	Low	Low
Signboard	*Medium*	*Medium*	Low	*Medium*
Streetlight	Low	Low	Low	Low
Pole	Low	Low	Low	Low
Fountain	Low	Low	Low	Low
Traffic light	*Medium*	Low	Low	*Medium*

The higher agreements between the two studies are focused on the presence of trees, buildings, and the paved surface
The unpleasant and arousal effects are both emerging as converging factors for the two studies' agreement

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Patent and Copyrights: Through an architectural\psychological integrated framework, the interaction with a real or simulated environment triggers an experience that can be reliably assessed using the exp-EIA ©—Experiential Environmental Impact Assessment method (Copyright BOIP N. 123453—06.05.2020 and N. 130516—25.02.2021; Patent for Invention application N. 102021000017168—30/06/2021).

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Machine Learning in Architectural Surveying: Possibility or Next Step of Development? From Photogrammetry to Augmented Reality of a Sculptural Group

Ylenia Ricci, Andrea Pasquali, and Pablo Rodríguez-Navarro

1 San Vivaldo

1.1 The Religious Site in the Past

The Franciscan complex of San Vivaldo, in the municipality of Montaione, rises in one of the most evocative places most evocative of the Valdelsa, in an area of high environmental and landscape value and in a central position with respect to cities of art and sites of tourist and cultural interest. Declared a national monument in 1984, it certainly represents the most important artistic emergence in the territory of Montaione and constitutes an important cultural, spiritual and tourist reference point for the Valdelsa and the entire Province of Firenze. San Vivaldo is a Sacro Monte near the Via Francigena, nestled in a wooded and hilly area in the municipality of Montaione, not far from Florence. This settlement is the latest transposition to the world of the Holy City on a smaller scale, arriving in our time still faithful to the initial design. A kind of *Charta Peregrini* is reproduced in San Vivaldo, which does not only reproduce the buildings of worship most frequented by the faithful in Jerusalem, but also the orography, the layout of the places, the distance between them and the orientation. It is an open-air play, with each chapel narrating an event, from the Last

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Supper to the resurrection. The Chapels of the Sacred Mount of San Vivaldo date back to the early 1500s and preserve inside terracotta statuary groups representing episodes from the life as well as the Passion of Jesus Christ. Leading the construction of the chapels was Fra Tommaso da Firenze, who spent many years at San Vivaldo and then died in Florence in 1534. Fra Tommaso had been, prior to 1500, in the East, on the island of Crete and in the Holy Land-a place where Franciscans had been settled since the time of St. Francis-where he met Fra Bernardino Caimi, the Franciscan creator in 1493 of the Sacro Monte of Varallo Sesia in Piedmont. Initially, the grandiose work completed in about 16 years included 25 chapels, which over the years some were lost due to wet and landslide-prone soil, while others were added, such as the Chapel of the Annunciation, the Flight into Egypt and the Samaritan Woman. The terracottas found inside the chapels were made by various artisans-whose workshops were particularly prevalent in Tuscany at the time as continuations of the della Robbia family-whose names we do not know, but who had a different professional level that can be seen by observing some of the details of the terracottas. Over the centuries, the various chapels were entrusted to private families for maintenance and repairs, while others were lost due to neglect and landslide terrain. Today they are under the Soprintendenza ai Monumenti di Firenze, which oversaw the last restoration that took place between 1971 and 1976.

2 Sculptural Group

The chapel of the going to Calvary, the first subject of this research, is located between the Chapel of the Holy Women and the House of Pilate. It has two entrances to access the group of terracottas depicting the scene of the going to Calvary, while outside, next to the chapel is the aedicule of the Crucifix. It is one of the most abundant terracotta groups of characters and represents one of the most dramatic moments of Christ's Passion. In this depiction one notices the Roman soldiers with the S.P.Q.R. (*Senatus Populusque Romanus*) insignia, the two la-drones, a civilian on horseback (perhaps Joseph of Arimathea), but most of all one notices the faces of the crowd to which contrasts the suffering but serene face of the Savior bearing the weight of the Cross and the sins of the world. The second subject of this research is the sculpture of St. James the Lesser was bishop of Jerusalem and was killed by Herod Agrippa the 2nd in the year 61 by throwing him off the pinnacle of the temple and then finished off with a beating, which is why he is depicted with a staff in his hand as can be seen in the wonderful terracotta inside the chapel. The last one is the sculpture of Ecce Homo.

3 Workflow

The work carried out on the entire complex began with the documentation phase and then continued with the processing of the collected data and restitution with digital models useful for understanding the work. The collection of the data was done by means of surveying techniques for digital photogrammetry that allow to obtain excellent results useful for being able to have a complete picture of the state of the art of the object under examination. Being in the field of Cultural Heritage, it will be with the help of digital photogrammetry that we will maintain a level of scientific attention in the process of digitization of the architectural and artistic heritage. The processing of digital photogrammetry represents the link between the phase of data acquisition (survey) and that of importation and structuring of the virtual environment (restitution). This highlights how the photogrammetry is the step of digitization of the subject.

4 Acquisition of Data

The survey campaign was carried out in a time frame of around 7 working days, thus allowing the collection of a substantial amount of photographic data. The survey covered the totality of the statues inside the chapels and in this paper the most significant ones will be analyzed and able to offer a clear representation of the importance that machine learning could assume within these long processes of workmanship, not only to be able to facilitate the work of the operators but also to ensure a better possible performance, considering that very often these are works that must be performed on sites where the working conditions are not optimal and that also at the level of timing do not permit to be able to be performed a second time. The instrumentation used in the data acquisition phase is composed of a Nikon D850 camera equipped with a 35 and 60 mm lens, and flash in order to ensure a quality of illumination that does not compromise the work and the subsequent restitution, thus going to break down any shadows and chiaroscuro. The photographic shooting of the statues was performed with the help of external flashes. The light emission was studied in order for it to arrive on the subject indirectly. The shots thus taken are characterized by homogeneous light. The absence of shadows made it possible to record the characteristics of the material uniformly, without rendering alterations on the color datum. This methodology of organizing the 2 flashes applied, was also possible due to the small size of the rooms. In the larger chapels, photographic umbrellas were applied to facilitate the rebating of light. The use of flashlight made it possible to keep the ISO level of the sensor low. However, it proved useful to perform a calibration of the light produced by the bulbs with the white balance on the camera. To produce a well working set of images, the camera in use was a digital SLR with a 36.3 MP unfiltered sensor. A camera capable to get high resolution images keeping a low level of noise even in high ISO settings, a proper condition for the low light of the chapels. On average, the number of photos taken for each sculpture group is 1000 shots, each of which passes under the careful control of the operator to be sure that the focus and lighting are correct, to be able to achieve an optimal result, and to be able to ensure that the workflow proceeds as smoothly as possible. One observation that surely must be made is how much responsibility is placed on the operator during these operations, which by requiring such painstaking attention make the process slow and cumbersome. The question to ask, then, is in what ways machine learning can also be useful in this early stage of photogrammetric surveying.

5 How Machine Learning Can Help

The intervention of automatism in photographic re-shooting can already be found in applications of digitization with SfM for several years. The use of re-shoot groups or sliding tracks have already found their way with tools for optimizing data acquisition. In this application, the limitation is the low presence of machine learning. These automation systems are programmed by an operator; the shot steps, thus the final number of frames, are chosen by a human individual [1]. Beyond that, the positioning of the object to be acquired and the instrumentation are also discretized and implemented by humans. With the use of robotic arms equipped with pattern projection cameras or scanners and proximity sensors, we can approach a true implementation in data acquisition. Although technologies are not self-sufficient to move in the environment, the mobility characteristics of the arm with the support of proximity sensors and a control hardware the acquisition procedure would gain more independence. An operator's control and validation could provide the machine with the necessary feedback to create its own knowledge, and in a case of similar subjects to be acquired sequentially (such as the one presented) an in-situ step speed could be developed. To this last cue, the strong limitation given by the high economic demand for this type of instrumentation should be emphasized, limiting its use to low to medium budget levels. The last cue to be highlighted in this chapter is the more recent presence of automated photo-acquisition technologies through flying drone UAVs. Automation and the ability to apply processors for machine learning can be found using flight plan scheduling applications, making flight and prediction of timing, data volume, and electrical consumption automatic. The insufficiency of this application is due to the morphological nature of our objects under study. Applications for flight plans are usable for larger portions than the sculptural groups in the studio. In the recent past we find the evolution of these for the detection of vertical surfaces, a digital augment-to that, when coupled with processors properly programmed to learning, can evolve the automation of in-flight shooting.

6 Data Processing

Processing of the data collected in situ was performed with digital photogrammetry software. The application of digital photogrammetry was the optimal option for this type of acquisition. The desire to perform a useful acquisition at a scale of 1:2, found in the survey procedures used the most appropriate result. The observation of the data processed by the laser-scanner acquisitions, compared with the point clouds derived from the alignment of the images, highlighted a much higher completeness of the data of the photogrammetric procedures. The instrumental settings used on the 3D laser-scanner were not at a level to record a dense datum, even if so set up however, the need to perform enough scans to cover all the undercut promotions of the sculpture would have lengthened the survey time. In addition to this observation, the material and painted alterations and degradations of the sculpture could not have been fully recorded by geometric scanning alone, even when associated with the color datum. Digital photogrammetry thus proves to be the most comprehensive and expeditious method when applied to studies of this type. The canonical steps for creating the mesh model with associated texture were performed. Note signified in this processing step is a pre-calculation step performed on image browsing software for checking and correcting light and color balances. In order to enter the calculation step with a uniform baseline data and possible filtering from incorrect and possible error-producing or time-consuming images in processing. In this pre-selection and control phase, the aid of machine learning intervention following the operator's first operations could take space [2]. The next phase, as mentioned, was performed with digital photogrammetry software. Automatisms are already present in this digital platform between calculation steps. Properly calibrated software settings of individual steps, it was possible to perform the repetitiveness of operations on the various sculptural groups. This is a total automatism without the automatic intervention for control and optimization. Finding the correct digital model asset, calibrated to the restitution methodology can become the best cue for useful data collection to be provided to machine learning processes by optimizing operations. This is the main focus of this paper and will be further explored later (Fig. 1).

Photogrammetry processes resulted in polygonal meshes computed at the highest level of topological density. As the data is derived from a high number of images with a large pixel density, the polygonal models are highly dense, in which redundancy of information could be detected. Taking away this (debatable or not) claim, mesh surfaces would not be usable in most cases of migration to external software. The main example, brought up in this paper is the statue of Ecce Homo. The digital copy derived from photogrammetry applied to 716 photographic shots is described by a model of 4,070,000 (407 M) polygons. This figure already highlights how the model results in high polygonization, so the need for optimization by decimation is obvious for smooth operation following export [3]. Beyond that, optimization is applicable by looking at the level of detail this level of polygonation provides to the subject. The statue has an area of about 5.6 m^2 so the polygon mesh resolution is about 7268 polygons/cm^2. A high density. Associated with this datum is the texture image

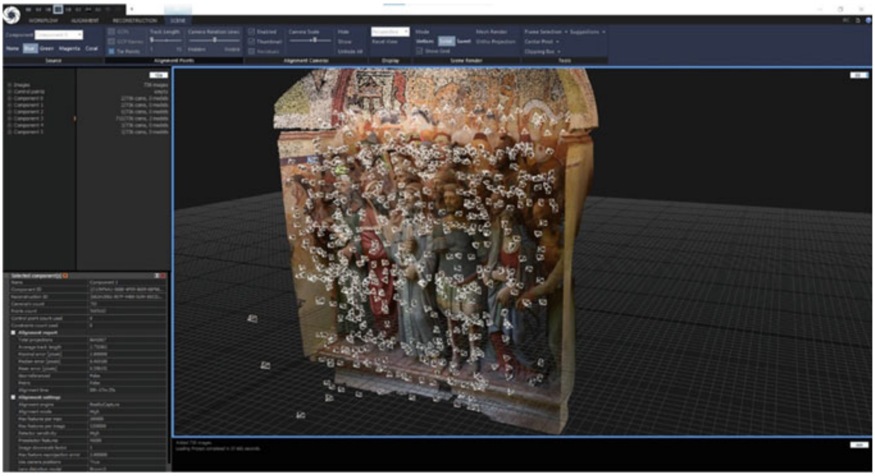


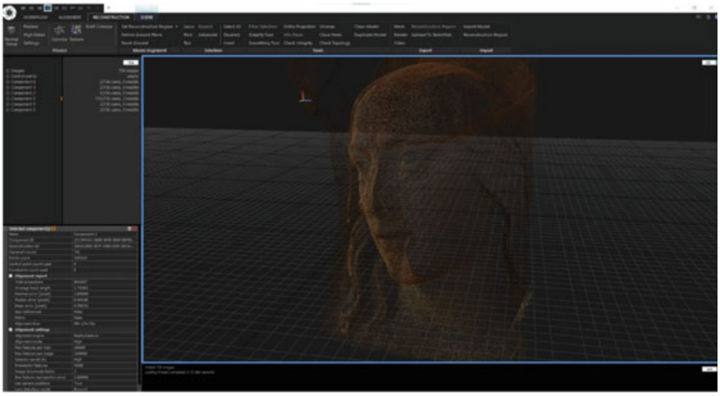
Fig. 1 Data processes in reality capture (*Source* Y. Ricci, A. Pasquali, P. Rodriguez-Navarro)

that completes the model, calculated at the resolution of 8000 × 8000 px and through projection with UVmap on the surface, returns a resolution of the color datum of about 1150 px/cm^2. to the model [4] (Fig. 2).

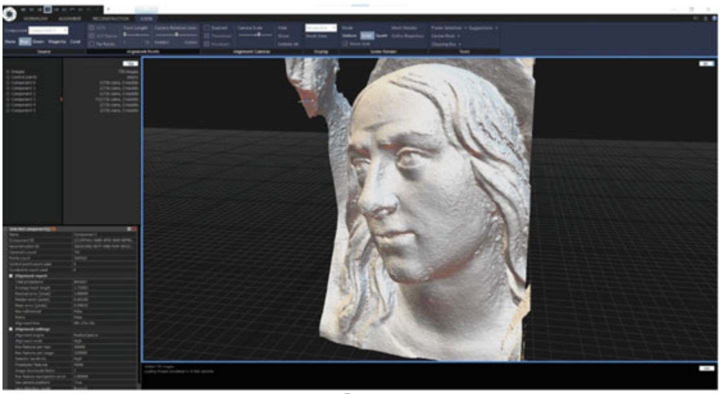
7 Output

8 The How to

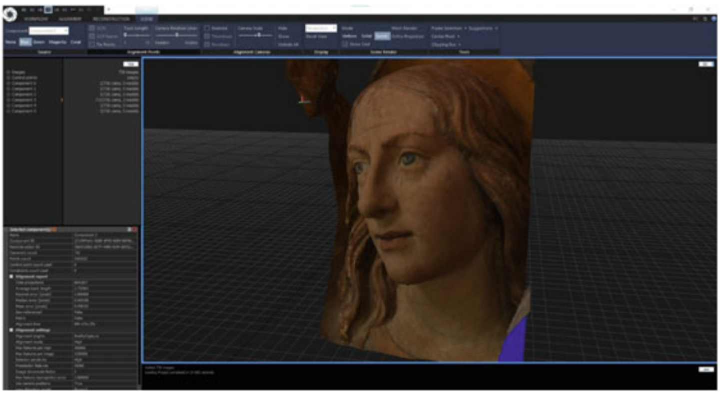
Survey procedures, which are useful for collecting the state of the artifact, are of little use without a communicative coding process of the data. Therefore, the choice of dissemination methods of the survey process is essential to make it useful and implement a true synthesis of the collected data. As mentioned in the previous chapter, the model obtained from the photogrammetric process is manageable and usable only on the software on which it is created. In this there are a variety of possibilities for analysis and study but also additional methods of modification and editing. Having said that, the path of spreading the model in the software platform of photogrammetry is declared not viable, because two possible problems could occur. The first is related to the editing action; the software allows direct, even destructive, intervention on the model. So the inexperienced user could compromise the veracity of the copy provided to him, this could happen unintentionally and unconsciously having as a result an incorrect study and investigation of the object. The second, far more significant, is the lack of the software in the users' software setup or a total inability to use it [5]. That being said, we must therefore choose optimization methodologies for the fruition of the data, focused on specific descriptions and already filtered by us practitioners and



a



b



c

Fig. 2 **a** Alignment process in reality capture (*Source* Y. Ricci, A. Pasquali, P. Rodriguez-Navarro). **b** Mesh process in Reality Capture (*Source* Y. Ricci, A. Pasquali, P. Rodriguez-Navarro). **c** Texture process in Reality Capture (*Source* Y. Ricci, A. Pasquali, P. Rodriguez-Navarro)

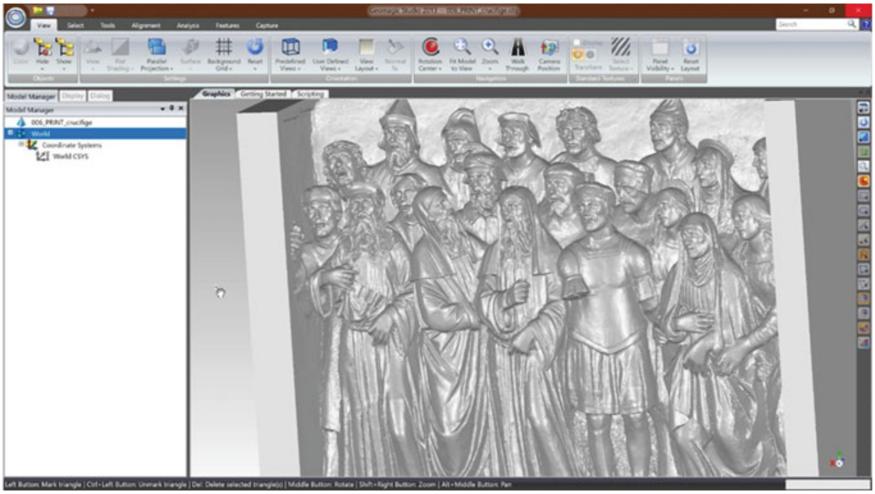


Fig. 3 Mesh optimization for AR content using Geomagic studio (*Source* Y. Ricci, A. Pasquali, P. Rodriguez-Navarro)

scholars in the field, thus providing well-defined messages and scenarios, facilitating their use (Fig. 3).

In the work presented, the restitution of the survey is mainly directed toward the creation of physical copies of the sculptures, transportable then scaled and implemented by Augmented Reality. The latter was strategically chosen to meet two basic requirements in our work, the first being the possibility of responding to physical reproduction with low-cost, single-material PLA digital 3D printing. The second much more relevant, to obtain a mixed digital setup that would allow any additions or modifications where needed, this was not to implement a digital restoration but to create parallel scenarios of use by increasing the experience.

The migration to software dedicated to 3D printing and AR creation was done by exporting the photogrammetry software with .OBJ format and .MTL and .PNG files. Before performing the export, the models were decimated on the photogrammetry software according to the final destination, going to reduce the number of layered polygons required for optimal handling. The reduction was performed in the native platform to minimize the presence of errors in the topology and to exclude or minimize any steps from mesh control and management software, to also reduce excessive control over material mapping as a result of polygon surface corrections.

The models thus exported were processed by two different routes depending on the final destination. The polygonal mesh addressed to printing was loaded into the printer driver, which allowed with dedicated tools (scaling, surface continuity control and elimination of unprintable components, creation of thickness and supports) to prepare the part for printing and execute the process. In parallel, the route to AR involved two exported models. One complete, without any optimization (High Poly model) and another heavily decimated (Low Poly). These were subjected to the

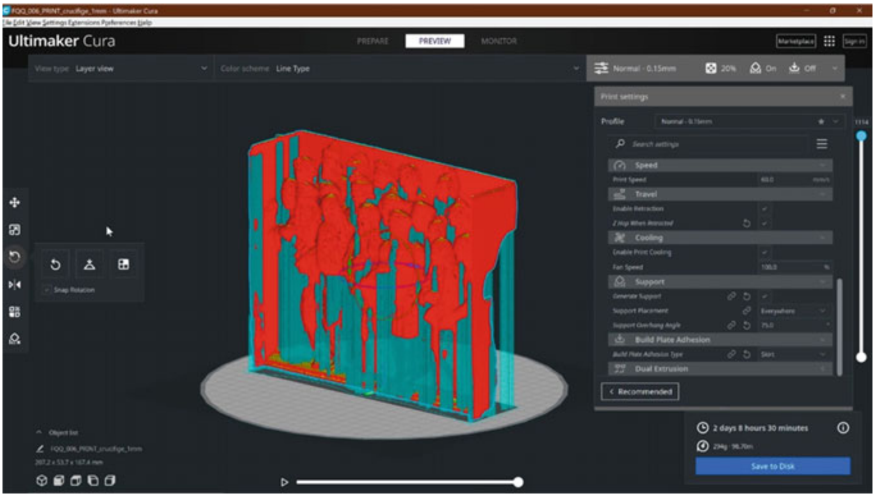


Fig. 4 Model optimization for 3D printing purpose using Ultimaker Cura (*Source* Y. Ricci, A. Pasquali, P. Rodriguez-Navarro)

baking process in order to have a lightened model but with quality implementation mappings (Fig. 4).

9 Machine Learning as a Support Tool for AR-Related Processes

In this case, the use of AR makes the process of popularizing these works easier and more immediate with the possibility of sharing information regarding the existing cultural heritage through tools and methodologies that can be considered as *vade mecum* for future projects. The importance of machine learning becomes heavy when we think about the need to obtain models that are optimized for visualization in AR, a method that in the traditional digital process involves several steps and different software in order to obtain the most appropriate result. Software for creating content in AR requires models that are optimized, with the right number of polygons, topology and mapping of surface such that they do not cause artifacts and bugs during visualization. Normally these steps are performed on software that manages to reduce the number of polygons by not going to affect the quality of the model, then moving on to baking the texture to be applied as a skin to the resulting mesh. The output obtained consists in a .OBJ file with the related .mtl, and the texture file, in .JPG format, lighter than the others. The next step usually is to import the “new model” inside the AR software and create all the assets needed for the creation of the app. The software used in this research are Unity and the Arkit package developed by iOS. Unity gives the opportunity to create contents usable for all the platforms, such as iOS and Android, and it requires less arrangements on the mesh, supporting a heavier model, unlike Arkit, that demands a more precise quality of the output [6]. The point of Arkit, however, lies in its immediacy of use; it is suitable even for beginners in AR content creation, and despite its simplicity of interface and use it allows for content with user interactions, such as accessing information regarding the model, animations, previously made on modeling software, or whether simple translations and rotations, the latter can be directly set up on Arkit. On the other hand, Unity is definitely a more structured software with a set of parameters and assets that allow for a wider panorama of interactions with the 3D model and modifications, since it is the quintessential software for creating applications even in the playground. The simple step of importing the model and planning interactions requires more experience on the part of the user, with multiple inputs being set (Fig. 5).

With the low poly model introduced before, an app is currently being developed, with the purpose to share the element itself, as part of the cultural heritage, and expand it with a series of content regarding the history behind these sculptural groups, even assuming trivia for the user, for greater interaction. The entire area of San Vivaldo is in a musealization phase so that more users can thus be involved, going to attract not only religious people or people interested in the theme, but also young people, tourists and scholars of other subjects, attracted by AR technology applied to these certain elements. All the steps listed above could be done in a faster way relaying on the optimization part to the Artificial intelligence, creating scripts that can create different kinds of optimization settings depending on the software and on the dimension of the output received from the data processing.

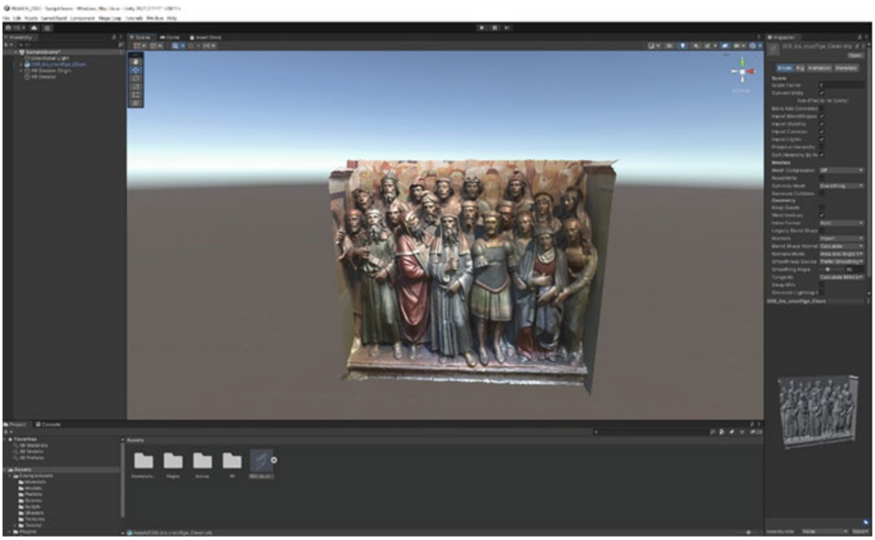


Fig. 5 Model imported in unity (*Source* Y. Ricci, A. Pasquali, P. Rodriguez-Navarro)

10 Conclusions

The ultimate goal of this great work lies in the creation of digitized content dedicated to enjoyment through augmented reality applications and the creation of a physical 3D model for tactile and visual interaction at the study site. As of today, almost everyone, whether scholars or just digital enthusiasts, has cognizance of what this technology is and what it is capable of, thanks precisely to its immense diffusion in the various work and play sectors. Augmented Reality is reality, as perceived sensorially and intellectually by the individual, enriched with data in digital format. In essence, an enhancement of the possibilities provided by the 5 senses and the intellect [7]. It is a technology that leverages mobile device displays and wearable devices to be able to access content and add information to the reality in which the user finds himself, and its applications are almost endless [8]. In the field of Architectural survey, the process of integration of digital techniques and instrumentation is now consolidated. The knowledge and development of computer science has reached a high level and now allows to consider digital techniques as the main applicable solutions, thus fully overcoming the traditional method. The artificial intelligence, instructed on the optimal requirements for the use of the 3D model in the different restitution environments, should be able to apply processes of decimation (in computational software) and organization of the digital product (in save formats for interchange) aimed at producing distinct files, put into system by the researcher to obtain the result of the restitution of the object under study. Observations and evaluations on the processed data and its compatibility with Augmented Reality software and 3D printing drivers constitute a first operational indication to gather useful information for training artificial intelligence [9]. The possibility of evolving automatisms by instructing Artificial Intelligence passes through the framing of the qualitative characteristics of the 3D model under study and restitution. The framing of the model is a function of the restitution tool and its geometric and material nature. By setting standards, a first step towards Artificial Intelligence facilitation in architectural surveying will be possible. Once a dense base of information has been created, Artificial Intelligence will be able to propose optimization and shelf management solutions according to the object under study. The need to expand the information picture of this place so significant for its religious, historical and architectural value can only be met through the use of augmented technologies capable of ensuring an interaction between the visitor and the place itself, supported in the realization of the final output, throughout the process, by machine learning. The work presented proved to be very interesting in demonstrating the application of current restitution techniques to architectural surveying processes. This is intended to highlight the importance of dialogue between devices and technologies not strictly related to the world of architecture with academic studies. The actualization of restitution strategies with digital methods is considered the key to revitalizing cultural heritages. The case of San Vivaldo will be an important model, a site of high cultural importance that has been suffering from tourist neglect in recent decades and now needs to find new channels of dissemination to publicize itself and attract new streams of visitors.

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Neural Networks as an Alternative to Photogrammetry. Using Instant NeRF and Volumetric Rendering

Caterina Palestini, Alessandra Meschini, Maurizio Perticarini, and Alessandro Basso

1 The Revolutionary Introduction of Machine Learning in Computer Vision

In the field of communication, artificial intelligence and machine learning algorithms can be used in many ways to make machine-human interactions more natural, speeding up the technical development of applications that are useful for digitizing real spaces and artifacts and thus can be employed in interesting ways for heritage enhancement. Such extraordinary tools have in recent times revolutionized multiple fields, most often bringing improvements in application workflows and simplifications in creative processes. In a hypothetical construction of a virtual reality serious game, for example, the use of a Natural Language Processing (NLP) algorithm can improve the interaction between the user and the computer-controlled virtual character, making the game's narrative more fluid and natural. On the graphical-visual side, the introduction of the GAN (Generative Adversarial Network) algorithm, on the other hand, can be used in the concept phase to generate realistic and fully artificial images of spaces, objects and human faces, applicable in the design and construction

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of interactive environments for the enhancement of cultural heritage, allowing users to relate to spatiality as realistically as possible, surrogating an experience of exploration, such as that of museums. In addition, the use of machine learning algorithms can improve the adaptability of the game to the user, for example by almost automatically structuring the difficulty level or plot of the game based on the user's actions. In general, the use of artificial intelligence and machine learning technologies can greatly enhance the experience of a virtual reality game for Heritage enhancement [1, 2]. The use of machine learning techniques, used so far as a tool for reinforcement learning, where an agent interacts with an environment to obtain rewards to maximize the amount of rewards obtained over time, can now also be used in the more strictly creative phases in addition to the concept structuring phases of virtual spaces, to create digital models of environments based, however, on real data: this allows for the generation of more faithful and realistic environments based on a multiplicity of complex inputs derived from the real-original model.

In sum, the use of artificial intelligence and machine learning technologies can help create more realistic and immersive Digital Twins that can be used in a high-performance way for heritage enhancement. Thus, in recent years, new artificial intelligence processes have been emerging that have surpassed the generative capabilities of GAN algorithms, which basically work to produce 2d images of nonexistent features. Referring to the many uses of Generative Adversarial Networks (GANs) algorithms, only one study by Professor Fabio Remondino has investigated its use to regenerate 3d data from archival photographic images, but the resulting models are not optimized for defining detailed and complex digital environments. The algorithm in question is called Z-Gan. However, some techniques such as the use of GANs in combination with other machine learning algorithms or traditional 3D modeling techniques could be used to create better-performing environments, at least at the concept stage. In general, the use of artificial intelligence and machine learning technologies is constantly evolving, and new technologies and methods are being developed to generate more realistic and immersive 3D environments. NeRF (Neural Radiance Field) [3–6] is a technology developed by NVIDIA supported by a complex neural network recently optimized through a proprietary code called Instant NeRF, however, which enables the generation of detailed 3D models of physical environments quickly and accurately, using far less photographic data than alternative photogrammetric techniques that do not directly support AI. In the future, it is possible that this technology could be used extensively to generate virtual environments indistinguishable from reality so as to return a higher-performance VR experience. Instant NeRF could be used to generate 3D models of historical buildings, archaeological and tourist sites, to create more realistic and immersive VR explorations for the user. In addition, this technology could be used massively in architecture, surveying, restoration, engineering, training and education, expanding to many other applications to monitor or promote the fragile architectural context in order to preserve it. In general, Instant NeRF, as three-dimensional photogrammetry already does, helps generate detailed and realistic virtual environments that immediately usable in various virtual reality applications, finalized in heritage enhancement, education and entertainment. However, it is important to note that the application of this technology depends on the current state of research and development, and currently there are still some technological limitations. A recent use of NeRF technology, very frequent in the architectural field, is the one made for Indirect Survey applications in image-based 3d acquisition, exploiting machine learning and neural networks for obtaining already mapped and textured, measurable and scalable three-dimensional models, with the useful contribution of some improvements related to application methodology and data management, while lowering the processing times found in canonical photomodeling. Have we therefore reached the beginnings of a fourth digital revolution?

2 How NVIDIA Instant NeRF Works

The research conducted aims to test through some case studies the recent NeRF technique [7–9]. This type of artificial intelligence is able to generate the missing frames of an image-based acquisition (a process similar to photogrammetric but working with the alternative method of homologous points) and configure 3D scenes of environments or objects through the reverse process of volumetric rendering: volume ray merching. Until now, this process used to take a long time to provide discrete results, but today, thanks to new algorithms developed by NVIDIA and the use of current RTX video cards, it can take advantage of drier and more manageable timelines in order to generate high-quality three-dimensional models. The source code development environment is CUDA, using a particular framework called Tiny CUDA.

In summary, the processing procedure is structured in two phases: the first training phase, common to all machine learning procedures, carried out after pointing the software to the image folder is structured as an operation in which the software acquires the data and interprets it; the second phase, on the other hand, is structured as a kind of volumetric rendering of the scene or object represented in the image data by constructing the actual three-dimensional space to scale, which includes the colorimetric and textural factor with the associated refractions and reflections of the light inputs. To explain the operation of this second stage, a distinction must first be made between the two rendering techniques present in the computer vision landscape today: rendering based on the ray tracing algorithm, founded on the calculation of the paths made by light rays and their interaction with surfaces, and the Volume Ray Marching technique—or more commonly called Volume ray casting—based on the computation of 2D images from volumetric data. Thanks to this new rendering model, there are advantages especially in rendering reflective or transparent objects, such as mirrors or glass surfaces. In fact, if we want to draw a parallel with techniques based on photogrammetry, the main limitation of them turns out to be in fact to make use of the Ray tracing algorithm by interpreting light rays to delineate the actual 3d shapes, a technique that is inapplicable in poorly or totally unlit environments, failing to better understand reflective or semi-reflective surfaces. Volumetric rendering, on the other hand, does not generate secondary rays but samples objects through the

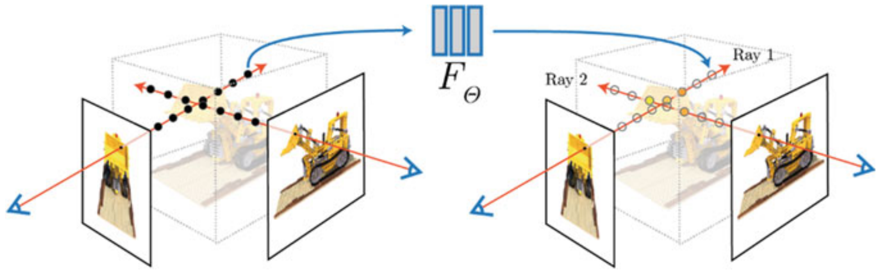

Fig. 1 Nvidia Instant NGP operation scheme (*Source* Mildenhall, B. et al.: NeRF: Representing Scenes as Neural Radiance Fields for View Synthesis)

primary rays that penetrate them, establishing their volumetric properties. What is generated then is not a mesh, but a series of volumes composed of Voxels (volumetric pixels).

As can be seen from the image below (Fig. 1), from each point from which the object is framed, a single ray is generated which identifies a concatenated series of points in space. Volume Ray casting in fact consists of four phases: the first in which the ray is projected through the object, the second phase is the sampling of the points; the third phase is that of shading, in which a transfer function attributes a color to the intercepted material (RGBA) and thus the illuminance gradient is calculated; the fourth phase is that of the composition, that is the union of the information coming from each point determined by each ray.

One of the case studies focuses on the survey of the statue Sfinge e Colomba by Alba Gonzales using NeRF computation. The Roman sculptor—born in Rome and active since 1975, but who, starting from 1978 characterizes her works with shapes of fantastic and mythological inspiration—is known for a style that tends toward the stylization of forms and the 'use of different materials, including bronze. The work, which is located in Piazza Statuto in Pietrasanta, is a bronze statue characterized by the harmony of anthropomorphic forms and shiny, reflective material. The special light conditions encountered during the survey and the particular material characteristics provide an ideal opportunity for experimentation with this new technology. The results are satisfactory, obtained with the latest generation NVIDIA RTX graphics cards, specifically an RTX 3090 and an RTX 4090, the latter with the fourth generation Ada Lovelace tensor cores and DLSS 3 which introduce an AI-based graphics innovation that allows to generate new high-quality frames. In the figure below the first results obtained only after a few seconds of rendering in Instant NGP (Fig. 2).

The main difficulty of the experiment is found during the output phase: being a model generated from a volumetric rendering, it is complex for the software to convert it into a closed mesh, which can be obtained by means of multiple degrees of detail, by going to select the number of polygons from which it should be composed.

In conclusion, it can be said that this innovative method can possibly solve a variety of problems related to ambient light conditions and material reflectance, reducing the time to conceive the actual three-dimensional space compared to the canonical

Fig. 2 Statue Sfinge e Colomba processing of the 3D model with instant NGP (Modelling: A. Basso)

photogrammetric technique. This experimental method is still very immature from the point of view of extrapolation of the data obtained and in relation to the interoperability of formats that can be used on other software. The system, however, has been improving exponentially over the past year, so it is hoped that in the near future it can replace photomodeling as we know it today by soon becoming stable and affordable (Fig. 3).

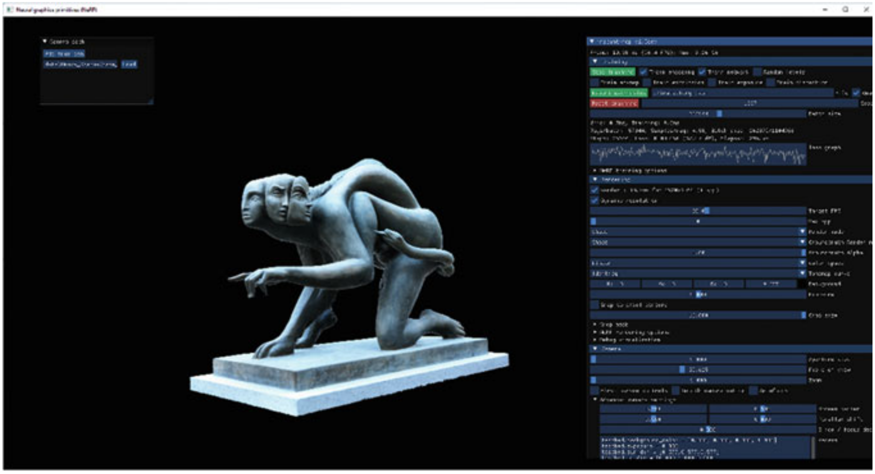

Fig. 3 Result of the elaboration of the model generated by cropped photographs (Modelling: A. Basso)

3 Use of the New NeRF Application Systems: Luma AI

In recent times, NeRF systems have become more widespread, and applications that massively implement their use in image set training methodologies to generate metrically correct and photorealistic three-dimensional scenarios in material rendering are beginning to multiply. The best results have been obtained through the use of two algorithms based on the same code but then developed and enhanced for different purposes: LumaAI, developed by a group of independent researchers also in collaboration with the Berkeley Artificial Intelligence Research Lab and funded by NVIDIA itself (NVentures) along with General Catalyst, Matrix Partners, South Park Commons and Andreas Klinger of RFC., and Nerfstudio, developed by researchers at UC Berkeley. Nerfstudio, between the two image-machine learning methodologies just mentioned, offers many more resources and possibilities of using the algorithm as a real alternative to photomodeling for 3D scanning: although its creators focused on NeRF as a means to synthesize new views of a scene through volumetric rendering, the volumetric representation can be finalized quite completely to the conversion into a 3D mesh, making the export procedure of the voxel mesh simpler and more intuitive, but even more the export of the cloud of dense dots including the colorimetric factor.

In summary, using Nerfstudio, artists can train a neural network using a series of custom images and simply export the generated 3D data to DCC software, either as point clouds in PLY format or textured meshes in OBJ format. The operations therefore allow the complex point clouds to be exported to other platforms in order to be completed and, if the results of meshing are not satisfactory inside the Nerfstudio, transformed in meshes through a different method, for example using the Cloud Compare software which implements the use of the Poisson algorithm for detailed generation of polygonal models from point clouds.

The framework comes with a dedicated add-on for Blender, and the project Web site includes instructions for exporting Nerfstudio models directly to Unreal Engine 5 in NVOL format. This really helps the pipeline within elaborate 3d graphics projects. Nerfstudio provides a simple API that enables a simplified end-to-end process of NeRF creation, training and visualization. The library supports an interpretable implementation of NeRF by modularizing each component. With modular NeRF components, one can access a user-friendly experience in exploring this new technology. Nerfstudio is a collaborator-friendly repository with the goal of creating a community where users can easily build on each other's sharing of results.

The API also comes with many learning resources to help master the methodology on everything NeRF. In addition, one of the new features of the most updated version, 0.1.19, it is possible to include videos and photographs in spherical 360° equirectangular format in the training, making it easier to reconstruct large outdoor and more complex indoor environments. This improvement helps so much with the digitization of architectures by now being able to more easily even from the ground and without using drones, acquire photographic data useful for calculation, making a more correct metric and material survey.

It was intended to experiment with the same case study, related to the digitization of the statue, using one of the two applications just mentioned: Luma Ai. The reason is related to the simplicity of use and installation, mainly structured to be able to start working immediately and be experimented with, acquiring information about its development, taking advantage of the power of cloud servers directly on an Internet platform, or using your smartphone conveniently.

Luma AI Inc., as already mentioned, it is a company composed of a team of engineers and researchers, including both the author of the well-known open-source NeRF projects Neural Scene Flow Fields (an algorithm that enables the acquisition of dynamic scenes) and Instant-NGP, as well as the creator of the two systems DONeRF and AdaNeRF [10–12] that represent the most recent optimizations of the algorithm. Luma AI Inc. provides a web platform in which one can upload photographs or video of the object one wants to represent in 3d, as well as an APP for IOS and Android with which to capture in Real Time the surrounding reality, using the smartphone camera.

The case of the Sfinge e Colomba statue involved uploading the same shots used in the Instant-NGP system within the web platform. After about fifteen minutes—time required for the NeRF training process via server—the web platform allowed access to the integrated viewer, in which a preview of the processed 3d object is shown. As in the App on smartphones, the object is also shown in the web platform in three modes: first in the form of a video, in which a virtual camera performs smooth movement between viewpoints of the shots taken (Fig. 4); second in the form of a 3d viewer of the framed object (Fig. 5); and third in the form of a viewer of the entire 3d scene.

The platform allows (like the smartphone App) to export the result in the GLTF USDZ and OBJ formats (as far as the framed object is concerned) and in the PLY format (as far as the whole scene is concerned). In the illustrated case, the export to OBJ was used and it was immediately noticed the presence of the texture combined with the mtl file; this is a very important detail because in the experiment done with Instant-NGP it was impossible to get the texture export, rather the coloring of the details was transferred only through the vertex color which was subsequently loaded into the open source software Blender 3D, which allowed to verify the conformation of the mesh. In Fig. 6 it can be seen that the object appears very well defined in the shader view mode, and if we change the view mode, we can see that the mesh, although without high detail, does not have serious shape errors (Fig. 7). In Fig. 8, through the select boundary loops command, we highlight the points where the mesh has gaps and therefore holes, but in general we can see that it is a discrete mesh and especially hollow in its interior (it no longer has the volumetric voxel appearance as in the experiment done with Instant-NGP).

In conclusion, it can be said that the system developed and optimized by Luma AI, is much more immediate and cleaner, both from the point of view of mesh conformation and from the point of view of scene noise: in fact, the characteristic fog produced by the Instant-NGP system is completely absent (Fig. 9).

Fig. 4 Outcome of the training in Luma AI (Modelling: A. Basso)

Fig. 5 Processing result in Luma 3D (Modelling: A. Basso)

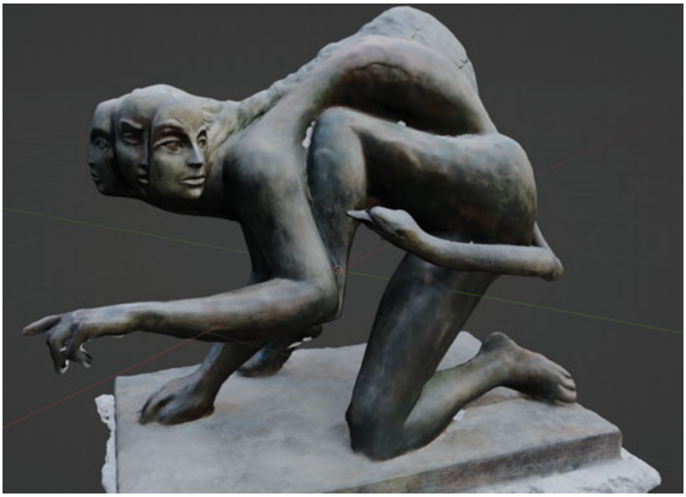

Fig. 6 Result of the Import of the model into the Blender 3D software (*Author* M. Perticarini)

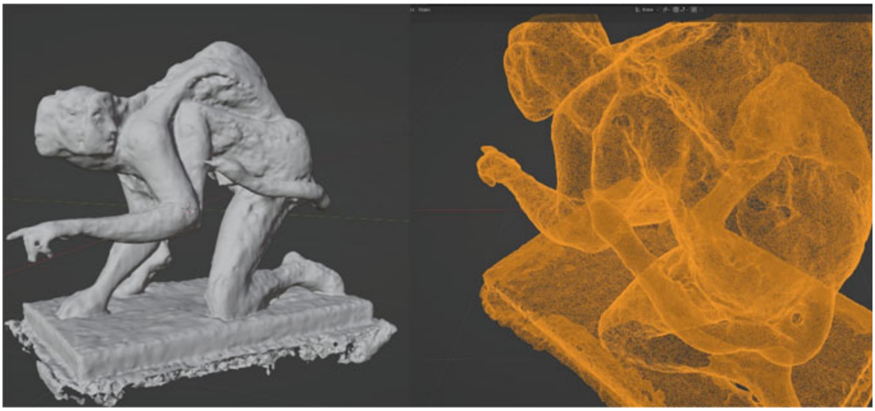

Fig. 7 Detail of the mesh structure and polygon density (*Author* M. Perticarini)

4 Conclusions

Artificial intelligence and machine learning have recently been used to revolutionize many fields, including the enhancement of cultural heritage through the creation of virtual and interactive environments. In particular, the use of technologies such as Generative Adversarial Networks (GANs) in combination with Neural Radiance Fields (NeRF) allows for the generation of realistic images of environments and objects, both in 2D and 3D form, and for the adaptation of interactive environments to the user. These algorithms can be used in the development of immersive VR games

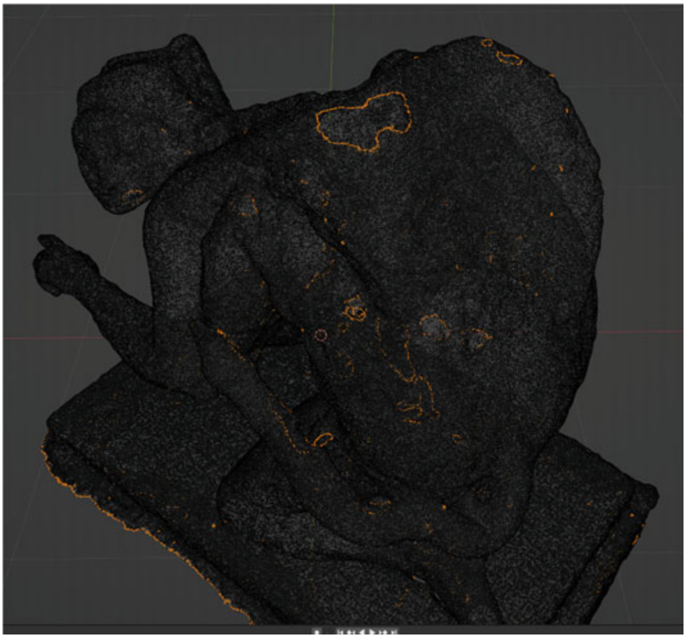

Fig. 8 Highlighting mesh holes with the boundary loops command (*Author* M. Perticarini)

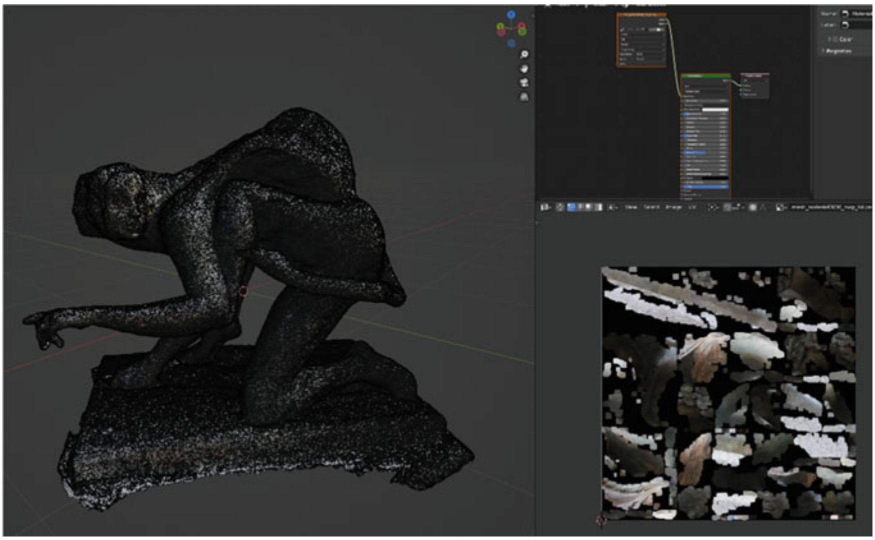

Fig. 9 Texture generated by export from Luma AI (Author: M. Perticarini)

for the enhancement of cultural heritage. In the future, NeRF technology may be used to generate virtual environments indistinguishable from reality.

The use of artificial intelligence and machine learning technologies can improve the interdependence between humans and machines, as well as between humans and historical heritage, constituting an extraordinary tool capable of moving us forward and backward on an evolutionary timeline, looking towards the future of technology while also valuing the past. The potential use of AI technologies for the enhancement of cultural heritage through the Digital Twin, and its use in the VR dimension, is therefore vast and still under development. NVIDIA's NeRF technology, for example, but as mentioned, there are many other competing technologies that develop and are based on the same family of algorithms, can be used to quickly and accurately generate detailed 3D models of physical environments, making it possible to create highly detailed virtual environments.

Although the acquired 3D information can be managed and manipulated based on the intended purposes, it is always important to keep in mind that the data acquisition with these methods captures not only the target objects of interest but also general data related to everything that constitutes the scene, without discretization. Therefore, it is important to consider that the use of these image training-based technologies also entails some ethical challenges, such as concerns for user privacy and data security.

In conclusion, the use of machine learning can be considered the true contemporary alternative to laser scanning and photogrammetry, making acquisition processes leaner and easier to manage, thus giving everyone the opportunity to generate better interactive and immersive virtual experiences for the enhancement of cultural heritage, allowing users to interact with virtual environments and objects in a realistic and engaging manner, leveraging well-structured digital twins.

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A Parallel Between Words and Graphics: The Process of Urban Representation Through Verbal Descriptions, from Historical Painters to the Automatically Generated Images by Artificial Intelligence

Giorgio Verdiani, Pelin Arslan, and Luca Albergoni

1 Introduction

In many frescoes, the presence of a town, landscape, or symbolic cityscape is something rarely casual but refers to the contents of the represented story or has very explicit links to a symbolic value. The presence of these symbols was closely connected to real scenarios mostly on the basis of iconic elements and significant landmarks. In the artworks from the medieval to the renaissance ages, the use of background with cities and landscape is extremely common and often they reflect existing real cities. The representation of these urban elements is mostly guided by common styles and similar matrices. The representation of faraway cities and landscapes is probably based on visual knowledge. Still, it is possible to imagine that it was quite common to use written or oral descriptions of the places. A representation based on written or oral description is obviously directly connected to the patrimony of knowledge of each author and to his/her capacity to transfer the description into a proper and personal graphic code [1]. In our present times, the construction of scenes on the base of words is back in the form of the relationship between humans and machines in the use of AI software for image generation. A solution resulting as spectacular as practical in bringing a large number of users towards the use of these tools (Fig. 1).

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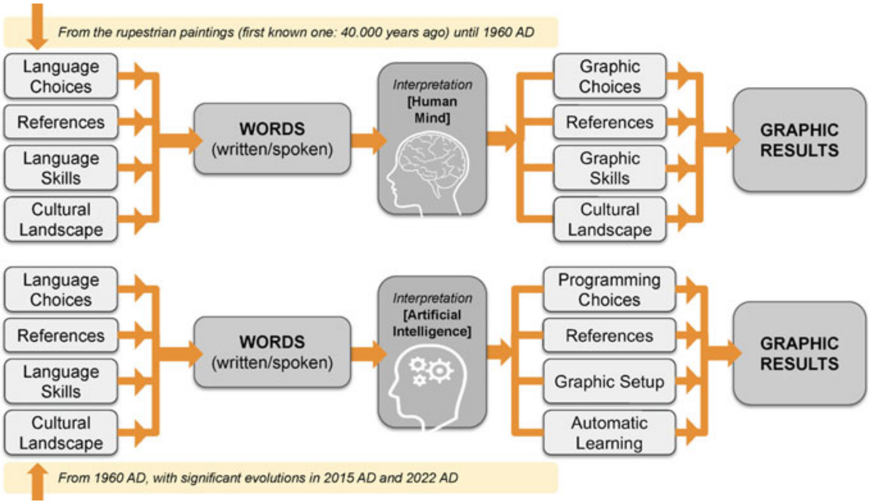

Fig. 1 A parallel representation of the workflow in the creation of an image from words, a human process compared to Artificial Intelligence (*Editing* G. Verdiani, P. Arslan and L. Albergoni)

Establishing a parallel about the transposition of words, or better, indications, to the graphic in different times and through very different process create a match between old authors, present authors, and digital authors, which is then extremely interesting, while a better understanding of the creative process and a better address for emerging technologies may pass even from this articulated reasoning.

2 A Long Tradition of Representation

The representation of towns in Middle Ages artworks varied depending on the artist, the time period, and the purpose of the artwork. Art was typically commissioned by the Church or wealthy patrons, and often served a religious or political purpose. The most common ways that towns were represented in those artworks can be resumed as follow:

Cityscapes, the authors depicted cities in detailed scenarios, showing buildings, streets, and people in their daily lives. Landscapes were another common way that towns were represented in Middle Ages artworks, often these landscapes were used to set the scene for religious or historical events. They might show a town or city in the distance, surrounded by fields, forests, and rivers. Maps were often designed to help travelers navigate their way through a town or region, and included landmarks and buildings. In many cases, towns were represented through religious symbolism. For example, a city might be depicted as a metaphor for heaven, or be the symbol of an event connected to social, political, or religious facts. Allegory was a common technique, in which abstract concepts were represented through symbolic images.

Then, towns might be used to represent concepts like community, civilization, or order. The style of representation of urban scenarios became even more structured in the artworks from the International Gothic style, which emerged in Europe in the late XIVth and early XVth centuries [2]. Recursive common features of these artworks were the presence of well-cured architectural details. Towns and cities were often depicted with intricate and highly stylized buildings. Towns and cities were often depicted as part of a religious narrative, such as the story of the lives of Christ and of the saints. This helped to give a sense of meaning and context to the urban landscapes being depicted. During the International Gothic period, artists began to experiment with the use of perspective to create more realistic depictions of towns and cities. This allowed for more detailed and accurate representations of architectural elements, such as the interplay between buildings and streets. The representation of towns and cities was aimed to emphasize the characteristics and importance of urban centres.

2.1 Three Significant Artworks

Stefano Di Giovanni Di Consolo Detto Sassetta, Città sul Mare (City on the Sea, about 1340), Siena. This work, sometimes considered one of the earlier representations where the image of a town is the main subject, has a complex story of identification. Together with other fragments, it entered the collection of the Art Gallery of Siena in the XIXth century. Its size is quite small: 22.5 × 33.5 cm, realized painting on wood, its provenance before entering the Gallery is unknown (Fig. 2).

The artwork presents the scene of a walled town, the urban settlement is divided into three main sectors, and the separation from nature and the external landscape is clear and well-marked. The walls have gates, and they isolate a castle on the right part of the urban centre. Out of the walls, it is possible to notice a tower, defending the coast. The aspect of city is characterized by tall towers rising over a dense urban pattern. All is in the logic and solid aspect of the Italian towns of that period, with a quite central square on which the church and other buildings face and define the

Fig. 2 On the left the original City on the sea by Sassetta, on the right two AI generated images created using sentences referring to Medieval walled city on the sea, isometric view (*Editing* G. Verdiani, P. Arslan and L. Albergoni)

urban reality of the medieval settlement. The city that appears in this artwork seems not recognizable in reality, it can be considered an exercise of style where the author invented the whole scenario according to ideals of beauty and quality. This small ideal city was long attributed to Ambrogio Lorenzetti, and later to an anonymous author from the early XVth century. Federico Zeri in 1973 [3] hypothesized that it was a part of two landscapes of the great panel of the Polyptych of the Art of Wool (1424). A thesis that has been increasingly confirmed over time [4]. According to this interpretation, the city is no longer an autonomous element, but it can be considered as a background scene in a major scenario.

Spinello Aretino, Salita al Calvario (Ascent to Calvary, end of the XIVth century), Firenze. Spinello Aretino was an Italian painter from the late Gothic period who lived in the XIVth and XVth centuries. One of his notable works is the fresco he painted in the Sacristy of the Basilica of Santa Croce in Florence. The fresco (1385–1387) was commissioned by an uncertain committee and depicts the classic scene of Christ walking to the mount Calvary bearing the wooden cross. This artwork was the object of some critics, while it was pointed out how it looks affected by a construction of the scene that comes out a little tiring, with the separation of the foreground and a too-sharp background, marked by a gathering of vaguely standardized heads that form almost a continuous barrier [5]. Focusing on the cityscape in the background it emerges quite clearly the presence of bold walls, but where Jerusalem looks interpreted to recall the Florentine urban scenario of that time. The presence of a central building with a dome may recall the Florentine Cathedral, even if, at that time, Brunelleschi was far from starting that courtyard. The various towers, the general impression coming from the cityscape, make it realistic to think about a representation gathering elements from the city just outside the building hosting the fresco. The consistent walls, with the large opening in the gate, just underline the sense of exiting the city perimeter for the group moving all around the figure of Christ (Fig. 3).

Pisanello, San Giorgio e la Principessa, this large fresco, depicting a scene just before the battle between St. George and the dragon, is a complex artwork showing

Fig. 3 A parallel representation between the fresco by Spinello Aretino, depicting the Ascent to Calvary and two AI-generated images based on the sentence View on a gate from the outside of the wall of Jerusalem (*Editing* G. Verdiani, P. Arslan and L. Albergoni)

Fig. 4 The Pisanello's fresco St. George and the Princess in the Church of St. Anastasia in Verona, orthographic view (*Editing* G. Verdiani, P. Arslan and L. Albergoni)

the main subject, but also enriched by many other characters, a complex landscape, a robust presence of the cityscape. It was realized between 1432 and 1438, in the Church of St. Anastasia, Verona, Italy [6]. Starting from an exhibition which took place after World War II and especially in recent times, the fresco was often indicated as "St. George and the Princess of Trebisonda" [7], where Trebisonda is the ancient name of the modern Trabzon, Turkey, port city on the Black Sea, which thing seems at the same time weird and intriguing. In the Leggenda Aurea Jacopo Da Varagine fixed the place of the legendary battle in Silene, Cyrenaica (a region of present Libya) and defined also the fundamental elements of the town, the description of the place as some mandatory elements that are needed in any following representation to allow the scenario of the legend to work properly: the fight with the dragon happens out of the city walls, then the city has walls, St. George enters the town from a gate. The sense of division between outside/inside is clearly identified by all the elements of the legend. But the mere aspect of having a walled city is not the main element to support this attribution. In the same period the court of John VIII Palaiologos, Emperor of Trebisonda, was visiting Italy. Pisanello was directly at work for them, realizing a set of portraits on bronze medals (Fig. 4).

This relationship may have suggested the connection between this fresco and Trebisonda, thus no direct indications are supporting this theory. Overall, looking at the artwork, a various number of elements may suggest the parallel: the walls with towers, the castle inside the walls, isolated on a higher hill, the presence of a gate towards the seafront, the presence of a Church over a hill out of the walls (in Trabzon, the present Aghia Sophia Mosque is a reuse of the previous church built on an external hill). Also, the presence of rich and complex buildings inside the walls may suggest something, and it is something that it is not exactly this is Trebisonda but it appears more like this is a town described by an oral narration and transposed in the fresco by the artist. If this really happened at any point during this old and complex story or if it is just a vane suggestion some years before the fall of Trebisonda (1461), it will probably remain an unanswered question.

These three artworks came from different contexts, but all of them are connected by a specific will in representing a cityscape as a fundamental part of the artwork. The starting point and the intentions follow specific approaches, in Sassetta the city is almost represented as a perfect model, an ideal condition based on the state of knowledge about how to build a perfectly functional and safe walled town on the sea. It mixes the rigorous shapes and military logic of the fortress with elements of variation brought by the arbitrary differences of each building, collecting a series of constants and variations that are typical of the Mediterranean settlements. They are just throwing examples out of many but the curiosity about seeing them redrawn in a completely different context to check constants variables in the human and digital approach was the very first start in this research.

3 AI-Generated Images Enter the Scene

Artificial Intelligence procedures for the automatic generation of images and graphics are without any doubt the dancing bear on the stage of the present computer graphic circus. Like this questionable past show, AI-driven automatic image generation is capturing the attention of the public operators and curious, the subject is fully available for building sensational titles. Accordingly to the main lines of this tendency to make the thing just sensational, no one is really interested in the fact if the bear is dancing because it is well instructed, if it is well fed, about which is the quote of casualties in its steps or if the dancing is just caused by some pain in its teeth. All of the attention is on the results of its dancing, and how corresponding is its pace to the music, but the main question is will the bear eat someone before the end of the show? The tamer? The music player? Someone from the public? (Fig. 5).

3.1 Effects on the Creatives' Scenario

The main issue that seems to emerge in the present debate about AI for image generation looks like caused by two different and rarely connected approaches. On one side there is the well-detailed scientific approach: it is accurate, and very technical in the informatics field, but often quite too far from general communication. On the other hand, there is the approach from the Mass media: it is often quite superficial and mostly in search of sensational effects. The debate easily falls into drama tones. It sounds easy to confuse a creative process with an automatic creation, most of the works are presented as generated by AI and not as generated by name of the author using an AI. In this messy debate, the factor pushing the whole thing seems all based on money-making and proposing tools suggesting a solution for making easy money, like the easy production of large amounts of NFT products [8]. During the whole process, the shadow of some Snake Oil seller mechanism looks like a depreciable but well-present entity. Many tones in the debate are extremely similar to those about

Fig. 5 The computer graphic's circus and the AI dancing bear, Midjourney generated image (*Editing* G. Verdiani, P. Arslan and L. Albergoni)

is photography an art? In the passing between XIXth and XXth centuries. Extreme cases, like the one connected to the recently deceased Korean cartoonist Kim Jung Gi. An admirer thought to honor him with a series of drawings generated by an AI trained in his works, who recreated the painstaking style of his drawings. The very good results caused a strong online debate on various social media about how appropriate and correct was this act [9].

3.2 Main Solutions on the Market

The scenario of the AI solution for image generation is continuously in rapid change and evolution [10]. Tracing a detailed map of all the available offers is quite difficult and subject to constant changes, here following a shortlist of twelve of the (probably) best promising AI for image generation that appeared as well promising at the moment of the writing of this paper. Each of them is accompanied by a short text illustrating the main features and costs.

Artbreeder https://www.artbreeder.com—Free to try, various payment plans, it works only online as a web page. Pros: Free use option, generation by graphic steps and with control on variables, direct visual control on results, the possibility for creating video sequence. Cons: low quality in free mode, no text input.

CrAIyon https://www.craiyon.com/—Free, online only. One of the earlier solution available for experiencing AI image generation. Previously named DALL-E. It is the base development of DALL-E2. Pros: Fully freeware, interesting results from simple sentences, nine variations for each sentence. Cons: low quality, the generated images have low resolution, square-only frame.

DALL-E 2 https://labs.openai.com/—Both free and payment (based on the use of tokens, one token equal to one image generation process). Pros: Speed, quality, easy to use, personal gallery, easy process on existing images. Cons: Oriented to square images, no upscaling.

Dream Art https://smartwidgetlabs.com/—Both free and paid (with various plans). Pros: easy to use and with various templates. Cons: no editing of the frame ratio, limited free access, the sentence is limited to 100 keystrokes, the results tend to be mainly pictorial with strong abstract effects, invasive ads during the use, available in smartphone APP version only.

Dreamfusion https://dreamfusion3d.github.io/—Text-to-3D, the project is under development, very interesting in the perspective of having 3D components directly generated. Not yet available to the large public.

GauGAN2 http://imaginaire.cc/gaugan2/—NVIDIA image-from-sketch generator. Dedicated to the generation of landscapes (without animals or people). Pros: free, online, easy to access. It is possible to use different input styles. Images, sketches, or segmentation maps can also be uploaded. Cons: needs tutorial and tentative to fully understand capabilities. Limited to square images. The outputs are limited to low resolution images.

GauGAN 360 (beta) http://imaginaire.cc/gaugan360/—Owned by NVIDIA. Free to use. Simpler than its 2D counterpart (GauGAN2). Pros: creates 360° views from sketch inputs. Quick computational time. Cons: Lack of perspective. Results are often random. No possibility of visualizing 360 images directly from the. Limited inputs.

Images.ai https://images.ai/—Considered one of the best AI image generator solutions in early 2023. Pros: Freeware, fast, instant access for non-registered users. Cons: Low resolution of the resulting images, limited variety of frame size.

Midjourney https://www.midjourney.com/home/—Payment (10$ monthly for 150 images, 35$ month unlimited). Pros: High quality, collaborative environment, image upscaling option, variable frame geometry, speed, impressive results. Cons: the collaborative environment may turn out to be quite chaotic, the command line and Discord environment may be a little odd for some users, and some words are forbidden. In Discord the management of the produced images may be messy (thus using the personal gallery solves this aspect).

NightCafé https://nightcafe.studio/—Considered one of the best AI image generators in early 2023. It allows both free and paid (starting from about 5$ per month) uses. It develops images on the basis of different AI engines (Stable Diffusion, Dall-E2). Pros: Fast, options for free use, many editable settings, cheap paid plans, option for upscaling the resulting images to high resolution, good quality of the results. Cons: Upscaling at high quality may look more interpolated than computed). Limited length of the sentence.

Photoleap AI Art https://www.photoleapapp.com/—Fully free for seven days, mostly free in the following period, based on smartphone APP (IOS and Android). Pros: high speed, no limit in text length, various templates/styles available, efficient and with good quality results. Cons: watermark on images, limited resolution, with long texts the templates seem not to be working any longer, no gallery or history for the produced works.

Shutterstock https://www.shutterstock.com/it/generate—The obvious integration in one of the most diffuse stock image services. Free (with various limitations) and paid (included in the Shutterstock plans). Pros: fast with good quality, accepts multiple languages, localized interface. Cons: Limited free function, large watermark, and low resolution on free images.

Skybox Blockadelabs https://skybox.blockadelabs.com/—The first AI dedicated to the creation of VR panorama environment, in alpha version at the moment of the writing. Pros: Unique features, templates, speed, completely free. Cons: reasonable but not high resolution, some random behaviors.

StarryAI https://www.starryai.com/—Both free and paid (image generation based on credits, a small amount freely available and with various options for free increments and for buying them). Pros: Various fixed styles available and with the option for summing them, efficient in creating interesting results, good speed, online and APP versions. Cons: no editing of the frame ratio, the sentence is limited to 300 keystrokes.

Wombo Dream https://www.wombo.art/—Both free and payment. Pros: Fixed styles, some very efficient in creating interesting results, good speed, easy process on existing images, online and APP versions. Cons: the AI generates four variations, but then randomly chooses one to complete, the sentence is limited to 100 keystrokes.

Wonder AI https://play.google.com/store/apps/details?id=com.codeway.wonder&gl=IT—Both free and payment. Pros: High quality, interesting results, good speed, lifetime license. Cons: Android APP only, limited resolution, 9:16 frame only.

4 The Experiment (Human Side)

A special test was conducted with a group of architecture students and graphic designers to see what happens when a city is represented only by an oral description. The main subject of the test was decided using Pisanello's fresco, and fully focusing on the image of the city. In this experiment, the test began by asking for a sketch (using any preferred tool) of the city as described here following:

Imagine a historic city, of ancient construction, settled on the coast of a sea, on which it overlooks, the city is a bridge between West and East, surrounded by walls with towers, it has a sheltered harbor on the sea, in a bay where the water is lower, it is the destination of ships that arrive with travelers and merchants who undertake long journeys with their goods. The walls face the port and have access to it. The plan of the city stretches from the sea, towards the inland where hills and mountains rise up. Within the walls, buildings and palaces, churches and markets, streets, squares and people, in the innermost part, towards the hills, a castle concludes the urban structure. Outside the city, fields and hills full of lush greenery and clearings and paths along the coast and an external church with a bell tower on a small hill.

The test took place in a series of sessions: in 2021 in Florence, at the Department of Architecture, University of Florence, there were 78 students taking part, in the following tests, taken in parallel at the Department of Architecture in Florence, and at the Faculty of Architecture at the Beykent University in Istanbul, the groups were about 80 and 70 respectively. They all got around four hours to do the drawing. The participants' ages ranged from 19 to 24. Nine people were chosen from each test who had the finest graphics. Five graphics experts were then commissioned to produce a drawing based on the same description (Figs. 6, 7, 8 and 9).

The participants in none of the tests were given any information about Trebisonda or any other mention of Pisanello's masterpiece; they were only given the written description. The results show how iconic references and individual approaches can influence the translation of words into images. In any case, the graphic project shows every detail mentioned in the text, including the harbour, the towered walls, the church jutting out of the walls, etc. The description always matches what is displayed. While also being obvious that a description of a distant town quickly devolves into an amazing reference to a spectacular landscape, legends require legendary locations. The patrimony of things seen may serve as inspiration, but the rules and choices of the graphic ultimately determine how everything is displayed. A mental process that has most likely not changed in nearly six centuries (Fig. 10).

Fig. 6 Best results from the test session 1, September 2021 (*Editing* G. Verdiani, P. Arslan and L. Albergoni)

Fig. 7 Best results from the test session 2, University of Florence, September 2022 (*Editing* G. Verdiani, P. Arslan and L. Albergoni)

Fig. 8 Best results from the test session 2, Beykent University, Istanbul, September 2022 (*Editing* G. Verdiani, P. Arslan and L. Albergoni)

Fig. 9 The expert drawings (*Editing* G. Ferrara on the left and L. Albergoni on the right)

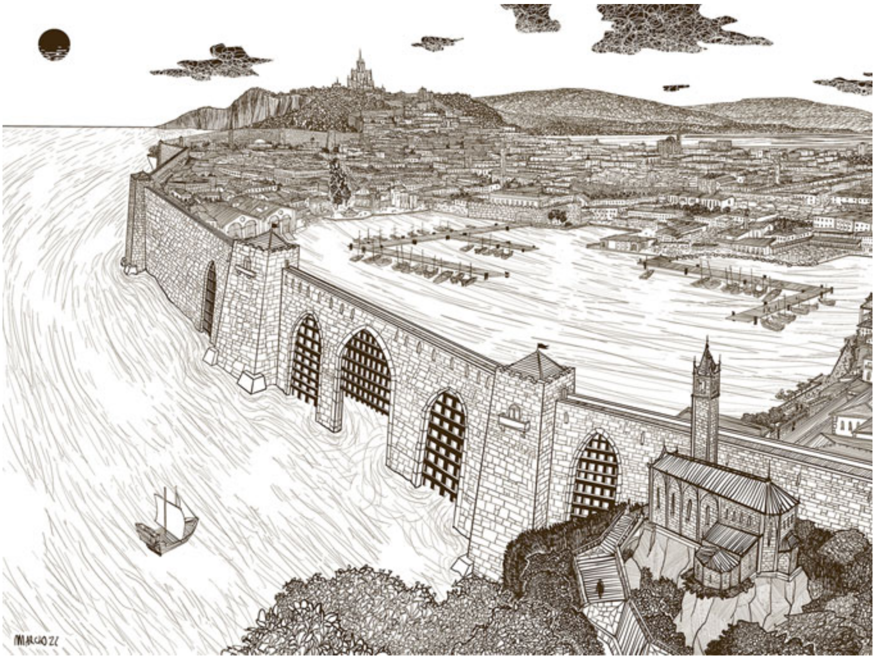

Fig. 10 The expert drawing (*Editing* M. Fabri)

Fig. 11 Very first results in the submission of the sentence describing Trebisonda to the Midjourney, May 2022 (*Editing* G. Verdiani, P. Arslan and L. Albergoni)

After the gathering of the tests developed with students and creative experts, the main evident aspect was clearly the direct relationship between the personal graphic style of each participant and his/her ability in connecting their own patrimony of knowledge about representation and architecture to the request of creating a view of the described city. The possibility of understanding the value of various words in the sentence and the following graphic creation was all bearing on the articulation of memory and skills of each author.

A clear influence comes from personal choices, with the presence of preferences towards certain parts of the sentence that obviously were stimulating in different ways the attention of the authors, producing variations in the focus, in the choice of the viewpoint and in the level of details and in the end, in the final results (Fig. 11).

5 The Experiment (AI Side)

The following step was to test the same sentence in AI. The test was conducted using various AI software with a main focus on Midjourney, Dall-E2, StarryAI and Midnight Coffee. The results from the direct use of the sentence were extremely interesting since the beginning, and they were extremely changed because of the evolution of AI all along the duration of this research. It was then decided to test a series of variations to check their influence in the final images. To allow a more rational approach to the variation in the sentence a specific grid was developed to define a table capable of unmounting the main sentence in all its significant parts. On the base of this grid, it was then possible to define all the variables, balancing the sentence to different results. While the number of possible combinations at that point was very large it was then decided to develop a simple software solution using Microsoft Access to allow the automatic mixing of the sentence following the various possible variable and then generating always complete sentences suitable for the AI use. In between the numerous results, here are presented the most impressive ones.

None of them is close to the image of the present Trabzon, nor they are close to the fresco of Pisanello, as well as the representation produced by students and by graphic experts. One possible alternative in the approach to the image generation was obviously to address the results loading and using the images from the towns in these and other artworks to obtain very similar results in graphics and style, but these would result in a mimic process that was looking too much copycat and less interesting in front of getting very different results that are, in the end, a different reply to a similar starting point (Figs. 12 and 13).

Without links or connections to the real artwork, the procedures go straight to the concept of the representation of the cityscape, using specific and contemporary references, a way to produce content that opens towards a better understanding of the present and not only one more possible weird clue over an interpretation that cannot reach a completely trustable result after so many times. The variety of results simply underlines how the invention, artificial or human, when starting from a completely

Fig. 12 Results in the submission of the sentence describing the city in the Pisanello's fresco to the Midjourney including the presence of the fight with the dragon (*Editing* G. Verdiani, P. Arslan and L. Albergoni)

Opening of the sentence	Primary Architectural aspects	Primary Urban aspects	Primary Landscape aspects	Secondary Architectural aspects	Secondary Urban aspects	Secondary Landscape aspects	Style 1	Style 2	Age of the artwork	Effects 1	Effects 2	Effects 3	GEOMETRY (Midjourney)
Cityscape of a [variable],	With Walls	Dense urban tissue	On the cliffs along the sea	With Walls	Dense urban tissue	On the cliffs along the sea	In the style of fresco	In the style of fresco	Renaissance artwork	Thick lines	Thick lines	Thick lines	EMPTY (Square)
An ancient [variable],	With Towers	Harbour at the entrance of the town	In front of the sea	With Towers	Harbour at the entrance of the town	In front of the sea	In the style of Leonardo Da Vinci	In the style of Leonardo Da Vinci	International Gothic artwork	High details	High details	High details	--ar 16:9
Cityscape of a an ancient [variable] on the waterfront,	With a Castle inside the walls	In front of the sea	Surrounded by hills	With a Castle inside the walls	In front of the sea	Surrounded by hills	In the style of Michelangelo Buonarroti	In the style of Michelangelo Buonarroti	Medieval artwork	Photorealistic	Photorealistic	Photorealistic	--ar 4:3
Cityscape of a walled [variable], along the sea,	Building with mixed styles, roman and medieval	On the coast along the sea	One church on a hill out of the city walls	Building with mixed styles, roman and medieval	On the coast along the sea	One church on a hill out of the city walls	In the style of Giorgio Vasari	In the style of Giorgio Vasari	Gothic artwork	Painted on plaster	Painted on plaster	Painted on plaster	--ar 9:16
Cityscape of a an ancient walled [variable], along the sea,	With tall Walls	Narrow streets and dense urban pattern	Out of the walls there are hills with trees and meadows	With tall Walls	Narrow streets and dense urban pattern	Out of the walls there are hills with trees and meadows	In the style of a map	In the style of a map	Mural painting artwork	Painted on canvas	Painted on canvas	Painted on canvas	--ar 3:4
Panoramic view of the waterfront of an ancient [variable],	With tall Towers	Out of the walls there is a harbour	Out of the walls there are stones and woods	With tall Towers	Out of the walls there is a harbour	Out of the walls there are stones and woods	In the style of a mural painting	In the style of a mural painting	Fresco artwork	Legendary subject	Legendary subject	Legendary subject	--ar 1:2
Panoramic view of a medieval [variable], settled on a sea waterfront,	With a large Castle inside the walls	Layered [variable] with roman buildings and medieval architectures	The sea in front of the [variable], is in a large, closed bay	With a large Castle inside the walls	Layered [variable] with roman buildings and medieval architectures	The sea in front of the [variable], is in a large, closed bay	In the style of a drawing	In the style of a drawing	Christian myth artwork	Cracked paint	Cracked paint	Cracked paint	--ar 2:1
Panoramic view of an ancient maritime walled [variable],	With a Castle inside the walls, on a hillock	Layered [variable] with roman origins and medieval buildings	The sea is surrounded by coasts, with far away [variables],	With a Castle inside the walls, on a hillock	Layered [variable] with roman origins and medieval buildings	The sea is surrounded by coasts, with far away [variables],	In the style of gothic painters	In the style of gothic painters	In the style of the 14th century	High level of details	High level of details	High level of details	--ar 3:1
Cityscape of historical maritime [variable],	With tall Walls reinforced with towers	It is a Fortified town	Out of the walls there is a crowd of people,	With tall Walls reinforced with towers	It is a Fortified town	Out of the walls there is a crowd of people,	In the style of international gothic painters	In the style of international gothic painters	Dark age artwork	Intense colours	Intense colours	Intense colours	--ar 1:3
Cityscape of a medieval maritime walled [variable],	With rich buildings and churches	Out of the walls there are no building	Out of the walls there is a crowd of people, a dragon and Saint George fighting the dragon,	With rich buildings and churches	Out of the walls there are no building	Out of the walls there is a crowd of people, a dragon and Saint George fighting the dragon,	In the style of the middle age	In the style of the middle age	Mythical artwork	Ancient drawing	Ancient drawing	Ancient drawing	--ar 6:7
Cityscape of a waterfront from a medieval [variable],	Medieval buildings	Buildings are very close one another	Out of the walls there are animals, a dragon, knights, and soldiers,	Medieval buildings	Buildings are very close one another	Out of the walls there are animals, a dragon, knights, and soldiers,	In the style of a humanistic artwork	In the style of a humanistic artwork	Christian artwork	Flat perspective	Flat perspective	Flat perspective	--ar 7:6
The whole view of a walled ancient [variable],	Architectures with mixed features	Urban pattern similar to a labyrinth	Out of the walls there are woods, stones, animals and one dragon	Architectures with mixed features	Urban pattern similar to a labyrinth	Out of the walls there are woods, stones, animals and one dragon	In the style of a classical artwork	In the style of a classical artwork	Saints and Prophets artwork	Orthographic view	Orthographic view	Orthographic view	--ar 210:297
The whole view of a maritime walled ancient [variable],	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	--ar 297:210

Fig. 13 The sentence describing the city in Pisanello's fresco, structured in a table (*Editing* G. Verdiani, P. Arslan and L. Albergoni)

different media, like a sentence, always moves towards an original product while the mix of variables is so extended to make it almost impossible to have the same or even similar result twice (Figs. 14 and 15).

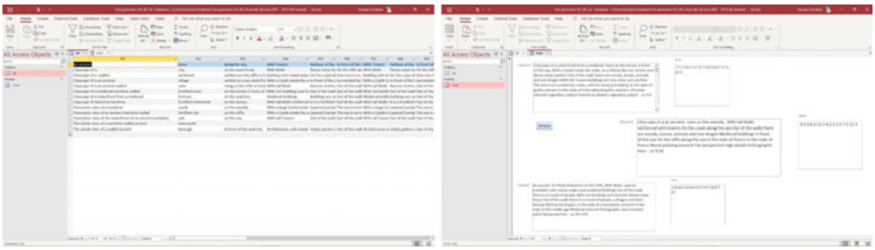

Fig. 14 The Microsoft Access solution for mixing the variables in the sentence describing the city in Pisanello's fresco and creating new variations (*Editing* G. Verdiani, P. Arslan and L. Albergoni)

Fig. 15 Two results coming from the sentence describing the city imagined in Pisanello's fresco, both generated in Midjourney (*Editing* G. Verdiani, P. Arslan and L. Albergoni)

Fig. 16 Same sentence, different frame layout ratios: very different results (*Editing* G. Verdiani, P. Arslan and L. Albergoni)

6 Conclusions

This large experiment leaves various open topics but also allows bringing back at least five lessons learned along the way in the use of AI for image generation applied to architecture and cityscape contexts. Some are very direct ad practical, some others have a wide range of possible situations according to each AI solution [11], but all can be of some help to any newbies facing the AI image generation process.

6.1 Lesson Learned: One, the Aspect Ratio Influences the Results

It may seem naive, but changing from square to horizontal or vertical rectangles and varying the ratio in height/width of the frame directly influence the result, creating strong variation in the general layout and contents of the resulting images. This goes clearly towards an easier way of solving the final result in the most efficient way, thus, all the AI software allowing a variation in the frame ratio may produce extremely different results starting from the same description. This cannot be considered a positive or negative aspect, but simply a factor to keep in mind while creating this kind of graphic, maybe the desired result is simply hiding in a different frame ratio (Fig. 16).

6.2 Lesson Learned: Two, the AI System Widely Benefits from a Particular Stimulation on the Human Perception

Image generation, no matter the complexity or completion of the description at the base of its creation, is clearly the object of some kind of pareidolia. This well-known and popular tendency brings the observer to perceive a specific, often significant

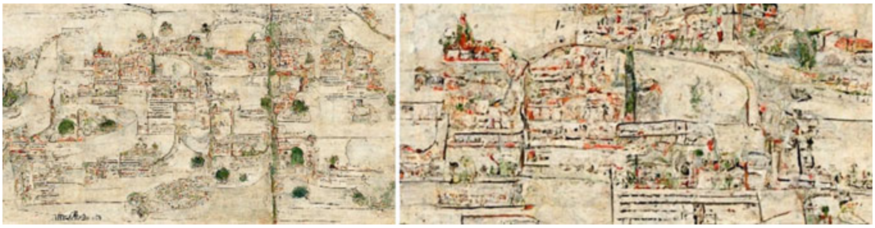

Fig. 17 An evident Pareidolia effect: it looks like an old map, but it is not a map, nor it is old, it is just something graphically similar to an old map generated using Midjourney AI (*Editing* G. Verdiani, P. Arslan and L. Albergoni)

image from a random or ambiguous visual pattern. For example, it may happen to see dragons, ships, faces, in the shape of clouds, stones, in a texture generated by casual events, in a series of elements placed one near the other (Fig. 17).

This effect applies also to those who write the sentence to generate graphics, the mind is waiting for a result and the operator will be looking at the results trying to recognize the expected elements. So, any minimal correspondence between expected results and the resulting image is easily identified as well as fitting the request, the user may even re-direct his/her expectations and find new potentials in the final results, for the simple reason that the creation of the image removes uncertainty and offers a clear and defined solution.

6.3 Lesson Learned: Three, the Process May Focus on Certain Texts and May Neglect Others

Some words are stronger than others, and for sure the most used and common words inside an AI procedure may return the most evident effect, but no matter the accuracy of the sentence or its detailed descriptive choices, the AI software will often brutally ignore some part of the sentence, returning in apparently random mode only some parts or giving from minimal to no importance to other. This may be caused to some redundant contents of the phrase or by some parts that result not that compliant with each other, thus, when the AI starts to generate results far from expectations, the best choice is rarely a small series of corrections, better reconsider completely the whole sentence and focus well to the main priorities and made these parts more incisive and clearly expressed.

6.4 Lesson Learned: Four, the Process Tends to Excel on Mainstream Subjects

There is no doubt about this when the requests are very numerous on certain subjects, the AI produces the best quality results. Science Fiction or Fantasy characters or scenarios, complex characters referring to existing actors, movies, or comics, will emerge with the satisfaction of the users. In subjects like architecture, cultural heritage and arts, the results may be more difficult in satisfying the users, not only for some limits in graphic quality but mostly because of the gap between a purely graphic process (where once more it is the pareidolia effect influencing the evaluation of the results) and a creation of representation that have a fully coordinated architectural or urban element behind. The thing does not mean that in the future AI software will be unable to generate a full architecture and take out a view of it, but at the moment these well-popular solutions just generate graphical views that are just mimic a concept design, and that is graphically impressive and maybe even produce some inspirational values, but is a kind of representation of the cities in the background of the frescos that a complete expression of cultural concepts.

6.5 Lesson Learned: Five, Short Sentences = Surprise, Is It All by Chance?

Funny, but true, one of the most amusing and productive ways to use AI for image generation is the creation of graphics from short, occasional, casually inspired sentences [12], in this case, the mind of the user is expecting nothing else than some surprise, and when it arrives, it's all satisfaction and pleasant sight. No doubt that the play between expectations and the potential of the AI here works at its best.

The present research is then still ongoing, the extended experiment conducted from Pisanello's fresco showed potentiality and possible retesting evolutions. The next possible challenge will be the instructing of an AI for city representation in old paints and frescos, especially from medieval, gothic, and international gothic authors, pushing the results towards graphic rules more and more similar to those coming from the originals. This step considered non-productive in the first part of this research is now worth to be explored, to see how it can evolve in the final results. In the while, there is no doubt about how such research may benefit from more extended functions on AI generative process, like the direct production of complete 3D models, something on the way, but yet far from being really useful for end users like the architects are. So, these subjects for now will keep on waiting for an appropriate 3D shape generation solution, sooner or later it will arrive. A similar situation may be identified for the generation of VR panorama images, this solution looks now just at the beginning but will be soon more practical for generic users, with this kind of graphic directly moving towards the creation of virtual reality environments (Fig. 18).

Fig. 18 Simple sentences: great surprise, view generated in Midjourney AI (*Editing* G. Verdiani, P. Arslan and L. Albergoni)

AI systems probably are not an attack or a replacement for creativity, at least not when creativity has quality standards and rules and needs of a robust knowledge background. It is more a robust attack to stock image services and a specific contribution to creating more original content in these uses. The original, weird, freaky, and sensational events are just an inevitable part of this step. The intelligent uses of AI for image generation may help in better understanding certain creative processing, creating an inspirational opportunity usable by almost any user. The next years are well promising in terms of user-oriented solutions and software integration, it will be extremely interesting to come back on this same presentation in the turn of one year from now.

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A Blockchain-Based Solution to Chain (Im)Material Art

Marinella Arena, Gianluca Lax, and Antonia Russo

1 Analogon

Data management, in the last twenty years, has been delegated to the digital system. The apparent neutrality of the medium made us think that the transition would have been painless and that it would not have affected the cornerstones of our society. But the medium, as Mc Luhan reminds us, is never neutral with respect to the message [1]. The potential of the medium has facilitated the birth of real parallel worlds, analogous to reality and profoundly different: persuasive and inviting in some situations; dystopian and repulsive in others.

The digital new worlds are configured as an analogon of reality. While maintaining some aspects of reality, some logical plots, some forms of likelihood, they produce infinite variations in a combinatorial game that leads to the threshold of infinity.

In the new worlds we witness the reconfiguration of space, the subversion of the laws of physics and genetics. New animal and plant species arrive on our screens ferried by a modern and incorporeal Noah's ark: the virtual image.

The representation of these worlds invests us with all its dialectical power which is then a link between the real and the digital. A thin layer, a film, which contains boundless worlds inside a computer screen that emerge from time to time and manifest themselves only partially.

The links between reality and cyberspace are all the closer the similar the language of the medium is. Art in the age of its technical reproducibility has experimented

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with new forms of expression, elaborating a progressive distance between form and content as underlined on several occasions by scholars of the caliber of Baudrillard [2] and Lévy [3].

2 Dissolution of the Concept of Art

It is useful to briefly retrace the focal steps that led to the dematerialization of analog art, paving the way for digital art.

In fact, until the invention of photography, works of art were irreproducible, the dissemination and knowledge of the work took place through copies, more or less successful, by disciples or schools attributable to the artist himself. The fame of a work, and the prestige of its author, grew slowly fed by the word of mouth of a few followers: the judgment was rarely entrusted to the non-initiates.

Art was therefore an exclusive phenomenon to be enjoyed in defined places, with precise times and with a liturgy that consecrated its value. The reproducibility of the work, on the one hand, has expanded the catchment area and made the fruition of art democratic but, on the other hand, the fruition, outside expressly designated places such as museums, has undermined its sacredness downgrading art to a visual phenomenon.

In contemporary works of art, the theme of reproducibility changes radically. Many scholars have analyzed the phenomenon by referring to the reflections of Benjamin and McLuhan, emphasizing the power of the medium. Baudrillard [4] comes to theorize, with impressive foresight, that in the contemporary era the simulacrum of simulation defines hyperreality: the real object is no longer necessary, its simulation is sufficient.

In this regard, the work by Rauschenberg created in 1953 is emblematic: Robert Rauschenberg Erased de Kooning Drawing (Fig. 1). The artist asked de Kooning for a drawing and then destroyed it. The final work represents the time and energy spent by Rauschenberg to cancel the original project. The simulacrum is the real work. The work of art is dematerialized precisely in conjunction with the first documented digital art experiments that date back to the 50's with Laposky's work Electronic Abstractions displayed at Sanford Museum in Cherokee, Iowa (Fig. 2).

3 The Aesthetics of Value

Furthermore, since the 1990s, art is no longer a simple trophy for aristocrats and oligarchs but is transformed into a new category of investment. In this case, the medium reaches a further level of abstraction: it is no longer linked to the visualization of the work but to the manipulation of its monetary value: the medium generates value.

In recent years, society has developed the ability to reproduce every aspect of reality through IT procedures. Artificial intelligence is able to represent something

Fig. 1 Robert Rauschenberg Erased de Kooning Drawing 1953 (*Source* © Robert Rauschenberg Foundation)

Fig. 2 Ben F. Laposky, Oscillon 40, 1952 (*Source* © Victoria and Albert Museum, London/Sanford Museum)

Fig. 3 Girl with Balloon Banksy 2002. The painting destroyed, by the author, after the sale at Sotheby's in 2018 (*Source* abc NEWS, M. Osborne)

that still does not exist, to create a man's face, including wrinkles and imperfections, to complete the n.10 unfinished symphony of Beethoven, or to paint a picture in the manner of van Gogh.

Does it still make sense to talk about reality in the digital age? It is real only what is material and tangible? Or only what comes directly from it? Our society prompts us to reflect on the increasingly jagged boundaries of this issue.

Baudrillard argues that we are witnessing the precession of simulacra. In other words, we are at a juncture in which simulation no longer imitates reality but literally creates it through representation (Fig. 3).

The translation of some aspects of real life into the immaterial world of simulacra and virtuality is a fact. The phenomenon involves the very young with increasingly sophisticated and transversal video games and a niche in society with products that are halfway between experimentation and speculation such as Decentraland and SandBox.

The virtual world, analogous to reality, recreates both spatial configurations (paths, buildings, landscapes) as well as social and economic ones. Thus, virtual currencies are developed in cyberspace for new, incorporeal, objects of desire: from traditional high-fashion clothes of the most exclusive brands, to digital terrains with a strategic location up to collections of kittens, CryptoKitties, to raise and look after.

The virtual objects of desire leverage the notion of uniqueness and possession, effectively generating a contradiction in terms between infinite reproducibility and authenticity, between possession and immateriality, between multiplicity and uniqueness.

The virtual world indefinitely amplifies and multiplies some aspects of its real analog, apparently without consuming resources. But in order to sustain itself, the virtual needs to rework an aesthetic of value, to define precise areas in which to regiment the magmatic flow of its products.

Is the virtual work of art, designed and created exclusively in the digital environment, still unique, exclusive, original?

This research tries to address the controversial and complex theme with two different but complementary approaches. On the one hand, we have tried to analyze the changed needs of communication and reproduction of contemporary art or rather the sense of art in the era of virtual images, on the other hand, we have carried out an experiment to verify, and experience, the potential of Digital as a tool to enhance digital art but also analogical one.

4 The Galaxy of NFTs

Immateriality, and the contemporary need for visibility, have generated the need for new IT tools in digital art for the definition of possession and uniqueness. The procedure that identifies the creation of a Non-Fungible Token (NFT) in fact replaces the art expert and all the documents that accompany a work and certify its history, possession, and even its value in some cases.

Our research aims to investigate the potential of digital art through a dual approach. On the one hand, the approach seeks to reconstruct the virtual galaxy to which these digital works belong, and on the other hand, experiments with techniques for the ad hoc definition of NFTs without relying on standard and widely used platforms. Through experimentation, we analyze the strengths and weaknesses of using blockchain and quantify the time and cost of building a custom NFT solution through a low-level implementation. The ultimate goal of our research is to offer a synthetic reference framework that highlights the specificities of digital art and the new dissemination and qualification tools.

But let us take a step back: what are NFTs? Tokens are defined as fungible if they are equal to each other and are easily replaceable with an asset with similar characteristics on the market. Unlike fungible goods, non-fungible goods have the characteristic of being unique, non-replaceable, non-repeatable, and non-divisible. Among the non-fungible assets, we can include paintings, musical events, car sales contracts, and in general, goods or services with unique and unrepeatable qualities: since there is only one original, that asset has a distinctive property that does not allow an exchange with something similar. An NFT is a digital certificate based on blockchain technology that can be bought and sold online using various currencies.

One of the main features of NFTs relates to indivisibility: possession requires the purchase of the entire asset. While it is not possible to split an NFT into multiple tokens, it is easier to represent an asset in the form of multiple NFTs. A striking case of a digital asset based on an analogical work of art is the one created by the Belvedere Museum in Vienna. On Valentine's Day 2022, the museum sold 10,000 NFTs which represent as many small pieces, scanned at very high resolution, of Gustav Klimt's Kiss, making a collection of 3.2 million euros.

The value of NFTs largely comes from their uniqueness. For example, it is not possible to trade NFTs that represent two different works of art. Uniqueness is one of the prominent NFT attributes that establish its value. Ownership of NFTs is considered to be similar to the ownership of a collectible antique or vintage work of art.

Finally, the most important feature of NFTs is that of authenticity. NFTs provide a representation of real-world assets and it is important to have authentic NFTs.

Marketplaces are real digital museums where it is possible to get in touch with cyber art: to observe it but also to do business. Crypto.com, Coinbase, OpenSea All Art, are the digital places of exchange (Fig. 4): they have an architecture that defines the location of the works and a commercial structure that regulates their functioning.

The graphic design, the elaboration of the virtual space, and the logical structure of the marketplaces, today, are not the reflection of the profound renewal that the digital world promises. The phenomenon of the digital art market is still evolving. Associated products are often graphics, gifs, or portions of virtual worlds. The vaunted uniqueness of NFTs, in the form of digital art, seems to sink into the vastness of the offers. Some characters are created in automatic, almost combinatorial ways, generating unique but depersonalized versions. Other successful examples are very

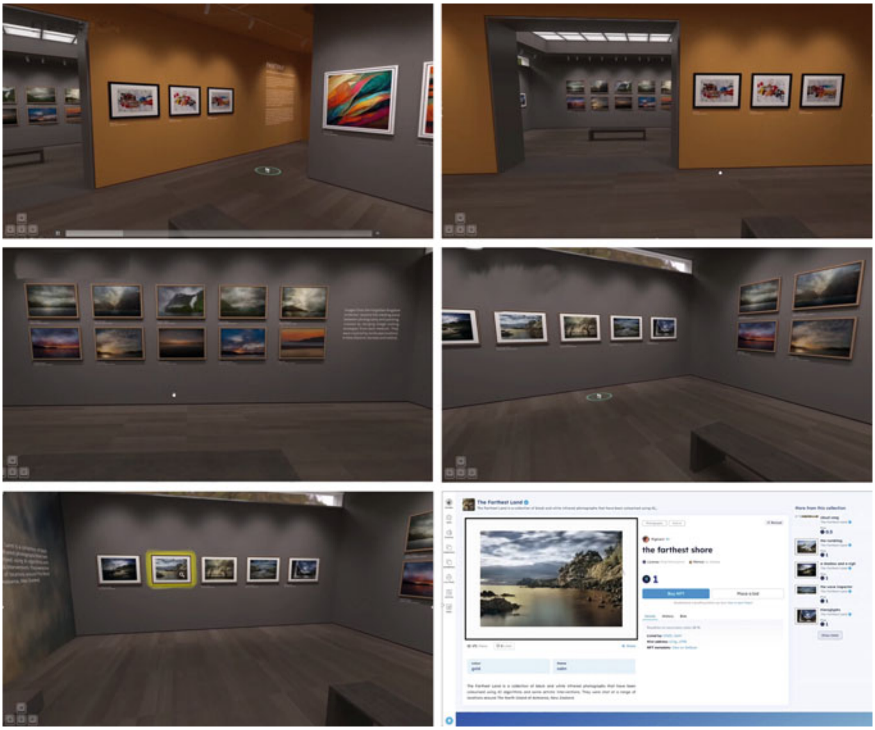

Fig. 4 Purchase simulation on the ALL Art marketplace (*Source* ALL.ART)

Fig. 5 Everydays: The First 5000 Days, Beeple (*Source* English Wikipedia)

popular such as the Bored Ape and a bit like the meme phenomenon feeds itself by generating new versions and increasing the previous value. Other NFTs have had a worldwide echo, such as Everydays: The First 5000 Days (Fig. 5), a 21,069 × 21,069-pixel collage of Beeple's first five thousand daily works. The work was auctioned by Christie's for $69.3 million.

5 Technical Details

In this section, we introduce Blockchain, a disruptive technology that impacted and impacts various sectors of the digital economy.

Blockchain technology was proposed by Nakamoto [5] and is known as Bitcoin. A blockchain can be considered a distributed ledger that produces and stores digital transactions from blockchain users to blockchain users. Each user is identified by an address. From the technical point of view, each transaction is saved in a block and stores the transaction recipients, the transaction value, and a digital signature used to prove the authenticity and integrity of the transaction. The digital signature is generated by public-key cryptography, and the user's address is derived from the public key. Moreover, each block of transactions is linked to the previous block by storing the result of a cryptographic hash function calculated over the whole previous block.

A consensus algorithm is adopted to guarantee that every transaction is confirmed and validated by blockchain participants. The obtained chain of blocks is used in such a way that any (even little) change in a transaction of a block would require updating the hashes stored in all the subsequent blocks. This is the reason why blockchain provides the properties of immutability and accountability.

A Blockchain can be permissionless or permissioned [6]. In the first case, we deal with a public blockchain, which can be read and written by everyone. This type of blockchain is widely used in financial markets and provides also the properties of transparency and pseudo-anonymity.

In the second case (i.e., permissioned), we deal with a private blockchain, which is mainly used in closed contexts by one or more private entities, which control who can read or write transactions and access blocks. When more organizations manage the distributed ledger, we refer to consortium blockchain.

The introduction of the second generation of blockchain, said Blockchain 2.0, has added the possibility to use smart contracts, which are code scripts distributed over the blockchain and executed by various nodes. By a smart contract, predetermined actions (e.g., sending a transaction) are performed whenever some conditions occur. Both actions and conditions are defined by a specific programming language, and Solidity [7] is the most used one. Solidity is a high-level object-oriented language that allows the development of applications distributed over the blockchain [8].

Blockchain technology can be used for cryptocurrencies, and the name of the currency usually comes from the name of the blockchain. The first and most known example is Bitcoin, which refers to both a cryptocurrency and the underlying blockchain. Bitcoin was designed to exploit peer-to-peer technology to trade without any bank or central authority. By transactions, bitcoins are issued and stored collectively by the network. Bitcoin uses open-source code and anyone can run its code to take part in the project. In January 2023, one bitcoin is about 20k euros.

The second most common blockchain is Ethereum. It is a Blockchain 2.0 and the related cryptocurrency is called Ether. Ethereum is another open-source project launched in 2016 whose aim is not limited to cryptocurrency but includes a decentralized platform for the creation and publishing of smart contracts created in a Turing-complete programming language. These contracts can be used to support a large number of tasks such as voting systems, crowdfunding platforms, object tracking, and copyright protection. In January 2023, one Ether is about 1,5k euros.

A common characteristic of cryptocurrencies is that they rely on a digital token, defined as digital information saved on a distributed ledger and associated with a specific user of the ledger to guarantee some form of right. For example, tokens are typically used to access a service or prove the ownership of assets.

Non-fungible tokens introduced in the previous section are a type of digital token. They are commonly used for works of art. For example, the buyer of a painting can link the purchase to a non-fungible token to store into a blockchain her/his ownership.

In general, a digital version of a work of art (e.g., a picture) is stored together with the personal data of the owner and through a smart contract this link can be proved.

The owner of a work of art can prove her/his rights without the need to contact any intermediary party and without time limits as long as the blockchain storing the NFT is active. Also, the owner can sell the NFT to another person and the smart contract will update the information about the owner of the work. In this way, the

NFT keeps track of sales internally and it is possible to trace the changes of hands up to its creator.

For this purpose, several standards for NFTs have been developed and the two commonly used for creating NFTs are ERC-721 and ERC-1155. The former enables the possibility to determine whether copies exist, who owns a token, and information including creation date, creator's address, the price paid for each time it was sold, and all the transfers already made.

The ERC-1155 standard allows for non-unique digital assets; thus, it enables the possibility of having numerous copies of the same NFT, and these copies may have multiple owners.

One of the main differences between the two standards is that ERC-721 allows the transfer from one wallet to another wallet for one token at a time, whereas ERC-1155 allows for the massive transfer of tokens in a single transaction.

From a practical point of view, to generate an NFT it is necessary to carry out the transaction necessary to store on the blockchain the information associating the work of art with the owner.

Nowadays, this service is provided for a fee by several providers. If we consider the case of Open Sea, one of the most used providers, the Ethereum network is used. To generate the digital work, one of its images or videos is used which represents the reference to the work. For reasons related to the blockchain, this reference must have limited space (up to a hundred megabytes).

After paying a certain amount of money, the platform stores the transaction on Ethereum and the owner can use the NFT to state her/his ownership. Furthermore, the user can resell the NFT at a fixed price or in an auction, awarding it to the highest bidder. Once a subject has offered the requested price or has won the auction, she/he will be will receive the NFT, and a proof of this purchase is stored in the blockchain to prove the fact that the purchase comes from the legitimate author or the previous owner of the work.

It is worth noting that the price of this service depends on the used platform but, in general, is very high with respect to the actual cost of the transactions. For studying this aspect, in the next section, we will discuss and design a smart contract for claiming ownership of a work of art and will compare the cost.

6 Proposed Solution

In this section, we design a minimal yet effective solution to prove the ownership of a work of art. Our solution is implemented by an Ethereum smart contract, and we will show that the solution cost is very cheap.

The smart contract has been implemented by Remix—Solidity IDE [9] connected with Metamask [10], an extension for accessing Ethereum-enabled distributed applications from the browser. The implemented smart contract has been built on Goerli, a net widely used to test Ethereum solutions [11].

The smart contract used to prove the ownership of a work of art is shown in Fig. 6. It is called Artwork and is implemented in Solidity: the source code is compiled into bytecode and executed on a virtual machine (EVM).

It exploits a mapping (Line 6) to associate the id of a work of art with the owner. Specifically, the id could be the hash of a picture (for example, computed by the Ethereum's cryptographic hash function Keccak-256) or a QRCode shown near the work of art, whereas, for the owner, the Ethereum address returned. With an additional mapping, it is possible also to store any other personal information of the owner (as done in [12])—for the sake of simplicity, we omitted to do it. Observe that the digital resource of the work of art (e.g., its picture or video) could be stored by InterPlanetary File System (IPFS), a distributed system for storing and accessing files: several IPFS service providers are offering some gigabytes of space for free.

```
1   //"SPDX-License-Identifier: UNLICENSED"
2   pragma solidity ^0.8.6;
3
4   contract Artwork {
5      //from a work of art to the owner
6      mapping (string => address) artworkOwner;
7
8      //for event log
9      event Modify (address owner, string art);
10     event Purchase (address owner, string art);
11
12     function purchaseArtwork (string memory artwork, address Aowner) private {
           artworkOwner[artwork]= Aowner;
13         emit Purchase (Aowner, artwork);
14     }
15
16     //return the owner
17     function discoverArtworkOwner (string memory qrCode) public view
18     returns(address owner){
           return artworkOwner[qrCode];
19     }
20
21     //change the owner
22     function modifyArtworkOwner (string memory artwork_to_modify, address
23     new_owner) public returns (bool success) {
           //only the owner can sell
24         if (artworkOwner [artwork_to_modify] == msg.sender){
25             artworkOwner[artwork_to_modify]= new_owner;
26             emit Modify (new_owner, artwork_to_modify);
27             return true;
28         }
29     }
30  }
31
```

Fig. 6 Sketch of the smart contract (*Editing* G. Lax and A. Russo)

The smart contract includes also two events (Lines 9 and 10) that are used to store the changes in the ownership of any work of art. Any user can:

(1) Claim the ownership of something by calling the function purchaseArtwork, which includes this event in the blockchain.
(2) Verify who is the owner of a work of art by calling the function discoverArtworkOwner.

Moreover, only the owner of a work of art (see the check at Line 25) can sell or donate it to another user by calling the function modifyArtworkOwner.

In order to test and study this smart contract, we used Etherscan [13], a Block Explorer and Analytics Platform for Ethereum, where it is possible finding all the Ethereum transactions. After calling a function of the smart contract, the transaction is sent to the blockchain and, after about 10 s, it is visible on Etherscan. Etherscan shows also the events emitted by the functions.

This implementation allowed us to study the cost of running our solution. In particular, we obtained that the smart contract deployment costs 0.0010621 Ether, which is about 1.65$ in January 2023. Claiming the purchase of one work of art costs 0.0001205 Ether (about 0.19$), whereas modifying the owner of a work costs 0.0000798 Ether (about 0.12$). Note that calling the function to know the owner of a work of art is for free because no change to the blockchain occurs.

In conclusion, the analysis shows that it is not necessary to exploit commercial platforms to manage the ownership of a work of art and the development of the blockchain technology allows anyone to build an ad-hoc solution customized to personal needs. Moreover, we showed that a simple yet effective solution can be implemented with a very limited budget.

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Point Cloud Data Semantization for Parametric Scan-to-HBIM Modeling Procedures

Anna Dell'Amico, Anna Sanseverino, and Stefano Albertario

1 Introduction

The configuration of a digital model shows its usefulness as it reaches a communicative level that is no longer influenced by cultural constraints; still, it evolves into a universally shared system of conveying culture. Digital culture has always served the purpose of representing state of the art. Architecture fits into the digital medium by carrying theoretically unlimited possibilities for the contemporary design and conservation process.

On the one hand, digitization is simulation and scenario; on the other hand, digital architecture is used as a preliminary and decision-making step as to how to actually proceed to design, or rather execute, while applying to modeling the technological criteria related to the environmental and conservation sustainability of the building [1]. The benefits of using computational tools and algorithms are evident in many aspects of iconic contemporary design, such as the generation of new architectural forms, fabrication methods, performance optimization, and artifact management. Simulation presents an equal-versus-different dichotomy; these ideas have common conceptual (and semantic) denominators processes of simplifications that tend to distance the form of the real object from the modeled object [2].

On one side, the trend is to increasingly rely on artificial intelligence systems as thinking and digital representation systems, shifting expertise to AI intelligence to minimize time consumption. For another, it is not yet possible to fully entrust

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such systems; even though they are progressing rapidly with new algorithms that are increasingly high-performing, they still need interpretation and verification for the design to be considered reliable.

The present research experiments with a modeling protocol from survey data to develop a semantically aware architectural model [3]. Through a process of critical analysis, a digital information model has been developed according to the following steps: Metric data acquisition; Point cloud data analysis and interpretation; Modelling system development; Point cloud segmentation actions to isolate elements subject to ad hoc modeling, simplification, and cataloging; Modelling process analysis; Information model generation; Thought-searching and analysis via critical knowledge analysis processes.

These issues impose a reflection on the topic of the architectural representation techniques: namely, the transition from aided representation, i.e., CAD, to parametric 3D modeling determines the transition from representation through geometric primitives (points, lines, polygons, etc.) to the development of responsive model components, i.e., families, inquired and configured, both geometrically and informatively, within the intricate network of relationships existing between the ensemble of components and the building system [4]. Nevertheless, as always occurs in the design process, the need to discretize a priori the object in fieri, by establishing the level of detail for information conveying does not disappear [2].

In the context of the representation of the built environment, rapid technological development has resulted in increasing accessibility of technologies supporting data acquisition, modeling, and exchange processes. However, the existing built heritage is characterized, mainly if historical, by architectural elements defined by complex geometry such that the processes of surveying, interpretation of the surveyed data, and 3D representation are peculiar when compared with the design of new construction [5].

Therefore, the set of specifics of built architecture seems to hinder the possibility of identifying unambiguous protocols for the application of technologies concerning the information modeling methodology. Indeed, the characteristics peculiar to the existing built environment, such as the typological and morphological variety of building elements, mandate the implementation of modeling processes structured on a case-by-case basis in order to be suitable for the intervention project on the existing heritage [6]. Several factors influence modeling procedures' decisions regarding the project's sustainability, i.e., expertise in parametric geometry design, time and cost of model development, limitations and opportunities for model implementation over time, and target requirements [7].

Historic Building Information Modelling (HBIM), therefore, is assigned the task of fostering research in the area of integrating digital data acquisition and modeling technologies for the development of libraries of parametric objects characterized by complex geometric shapes and free forms not yet contained in the libraries made available by commercial software. Nevertheless, a universally shared standardized ontology able to convert BIM data into a semantic format has not been developed yet [8].

2 Methodology for the Setting up of a Hierarchical Database of Historic Building Object Models

When compared to new buildings, existing assets require the acquisition of additional information for a correct assessment of their current state, i.e., historical information, degradation or deformation analysis [10]; to this purpose, HBIM methodologies are considered the most well-performing for historical architecture management. Indeed, HBIM models provide accurate morphological features and represent a suitable database where each architectural object includes all information with a hierarchical structure [8].

Ideally, the whole data set coming from a three-dimensional survey is indispensable for the so-called Scan-to-BIM modeling of built heritage; anyhow, it is rarely possible to use the complete raw information. Recent applications of Artificial Intelligence (AI) for the semantic subdivision of 3D point clouds go in the direction of speeding up architecture's analysis, maintenance operations, and conservation plans, leading to a semantically enriched hierarchy that can be preparatory to successive applications such as the reconstruction phase of 3D models [11, 12]. The subsequent step is the classification of segmented point clouds to serve as a basis for the characterization and the accurate interpretation of the asset under study by identifying distinguishing features [13].

In the HBIM field, it is essential to declare the purpose and the workflow adopted to make the infographic modeling implementable and reusable, defining the advantages and the limits concerning the efforts needed and the expected use of the model. Indeed, the digital reconstruction of complex shapes is a challenging task; therefore, once having obtained the point cloud and identified the single elements and their mutual relationships, the modeler can either decide to build an in-place family directly environment, create build components that can be reused in other projects or import 3D objects created in another software package [14].

For said reasons, the methodology hereby proposed focuses on the setting up of a database of parametrized and adaptive Historic Building Object Models (HBOM) [9]. Starting from an accurate three-dimensional integrated survey, each element was cataloged through a unique identifier encoded according to a tree structure aiming to define an accurate taxonomic description [15]. Furthermore, setting up unique relationships between segmented portions of point clouds and BIM objects within a hierarchical framework is aimed at future experimentation of automated modeling procedures concerning the assignment of HBOM objects to similar architectural assets, subsequently fitted by simply modifying the parameter values.

2.1 Integrated Three-Dimensional Survey

An accurate three-dimensional survey is the mandatory first step within a Scan-to-HBIM workflow in the field of Cultural Heritage so as to capture even the finest detail defining the historical value of the object of study [16]. Having in mind detailed modeling of the architectural elements that usually comprise historic buildings is therefore mandatory for carefully planning integrated survey campaigns. LiDAR and Photogrammetric techniques have specific strengths and limitations; thus, selecting one or more tools is subordinated to the objectives and to the required level of accuracy (LOA—According to the United States Institute of Building Documentation, the LOA is organized in a five-level schema, ranging from LOA 10 to LOA 50 for the measurement comparison to be considered acceptable [17]) and detail (the LOD definitions, intended to classify the level of complexity of a BIM model, range from a LOD 100 to 500, according to the American Institute of Architects [18], and A to G in the Italian regulations [19]) [20–22]. Considering the challenges presented in managing heterogeneous point clouds, the current literature is constantly formulating methods and defining criteria to obtain an optimized survey database. Applications vary from point cloud segmentation [11, 20, 23] to noise reduction [24] and feature recognition [15, 25].

At an architectural scale, Terrestrial Laser Scanning (TLS) is often the first option due to its high quality and speed, making it ideal for acquiring complex geometries. On the other hand, Simultaneous Localization and Mapping instruments (SLAM) instruments prove to be even faster and more capable of registering intricated spaces, possibly under emergency conditions, when lesser detailed outputs are required. Furthermore, these technologies include reliable georeferencing systems that facilitate integrating aerial-photogrammetric data in a post-processing stage [26]. Namely, photogrammetric acquisitions—both close-range and employing Unmanned Aerial Vehicles (UAV)—are the best option when aiming at an optimized graphic and colorimetric detail, i.e., in terms of texture, and to fill the gaps in the laser point cloud, occurring in those areas unreachable from the ground, like the top of the roofs [27].

Therefore, to bridge the gap from a discreet model (point cloud) to a semantic-aware catalog composed of smart objects, a thorough analysis of the existing element has been carried out, leading to a manual segmentation of the point cloud areas identified for each component. For the proper generation of an ontology, it is mandatory to set up an unambiguous reference system characterized by a shared vocabulary of terminologies. Thus, an accurate taxonomic description was organized a priori and implemented in the BOM modeling stage [8].

2.2 HBIM Modeling of the Cataloged Architectural Components

HBIM modeling and the setting up of a semantic classification system is, first of all, a cognitive process in which typological and morphological variants and invariants are to be recognized [28], breaking the layered built asset into its elemental components.

Scan-to-HBIM is a reverse-engineering procedure that employs a survey database as the basis for the parametric modeling of existing assets. When working with the

Autodesk software package, the suggested pipeline starts by importing the integrated point clouds into an Autodesk Recap Pro Environment for their segmentation in homogeneous regions to facilitate the subsequent BIM modeling stage within Autodesk Revit [29].

A synthesis step then followed the propaedeutic analysis and cataloging stage. A Revit category and a family typology were assigned to the discretized subcomponents according to their structural nature. Global vs. Local, Parametric vs. Non-Parametric, and Geometric vs. Information are the practical scenario available, not to exclude hybrid solutions [14]. Namely, although encoded under the reference tree structure, walls, and floors were modeled locally as system families, while for the other structural and decorative elements ad hoc loadable parametric families were designed, resorting to in-place modeling for just a few peculiar urban objects.

The general objective was to develop a customized and customizable three-dimensional abacus of architectural elements reusable for other reconstructive models. Indeed, flexible objects allow for the generation of a database of smart objects that can also be used in historical architecture by implementing the most widely used BIM authoring software and enabling the adoption of HBIM modeling procedures [28].

The portions of the point cloud previously selected were later imported into a three-dimensional CAD environment for a first definition of the generative geometries. The in-this-way-identified profiles were imported into the BIM editor environment for the parametrization and the reconstruction of the 3D geometries. Furthermore, we also developed adaptive parametric components to fit the as-built geometry better.

3 The Fraccaro University Residence

The focus of the work now presented is on the generation of survey databases and parametric modeling preparatory to the generation of a digital duplicate of the monumental complex of the Fraccaro University Residence in Pavia. The systematization of information through an ordered hierarchical structure will eventually provide the reuse of the models created for automatic modeling experiments. For this purpose, we developed an HBIM model that would be configured as an informative, geometrically reliable, and implementable digital database capable of producing multiple outputs. From the in-depth knowledge of the architectural artifact and its documentation, a model is generated to support the management and enhancement of the historical heritage.

Located in the historic center of the Italian city of Pavia, the Fraccaro University Residence is situated on the University's main campus and is designated for humanistic subjects (Fig. 1). The complex consists of five levels around two main inner courtyards and a minor one. The basement is reserved for cellars, recreation room, and gymnasium; the ground floor is allocated to common rooms, study rooms, library, and cafeteria; the upper floors are reserved for rooms, kitchens, and student services (Fig. 2).

Fig. 1 Overview of the Fraccaro University Residence (Editing: A. Dell'Amico, A. Sanseverino, and S. Albertario)

In the early nineteenth century, the *insula* of the Roman *Ticinum* on which the Fraccaro complex today is located was donated by wealthy Pavia families to San Matteo Hospital.

The pre-existing buildings were demolished in 1818 to build the new Medicine and Surgery wing, between 1843 and 1871. The spatial organization echoes that of the structure of San Matteo Hospital. The two arcaded courtyards of the complex are aligned with the fifteenth-century hospital, just as the western façade almost mirrors the eastern façade of San Matteo designed by Leopoldo Pollack in 1787 [30]. In 1932 the entire hospital was moved to its new location on Via Golgi, and the complex was turned into the School for Student Officers of the Engineer Completion. Then, during World War II, the building was occupied by German troops first, to later serve as a shelter for evacuees.

Between 1951 and 1957, the structure of the former San Matteo Hospital was acquired by the Rector of the University of Pavia Plinio Fraccaro, who decided to

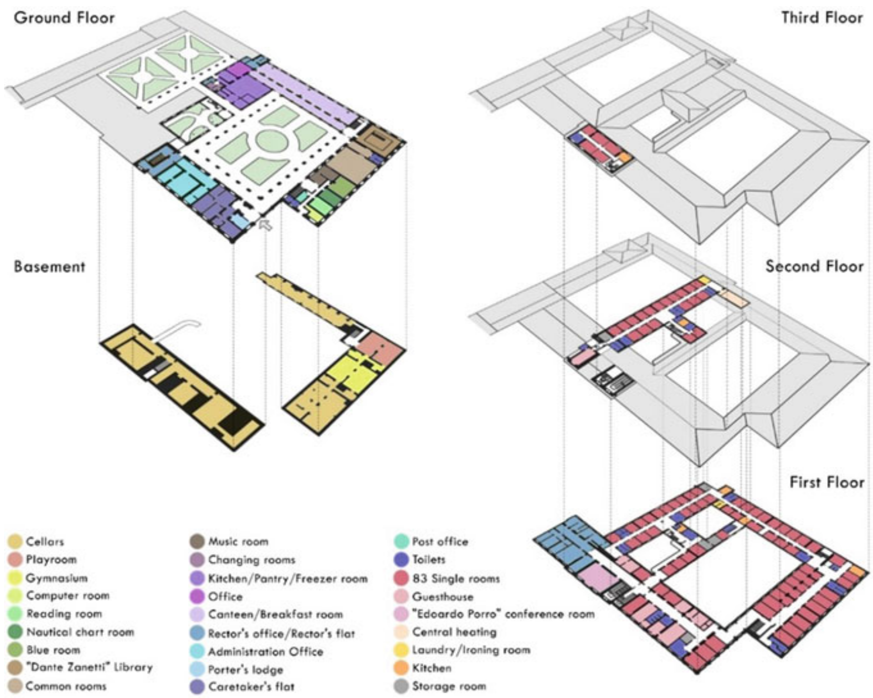

Fig. 2 Functional destination of Fraccaro's interiors (Editing: A. Dell'Amico, A. Sanseverino, and S. Albertario)

allocate the 19th-century part of it to the realization of a new university residence. Refurbishment works included: the opening of the walkway through the Cortile Teresiano and the receding of the entire front on Via Defendente Sacchi, thereby freeing the towers that had been embedded in the building. The official inauguration took place in 1963, and in 2004 it became part of EDISU (Ente Regionale per il Diritto allo Studio Universitario della regione Lombardia).

4 Results

The procedural workflow was developed in three consecutive stages of shared working listed as follows (Fig. 3).

- 3D digital survey. The first phase involved the integrated architectural survey campaign carried out through the use of 3D photogrammetry and laser scanning techniques and the collection of the acquired data into a digital database.

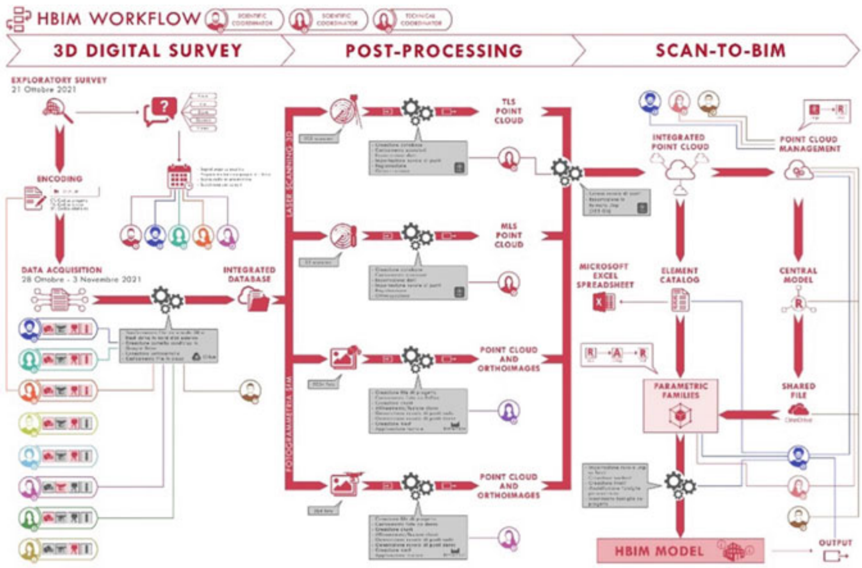

Fig. 3 Schema of the shared HBIM workflow organization (Editing: A. Dell'Amico, A. Sanseverino, and S. Albertario)

- Post-processing. The second phase focused on processing the data collected as a result of the survey campaign, i.e., the post-processing process that led to the merging of the different point clouds into a single cloud representing the surveyed artifact.
- Scan-to-HBIM. The third and final phase involved the application of the Scan-to-HBIM methodology, i.e., the construction of the HBIM model from the point cloud, by designing the parametric elements that constitute it.

4.1 Integrated 3D Digital Survey

Further to the exploratory survey on October 21, 2021, we decided to employ the photogrammetric technique and the terrestrial laser scanner to survey the exteriors, the hand-held laser scanner for the interiors such as classrooms, rooms, and hallways, while for the more complex and dark environments, such as the cellars and the attic, it was, afterward, decided to use the terrestrial laser scanner one more time, so as to obtain a denser and more detailed point cloud. After categorizing the areas through a priori-defined hierarchical coding, it was possible to carry out data acquisition organized as listed below.

Close-Range photogrammetry

Photographic data acquisition was carried out with a dual purpose: to perform Structure from Motion (SfM) photogrammetry of the elevations and to obtain comprehensive documentation for the digital photo archive [27]. Three Canon EOS 2000D reflex cameras were used for terrestrial photogrammetry. A total of 5034 shots of the elevations and 1875 shots of the interior rooms were taken; the overall acquisition time was 9 h.

Aerial photogrammetry (UAV)

This technique was employed to study and survey the roofs of the Fraccaro residence. The equipment used was the DJI Phantom 4 Pro drone, and 384 shots were taken, placing 11 artificial targets (GCP—Ground Control Points) [31]; the overall acquisition time was 2 h.

Photogrammetric captures were made either with axes parallel to the ground and at concentric flights by taking photos with a zenith camera (normal to the ground at 90°) or with a tilted camera (about 30°) for better acquisition of vertical facings [32]. The flight height was set equal to 45 m (Fig. 4).

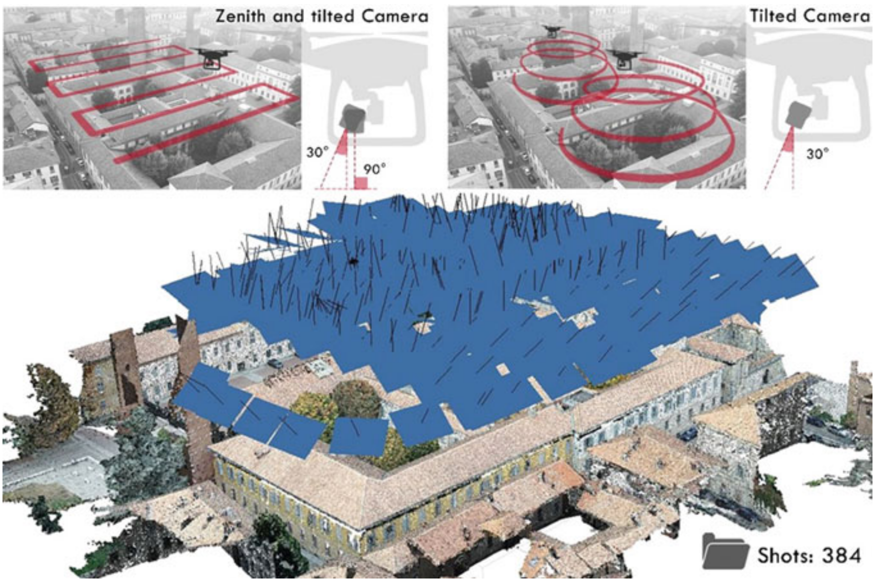

Fig. 4 Overview of the UAV photogrammetric acquisitions and processing within the Agisoft Metashape (Editing: A. Dell'Amico, A. Sanseverino, and S. Albertario)

Terrestrial Laser Scanning (TLS)

The equipment employed for the survey campaign was the Leica Geosystems RTC360 laser scanner, a fast and very accurate instrument capable of acquiring color scans and High Dynamic Range (HDR) images in about 2 minutes.

Thanks to a combination of IMU (Inertial Measurement Unit) motion sensors and VIS (Visual Inertial System) technology, the scanner can track and locate itself. Therefore, it automatically records movement from station to station to pre-register scans in the field without manual intervention. The scanner's onboard Edge Computing Technology allows images and point clouds to be visualized on the tablet directly on the field.

The RTC360 was used to survey the elevations, courtyards, basements, and attic. On the ground floor, 171 scans were taken, in the basement 38, and in the attic 46, for a total of 255 scans. Most of the scans were made in color (2.42 min/scan), thus providing the point cloud with the detailed materic datum; in the attics, a black-and-white survey (1.21 min/scan) was opted for so as to densify the point cloud in an environment with a low light condition, thus not suitable for RGB color acquisition through the instrument's integrated cameras (Fig. 5).

Mobile Laser Scanning (MLS)

The instrument used for the survey campaign was the Leica Geosystems BLK2GO mobile laser scanner, equipped with a LiDAR sensor and Visual SLAM technology, with three integrated panoramic cameras. The app used to monitor real-time scan development, tracking, and three-dimensional space reconstruction is the BLK2GO LIVE [33].

The BLK2GO was used to survey the interior rooms and courtyards, taking 1 scan on the basement floor, 11 on the ground floor, 7 on the second floor, 2 on the second floor and 1 on the third floor, for a total of 22 scans (Fig. 6).

Fig. 5 View of the TLS point cloud within the Cyclone Environment (Editing: A. Dell'Amico, A. Sanseverino, and S. Albertario)

Fig. 6 View of the MLS point cloud within the Cyclone Environment (Editing: A. Dell'Amico, A. Sanseverino, and S. Albertario)

4.2 Post-processing and Setting up of the Modelling Phase

For the realization of the integrated post-production survey database, the photogrammetric outputs—processed with Agisoft Metashape software, obtaining a Ground Sample Distance (GSD) of 1.8 mm/pix for elevations and 1.4 cm/pix for roofs—and the TLS and SLAM point clouds were registered in the Leica Geosystems HDS Cyclone environment (v. 2021).

The survey database obtained after registration in IMP format (proprietary format of Leica Geosystems Cyclone software) has an overall size of 358.41 GB. The preparatory step to the next BIM modeling phase is the export of the integrated point cloud in a format suitable to be later reimported into the Autodesk ReCap environment (Fig. 7).

Here, a comprehensive catalog of the architectural objects featured throughout the complex was developed using, as a shared database, a Microsoft Excel spreadsheet. Each component was assigned a coding according to the following structure (1):

$$\text{AAA\_BB\_C1\_22} \tag{1}$$

whereas AAA stands for the structural typology of the element, based on which to assign the corresponding category in the Autodesk Revit environment; BB is the project acronym—in this case, CF was used standing for Collegio Fraccaro; C1 represents the reference environment indicated by letter and sequential numbering; 22 is the sequential numbering of the elements of the same typology (Fig. 8).

Following this discretization, manual point cloud segmentation was then undertaken for an initial vector redrawing (Autodesk AutoCAD) of the elementary three-dimensional generator profiles corresponding to the cataloged architectural objects (Fig. 9).

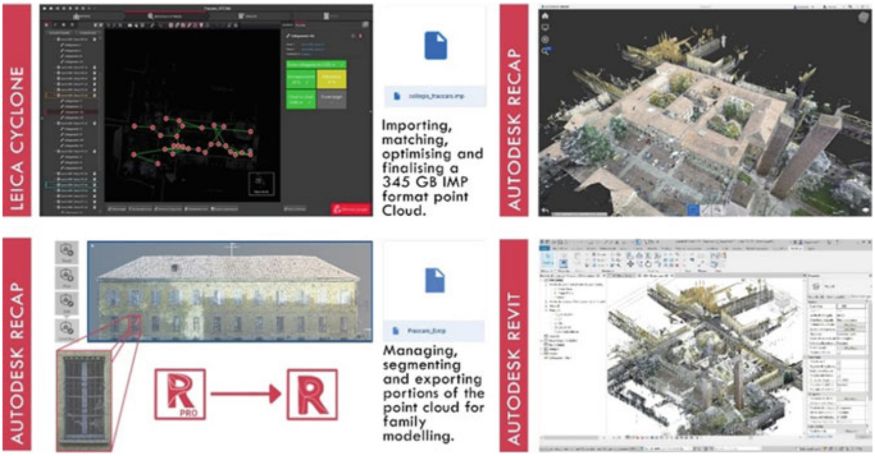

Fig. 7 Overview of the Scan-to-HBIM process management system. From left to right, and top to bottom: Survey and registering phase; Integrated point cloud importing to Autodesk Recap; Component cataloging and point cloud segmentation; point cloud linking within the Autodesk Revit environment (Editing: A. Dell'Amico, A. Sanseverino, and S. Albertario)

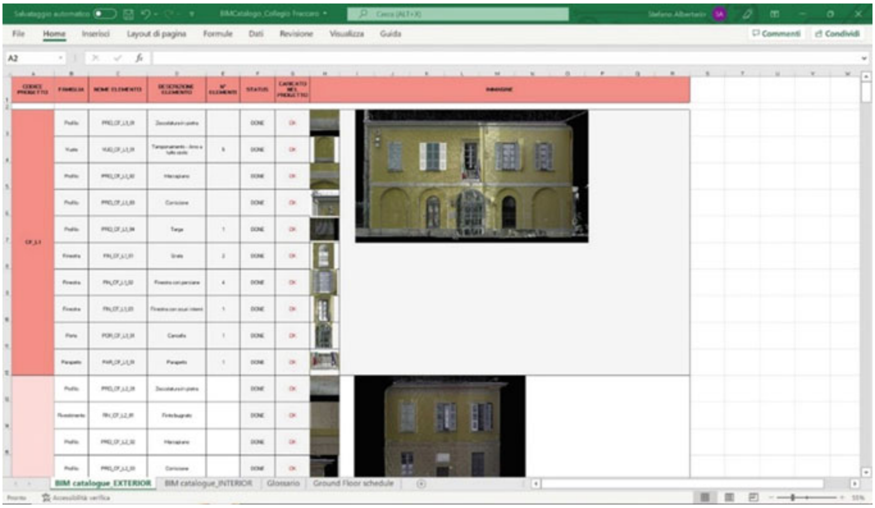

Fig. 8 Example of the Eastern Façade's components cataloging (Editing: A. Dell'Amico, A. Sanseverino, and S. Albertario)

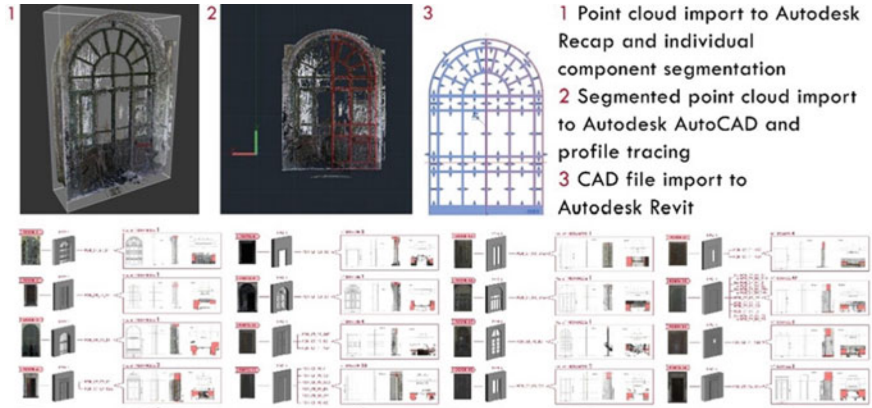

Fig. 9 Profile tracing over the point cloud: example of the Door families (Editing: A. Dell'Amico, A. Sanseverino, and S. Albertario)

4.3 Scan-to-HBIM Modelling

The aim of the HBIM modeling procedures developed was to obtain a model with a LOG (according to the Italian UNI 11,337–4:2017 the Level of Development—LOD is intended as a composition of the Level of Geometric Detail—LOG and the enclosed Level of Information—LOI) equivalent to an as-built. We opted for a shared modeling approach implemented by setting up a central model—in RVT format (proprietary format of Autodesk Revit software)—to give access to personnel with different assignments among the DAda-Lab researchers, i.e., modelers, supervisors, and coordinators. The central model was stored in cloud (using the Microsoft One Drive platform) and would be updated upon synchronization of the modified local copies downloaded onto the terminals of the various operators. Further preparation steps involved linking the point cloud in RCP format (Autodesk ReCAP software's proprietary format) in the Revit environment and setting up worksets assigned to each user.

Following initial modeling of the reference elements such as walls and floors, which were treated as system families—hence not exportable nor importable—the library of loadable parametric families corresponding to the architectural elements identified in the previous cataloging phase was generated. The following descriptors were identified for each of them: family, name, definition, number, modeling status, and upload status in the project to ensure their validation.

The modeling of the system families was carried out by paying great attention to compliance with the geometries deduced from the point cloud directly in the project environment. On the other hand, for the modeling process of the loadable families, it was necessary to export the portions of the point cloud corresponding to the identified object and work separately on them. Once the single element was obtained in RCP format, it was imported into Autocad for an initial tracing. The tracing of the cloud was accomplished by means of vertical and horizontal section planes so as to ensure the thorough identification of all the generating profiles of the elaborated moldings.

These 3D profiles were then imported into Revit's Family Editor to prepare reference planes governed by dimensional parameters and the generation of the attached volumes. Once the parametric-information modeling operations were completed, the families were loaded into the general project (Fig. 10). Moreover, for optimization of the cross vault complex geometry modeling, an adaptive component on four adaptive points was designed. Choosing to parametrize the boundary geometry of the vault panels [34] makes the smart object suitable for the accurate representation of historical architecture, even fitting the small displacement necessary for an as-built type of modeling (Fig. 11).

The HBIM process developed for Fraccaro University Residence goes far beyond the generation of a purely three-dimensional model, aiming at the digitization of an existing architectural asset, ultimately resulting in the establishment of a real repository for the storage and management of an integrated database consisting of point clouds, documentary and photographic archives, and smart objects (Fig. 12).

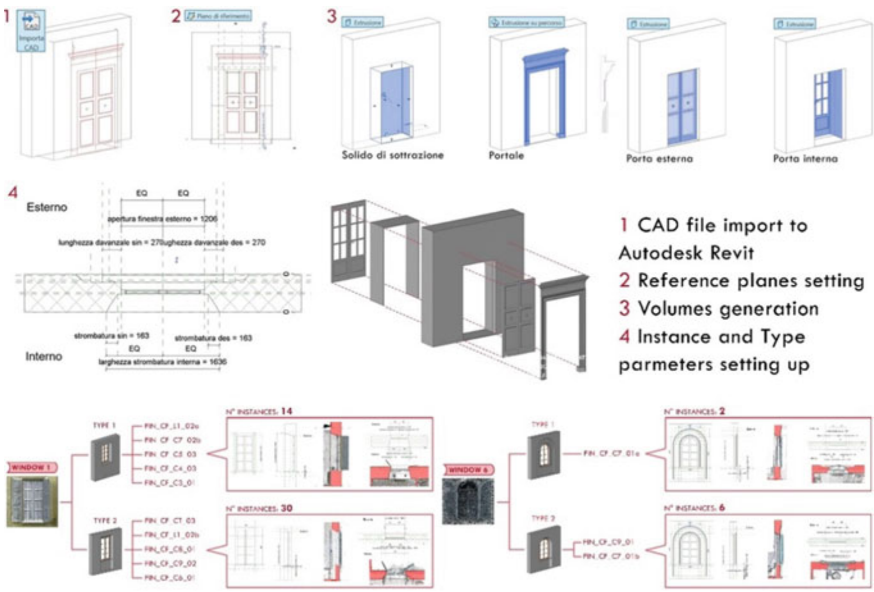

Fig. 10 Parametric volumes generation: example of the Window families (Editing: A. Dell'Amico, A. Sanseverino, and S. Albertario)

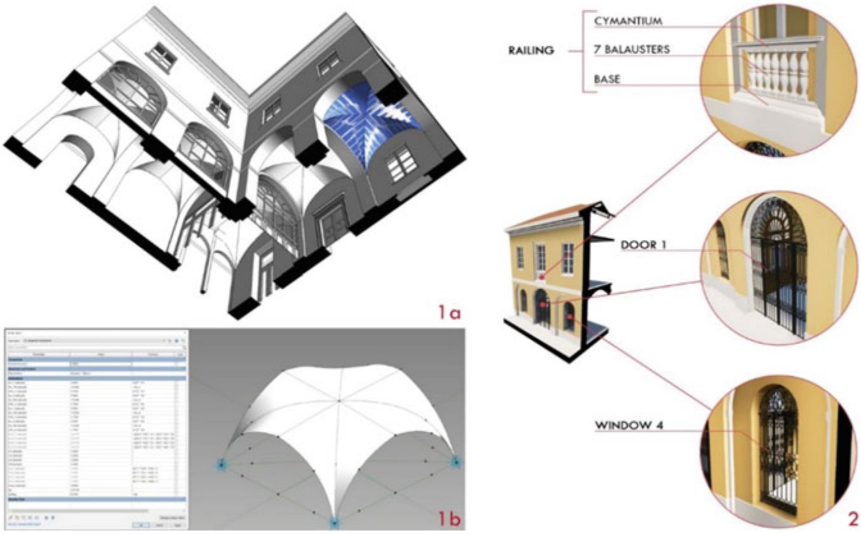

Fig. 11 Adaptive parametric Cross Vault within the Revit Family Editor (1b) and placed in the project to reconstruct the arcaded courtyard. Rendered details of the ad hoc modeled Smart Objects (Editing: A. Dell'Amico, A. Sanseverino, and S. Albertario)

5 Conclusions

The research project focused on testing actions to validate the acquisition and digitization process finalized to develop methodological protocols for generating HBIM systems on historical architecture. As for data acquisition procedures, we experimented with an integrated acquisition method using mobile SLAM technology and TLS laser instruments, remotely piloted aircraft systems, and digital cameras for photogrammetric acquisition; the standpoint was to verify upon a monumental complex and historical architecture that operational paradigm of the Scan-to-BIM process that sees in these tools the most suitable towards the operational streamlining of time-consuming processes [35].

In terms of time sustainability, the use of cutting-edge mobile laser scanner (MLS) instrumentation made available by Leica Geosystems has demonstrated the halving of on-site work schedules. Thus, as a result of a conscious and oriented decision-making process, it was possible to optimize the survey activities of the interior complex by concentrating them within three days. Furthermore, in terms of economic sustainability, implementing a Scan-to-BIM process makes it possible to develop a three-dimensional simulacrum on which technical facility information can be implemented and then program monitoring and maintenance actions for the building [36].

The segmentation methods and protocols adopted in the point cloud model's survey and post-production phase greatly influence the final model's overall accuracy, the subsequent stage of interpretation of the surveyed data, and thus the processing of models at different scales of representation or levels of detail. Current possibilities

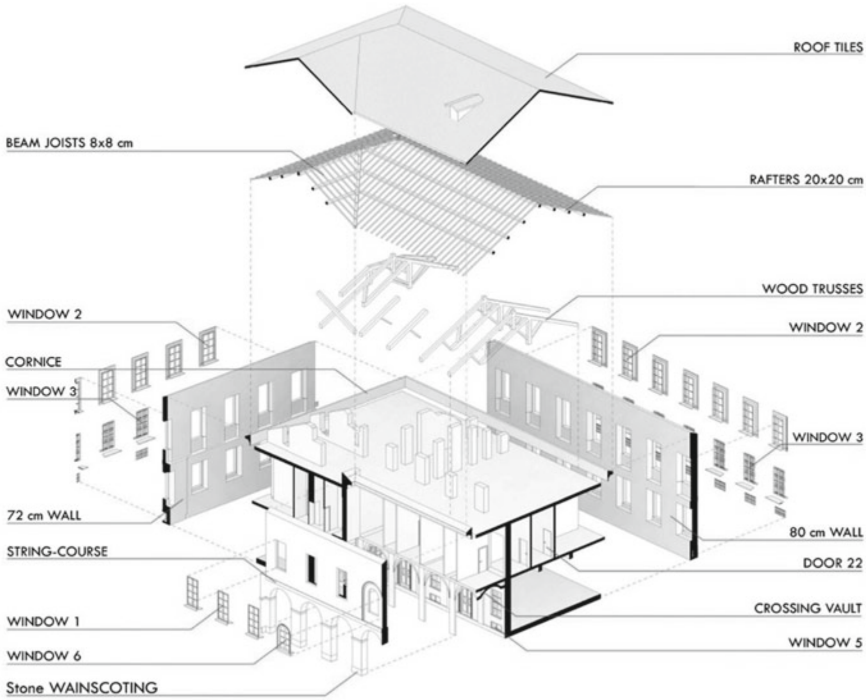

Fig. 12 Axonometric cross-section of a selected portion of the HBIM model, underlying the loadable families generated ad hoc (Editing: A. Dell'Amico, A. Sanseverino, and S. Albertario)

of visualization and segmentation of the cloud allow the contextual verification of the points belonging to the detected section plane in relation to the infinite planes parallel to it, thus, ensuring the possibility of investigating the three-dimensional model as a whole in the direction of facilitating the process of understanding and representation of geometries.

Documented research experiences and case studies show the current approaches to the application of Scan-to-HBIM tools to the existing built heritage; the complex geometry of building elements such as vaults [37], features of the architectural order such as capitals, pilasters, columns or the sculptural decorative details [38] are indeed being studied, by professionals as well as researchers and companies, in order to define optimized workflows that overcome the specificity of each case [39] (Fig. 13).

Therefore, within the described scenario, it is possible to identify two prevailing research directions, development and innovation of methods supporting representation procedures, on the one hand, and model management, on the other.

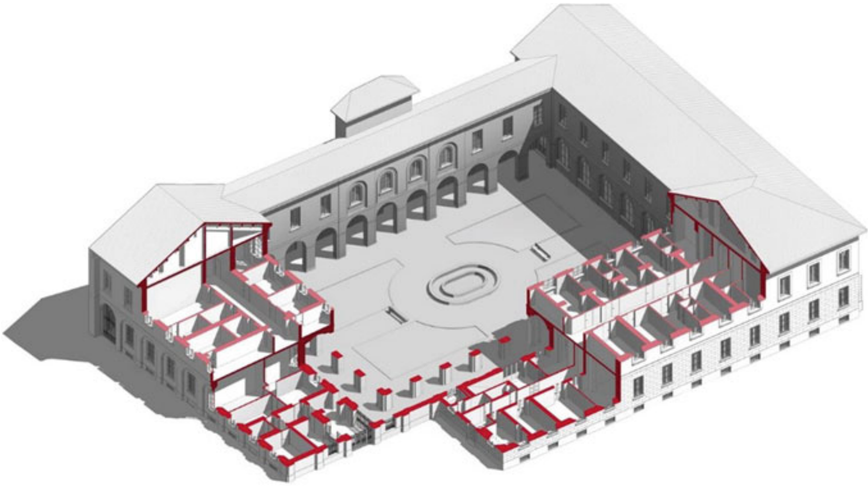

Fig. 13 Axonometric cross-section of the Fraccaro HBIM model showing the inner space layout (Editing: A. Dell'Amico, A. Sanseverino, and S. Albertario)

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Classification and Recognition Approaches for the BIM Modeling of Architectural Elements

Pierpaolo D'Agostino and Giuseppe Antuono

1 Introduction

Parametric and algorithmic modeling stands as an increasingly diffused key tool for virtualization and automation processes, also aimed at the cultural heritage's management and fruition. In recent years, the latter has benefitted from digital tools for the maintenance and restoration of the built heritage.

Indeed, Building Information Modeling (BIM) notoriously represents the current solution for new constructions and a feasible solution for the built environment. Concerning the latter, this definition is due to the key role of the construction of coherent digital models through suitable automation modalities of the geometric reconstruction and information population processes.

At the same time, in recent years, numerous research works have focused on the definition of processes for the recognition and modeling of architectural forms based on images or point clouds (Fig. 1) [1–4]. The automation of these data-based parametric modeling processes, employing data from integrated image-based and range-based surveys, represents the cornerstone of a very active field in contemporary scientific research. On the one hand, new visual scripting and programming approaches prove to be useful tools to create an interaction between material objects and their digital twins in the management of the built environment; on the other hand, they can also allow a simplification in cloud-to-BIM digitalization processes [5] through the automated recognition of parametric objects and complex forms.

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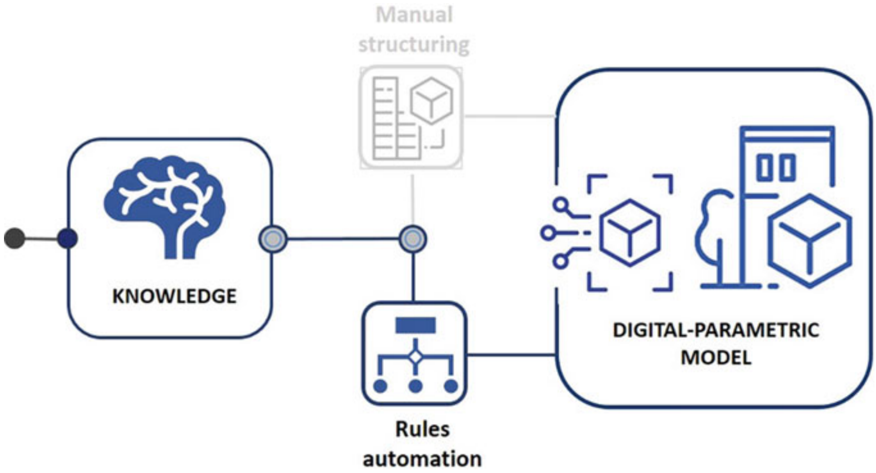

Fig. 1 Synthetic representation concerning the goal of the recognition and digitalization of architectural elements in a BIM environment (Editing: G. Antuono)

Hence, the virtualization of the built environment is increasingly seeking modalities for the automatization of the recognition processes of unstructured data from digital surveys and the related generation of solid instances in BIM platforms.

This paves the way for experimentations with machine learning techniques: this could become a deeply relevant theme, particularly for the Italian context, where a vast heritage that is involved in regeneration and restoration processes—even before maintenance—displays valuable characteristics whose geometric component must be structured into a digital object that fits the level of development of the representation.

This investigation, aiming at the creation of structured data models, retraces the approaches and processes that have been adopted to speed up automated reverse engineering operations, in cases where standardization can be accepted if it fulfills the digital reproducibility of instances in a stable and shared way, following a necessary process of interpretation and manual modeling.

1.1 Toward the Automation of Parametric Modeling

Our research has joined this diffuse spirit of participation to the automation of modeling approaches and has examined the theme of the construction of rules for the segmentation, classification, and digitalization of architectural elements, both in valuable and civil buildings, employing a mainly scripting-based approach.

The contribution to the definition of automated workflows for recognition and digitalization of the historical and cultural heritage from images and point clouds (Fig. 2) [6] is outlined along the recent research work, developed through the activities of our Departmental Survey and Modeling Laboratory (ReMLAB).

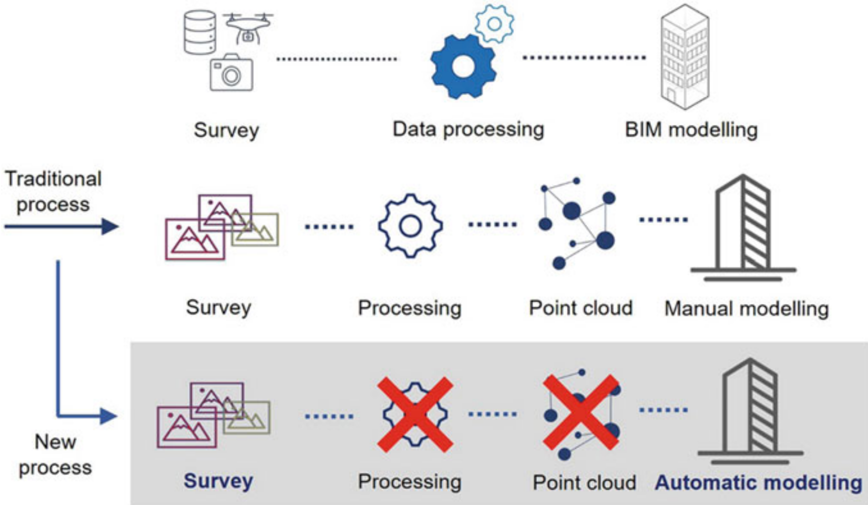

Fig. 2 Toward the automatization of reverse engineering operations (Editing: P. D'Agostino)

In the process from the survey of a building to the realization of coherent digital models that serve as digital twins of the existing building, there is an evident need to implement automatization processes of operational flows in the processes of recognition and management of unstructured data deriving from digital surveys and the related generation of solid instances in BIM platforms [7].

Indeed, the modeling process shows several intrinsic problems, related to the object-oriented ontological definition of the elements of the built environment—characterized by diversified geometric-formal components—whose modeling processes often employ manual Cloud to BIM approaches.

With the aim of making a step toward new procedural approaches for the recognition and reconstruction of complex objects and forms, an AI-based methodological approach was adopted (Fig. 3). It is articulated into 4 key steps: the first one is the definition of the problem and is followed by the individuation of an algorithm through which the analysis process is rendered into an IT architecture, then a training and testing session for the recognition, and finally the modeling of the examined element, which stands as the result of the automatic process.

On this theme, this paper presents some case studies, focused on architectural components whose characteristics require a highly complex segmentation and classification process, due to the high degree of characterization, especially in historical buildings. On the one hand, their characterization derives from their main typological reference, which may underlie a diversity of construction techniques, to be individuated. On the other hand, it is also a specific characterization due to the unavoidable modification process of the real object that is being modeled, which is an active part of a historicized—sometimes, ancient-building.

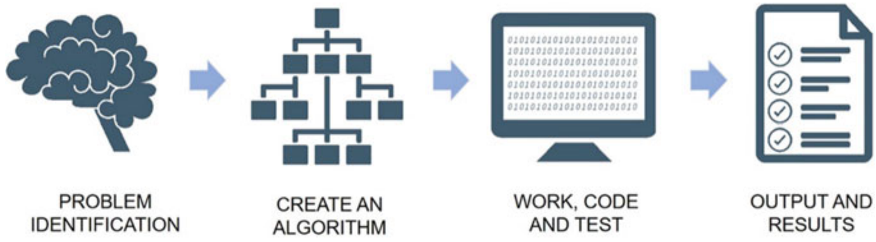

Fig. 3 Synthetic diagram of the methodological approach adopted for the experimentations that are oriented to the implementation of AI techniques. (Editing: G. Antuono)

In particular, (Fig. 4) a focus will be made on specific approaches: a part of them ranges from visual algorithmic programming for the recognition and modeling of architectural orders to visual scripting and programming for the recognition, classification, and modeling of wood trusses; others are based on programming through AI algorithms for the recognition, classification, and modeling of walls in parametric BIM platforms.

After mapping the elements, the structuring of parametric objects has adopted a discretization of geometric parameters, derived from studies and research works conducted on the morphology of the components, and evidence related to historiographic knowledge. In particular, concerning architectural orders, their parametric reconstruction was also based on manuscripts, from Vitruvius to 18th-century architecture manuals [8]. This has allowed obtaining geometric rules, which are useful both for automat-ic digital reconstruction and for the validity assessment with respect to canons in the proportional analyses of the orders of existing elements. Moreover,

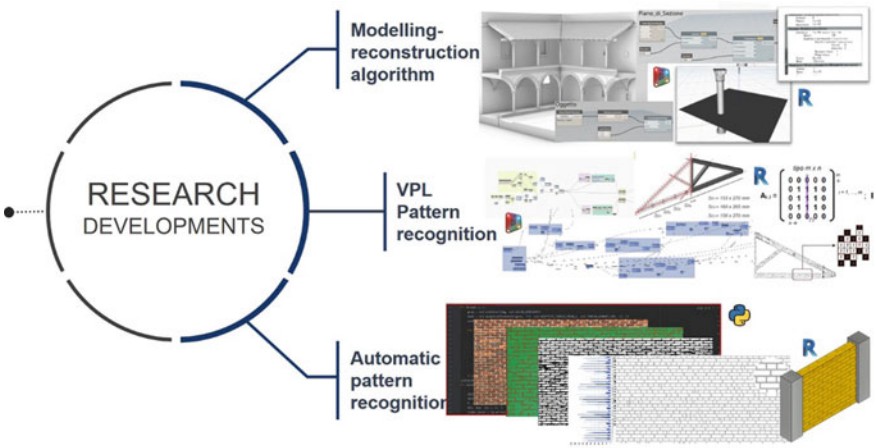

Fig. 4 Synthetic diagram on research developments in the field of visual algorithmic programming, and programming for the recognition, classification, and modeling of architectural orders, wood trusses, and walls in parametric BIM platforms (Editing: P. D'Agostino)

the definition of rules has contributed to the recognition of significant deformations and/or irregularities [9] due to the artisanal nature of their realization, paving the way for the implementation of information for the management and maintenance of the buildings [10].

The complete knowledge of the ideal model was fundamental also in the second study experience, that is the digitalization of wood trusses, whose operational workflow was aimed at the reconstruction-by-parts of the element. The first step was the individuation of their points, then the reconstruction of the polylines; finally, the recreation of the surfaces, which allowed obtaining the solid-parametric configurational representation [11]. Based on the analysis of preliminary studies on the theme—for example, with reference to the manuscripts by Andrea Palladio, Guarino Guarini, or Gustav Adolf Breymann—an initial discretization was performed for the morphological properties of the wood trusses, to facilitate their recognition and algorithmic-parametric modeling, including the characterization of the existing element and the structuring of specific families. This necessity also belongs to another category of architectural elements, the walls, yet articulated according to their specific characteristics. These objects have already been the object of previous studies, concerning automatic texture richness recognition [12] and have fostered experimentations with approaches for the automation of modeling processes. The chosen path included the use of ArUco markers and the employment of pre-trained neural networks for the automation metric acquisition processes, through an informatic, then algorithmic approach for the generation of solid-parametric instances in system families, within a BIM environment. This latter phase required a focus on the programming codes for the hierarchical categorization of construction elements; in other words, it was necessary to get into APIs (Application Programming Interfaces), the set of definitions and protocols for the creation and integration of applications, opening up to new digital design methods.

2 Digital Paths for the Classification by Construction Elements

In recent years, the interest in the studies on digital reconstruction through algorithmic and automatized as-built modeling procedures [7] has led us to investigate other methods that employ point cloud images for the recognition and modeling of architectural characteristics [13].

Concerning the first case study, the research focused on the structuring of a segmentation and modeling algorithm from a point cloud, applied to the columns of Chiostro Grande in the Santa Croce Complex in Florence (Fig. 5), with reference to the proportion rules of the orders.

In particular, this included the adoption of Vitruvius's indications—synthesized as the Method of successive partitions by Prof. Riccardo Migliari [14]. This favored the description of algorithmic scripting modeling processes (Fig. 6).

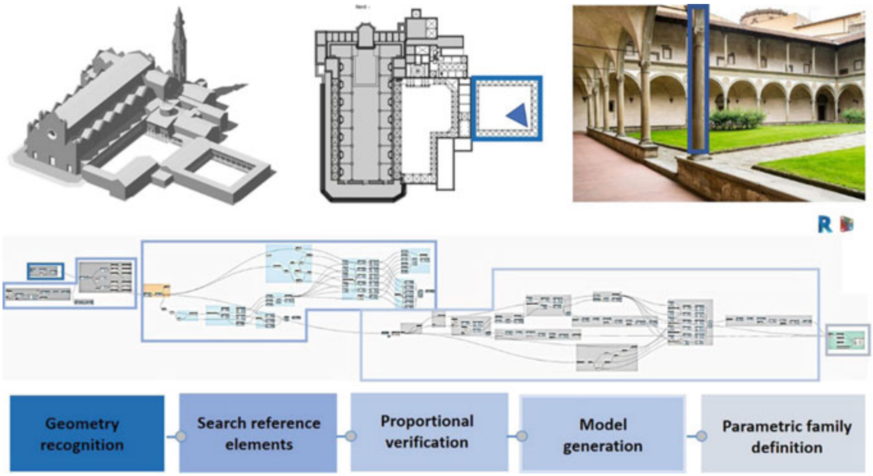

Fig. 5 Methodological diagram of the algorithm structured for point cloud-based segmentation and modeling of Chiostro Grande in the Complex of Santa Croce in Florence (Editing: G. Antuono)

The method of successive partitions is performed by correlating parts of the order according to a set of rules that modulate the correct proportions between the pedestal, the column, and the trabeation. Within this first categorization, the geometric reconstruction in the digital domain adopted a further level of subdivision: the pedestal was divided into cymatium, dado, and socle; the column into capital, shaft, and plinth; the trabeation into architrave, frieze, and cymatium. This is compounded by the hierarchization of each architectural order into three main levels: structural, functional, and decorative. The structural level is related to the general proportional organization that is needed to ensure stability, with respect to the proportion between the parts of the element. Specifically, Vitruvius's modulus, which he sets as the diameter of the low part of the column, is used to determine the height of the column, base, and capital, the width of the upper trabeation, and the inter-column span, that is the space between imposts or adjacent columns.

The functional level regards the definition of the dimensions of the single components: the pedestal, the columns, and the trabeation. In particular, after determining the base modulus, the height of the column is obtained as a repetition of the unit measurement on the central axis of the trunk, for a number of times that depends on the considered architectural order. Then, the diameter and the height of the pedestal and trabeation are described according to the repartition of the height of the column, according to the typical rules of each order. Finally, the decorative level defines and sets the proportion for each molding, differentiated according to the order.

More complex decorations have been obtained by assembling moldings through the generation of a series of standard profiles, which were then aggregated singularly, repeated, or overlapped with scale variations.

Specific research has been conducted on the Corinthian order. It resulted that the Visual Programming Language transcription of the geometric modulation rules

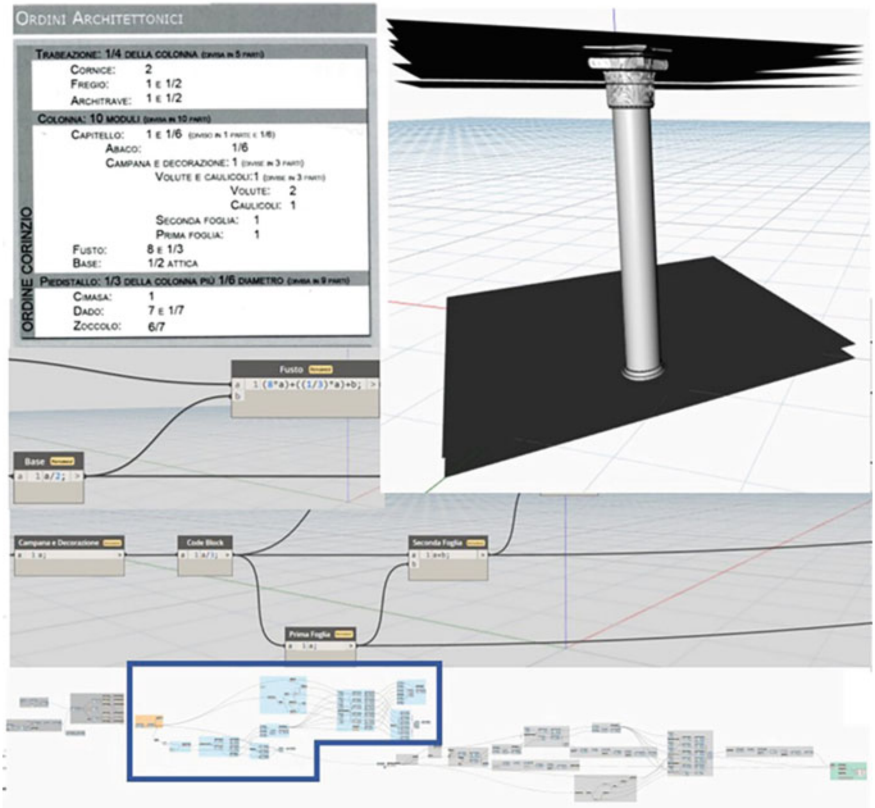

Fig. 6 On the left, the modulation criterion of the architectural orders: the Method of successive partitions by Prof. Riccardo Migliari [14]; on the right, the results of the research conducted on the Corinthian order for the Visual Programming Language transcription of the geometric rules of modulation and verification of canonical criteria (Editing: P. D'Agostino)

both favors modeling and facilitates the verification of the canonical criteria of the parametric model that stands as the virtual copy of the real object (Fig. 6).

The research and the reference to ancient construction models was a starting point also in the second research experience, aimed at the recognition, classification, and modeling of wood trusses.

The geometric-typological classification has allowed deducting the rules required for the categorization of the parametric model, tested on a real case by applying a segmentation and classification approach based on photogrammetric data. The RGB photograms acquired through image-based survey techniques have allowed identifying the key areas, that is the regions defined by the constitutive element of the truss, extracting the data needed to classify and model its structure (Fig. 7).

In particular, through the Python programming language, the raster result of the photogrammetric survey was processed to obtain thresholds using a binary method

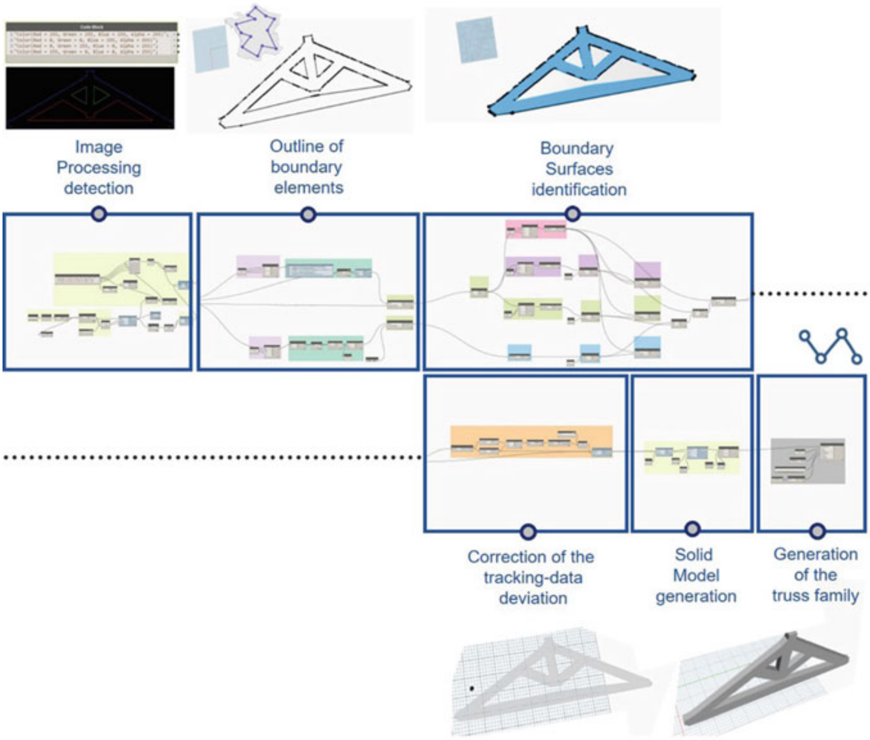

Fig. 7 Algorithmic workflow for the recognition, classification, and algorithmic-parametric modeling of wood trusses (Editing: G. Antuono)

among those based on color shades or color inversion. It allowed extracting two lists of elements based on the image: pixels that do and do not belong to the object, that is those representing the truss and those representing the background.

This allowed individuating the boundary of the objects and outputting their hierarchy through the RETR.LIST function. The use of color to differentiate data facilitates the redrawing and polyline vectorization process through a Dynamo script, with four lists to associate the points with the corresponding chromatic data. It is worth noting that this organization in lists is only one of the possibilities that have been tested in this work; similar results can be achieved with different IT procedures; the division into chromatic lists has been chosen as it allows simplifying the following steps.

The reconstruction of the boundary of the objects has been performed through the analysis of a mathematical/geometric issue called the Traveling Salesman Problem. Its solution is obtained by connecting different points on a plane through a shortest-path optimization.

Finally, our research work included finding a solution for the recognition of walls, optimizing traditional workflows, eliminating the manual post-processing phases, and employing AI algorithms for the classification and modeling of their state. A process to render unstructured data into a BIM environment was tested on a wall element prototype (Fig. 8). The method was articulated into design phases for the definition of image analysis and processing algorithms, data elaboration and transfer algorithms, and finally algorithms for data re-elaboration in a BIM environment. The recognition phase of the instance in the image was solved by employing a neural network for the individuation of construction elements; the results have shown good quality, but it is worth noting that the untrained network cannot individuate the pillars on the sides of the wall, nor parts of the context (Fig. 9). The issue of the automatic recognition of geometric measurements—specifically, width and height—was tackled through ArUco markers (Fig. 10). This tool consists of a synthetic square made up of a large black border and an internal binary matrix which determines its identifier (id). After an initial test in verifying their detection, since this phase depends on the size of the marker within the image and on the distance at which the gripping point is located (i.e., the camera or the instrument used for acquiring the images), markers of various sizes were applied to the case study under various light conditions.

Subsequently, the binary codification allows identifying them for the dimensional description of the elements recognized by the neural network. The conversion of these data into BIM objects within specific platforms requires operating on programming codes, to understand the hierarchy at the base of the categorization of construction elements. In other words, it is necessary to operate on the APIs, which are available on the website of the software house of the employed application and contain the classes for the creation of the objects.

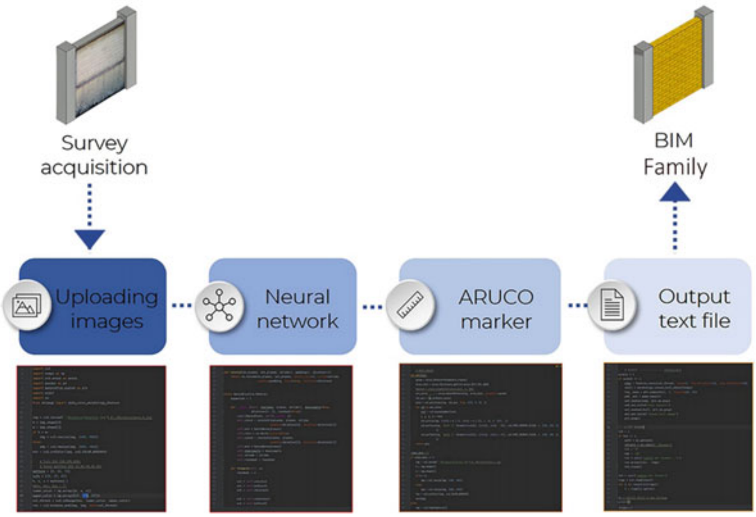

Fig. 8 Operational workflow to render the unstructured data of a prototypal wall element in a BIM environment (Editing: P. D'Agostino)

Fig. 9 Employment of a neural network for the individuation of construction elements in the image (Editing: G. Antuono)

The available classes for the elaboration of new procedures are provided in C# and Visual Basic languages. The class available on the Revit Site—API docs, for creating the wall element, consists of five methods, each of which provides a different number of attributes (in programming, attributes are defined as variables) that can be assigned at the instance. Among the various methods, the one called Wall. Create (Document, Curve, ElementId, ElementId, Double, Double, Boolean, Boolean) was chosen which, requiring a greater number of attributes (variables) to be defined (inserted in the code), allows greater flexibility in modeling the element by changing its individual parameters. Considering the need for the conversion into the Python language for the use of applications in the platforms, the translation was performed with significant attention, taking into account the variables to insert in the class of the wall instances (Fig. 11).

Fig. 10 Employment of a neural network for the individuation of construction elements in the image (Editing: P. D'Agostino)

3 Conclusions and Future Developments

The results obtained in the presented studies for the management, classification, and reconstruction of architectural components have paved the way for the implementation of innovative approaches for the automated reconstruction and digital parametric modeling of typical elements of historical architectures, including both structural components, accessory parts, and finishing. The research about the reconstruction of ancient architectural artifacts using digital parametric models, used in both cases of the Corithian column and modeling wood trusses, the start from historiographic documentation represents an essential phase with the aim of data recognition and classification.

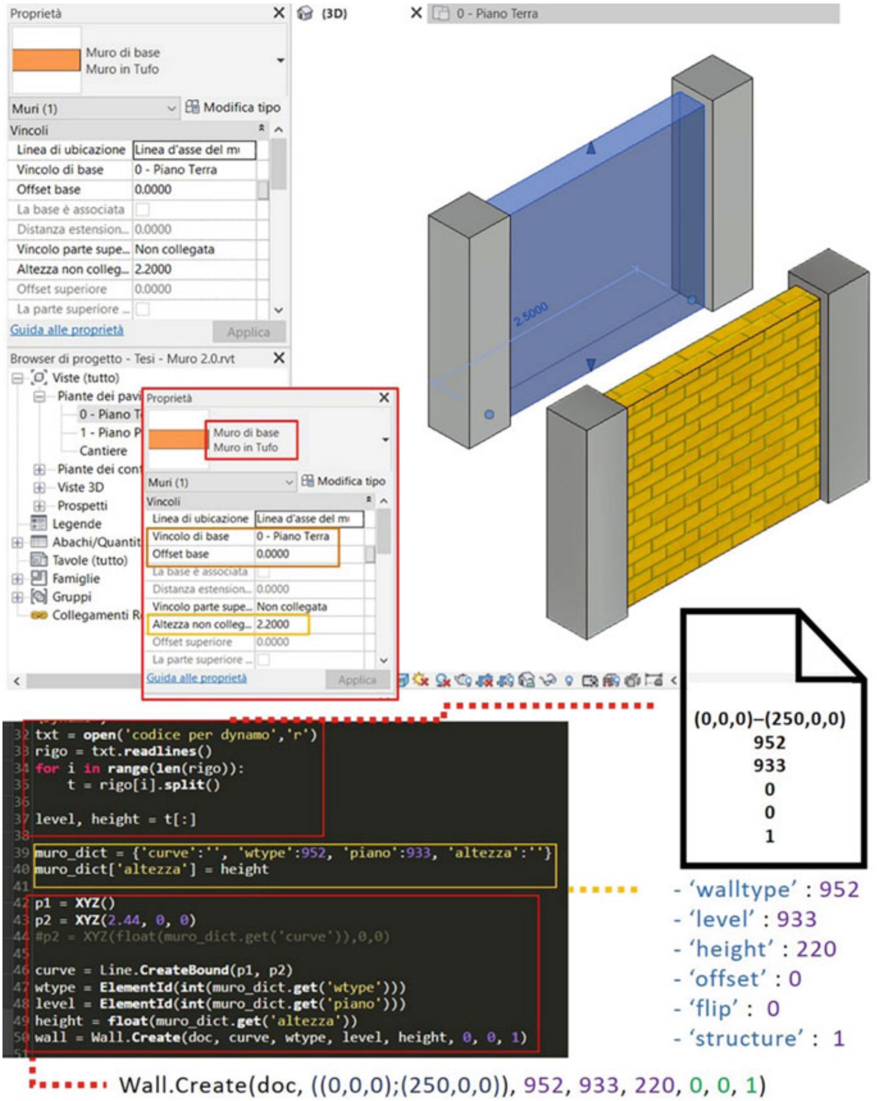

Fig. 11 Adaption of the information script to the available API programming codes in the respect of the specific syntax and translation of the model in the BIM environment in the wall instance class (Editing: G. Antuono)

In the first case, the verification of the hierarchy of the components of the order is performed through horizontal cut planes, able to reveal the proportional rules reported in historical treatises in order to assembly the parametric solid geometries.

About the second experience, the structuring of a corresponding algorithm first led to the reconstruction of the external surfaces, and then the overall parametric object allows to the integration in BIM platforms, like the use of a family in the Autodesk Revit environment, at a low level of geometric detail, yet opening to further focus on the recognition of variable-section elements, or connection elements between the components of the truss.

In the last case described, the digitalization of the built environment required the development and implementation of specific neural networks and methods for the calculation of the geometric characteristics of existing construction elements. The data on the dimensions of the wall—width and height—are processed by several algorithms, but the optimization by the one for the recognition of wall thickness and different covering textures is still an open issue. As of today, there are already encouraging elements, which show ample room for development.

The work is therefore clearly far from being completed but shows several interesting perspectives. For example, it is worth noting that the above-detailed classification procedures provide encouraging results, with respect to the possibility to generate—albeit through deduction—detailed reconstructions for the variable layout of the elements.

Moreover, these procedures of automatic classification and reconstruction are pushing research toward the digitalization and management of the built environment in VR applications, making use of the recognition potential of ArUco markers and the extension of raster image approaches to video sequences, to allow the real-time recognition and vectorization of elements.

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The Role of Semi-Automatic Classification Techniques for Mapping Landscape Components. The Case Study of Tratturo Magno in Molise Region

Andrea Rolando, Domenico D'Uva, and Alessandro Scandiffio

1 Introduction

The aim of this research is to test different mapping techniques that use semi-automatic recognition of the contents of satellite imagery, to understand how they may support a mapping work of the landscape crossed by the Tratturo Magno between the inner areas of Molise and the Adriatic coast. In particular, the aim is to evaluate the effectiveness of these techniques in mapping the path of the tratturo and in delimiting its areas of influence.

The procedures that have been applied try to integrate the different modes available, starting from those that divide the image into single pixels, which are classified according to their spectral properties, to object classification based on the recognition of geometric characteristics of the shapes, to texture analysis, verifying variations in intensity and shape of pixels close to each other, in order to recognize patterns and structures, up to the extraction of specific features from the images, such as for example the density of vegetation or the presence of water streams.

The research aims at searching for a method that automatically recognizes the shape of the tratturi, understood as a historical-cultural heritage, by exploiting the potential of multispectral satellite imagery. The tratturi, grassy paths about 110 m wide, already traced in prehistoric times [1], so called tratturi, were used until the

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first decades of the twentieth century for the transhumance of herds, in summer from Abruzzo to Apulia, in autumn in the opposite direction. The transport of herds by roads and railways has diminished the main function of such green corridors, true infrastructure that supports the shape of the landscape and whose original route has often been modified and interlaced with anthropogenic interventions along the margins. Renewed interest in the phenomenon of transhumance also stems from UNESCO's recognition on the Intangible Cultural Heritage List in 2019 [2], which through the tratturi reveals the extraordinary relationship of balance between man and nature, and which fuels the search for new knowledge tools aimed at a multi-temporal investigation that allows to establish their level of integrity with a view to conservation and enhancement.

From a conceptual point of view, the methodology used in this study is based on the approach of agricultural landscape archeology [3]. This approach aims to identify and interpret the traces that the presence of specific landscape structures has left in the territory.

In particular, the methodology seeks to read the traces left in the landscape by the presence of a particular structure, in order to identify and understand its characteristics and function. Using this methodology, it is possible to analyze the territory and detect the signs of the presence of these structures, even if they are no longer visible or recognizable to the naked eye. In summary, the agricultural landscape archeology approach makes it possible to reconstruct the history and evolution of the landscape, identifying the traces of human presence and agricultural activities and transformation of the territory.

2 Case Study

A tratturo is important as an element that defines the structure of a landscape for several reasons, due to its historical importance and cultural identity. They are often characterized by stretches of land devoid of vegetation, where the grass has been consumed by the passage of flocks, thus creating a distinct trace in the landscape, which has unique characteristics in terms of biodiversity, as they represent an important transit area for animals that move from one grazing area to another, thus allowing the maintenance of animal and plant species.

The automatic recognition procedures of the contents of the satellite images can in this sense be used to identify the path of the cattle track, while bearing in mind the difficulties involved in resolving the images, in particular if the cattle track is very narrow or if it is areas with dense vegetation, where the images are influenced by the seasonal variations of the crops and vegetation and where the geological and morphological differences of the land can hide or make the drawing on the ground less legible.

There are some areas of Molise where the Tratturo Magno is still particularly evident today and the methodology was therefore applied to this emblematic case study in the section that crosses the Molise countryside between Termoli and San

Giacomo degli Schiavoni (Fig. 1), where the Tratturo Magno is still clearly visible in the landscape (Figs. 2, 3a) and represents an important historical and cultural testimony of the past, although it has been part modified or absorbed by modern roads or other human interventions, making it less evident or even disappeared.

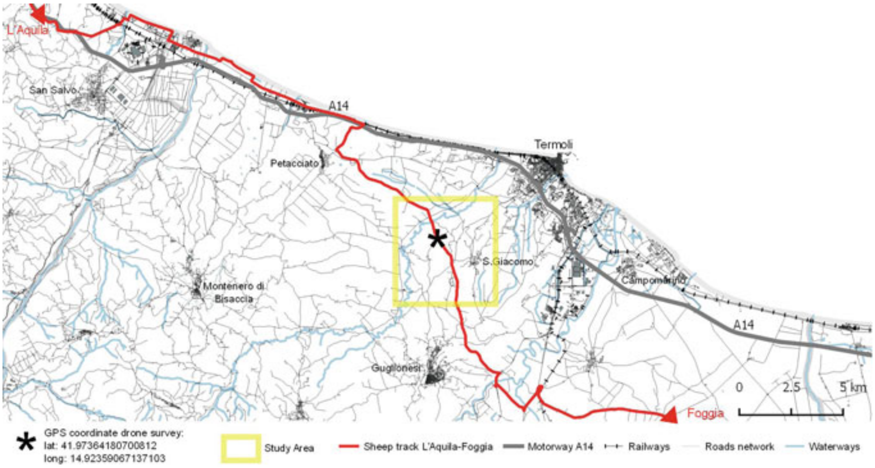

Fig. 1 Map of the Tratturo Magno in the area Termoli, in-between L'Aquila and Foggia, with evidence of the location of drone survey and study area. (Editing: A. Scandiffio)

Fig. 2 Bird's eye picture of Tratturo Magno, taken by drone in the study area. Drone Survey June 2022 (Photo: D. D'Uva)

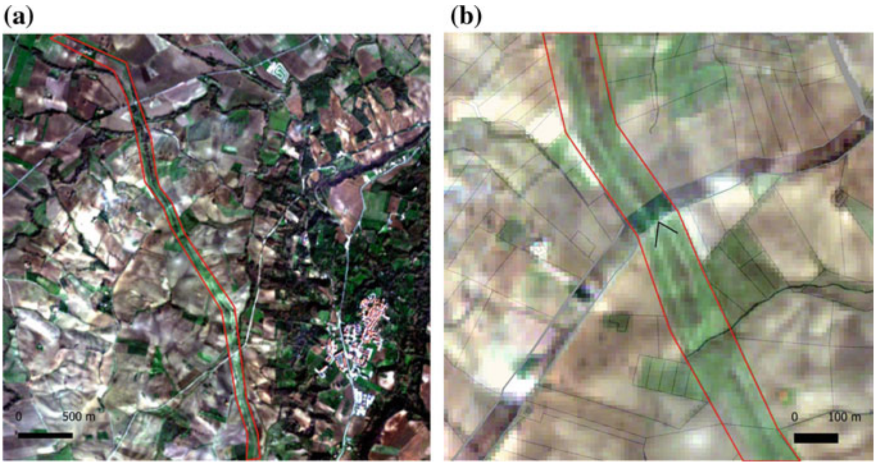

Fig. 3 **a** Sentinel-2 real color image of the study area with evidence of the tratturo. **b** Cadastre overlapping on the satellite imagery with evidence of the size of the tratturo. (Editing: A. Scandiffio and D. D'Uva)

The tratturo is a historic route used in the past for the seasonal transport of herds between Abruzzo and Apulia, passing through Molise carried out on foot. This network of trails, known as tratturi, was used for centuries as a common grazing path for sheep herds, allowing shepherds and sheep to travel between summer and winter pastures.

This phenomenon is now in disuse because transport is carried out by motorized vehicles. Tratturo Magno is the longest and oldest tratturo in Italy and although not used today by shepherds and their sheep, it represents a paramount heritage value, serving as an important cultural link, connecting the towns of this region to each other through the stories, songs, and tales that accompanied the shepherds and their flocks on their journey. The future use of this green infrastructure is being outlined as an important artery for sustainable tourism purposes, as a slow connection between the villages of the fragile territories of central southern Italy. There are already well-established experiences [4] of using the trattural route in its entirety, enhancing a 360 ° view of the landscape traversed on foot or by bike, as opposed to fast connection systems. The tratturo is the emblem of the possibility of perceiving the landscape by crossing the surface of the hills, in harmony with the context. Roads, highways and railroads that cross morphological systems by sewin hills and shaping the slopes of territories stand in total opposition to this vision of slow tourism.

The disuse of these trails has led to actions of encroachment of neighboring crops on the tratturo. This phenomenon, widespread in Abruzzo, is less present in Molise. Hence the choice of this track in this particular location, is due to the recognizability that is evident from the satellite imagery even at an intuitive level. Unfortunately, this feature is not very common in the route in its entirety. At the administrative level it is possible to detect the trattural track by analyzing the Cadastre (Fig. 3b)

[5]; at the perceptual level the identification of the track is not always evident. From this problem arises the need to clearly highlight the trattural track, both in the most obvious portions and in the more ambiguous ones.

3 Methodology

The methodology exploits the potential of multispectral satellite imagery by Sentinel-2, that nowadays are freely available in the Copernicus earth observations program by European Space Agency [6, 7], as high-resolution geospatial data (10 m) to extract spatial information for monitoring changes on the Earth. Other research centered on the tratturi in the area of Molise, have been addressed to understand the level of integrity of the tratturi by using historical maps and satellite observations [8], to examine the changes of tratturi, in terms of shape and land cover, through historical maps [9], and the potential relationships between land use (mapped by Corine Land Cover), municipalities and surrounding productive activities [10]. By examining the scientific literature it seems to be a lack in the definition of a semi-automatic procedure for recognize tratturi by satellite observations.

Particularly, this research aims to exploit the potential of the time series of multispectral satellite imagery for automatic recognition of the tratturo, by analyzing its spatial–temporal and environmental dimensions.

The methodology has tested three kinds of approaches to recognize the tratturi by multispectral satellite imagery. The first one is about the application of Vegetation Indices (VIs), which enable monitoring vegetation phenology [11], but also performing land cover classification by applying specific thresholds to the indices [12]. This approach has been tested by GIS. The second and third ones belong respectively to the unsupervised and supervised classification methods, which enable the pixel-based recognition of land cover classes by satellite imagery.

On the one hand, unsupervised classification is a method by which pixels are assigned to specific classes without any user's input about the type of land cover classes. In this first category, the research has performed the clustering method [13], by using the Semi-automatic Classification Plugin (SCP) in GIS.

On the other hand, supervised classification methods enable the mapping of the ground cover types of interest to the user, by a stage of training, classification and verification of the accuracy of the results. In this last category the tratturo features are searched by using GIS [14] and the Google Engine platform [15] which allows a spatio-temporal scan.

The preliminary step for the application of the quantitative approaches was the temporal analysis over the year 2022, in a real-color composite (RGB), of the study area crossed by the tratturo (Fig. 4). One single Sentinel-2A image has been selected per each month (cloud cover less than 5%) in order to examine how the tratturo surface changes over the year in terms of greenness.

This kind of analysis has allowed to understand which period of the year was more suitable to recognize the tratturo, as an independent green corridor. By qualitative

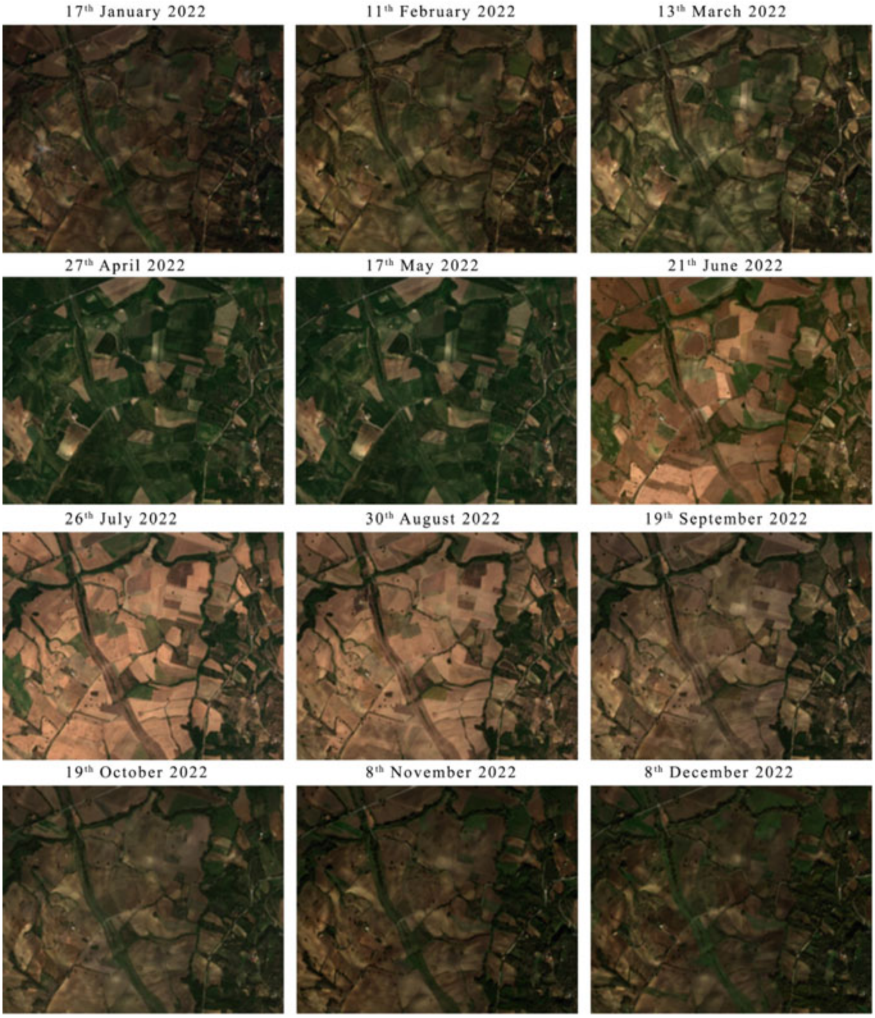

Fig. 4 Temporal analysis of the greenness features of the tratturo across the study area, visualized through RGB color composite over the year 2022. (Editing: A. Scandiffio)

analysis of the images, the spring and summer seasons do not appear significant for the purposes of the research, because the landscape takes on a uniform face; in spring because the vegetation is also growing in the surrounding agricultural fields by creating uniform green, in summer because both the tratturo and the surrounding fields appear as bare soil; on the contrary, in the autumn and winter seasons unveil interesting information, because the tratturo is recognizable, in its linear shape, as a green corridor across the landscape. This analysis supports the following steps, by prompting autumn and winter time as the best periods of the year to test the procedure of semi-automatic recognition.

In this range, one single satellite image of the 17th January 2022 has been selected as a sample for simulations. This date has been selected according to a qualitative analysis, based on the real color representation (Fig. 5a) and false color representation, which highlights the greenness component (Fig. 5b). In the next sections, the hypothesized approaches have been described more in detail and summed up in the synoptic table shown in Fig. 5.

3.1 Vegetation Indices Application

VIs are sensitive indicators for monitoring phenology, but they can be useful also for detecting land cover by applying specific thresholds [12]. As mentioned in the previous section, in the autumn and winter seasons, the tratturo appears as a green corridor in the real color representation. For this reason, two different VIs, which are largely used for vegetation studies, have been computed in this procedure in GIS: Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI) according to the following equations:

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{Red}}{\mathrm{NIR} + \mathrm{Red}} \quad (1)$$

$$\mathrm{EVI} = 2.5\frac{\mathrm{NIR} - \mathrm{Red}}{(\mathrm{NIR} + 6\,\mathrm{Red} - 7.5\,\mathrm{Blue}) + 1} \quad (2)$$

Both indices range between −1 and + 1. In this specific case, they have not been used for monitoring vegetation status, but as a proxy for the tratturo recognition. The application of the specific thresholds to VIs enable the detection of the linear shape of tratturo. By applying the threshold between 0.4 and 0.6 to NDVI (Fig. 5c), the linear shape of tratturo is clearly visible. For EVI (Fig. 5d) it is clearly visible in the range between 0.1 and 0.4. In the study area, the recognition of the linear shape of the tratturo is possible due to the presence of bare soils in the surroundings over the autumn and winter seasons. In addition to the tratturo even other green and evergreen vegetated surfaces have been detected through the same thresholds; it can be assumed that the application of thresholds to VIs has a good performance for the tratturo detection but, at the same, they are not unique for it.

3.2 Unsupervised Classification—Clustering

Unsupervised classification has been performed through SCP in GIS, with the aim to find out a way for the automatic classification of the tratturo. A clustering procedure, which computes the grouping of pixels based on spectral similarity, has been applied in this case. Within the clustering procedure, the isodata method, with 10 iterations

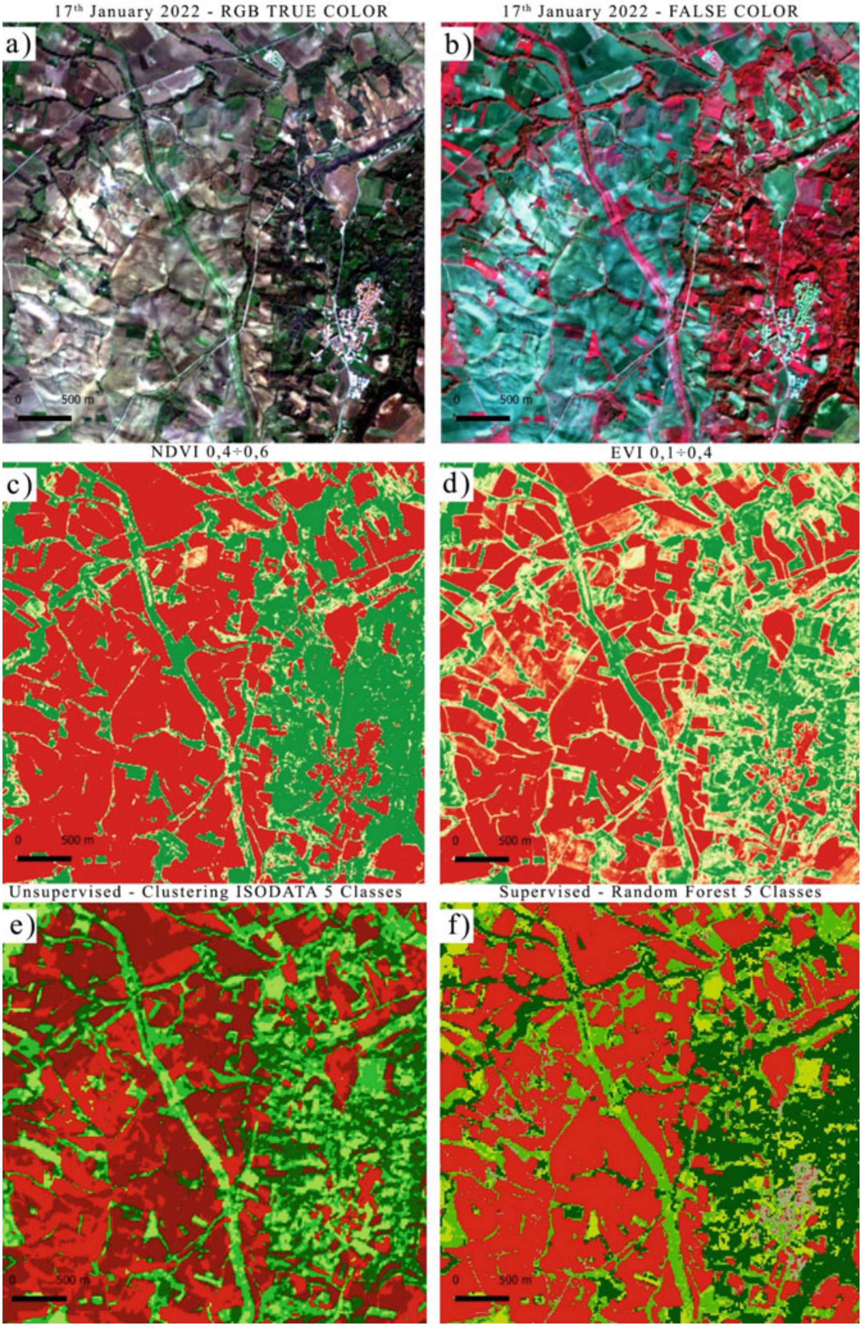

Fig. 5 All images have been carried out by processing Sentinel-2A image of 17th January 2022 into SCP plugin in QGIS. **a** RGB color composite. **b** False color representation which enhances different types of vegetation in the scene. **c** NDVI threshold between 0.4 and 0.6. **d** EVI threshold between 0.1 and 0.4. **e** Unsupervised classification with Clustering method, Isodata 5 land cover classes. **f** Supervised classification with Random Forest method, 5 land cover classes (Editing: A. Scandiffio)

and the recognition of 5 land classes has been performed in this operation. After that, each class has been labelled (tratturo-green up fields, built-up area, 2 types of bare soils, and woodland). The isodata method, more than k-means method, includes additional steps of merging clusters having similar spectral signatures and splitting clusters having too high a variability of spectral signatures [16].

The output of the automatic classification of the clustering procedure is shown in Fig. 5e. This figure shows the linear shape of the tratturo within 3 groups of pixels, and it appears less uniform than VIs method.

3.3 Supervised Classification—Random Forest

The supervised classification methods enable detecting land classes by segmenting the spectral domain into regions, by using geometric segmentation or statistical models [13]. Random Forest (RF) is a particular ML technique, based on the iterative and random creation of decision trees [16]. By using SCP in GIS, RF enables defining land cover classes, by training a model. A training input file has been defined for the study area, by setting 3 Region of Interest (ROI) for each of the 5 searched land classes (tratturo-green up fields, built-up area, 2 types of bare soils, and woodland). The output of the RF model is shown in Fig. 5f. The linear shape of the tratturo has been clearly detected, joined with green-up agricultural fields by RF. The other detected land cover classes, such as woodlands, built-up and bare soils, are clearly separate.

By comparing the outputs, shown in the synoptic table (Fig. 5), carried out by applying VIs, Unsupervised and Supervised classification models, it appears that the RF model is the most suitable tool, for the tratturo recognition by SCP in GIS, due to the capacity to isolate the tratturo, from other objects which are part of the same scene. In fact, both VIs and Clustering methods, enable the detection of tratturo joined with large portions of other land classe (e.g. woodland). However, no one of the presented methods in this chapter seems to be able to detect the tratturo in a unique way. Within this research field, more detailed analysis can be developed in order to measure and compare the mapped surfaces which match the tratturo.

A further work step is presented in the following chapter, with the aim of analyzing not a single image but a series of satellite multispectral imagery by Google Earth Engine (GEE).

4 Machine Learning Methodology by Google Earth Engine

Automatic pattern recognition methodology within an operational context is a widespread practice at the architectural scale, such as Image Segmentation technology [17]. It is much less widespread for the analysis of spatial contexts for a number of reasons, chief among them the complexity of the computation that requires substantial machine resources to perform. Recognition of known features at the territorial scale needs much more complex processing than the same operations performed at the architectural scale. This important limitation can be overcome with the use of an innovative tool as GEE.

GEE is an information technology platform developed by Google and hosted by the Google Cloud Platform. It is designed to process and analyze large amounts of satellite imagery and other geospatial data in order to detect changes, map trends, and quantify differences on the Earth's surface. GEE is a cloud-based platform, so data can be accessed and processed from anywhere in the world, making it easier for researchers to collaborate across continents. GEE has the capacity to store and process petabytes of data, as well as to extract information from satellite imagery at a global scale. It offers a suite of open-source tools for advanced geospatial data analysis, such as classification, feature extraction, and time series analysis. GEE also has the capabilities to integrate data from a variety of sources, including Landsat, MODIS, ASTER, and many other satellites. The platform is used in many scientific fields, from ecology and forestry to climatology and hydrology [18].

The chosen methodology for application to the case study involves the use of a particular feature of GEE, the use of the analysis of a defined temporal window for the recognition of the temporal track. Analyses that are based on the use of satellite data are usually done on only one shot at a time. In the applied methodology, on the contrary, all shots in a defined time frame. The choice of this time frame has been based on the temporal analysis of the period when the tratturo track is more visible in comparison with neighboring terrains (Fig. 4).

GEE code written ad hoc from an already precompiled base [19] allows patterns to be identified within a defined area by supervised classification. The latter allows the recognition of elements of an area as belonging to a given category on the basis of a manual election of areas belonging to that category. Clearly as the number of samples increases the detection will be more precise. For the case study, three families of elements were categorized, the tratturo, green areas and cultivated land.

The operational methodology involves a series of steps leading to the recognition of different portions of the territory. The first step involves map retrieval, which is done automatically by GEE. However, it is necessary to set the type of cartography to be used (Sentinel-2 MSI: MultiSpectral Instrument, Level-2A), the time window within which to extract the data, and the filters applied (e.g., discarding shots on days with cloud cover). The Sentinel satellite system has 11 different bands to choose from to achieve the desired result. The bands Green (B3) Red (B4) and NIR (Near InfraRed B8) were selected. The choice of bands from which to extrapolate data was guided by the composition of most used VIs, such as NDVI, resulting from a formula that includes red and infrared, as shown in Sect. 3.1. It was, finally, checked for consistency between the spatial resolution of all bands, which was 10 m to have the highest possible accuracy in the results.

It was useful for this phase to identify at what times of the year the tratturo is most visible because it is more clearly identifiable than the surrounding land. This particular condition is implemented in the period between November, December and January as it is evident from the previous section. The next stage is the placement of

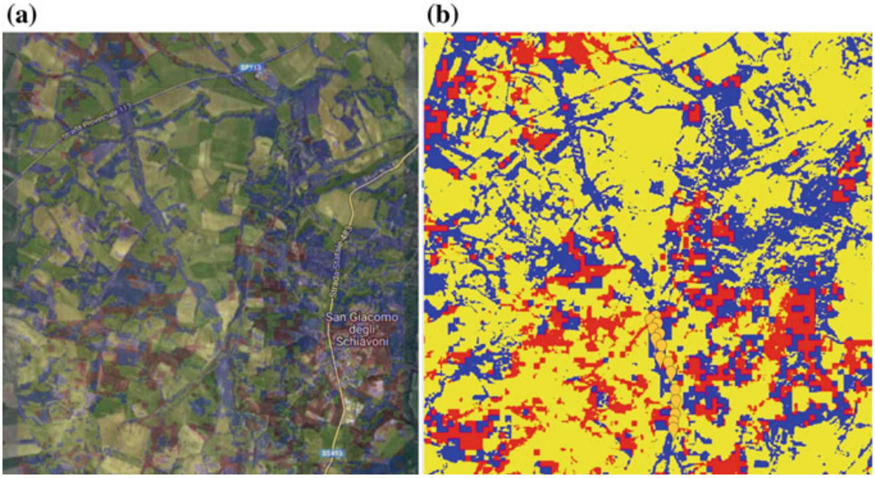

Fig. 6 **a** Supervised recognition with Google Earth Engine applied in the case study area. On the left there is the overlapping procedure result with Google Earth Ortophoto. **b** On the right there are the samples of points which drive the procedure. It is important to note that the points selected only in the southern part of the area form a clearly visible strip within which the tratturo runs from north to south of the box. (Editing: D. D'Uva)

the samples that form the basis for the training database (Fig. 6b). The placement that is done in a manual manner forms the basis of the supervised recognition methodology, as opposed to automatized recognition in which the process is fully automated. Once the pixels belonging to the three families of features are materially selected: the tratturo, green areas and cultivated land, the actual recognition algorithm is triggered which produces the final map in which the tratturo is highlighted. This, superimposed on Google orthophotos (Fig. 6a) allows the effectiveness of the methodology to be evaluated. It is useful to highlight how when a very limited portion of the tratturo is selected, even very distant sections of the track are recognized. The described method for recognizing landscape elements with the artificial intelligence technique provided by GEE allows a tractor-trail to be guessed with a good degree of accuracy. However, the system is flawed in distinguishing the track from all other non-cultivated green areas. To improve this technique, it would be necessary to increase the number of samples to have more accurate recognition.

5 Discussion, Further Developments and Conclusions

The aim of this contribution is to verify the application of image recognition techniques that can help to validate the traditional process of reading and interpretation of a landscape.

Fig. 7 Zenith flight over the case study area carried out with a drone. It is possible to see the difference in resolution showing the detail of the side hedge that characterizes much of the tract. The study of border flora in relation to the trail will be the subject of future research developments (Photo: D'Uva)

In the study case, the process recognizes the visible features on an aerial map, particularly a distinct and continuous line that is approximately 100 m wide, which characterizes a tratturo. In this sense, the procedure therefore supports the detection of the components of the landscape that characterize a tratturo. This is firstly achieved through a visual analysis that emphasizes the unique and prominent features of the tratturo. The techniques described are based on GIS and satellite interpretation integrated with the GEE and can effectively support the interpretation process (Fig. 7).

The work could be further developed by exploit high resolution data acquired through drone technology, that can be used to investigate specific geometric attributes, such as width and alignment to pixels that are aggregated based on their similarity.

For instance, the presence of landscape components such as rows of trees could be used to outline linear geometric objects; similarly, pollen analyses could be used to identify surfaces that are crossed by the path of an ancient tratturo in various ways.

In this case, sediment or soil samples taken along the possible route of the road can be examined to detect the presence of pollen from specific plant species that are typical of the areas crossed by the road. In addition, pollen samples taken directly from the vegetation growing along the road can be analyzed to identify the plant species that characterize the path. These data can then be compared with maps of the distribution of plant species in the region where the tratturo is located in order to identify its position.

With the techniques applied in the recognition of landscape analysis and interpretation, the method, though in the development phase, is not fully matching a correct procedure to uniquely map the features of the landscape crossed by the tratturo. This work should, therefore, be understood as a step within a broader, multidisciplinary research path. The results for both methodologies developed with GIS and GEE are effective in automatically recognizing this landscape component, but it is quite difficult to uniquely differentiate it.

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Author Contributions

Supervision A.R.; Section 3 A.S. Section 4, D.D. Section 1,2,5 by all authors. All authors have read and agreed to the published version of the manuscript.

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AR&AI and Education/Shape Representation

The Importance of GAN Networks in Graphic and Creative Learning Processes Associated with Architecture

María Asunción Salgado de la Rosa, Javier Fco Raposo Grau, and Belén Butragueño Díaz Guerra

1 Introduction

Throughout human history, any technological leap has been viewed as both a threat and an opportunity. The fear of those who sensed endangering their way of life, clashed with the curiosity of those who saw in these advances a new opportunity or simply the construction of a better world. The paradigm shift of our time comes hand in hand of artificial intelligence, a technology that has a huge capacity for transformation.

As with machinery during the industrial revolution, most of the AIs are designed to automate repetitive or tedious tasks where human interaction is not required. The spirit of this approach is to make life easier, allowing faster access to certain services, and looking for more efficient working systems or reducing bureaucracy. The goal of industrial mechanization improve efficiency in production processes. However, AI tries, among other things, to automate decision-making by imitating human thinking, which is not without controversy.

The latest advances in machine learning based on GAN networks (Generative Adversarial Neural Networks) have reached such a high level that, in some fields, they are beginning to match or even surpass human thinking. Deep Learning is a subset of Machine Learning, and within it, GANs constitute a specific type of neural networks. GANs were designed to solve generative models of probability, meaning networks that are trained based on a probability distribution of true or false [1].

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The key to designing this type of network is its training. When it comes to identifying and classifying images, that training must be based on convolutional neural networks, which are a type of network that are part of the GAN. The term convolutional refers to the way the machine identifies an image. We must understand that, for a machine, a photograph is a group of pixels without any meaning.

As human beings, we can move our eyes along an image and recompose the whole in our brain, which is highly trained to recognize images and give them meaning. Just by looking at an image, humans can learn to identify patterns, make associations, and even fill in areas hidden from our vision. An AI needs slower training, or deep learning, based on the systematic contribution of supervised images (which may mean hundreds of thousands or even millions of images) aimed at recognizing a specific pattern of things, as varied as an animal species or a pictorial style.

To give meaning to visual information, AI needs to feed itself through large amounts of labeled data, which allow it to recognize these patterns and specific characteristics of each image. In turn, with each representation learned during its training phase, the AI's convolutional neural networks produce a set of tags that describe the content of the image, allowing it to evolve on its own.

The more complex an image is, the harder it is to identify its labels. If an image is large, the machine must perform a sweep operation, identifying each of the fragments or windows of information until it covers the entirety of the content. These networks require supervised learning based on a large number of tagged images. For this operation, there are some labeling algorithms, but it is usually done manually.

Labeling is nothing more than the categorization of an image, encoded and translated into computer language. Generally, it is a tedious process in which a human assign meaning to each visible segment, either manually or through text analysis techniques associated with the images. The translation of these categorical data into a format that allows automatic recognition can be done through an encoding method called one-hot encoding or by label encoding, both designed to convert categorical data into computer-readable variables. One-hot encoding is an effective coding scheme for tackling classification tasks, as it translates data into a true–false matrix [2]. The result is a sparse matrix, in which each category is a new column, translating the label values into a digital format (1 or 0), which makes it the most widely used method. For each true value (1), many false values (0) are assigned that clearly differentiate the attributes shown in the image. Through these statements of true or false, the machine learns to differentiate the visual content of each file.

Label coding converts categorical data into numbers, so that models can understand the correlation between several variables with different characteristics. It is a simpler method of encoding labels, but also less reliable since some order problems may arise [3]. This happens because some algorithms misinterpret certain numerical values, sorting them based on their number rather than by categories.

Convolutional networks are essential for image identification, which makes them a prerequisite for GANs when training an AI focused on creating graphic results. But in addition to feeding them a lot of labeled data, these networks must learn to self-correct. How is this achieved?

To train the AI, it is necessary to establish a game of opposites between a G model (generative) and a D model (discriminative). Authors such as Goodfellow, Bengio and Courville, have used the simile of comparing model G as a counterfeiter trying to create fake banknotes and model D with the police trying to detect those fake notes [1]. The struggle between both models contributes to improving the methods of falsification and detection, managing to refine the learning itself. This is due to the progress made in that second GAN network, compared to the first one aforementioned. This second network can generate its own examples and offer them to the first network, previously trained, which will judge whether or not the new proposals fit the category required. Like a good teacher, the first network will not only accept or reject the proposals of the second one, but it will explain the possible problems, so they are reviewed and the learning process continues.

In the same way that human beings develop their critical thinking, the machine is in a process of continuous training since each time the generator and the discriminator compete, their skills are improved. It has been proven that, depending on the problem, after a few thousand attempts, the second network is already able to make its own brand-new proposals based on its learning. This opens the door to the generation of original works created by AI, which raises several ethical controversies with undesirable implications such as the proliferation of deepfakes.

2 Deep Learning Applied to Art

But what happens when the training of these AIs is oriented to intrinsically human fields such as artistic creation (music, acting, literature or graphic)?

For just over a year, platforms offering AI for the generation of artistic images from a textual description have become popular. One of the best known is DALL-E 2, which uses a machine learning technology based on GAN networks, to generate original responses by combining known elements described by the user. These are pictorial images arising from the interpretation of a descriptive text both in content and form. In response to the description: Interior space similar to Seagram Building in New York, DALL-E 2 presents a starting image from which up to 4 variations can be requested, (Fig. 1). In a second action, the data related to the final aspect of the same description can be expanded, which will yield a new series of results.

In this way, totally new images can be created by incorporating, eliminating, or replacing any element described, including figures, colors, shadows, or textures, which in turn allows the entire series of proposals to be displayed from the original.

The MidJourney platform got even more interesting results than DALL-E 2 and is presented with a very similar technology but with the ability to produce much larger images (more than a thousand pixels on its smaller side) and with a greater level of detail. In mid-2022, MidJourney became very popular when news broke that an image generated using this AI had won the annual Colorado State Fair art contest. Its author, Jason M. Allen, presented a work entitled Théâtre D'Opéra Spatial [4], a hyper-realistic representation of a theatrical scene of fantastic atmosphere,

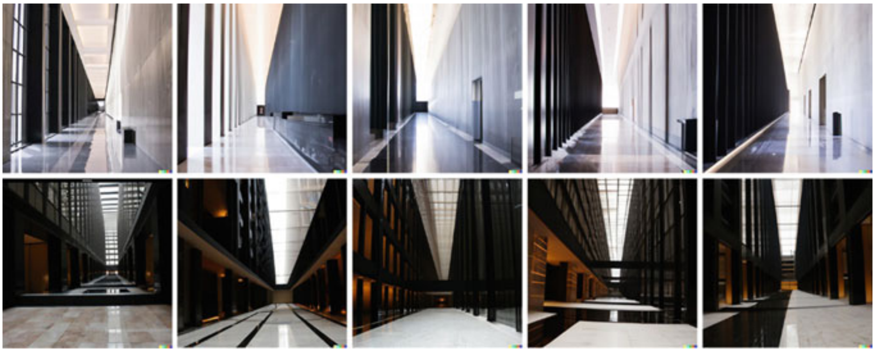

Fig. 1 Different variations made on DALL-E 2 from the description: Interior similar to Seagram Building in New York, 2023 (*Source* M. A. Salgado de la Rosa)

with which he won the award in the modality of emerging digital art (Fig. 2). The controversy was served since, in the opinion of some artists, this working system could be considered cheating since said image was not generated by the author from the composition of other images or forms but through a description typed in a text box.

In addition, the creative system of these images depends to a large extent on the data that has been provided to the AI which, in the opinion of many artists, collides with copyright. On ArtStation, one of the largest art networks on the internet, many

Fig. 2 Jason M. Allen. Théâtre D'Opéra Spatial, 2022 (*Source* Jason M. Allen)

authors have denounced that the fusion through which the proposals are elaborated on platforms such as MidJourney is fed by pieces developed by humans who are not valued, much less paid for their originals, even though these illustrations made by AI are being commercialized.

To make this issue visible, some users have even shared a capture of how one of these engines has left pieces of the human artist's signature by merging different backgrounds and elements to make the final illustration [5]. The issue of copyright is very complex, and jurisprudence varies from country to country. On the other hand, the use and transformation of original images to develop new ones is protected by law when it's considered fair use, but it does not necessarily mean that this issue has been considered by the developers of platforms such as MidJourney or DALL-E 2 from an ethical perspective.

This problematic has caused many voices to be raised predicting the end of art. Others have limited themselves to comparing this fact as a paradigm shift and it may require adjustment, as it occurred in the past with the invention of photography.

In reality, it all depends on the use we want to give to the technology. MidJourney is not perfect, it does not generate great images at first, since it depends on the amount of descriptive data that we enter. The most interesting aspect is that the program can spontaneously provide up to four variations on the first image generated, if requested. Appropriately, this tool could be used as part of the creative process, with no obligation to accept its proposals as final solutions.

Dream Painter is an AI capable of creating unique drawings in real-time. Other AIs, like AICAN, bet on a machine learning model that, in addition to images, introduces data related to different styles and artistic aesthetics so that the machine can create its own proposals. According to its designers, they created the algorithm based on GAN networks, following the theory of psychologist Colin Martindale. That theory seeks the originality of works by deliberately rejecting those themes, styles, or even forms that are familiar to the public [6]. This strategy tries to arouse curiosity and capture attention through a novel contribution. Unlike other AIs, a series of specific images was not chosen to teach the styles to the machine. On the contrary, the algorithm was fed with 80,000 images representative of the Western artistic canon of the last five centuries, like an express course in art history.

Other applications such as The Next Rembrandt, created by J. Walter Thompson in collaboration with ING Bank of Amsterdam and The Culture Collective, offer a study model of the combination of facial recognition technology with the study of the painter's images to create Rembrandt-style prints [7]. It is a multidisciplinary research project that, in addition to gathering knowledge about the painter's work, aimed to illustrate the capacity of an AI, when fed with the right data. In this case, the images of the 346 known works of the Dutch painter were analyzed, identifying more than 60 points in common that allowed to align any face with the face of the images made by Rembrandt [8] (Fig. 3).

To limit the error in the development of this new work, they narrowed down the motif to a portrait of a male (most of Rembrandt's works are male portraits), white, middle-aged, with facial hair, hat, dark clothes and white collar according to the fashion of the time and posing with his face turned to the right [9].

Fig. 3 Walter Thompson. The next Rembrandt. Data analysis and image printing, 2016 (*Source* ING and www.nextrembrandt.com)

This AI intended to give value to basic research and the collection of precise data associated, in this case, with the work of a painter, through the artificial creation of a new work executed with the same expertise as Rembrandt himself. In the presentation of the project, a 3D printer reproduced the first portrait, imitating even the relief of the author's brushstrokes, and obtained more than 10 million print copies on Twitter, which increased the listing value of the participating companies. This project was initially launched with no economic pretension, but it obtained more than 1,800 million print copies valued at 12.5 million euros.

The question that arises at this point is whether an AI can create original images without resorting to fragments or layers of previous images. The answer lies in the training model received. In theory, the greater the variety of data, the greater the propositional capacity that will teach the AI how to generate new and unique images. It will also depend on the need of each AI system for initial guidelines from a user, since that will limit its ability to propose absolutely novel results apart from any human intervention.

In fact, this capacity is what has allowed the generation of non-figurative artistic images through GAN networks. In theory, a neural network will be able to create its own proposals over time, if it is trained to generate images that resemble a set of reference images (taken from a large database that includes abstract and non-figurative art) and at the same time, it faces the discriminating neural network that determines whether it is an original proposal or is like those on the database. Through the repetition of these processes, the generating network will learn to create its own abstract compositions in line with those of the database, but without the need to extract elements from them. López de Mántaras states that, despite this fact, artificial intelligence has limits compared to the more versatile human intelligence, as it lacks common sense and understanding of the world [10].

The question of whether an image generated by GAN has artistic value remains unresolved. This debate is also unclear in relation to productions made by human beings. As we know, the artistic value of a work does not depend on a single factor; there is a historical and social context with many variants. There exists controversy both over the artistic value of a work generated by an AI and the identification of its authorship, especially due to the published news that the U.S. Copyright Office rejected Allen's artwork Théâtre D'Opéra Spatial copyright registration, alleging that "the deposit does not contain any human authorship" [11].

Although this multitude of factors could be applied to the images generated by GAN, it is difficult for us to assume that a machine can replace human beings in activities that cannot always be explained rationally, perhaps because there is still great ignorance about how an AI really works.

Ultimately, AI only shows intelligent behavior in a very specific area and does not consider other factors that a human being would. This ability is what differentiates weak AI from strong AI, as defined by the philosopher John Searle [12]. According to this classification, weak AI would satisfy specific tasks, even better than people, as long as they involve looking for solutions to logical formulas with many variables or any other aspect related to decision-making. However, strong AI is currently impossible since it would imply that the machine does not simulate a brain but becomes a brain, something that according to the criteria raised by Turing, would make it indistinguishable from a human [13]. According to López de Mántaras, to reach that point, it would be necessary to design systems capable of integrating developments in many areas of AI, taking into account that "the most complicated capabilities to achieve are those that require interacting with environments that are not restricted or previously prepared" [12].

3 The Use of AI in Architecture Design Processes

At this point we wonder if an AI could replace architects in the creation of spaces.

Fortunately, architecture is a highly creative discipline that requires the interaction of knowledge from different fields. The work of architects is closely linked to the world of artistic creation but also to the technical one, so any tool that allows a reduction of the workload will always be welcome.

At the end of the twentieth century, the work of architects underwent a radical transformation with the arrival of the digital world. A technological change that spanned from the design phase to the production phase filling "practically the entire world of architecture; there is no professional office in which all information is not drawn or otherwise managed" [14].

We can affirm that the digital evolution of the last decades in this field is fully incorporated to the daily dynamics of an office. There are three-dimensional modeling tools that allow the complete visualization of architecture and all its details. There is also an increasingly widespread use of Virtual and Augmented Reality in project presentations (Fig. 4). In addition, the analysis and simulation tools help anticipate future scenarios, (in anticipation of their environmental impact in line with sustainability requirements). Finally, there is new technology that allows the automation of processes. In all, we can affirm that all these tools are focused on optimizing the time and costs of the development process and not on replacing the work of the architect.

To understand the difference between a technology based on Generative Design or Machine Learning and those based on process automation such as parametric or computational design, it is necessary to understand the operation of each of them depending on their field of application. In the case of parametric or computational

Fig. 4 Virtual Reality and Augmented Reality Technologies applied to architecture. Photocomposition, 2023 (*Source* M. A. Salgado de la Rosa)

design technologies, its programming is based on the definition of a series of parameters set by the user, which, according to the programming of the set of geometric rules that generate it, yields one solution or another.

As a general rule, these are simple inputs in controlled environments, since their main limitation is that the starting conditions conform to the rules defined by their algorithm. This type of programming does not have the capacity to respond to the multiplicity of variables that architecture handles in the real world.

For this reason, users of parametric modeling do not usually look for finalist proposals, but for results oriented towards decision-making by the architect. Instead of creating static three-dimensional elements, parametric modeling allows you to specify relationships and dependencies between different elements of the model. This allows architects to make informed decisions, being able to experiment with different design choices more efficiently. There are several parametric design applications that are frequently used by architects such as Vectorworks (that includes some parametric modeling functionalities), Grasshopper (a parametric design plug-in for Rhino), ArchiCAD BIM modeling or Revit and Dynamo (a visual parametric modeling software that allows users to create dynamic models and experiment with different design options), (Fig. 5).

Data visualization and analysis tools can help you make informed decisions about any aspect that affects the space you are designing. In general, it is an essential informative tool for any professional who needs to collect, organize, and analyze a large amount of information about climate, demographics, or social behaviors, to help them make decisions prior to the realization of the project.

An example of these is Baywatch, an application to manage the information contained in different Revit models that acts as a quality control tool, allowing the

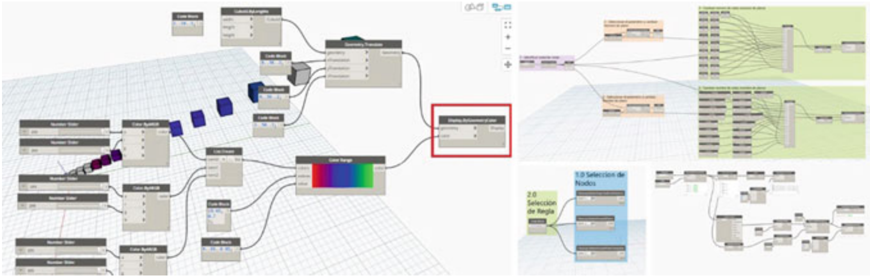

Fig. 5 Developments for the Final Master's Project of students of the Master in BIM methodology and management (ETSAM, Polytechnic University of Madrid). Different Dynamo displays. Change of the views name. Cleaning, references, imports, 2022 (*Source* J. F. Raposo Grau)

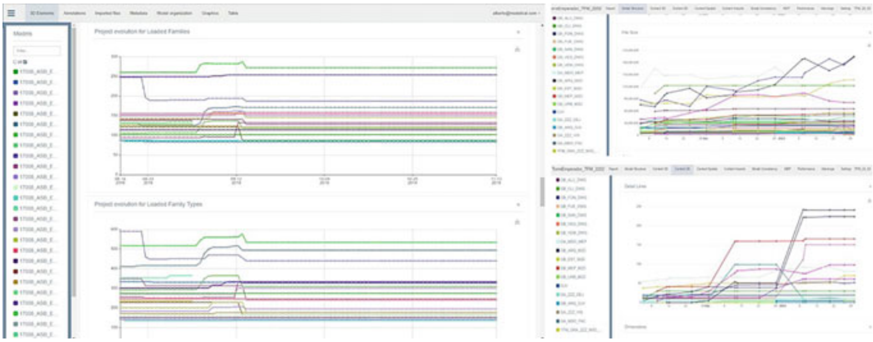

Fig. 6 Developments for the Final Master's Project of students of the Master in BIM methodology and management (ETSAM, Polytechnic University of Madrid). Different Baywatch displays. Cleaning, imports, references, 2022 (*Source* J. F. Raposo Grau)

user to detect problems in their models such as growth in the number of warnings, types of lines or families without needing to access them manually, (Fig. 6).

Automatic design generation systems, parametric modeling, data visualization, simulations or automated calculations, require algorithmic programming that responds to another kind of Generative AI (such as Transformer-Based Models or Variational AutoEncoders).

The Generative Design, on the other hand, is based on a technology of evolutionary algorithms, which adjusts the input parameters that help to meet the objectives, optimizing the design they assist. In this case, the architect is in charge of setting the initial parameters and limitations, allowing the system to optimize the process in order to offer various solutions tailored to the requirements or to show the evolution of a model according to environmental conditions. It´s a tool which requires the participation of the architect at the beginning and at the end of the process, for better decision making.

Simulation tools use a specialized type of software to create virtual models of architectural projects. Thanks to these virtual models, architects can recreate different circumstances that may occur during the construction process, such as the behavior of materials, construction phases, workflow or the number of resources required. It is a program that uses optimization algorithms and machine learning to analyze and simulate different construction options and find the best possible solution. In general, simulation tools exemplify a beneficial use of AI, since it allows architects and construction professionals a more efficient and safe planning and execution of projects, without giving up an author design.

Finally, the tools that allow the automation of calculations, also rely on machine learning algorithms and advanced mathematics, to perform complex and tedious calculations necessary in the project design process. Thanks to this automation, it has been possible to identify certain patterns and trends in the data, which went unnoticed by other analysis systems.

As we can see, the presence of AI in the development of architectural projects is a reality with more lights than shadows. For the most part, it is a technology designed to accompany the architect in his work, improving his conditions and making him more efficient. Nonetheless, current technology allows us to go further.

Automatic design generation systems already make use of deep learning to create proposals based on certain user preferences and restrictions. These are systems whose algorithms generate alternatives from a primary solution through an iterative process. Then, that solution is optimized based on the preferences of the user. Platforms like Higharc promise custom home designs without the need for an architect, which they consider a saving factor [15]. However, reality is not as flexible as it promises, since it always starts from a standard scheme but then offers the possibility of visualizing transformations in real-time, such as dimensions, spatial distribution, or orientation.

Not all technologies that respond to the Generative AI model use machine learning GAN networks. That does not mean that this technology cannot be applied to some of the aforementioned solutions. In fact, there are some initiatives underway that investigate ways to use GAN networks to generate images and representations of buildings that are not definitive as of today but still relevant.

The main leap that occurs when we introduce Machine Learning processes to generative design, is the fact that technology is no longer applied to help develop a process, but rather evolves and learns to offer an open-ended result. As data is fed into the system, the AI will provide its own conclusions.

To face a design problem, a Generative AI based on GAN networks must be fed with a huge amount of data that, in the case of architecture, corresponds to geometric, formal and technical elements of different kinds. The definition of these data sources is key when it comes to making the results of the designs more flexible, which in the case of a reduced set of parameters, will yield more closed and rigid results. This is the reason why platforms like ARCHITEChTURES are based on a series of databases containing geometries and abstract relationships instead of previously formalized construction units. The application is presented as a disruptive tool called to revolutionize residential design, based on the premise of designing "better buildings faster with AI" [16].

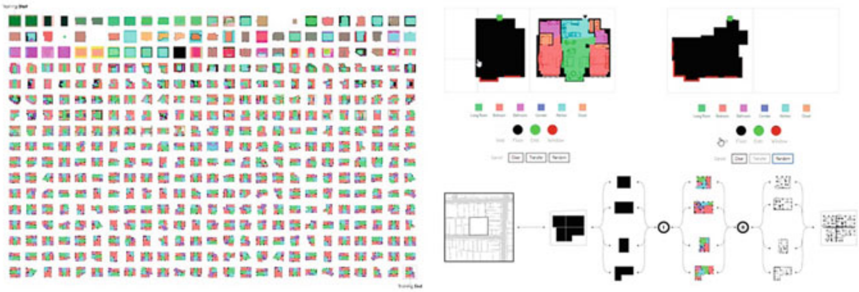

Fig. 7 Stanislas Chaillou. AI project based on GAN networks for the design of architectural plans towards a new approache, 2019 (*Source* S. Chaillou)

Other works, such as the one presented a few years ago at Harvard University by Stanislas Chaillou, propose a methodology for the complete generation of architectural plans through GAN networks. It has been proven that this kind of development based on GAN works very well when applied to the two-dimensional generation of information, which makes it ideal for the generation of architectural plans. His goal when training this AI was to generate a large number of plan designs, label them, and allow the user to navigate through those design options. Through two antagonistic networks, the new plan solutions created by the generative network from a collection of given images were reviewed by the discriminating network [17]. We observe that the generative GAN progressively learns how to design spaces for housing units during a 36-h training sequence, taking advantage of a closed feedback loop between the two networks, (Fig. 7).

The result is an AI capable of generating moderately coherent designs, although just as limited as those offered by the Higharc platform, but it is only the beginning. To this day, platforms such as ARCHITEChTURES promise to shortly present a tool for real-time energy analysis based on the same technology.

4 Conclusions

As in other fields, there is a real risk that architects end up being replaced by a machine, despite developing a complex and highly creative job. Without disdaining the achievements of any of the AIs mentioned above, we are still far from a scenario in which a machine can completely replace the human role in architecture, given the complexity of the architectural fact; but that does not mean that this would not happen if it was technologically feasible. The probability of this happening will depend on the development of machine learning technology based on GAN networks and on the value that society gives to the architects and the result of their work.

It does not seem that, today, artificial intelligence constitutes an imminent threat to architects, but a tool that has become essential to guarantee efficiency in their work. However, there are several companies and research groups that are exploring ways to implement the processes associated with architectural design, using machine learning technologies based on GAN networks. These include institutions such as the MIT Media Lab or the University of Waterloo in Canada, that has created the Artificial Intelligent Institute, fully dedicated to developing technologies based on neural networks. Other technology companies such as NVIDIA or architecture offices such as Foster + Partners, have funded projects that investigate new technological applications based on GAN networks focused on architecture.

Some AIs, such as the one designed by Stanislas Chaillou or the Higharc application, can generate moderately coherent designs, although they are very limited in creative and architectural quality. However, the solutions that can be generated by AI like ARCHITEChTURES, are more flexible and varied, which in turn opens the possibility for a presumable elimination of human decisions in the elaboration of economically non-competitive models.

With the current capacity of generative networks, it is expected that within a reasonable period of time, hybrid systems can be generated, combining the advantages of those AIs capable of reasoning based on knowledge, with those based on a large amount of stored data. As AI incorporates relationships with unbounded environments, it will become more involved in the design processes of the architecture. This technology could be used to improve the efficiency and quality of architects' designs, but it could also kill the work of small studios, which will no longer be competitive for private clients.

Somehow, it is already intuited that some of the concepts that are already handled such as Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR) and Machine Learning, can be used in the development of artificial intelligence to replace human designers in the genesis of virtual spaces for video game environments or in the metaverse.

Now, some of these AI technologies are already being used during the process of defining and building architecture, which can be improved over time to automate building design processes. These AIs include automatic design generation systems, which use algorithms or technology based on neural networks to create designs from user constraints and preferences.

As knowledge advances in the field of machine learning based on GAN networks, new applications will emerge that offer the possibility of generating all kinds of creative content associated with architecture. The extent to which these applications can completely replace human creativity will depend on advances in AI training and learning processes.

Humans and machines have different skills and limitations; hence, the learning processes must be different. The machines are trained by exposing themselves to a huge amount of data implemented thanks to the feedback they receive from machine learning algorithms based on neural networks. Humans, on the other hand, acquire their knowledge through observation, practice, imitation, experience, and trial and error processes. This makes us think that, to some extent, machines can be taught to behave similarly to humans through machine learning techniques.

However, these techniques are currently limited, and there are still many aspects of human behavior that machines cannot fully imitate. Many of the supposedly creative abilities offered by some of these applications are not actually creative since they ignore some transcendental aspects that are crucial in creative processes and that differentiate architecture from a mere construction.

It is important to note that artificial intelligence and machine learning are constantly evolving disciplines. It is possible that in the future, machines may learn to behave more similarly to humans. However, we are still far from completely replacing human decision-making when imagination is required.

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Experimentation of a Web Database for Augmented Reality Apps: The Case Study of Ruled Geometries

Alessandro Martinelli, Thomas Guido Comunian, Veronica Fazzina, and Simone Porro

1 Introduction

Augmented Reality is now well suited to teaching, as an auxiliary tool in different fields, as engineering, chemistry, medicine, and including geometry and the study of architectural forms. In the latter area, the state of research offers ample opportunity for in-depth study, as well as the spread of immersive tools in the national academic and cultural overview. Added to this is the current difficulty in finding advanced models and information in open source spaces, which can be assets (models that make up the contents of software) for apps with educational features. Therefore, the study intends to propose and experiment with a useful content base in the form of a website, an information aggregator that can be easily linked and able to feed itself through the users, aimed at visualizing three-dimensional geometries and comparing them with existing architectures. Through this process of experimentation, we can carry out a selection of the case study geometries, the ruled surfaces, are propose various methods of communication between users and websites for data transfer, and the issue of the digitalization of 3d models is addressed, catalogued in order to provide a digital archive useful for app development.

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2 State of the Art

2.1 Geometries

The ruleds, those surfaces described by the movement of a straight line in space, represent a complex section of three-dimensional geometry, for the many properties they have and for their application in architecture and design.

A fundamental characteristic of their genesis is the fact that they are always led by three leaders, who guide the movement of the generator line, which in turn generates the rift. The guidelines can be curves, straight lines, or improper lines (director planes), and the combinations of these three types give rise to a wide variety of surfaces, with specific properties and are sometimes recognizable in other families of geometry, such as quadrics or cubics, and this fact has forstered the interest in these surfaces, in history of design. That interest is shown by the many applications that the ruleds have found and still find today, in the field of architecture and design, just considering the use of these surfaces in the science of cutting stones (stereotomy), in the construction of gears, or in the realization of helical staircases and ramps [1]. Ruled surfaces have been studied by many mathematicians, but their systematization, in the form in which we know them today, is due to Gaspard Monge, who described their properties in *Geometrie Descriptive* [2], and in several other memoirs published during the years of his teaching at the Ecole Politecnique, and is due the contributions of the students of his school too, as Jean Nicolas Pier-re Hachette, author of significant works such as *Traité de géométrie descriptive* [3], in addition to other memories of those years. The study of surfaces was approached by Monge and his students by combining the synthetic description of the form with the analytical one. At the turn of the nineteenth and twentieth centuries, the synthetic approach to the study of ruled surfaces was reflected in the contributions of several mathematicians such as Otto Wilhelm Fiedler [4], Michel Chasles [5], and Gino Fano [6], well as many other.

Today, the introduction of new methods of digital representation offers renewed opportunities for experimentation on form through the synthetic method [7], operating in virtual space, and showing geometric properties with new declinations. One of these, in fact, is augmented reality, which still offers much material for the study of surfaces, although it still operates on an approximate display of the shapes (expressed by a finite number of viewable meshes), therefore many potentially interesting features are not sufficiently deepened or disclosed, making them less known and sometimes difficult to understand. Moreover, the cataloging of ruled surfaces is now consolidated and established in a theoretical-literary form [8] but has not yet achieved a communicative evolution in a digital or immersive environment, and it is on this point that virtual archives can contribute.

2.2 Immersive Visualization

Since the first experiments on immersive reality, we can identify the factors that most contribute to effective communication, including today we recognize the sensory experience, which is maximized thanks to various devices, such as the completion of perceptual impact with tactile inputs, the masking of artifacts such as targets, or multimodal feedback such as vibrations and sounds [9]. Despite these insights, the immersive factor is difficult to define concretely, but today remains a fundamental principle in many professional and non-professional fields [10], from the more generic visualization of data [11], to disciplines such as marketing, finance, healthcare, physics, engineering, up to architecture and education [12].

It is therefore no coincidence that many studies have confirmed the advantages of immersive access, useful for laboratory environments typical on architectural design, that can reduce loads of study and instrumentation [13]. But, if on the one hand is recognized to these a didactic effectiveness, on the other, the devices themselves involve various implications and challenges, starting from their learning, to the commitment to show them [14] or, again, the motivational and emotional load that they involve with the perceptual experience, which certainly requires further investigation [15]: this makes the development of virtual environments a multidisciplinary work [16] that with the width of the users base also increases its criticality. It is therefore the training field that receives the greatest benefits from this new media [17, 17], both for the large amount of specialist information [19], and, in more restricted cases, for the representation of forms at the level of primary education [20]. The geometries tested with positive results, in fact, go from the two-dimensional ones (although the AR appears as an optimized tool for 3D visualization) [21], to the more complex three-dimensional mathematical forms, although immersive functionality is still considered poor in design tools, advanced interactions, or interdisciplinary (e.g., communication to BIM exists only in experimental cases). And that's why research is moving in that direction [22].

Moreover, Augmented Reality, beyond the educational sector, is effectively suitable for the representative cases of problem-solving, since the basic and unique forms of elementary geometry are effective both for a general decrease in mental workload [23], and for the simplified learning proposed in universal design [24], where the playful aspect covers a fundamental and profitable character [25]. As for how these forms are presented, the standard lies in predefined static models, but sometimes the parametric system is also used for a more controlled and defined visualization, although it is necessarily restricted to specific experimental forms [23].

Augmented Reality is therefore a medium with a high expressive potential also in the geometric field, and its combination with the archives of easily accessible shapes could make easier and faster the diffusion of this knowledge. In this context, the research aims to fill its needs and observe its potential.

3 Experiments-Trials-Testing

In order to meet the needs identified, the testing of a website that can act as open-source content support for Augmented Reality Apps has been started.

The website creation platform used is https: wix.com, and the address chosen for the web experimentation is https://researchdatatry.wixsite.com/datatry (Fig. 1).

The site had to offer enough space for uploading, a layout containing information data on geometry and the availability of downloads in various formats and in various 2D and 3D previews.

The development process was divided into several phases, starting first from the choice of a sample content of geometric type, which has been identified in the web cataloging of ruled surfaces (Fig. 2). The classification adopted for the archiving and presentation of the models derives from a hierarchization of the geometries inspired by the work of Gino Fano in the collection *Lessons of Descriptive Geometry at the R. Politecnico di Torino* [5], in which he proposes a basic classification of the ruled surfaces, based on the combinations of directrixes:

Ruled with a straight line:

- *Biais passé.*
- Triangular thread screw.
- Director plan ruleds.

Ruled with two straight lines:

- Rectangular thread screw.
- The surface of the entrance vault of a round tower (similar to the generic conoidal surfaces).

Ruled with three straight lines:

- Striped quadrics.

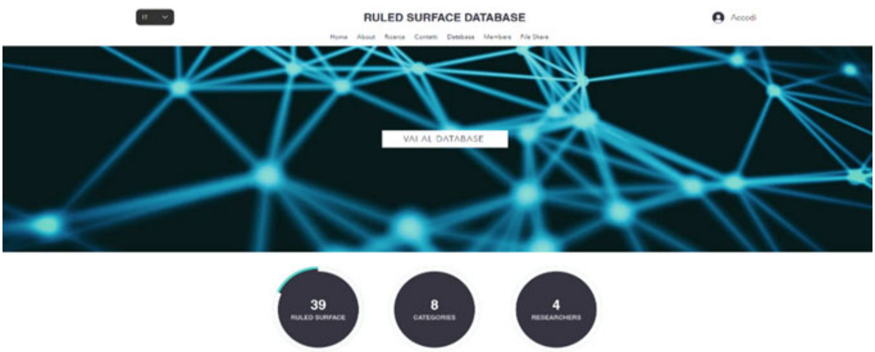

Fig. 1 Home page of the website https://researchdatatry.wixsite.com/datatry, the database containing the ruled geometries (Webmasters: T. G. Comunian and S. Porro)

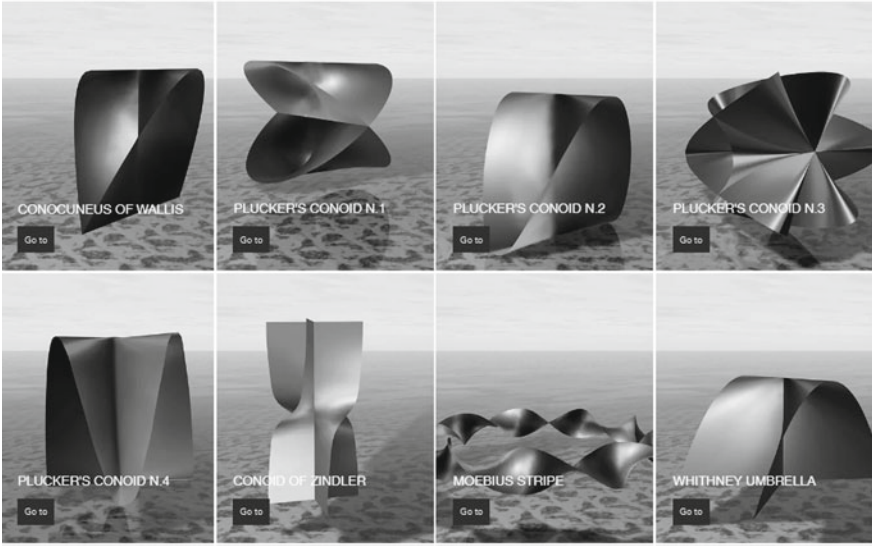

Fig. 2 Images of ruled geometries included in the database of the web site (modeling and AR: Alessandro Martinelli; webmasters: T. G. Comunian and S. Porro)

An extensive survey was therefore carried out aimed at building an implementable repertoire of models, capable of describing the relationships that exist between the different combinations of directrices and the final shape of the surfaces in space. These models can show some notable properties of the lines, such as the genesis, the degree, the Gaussian curvature, the symmetries, and the implications that these have in applications to real models.

Starting from this selection of geometries, the results were compared with particularly significant modern contributions such as those by Krivoshapko and Ivanov [8], and later by I.A. Mamieva [26] in a classification of over 50 types of ruled surfaces divided by Gaussian curvature and other properties which, however, unlike the hypothesis assumed in this research, are oriented more on the section profiles of the shapes to distinguish their classes, and less on the genesis through the combination of guidelines.

Therefore, together with this contribution and in the context of a broader research on ruled surfaces, the following classification into five categories is hypothesized:

- Generic ruled surfaces (three curved lines).
- Cylindroid (two curved and one straight directrix, proper or improper).
- Conoidal surfaces (one curved and two straight directors, one of which is proper or improper).
- Quadrics ruled (three straight lines, one of which is proper or improper).
- Planes (two directorial planes and a straight line, proper or improper).

This last category is still the subject of debate today [27, 28], as it is of less interest than the more complex morphologies of the ruled surfaces but is included in the framework for greater completeness.

This division is therefore derived from that of Fano, and contemplates every possible combination of directrices, since being three different types they can be approached in 10 different combinations, which in turn depend on the positions of the curves, branching the repertoire into a complex and articulated variety.

For each category, the 3d models of the ruled surfaces included in the web database have been loaded in alphabetical order, and consist of the following typologies: Quadric cylinder, Cylinder, Director plan cylindroid, Generic conoidal surface, Developable tangent, Open generic cylinder, Generic closed cylindroid, Generic cone, Quadric cone, Conocuneus of Wallis, Plucker's conoid n = 1, Plucker's conoid n = 2, Plucker's conoid n = 3, Plucker's conoid n = 4, Conoid of Zindler, Möbius strip, Whitney umbrella, Seifert Surfaces Double Ring, Seifert Surface two-edge knot, Moebius Surface, Cayley Ruled surface, Conocuneus, Parabolic conoid, Hyperbolic paraboloid, Normal helicoid open, Open oblique helicoid, Closed oblique helicoid, Right helicoid, Developable helicoid, Sinusoidal conoid, Guimard surface, Milk carton, Oloid, Sphericon, Collar surface, Hyperboloid one flap, Generic conoidal Surface, Cayley ruled surface, Developable tangent [29].

Secondly, as a result of the type of data that has been chosen to be stored on the web and also in function of the diffusion and communication purpose, we chose the type of web platform or website best suited and we identified a template that was suitable for communication and archival purposes, but still simple to use. Thanks to its versatility, although still in the testing phase, the platform can be used both via mobile app and through an ordinary Internet connection made with a personal computer. Figure 2 shows some of the ruled geometries on the page currently loaded on the website.

The research therefore focused on the potential technical and informative contribution that a geometric database can offer, and three main kinds of use that the members can have with the archive site have been implemented.

3.1 Direct Download

The first mode of use is the direct download of the models from the website, after accessing to the archive via login. In view of a possible use in augmented reality, 3D preview display modules have been added. This solution leaves the user room to load into their graphics engine all the models they want in the modes they prefer, defining themselves the user experience of their mobile App. In order to fully test the process, the downloadable clay models, free of assigned materials or textures, will be applied later in the design of an app in Augmented Reality classically set (whose target sparks the appearance of models and the consultation of their properties).

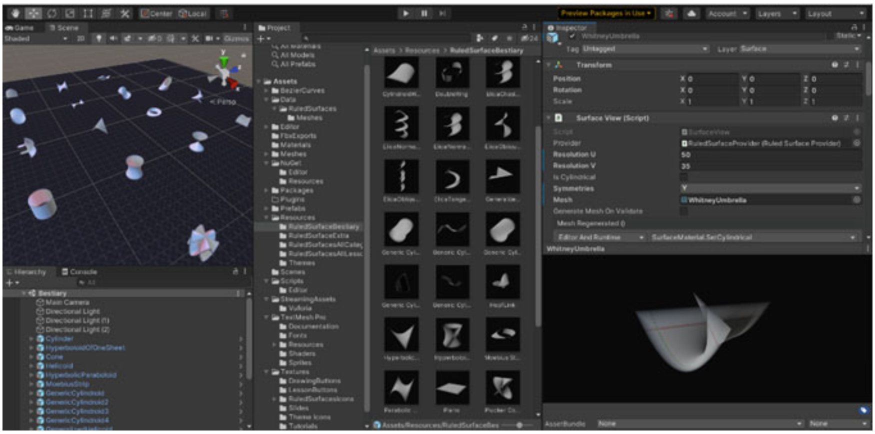

Fig. 3 Example of inserting shapes in the app, using the Unity graphic engine (Webmasters: T. G. Comunian and S. Porro)

Within the same research, the models submitted are configured to have shape, weight, center and axes suitable for a functional and effective immersive use (Figs. 3 and 4).

3.2 Download by Link to the Launched App

As an alternative to direct download, it will be possible to provide the models stored through a direct link to the app launched (Fig. 5), so that you can reduce loading and processing times and especially in order to lighten the size of the application files that will not have to load the data of all the geometries simultaneously.

For the developed app to obtain real-time web database models during use, it will be necessary to obtain an authorization token from the site itself by creating a specific account with access privileges, such that later in the game just it will launch a request to the site, which will respond by sending the models. In case the database has a login system, it will be necessary to verify that the library has a public API, not restricted to manual use of the web interface, and that it is also accessible through requests.

It is important, however, that the models are accompanied by the information attached to them (e.g. definition, properties, history, equations), and this is expressed by a JSON text file format, widely preferable to the download of the simple model. Through this feature, it will also be possible to filter the information to be downloaded, such as definitions only, or alternatively, only a certain category of geometry, keeping the communicative compartment light and customized.

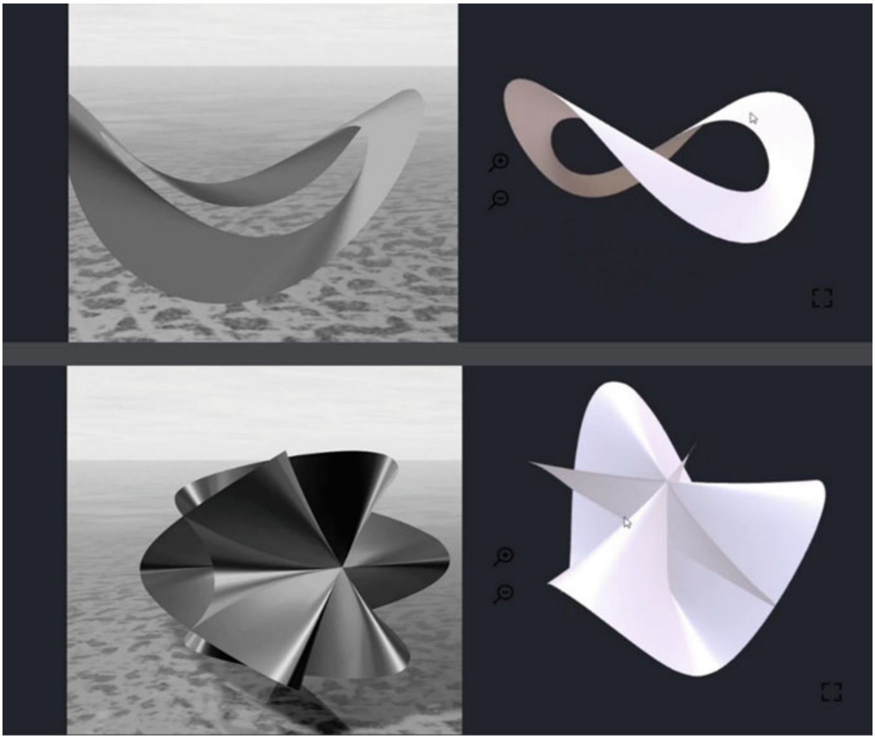

Fig. 4 Web page preview with direct download option (Modelling and AR: A. Martinelli)

Fig. 5 Example of inserting shapes in the app, using the Unity graphic engine (Modelling and AR: A. Martinelli)

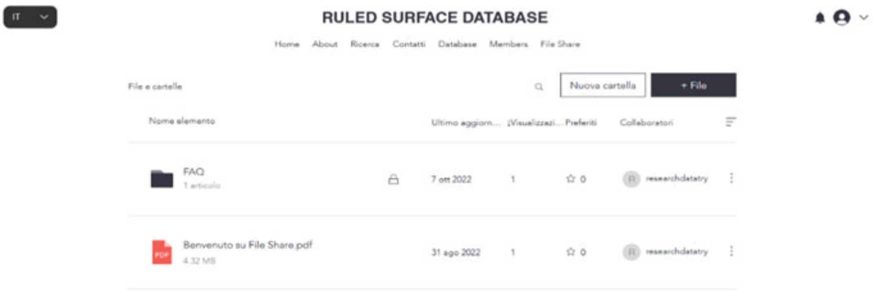

Fig. 6 View of the file sharing page (Webmasters: T. G. Comunian and S. Porro)

3.3 Model Uploading

An alternative use of the online database is the possibility to load models by the user (Fig. 6). This operation can in turn be carried out in two modes, which consist in the manual upload on the web, or in the loading through app in case the latter can produce or search for innovative or experimental data.

In both cases, the qualification of an authorized user to upload models through verified accounts is required. In case you configure a direct connection with authentication, as indicated above between web-database and app, the digital archive would not need to have continuous checks and maintenance. This mode of operation would therefore represent the greatest advantage that a digital archive site could offer, in order to encourage the exchange of information and teaching material, currently in transition to immersive reality.

4 Potentialities

Any prediction on the potentialities offered by the web database object of this experimental research may seem limiting, for many reasons, such as the rapid evolution of software languages in the computer field, the wide possibilities of implementation of web platforms and the wide panorama of applications. However, given the scope of this study, which is aimed at addressing issues strictly related to geometric shapes made in the digital environment and, specifically, issues such as the cataloging and storage of 3D virtualization web, it is possible in any case to outline a main purpose of the platform and to assume some of the potential developments that embrace themes of geometric representation, but at the same time different branches of research.

The web database was mainly created with a discloser function, and, as such, the platform could be further developed, firstly by the reference or the link to other websites and digital platforms or mobile apps that have as object the study of the mathematical surfaces and the geometry, strengthening and completing the educational aspect thanks to the virtualizations 3D. The web database offers the opportunity not only to enjoy the data in terms of visualization and download of geometric patterns of ruled geometries, but also in terms of loading three-dimensional objects and proposals for integrations designed to implement the elements already present, through the interaction between competent users on the themes of the site, and external users such as regularly registered researchers and experts. The creation of a forum-debate to develop new themes of study and disclosure is also a further form of sharing and disclosure itself. The creation of a section dedicated to further develop other topics in more depth, comparing typologies with architecture. A further study could be made through the use of a parametric application able to manage in real time the variations of complex surfaces. It could also improve the lightness and agility of the site through shared cloud spaces.

Finally, an interesting potential of this communicative expansion consists in the applicability to new visualization technologies such as the metaverse, a concept recently distinguished as a possible evolution of the internet and digital fruition. The term does not actually indicate a specific technology, and is very relative to social and cultural interpretations: it can mean the physiological convergence of digital technologies towards the use of immersive systems, These include some explorable virtual environments, such as Decentraland, Sandbox, or Axie Infinity. Among the various types of assets and avatars that can populate this digital universe, certainly the models described in the database can offer useful ideas of content, making its visualization even more immediate, filling further gaps in the knowledge of the form.

5 Conclusions

The web database object of this research study, containing the three-dimensional ruled geometries, is configured as an online platform with an intuitive interface and practical use, which fully fulfills the main purpose set out in a strictly informative orientation in the digital web of the issues dealt with. The more complex aspects of the geometries collected in the database are made easier to understand, thanks also to the immersive viewing mode and the easy consultation of the app.

The opportunities offered by the site are diversified and designed to be very much implemented also through the contribution of external inputs, for which a special section has been provided that allows the continuous implementation by a network of collaborators and can be extended to further case studies in the field of geometry.

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Design and Modeling Atelier: Interaction of Physical and Virtual Models for Augmented Design Experiences

Massimiliano Lo Turco, Giulia Bertola, Francesco Carota, Francesca Ronco, and Andrea Tomalini

1 The Interaction Between the Physical and the Digital. The Augmented Real Models

In architectural and urban planning and art, design, and engineering, the new scenarios of craft 2.0 are currently changing practices and processes for communication [1]. This process is also taking place due to the trend of combining new digital technologies with more traditional techniques [2].

However, innovative digital technologies for creating virtual 3D models or using Augmented Reality (AR) have kept scholars from moving away from the use of physical models. As noted by Tepavčević [3], technological processes challenge traditional architectural design models and lead to the definition of new requirements, with obvious repercussions for teaching methods. From this point of view, it is worth mentioning how the fruition of digital models is always mediated by screens or devices that reproduce a two-dimensional image. From a perceptual point of view, they cannot return the same feedback as an accurate model [4]. Recent Augmented Reality technologies give an almost real sense of the proposed object,

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but the limitation of the immateriality of the representation remains. This criticality confirms the self-evolve role of physical models, which, with their materiality and three-dimensionality, can return at a glance that information that would otherwise be more complex to convey. The maquette is defined as a storytelling artifact on which information can be anchored, thus generating different levels of interactivity and immersiveness and proposing an approach between amusement and edutainment aimed at communicating and understanding the architectural project [5]. As Piga reports, it should not be forgotten, however, that the use of physical models for visualization, verification, simulation, analysis, evaluation, and validation of different design solutions are not a new tool in the field of architecture. On the contrary, digital models are much more recent, although widely adopted worldwide [6]. Moreover, in recent decades, the opportunity to enjoy immersive experiences has expanded to the point where it is considered affordable for everyone, and the Real-Virtual continuum, with different levels of immersion, is a valuable, attractive, and informative tool [7].

2 Similar Experiences

Therefore, it is clear that how students represent their projects has inevitable implications for the design process within the Faculties of Architecture and Urban Planning. In this context, it is essential to illustrate to students the methods and techniques necessary to interpret and produce visual culture.

Interesting examples of the interaction between analog and digital in academia can be seen in some thesis projects from the Southern California Institute of Architecture. Drawings, models, renderings, and animations presented by SCI-Arc students and faculty testify not only to the ability to technically document and visually communicate the design of a building but also convey some interest in using these tools as generative creative media.

In these projects, some Digital Fabrication, additive and subtractive techniques such as 3D printing and laser cutting, and Augmented Reality (AR) experiences used at the end of a process as a means of communicating design intentions are proposed to students [6].

The right combination of an interactive experience in which digital information and real-world perception are merged together, constituting a valuable tool in education and beyond [8], aimed at improving the understanding of content, learning of architectural elements, functional aspects, spatial as well as learning of ideas and concepts.

The hybridization of real and virtual is also of strong interest in other research areas [9, 10]. Confirming the widespread attention in these hybrid applications, is the investigation conducted within the NEWTON project developed by the Pedagogical Assessment Committee (PAC) at the FabLab Madrid CEU. This project proposes AR and digital fabrication as teaching support technologies for students with disabilities within university classrooms [11]. Other research emphasizes how these solutions can create collaborative environments that enable real-time validation of alternative solutions. In the future, such approaches are expected to be implemented through the creation and subsequent adoption of standards to improve the efficiency of interoperable workflows [12].

3 The Description of the Case Study and the Proposed Sequence of Activities

Regarding the experience carried out within the Design and Modeling Atelier, it is necessary to emphasize the interdisciplinary nature of the teaching, which involves collaboration between the areas of Drawing (ICAR/17) and Architectural and Urban Composition (ICAR/14). The atelier aimed to re-design an urban void in a transforming area very close to the pertinence of the Politecnico di Torino. On the border of three districts of the city of Turin (San Paolo, Cenisia, and Cit Turin), lies the former Westinghouse plot. Initially, the Rapid company occupied the area as an automobile manufacturing company. However, since 1906 it has been home to the Westinghouse factory, which made significant structural changes to the complex. During World War II, the complex was heavily damaged by Allied bombs and resumed operations after World War I. Subsequently, the factory was demolished. In 2002 an urban transformation project envisioned the establishment of a multipurpose complex featuring: an internationally renowned cultural center (with an expected five thousand visitors per day); a library prepared for one million open-shelf searchable volumes; an office area.

The project was overseen by arch. Mario Bellini was abandoned due to lack of resources, fueling a long city debate that lasted for years.

In 2021 the affair was unblocked, and the site was purchased by the Esselunga Group and managed by Fiera Milano Congressi, which plans to establish a convention area with more than 5000 seats in front of the shopping center built in the Corso Ferrucci. The City of Turin, which played the role of mediator in the affair, also took an active part in defining the uses of the area. The real estate transaction just described has an estimated value of about 50 million euros and, given the large sum and the strategic location of the site concerning the city, this intervention continues, even today, to be the subject of debate and interest for the City of Turin [13].

Regarding the content delivered during the semester, an introductory lecture was employed regarding the role of models and physical modeling in design. To demonstrate how the model has always been an indispensable communication and design tool in ateliers. In addition to the topics introduced in the previously exposed state of the art, numerous images of study, design, and detail models from different eras were shown [14]. In particular, a large collection of construction models was viewed, historical models employed between 1865 and the end of the nineteenth century as teaching aids for the training of civilian students (Fig. 1); indeed, the cultural richness of this repertoire of models has prompted many studies, and they are currently on

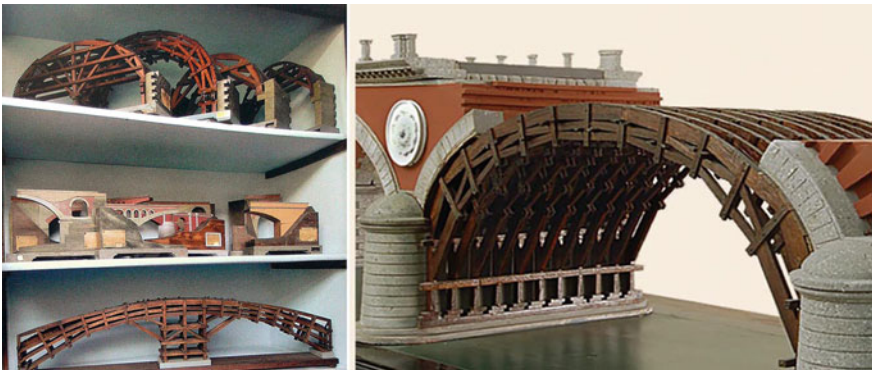

Fig. 1 Left: A collection of model buildings, historical models used between 1865 and the end of the nineteenth century as teaching materials. Right: a model of the Isabella Bridge, in Turin, Italy (1874) (Photos and editing: M. Lo Turco)

display for the exhibition L'arte di fabbricare—Giovanni Curioni e la nascita della Scienza delle Costruzioni ospitata nella sede di corso Duca degli Abruzzi.

The introduction to conscious use of models was conducted jointly among the disciplines involved to have a shared workflow (Fig. 2) and understanding of the content shown. The required exhibits were:

- 1:500 scale physical models made of polystyrene for the representation of the urban context.
- 1:500 scale study models made from recycled materials.
- A 1:500 scale physical model printed in PLA (polylactic acid).
- A 1:200 scale physical model produced using any technique.

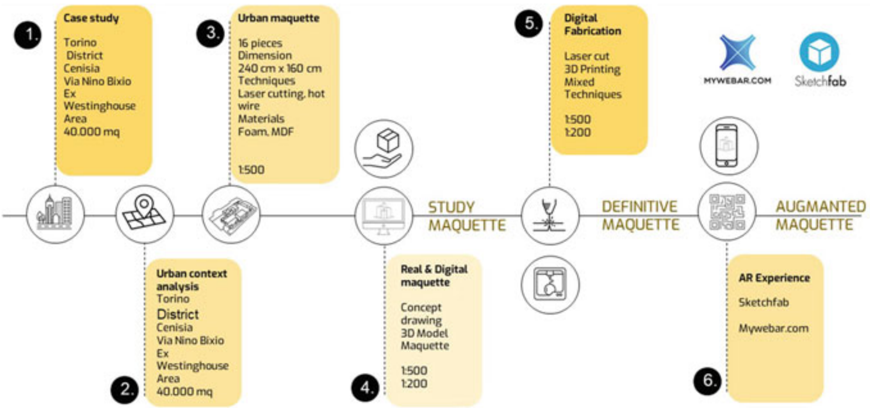

Fig. 2 The workflow (Editing: G. Bertola)

- A competition board containing digital models that summarized the design proposal, in A1 format.
- An AR application that would contain content complementary to the enjoyment of the physical models (thematic elaborations, exploded views, compared design solutions, infographics, animations, ecc…).

4 Introduction to Traditional and Digital Fabrication Techniques and Construction of Shared Maquette Among Students in 1:500 Scale

The first practical lessons on model making included an introduction to materials (cardboard, wood, plastics, textiles, vegetable cardboard, glues, and composite materials) and traditional tools (cutters, rulers, squares, compasses, hot-wire machines), with particular emphasis on safety-related aspects during the work.

Given the subsequent operations (1:500 scale physical modeling of the area investigated for the project), it was also decided to introduce the students to the laser cutter printer. This tool, part of the digital equipment, made it possible to create the base on which the investigated context was fixed at a scale of 1:500, with great precision and a fair speed of execution. The students were provided with the file of the master plan of the City of Turin and instructions showing the standards of representation and the standards referring to the work required.

The survey area was thus divided into sixteen portions, one for each group of students. Consequently, each group redesigned only the portion of the area assigned to them. The volumes of the buildings were made of polystyrene, working with the aid of paper profiles used as templates for cutting with the hot wire machine (again, guidance was given for preparing the profiles: the following simplifications were made for calculating the heights: for residential buildings: 4 m for the ground floor + 3 m for each floor above the ground floor; for commercial or industrial buildings: 5 m ground floor + 3.5 m for subsequent floors).

The groups organized independently to handle buildings whose ground footprint fell on the boundary of two different lots. The final result, depicted in Fig. 3, was used as the basis on which to place the first 1:500-scale study models made in subsequent phases. The critical issue in this phase was enforcing specific standards: laser cutting could not be started if the drawings did not meet these standards. The final result, despite the rather detailed guidelines, nevertheless generated a model in which it is possible to identify the authorship of each group (note, for example, the tracing sheets used and the types of nails used to make the trees), leading nevertheless to a result considered more than sufficient by the faculty.

Fig. 3 The shared maquette: plot subdivision, the mouting process, the final model, scale 1:500 (Photos and editing: F. Carota)

5 Construction of Maquettes at a Scale of 1:500

From this model, the students, organized into groups of three, began to develop their project at a scale of 1:500 (Fig. 4). They were required to integrate their initial graphic elaborations with study models to their ex-tempore design models, that would enhance their concept idea. Thus, at this stage, the mode of representation of the design concept was rewarded rather than the dimensional accuracy of the model. The priority of representing an idea related to architecture and not a finished

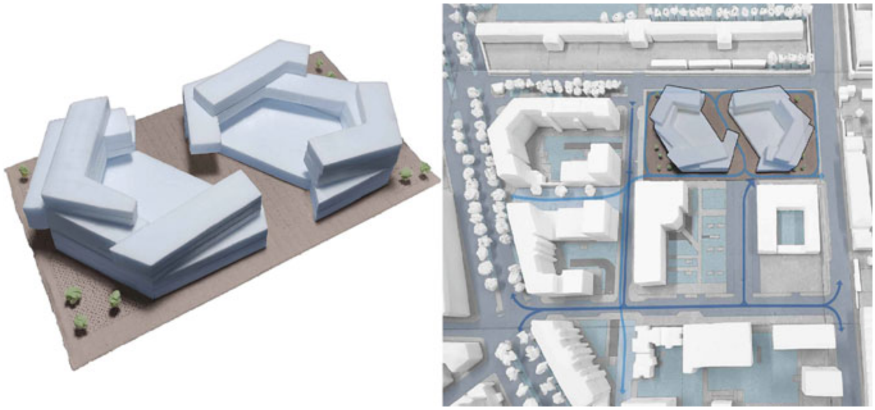

Fig. 4 The study model made by a group of students (Photos and editing: A. Tomalini)

architecture prompted students to identify new modeling techniques or new materials, often recycled and not illustrated during the face-to-face lectures. They were required to keep this model up-to-date, incorporating the insights that emerged during the reviews and the related evolution of their concept throughout the course.

The primary critical issue has been to make it clear that there is a clear distinction between conceptual models, contextual/urban models, design development models, descriptive models, and communicative models, as defined by Dunn in his volume [15]. A model for the final representation of the project is often a hyper-realistic and detailed representation of the project, while the study model, perhaps less appealing to the majority of people, must convey the process by which it was conceived.

6 Realization of Digital 3D Models at a Scale of 1:200

Parallel to the physical concept model at a scale of 1:500, student groups developed the 3D digital model at a scale of 1:200. Through NURBS modeling software (Rhinoceros 3D), they constantly updated the digital model in order to verify that the assumptions made on the physical model also matched the functional requirements of the project.

In this context, it was helpful for some groups to experiment with different Rhinoceros plug-ins to have more expeditious modeling. Depending on the design requirements, it was not always possible to suggest using the same application. Among those most suggested, we find VisualARQ, PanelingTools, RhinoVAULT, and LandsDesign. In particular: VisualARQ allows for the addition of BIM functionality within Rhino, although in this workshop, we focused on a few tools that greatly streamlined the modeling process; PanelingTools is a tool that helps the designer streamline complex geometries through the definition of panels and substructures suitable for manufacturing processes; RhinoVAULT is a tool that, through the Thust-Network approach allows intuitive creation and exploration of structures that respond to compression-only stresses; LandsDesign is an application developed for landscape design). The 1:200 scale digital model has always been modeled to be printed later, so each geometry must necessarily be a closed solid. This step did not involve any particular critical issues since the third-year students are already familiar with the basic principles of digital modeling.

7 Introduction to Digital Fabrication Techniques, 3D Printing

Once the design proposals (and the respective digital models returned with content that conformed to the 1:200 scale) had reached an acceptable level of maturity, the faculty again took up digital techniques, this time with a special focus on FDM 3D printing. Among the main advantages was the emphasis on its ability to create complex shapes as easily as simple shapes are produced; the main disadvantages involve a limited number of materials that can be used and long production times. Again, some standards were provided to be met during modeling: 0.2 mm < decors on elevation < 0.8 mm, minimum isolated element size = 0.8 mm, minimum wall spurs = 0.8 mm, wall thickness = multiple of 0.4 mm) and standards for GCode preparation with the UltimakerCura slicer (h Layer = 0. 2 mm, h Initial Layer = 0.15 mm, perimeter line width = 0.38 mm, inner line width = 0.3 mm, wall thickness = 0.8 mm, top layer thickness = 0.8 mm, bottom layer thickness = 0.8 mm, infill = 30%, infill configuration = grid, Print Temperature = 210 °C, Print Platen Temperature = 60 °C, media = Yes.

Under the faculty's supervision, Students could use the lab printer: an Ultimaker 5S, which was used for the preparation of the 1:500 scale model (Fig. 5) and for some parts of the 1:200 scale model (Fig. 6). The general idea among novice students was that the 3D printer could print anything. From this point of view, the biggest challenge was to make students understand the main critical issues related to this production tool. It was not easy to demonstrate how a seemingly correct model could be suitable for generating renders but absolutely unusable in the printing phase. Having only one printer available for the entire course did not afford the luxury of making mistakes. One had the opportunity to perform many tests and possibly make mistakes. Often the designs underwent minor changes after they had been sent to print; given the relatively long timelines, it was not always possible to reprint the updated models.

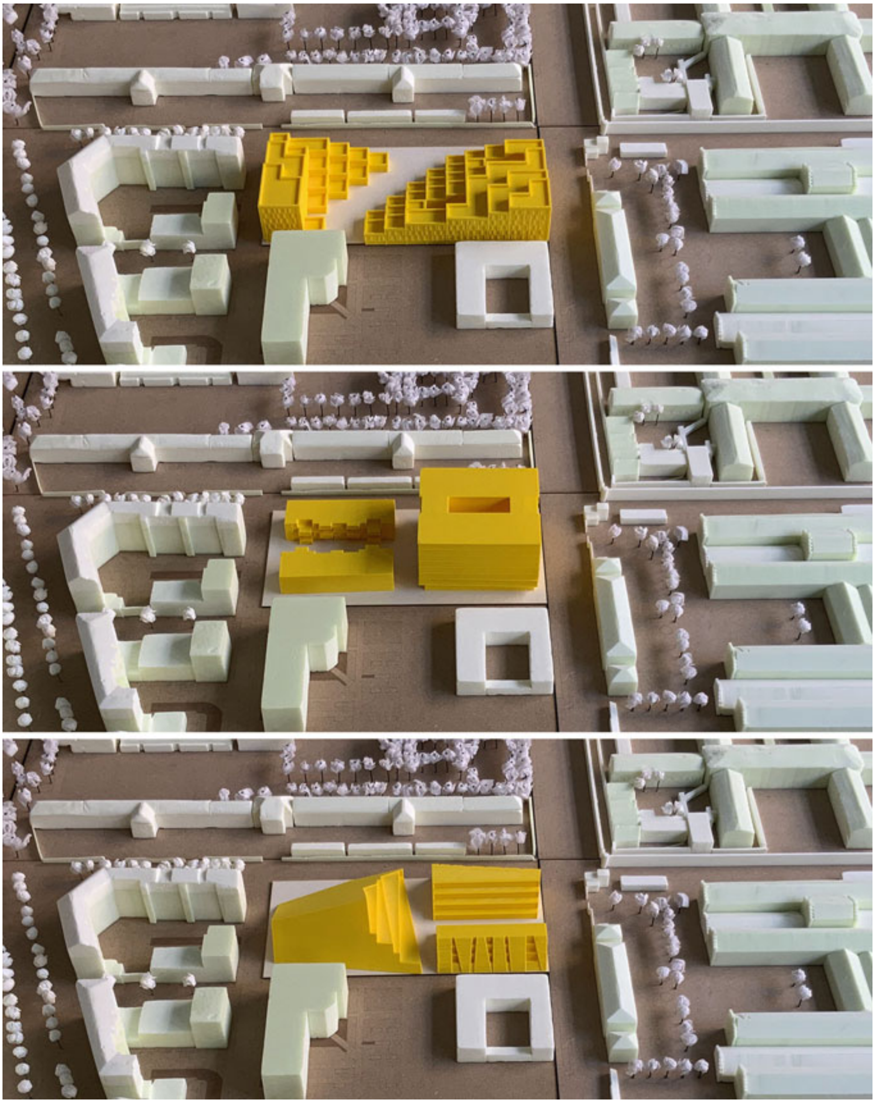

Fig. 5 Some printed models, scale 1:500 (Model: students; Print: MODLab Arch of the Department of Architecture and Design, Politecnico di Torino; Photos and editing: F. Ronco)

8 AR Application

As far as the experience of AR applied to models is concerned, since there is no real contribution within the course entirely dedicated to AR technologies, it was decided to propose to the students the use of two partly open source platforms, which are more intuitive so that they can easily and quickly obtain their first AR experience

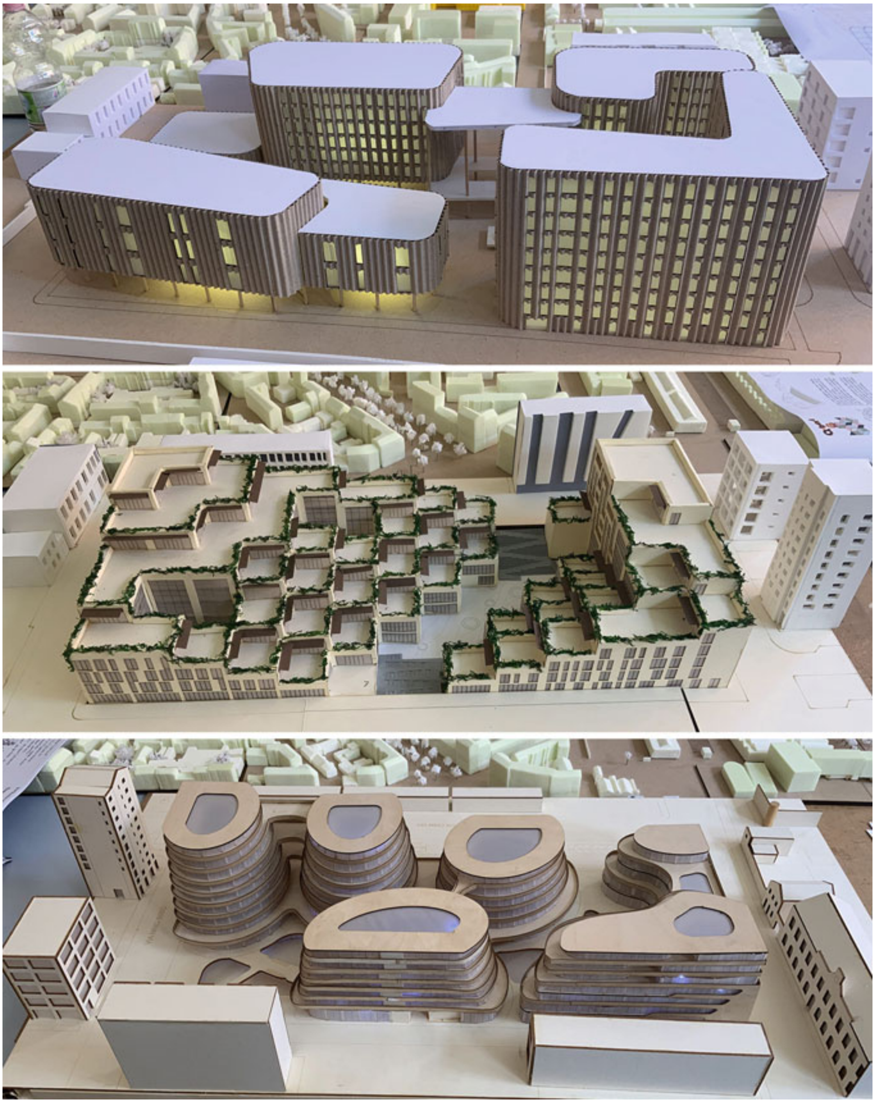

Fig. 6 Some models, scale 1:200, free tecnique (Model: students; Photos and editing: G. Bertola)

and avoid resorting to specific programming languages that are difficult to tackle in a short time and in the absence of a contribution dedicated to them. Therefore, we proceeded with:

- Inserting the 3D model in.obj format on Sketchfab's web platform, displaying its 3D mesh and giving the possibility to modify materials, textures and brightness of the scene online and in real-time through the advanced settings.

Fig. 7 Some models with AR experiences (Authors: students; Photos and editing: A. Tomalini)

- Once the direct link was obtained, we proceeded with the installation of the AR platform Mywebar.com. The model obtained from Sketchfab was imported in the platform. The platform allows some modifications such as adding simple animations, obtaining a project URL and a QR code. Once published, it is possible to view the project and model through any device that has a QR Code reader installed (Fig. 7).

Below are the pros and cons of using the two platforms. Both allow students to customize their model, but require payment to use the advanced features. In addition to the reasons stated above, in a purely didactic context, limited use was opted for.

During the course, a number of critical points were found to be addressed in future editions of the course. One of the major difficulties that emerged was the creation of an effective anchorage for the digital model. When working on superimposing the digital models on the real models, it was not trivial to identify an always visible position to insert the QR code. This criticality could be solved through the use of VuforiaTM®, a tool that works very well together with Unity®, and which allows the tracking of planes and three-dimensional objects in real time.

The use of more sophisticated tools allows to generate two types of target (Single Image and the Model Target), i.e. objects that the VuforiaTM® engine recognises in the real scene and traces in space. Then it is a matter of identifying the object to be tracked, the real model, producing a Model Target within the Model Target Generator (MTG) of Vuforia TM® by importing the digital model in.fbx format, and exporting the Model Target in a.unitypackage file, ready to be imported into the project on Unity® and visualise the experience in AR.

During the various steps from the 3D modelling software to VuforiaTM® and Unity® it is necessary to ensure: a correspondence of the coordinate system; the scale of the object set to 1:1; a rational reduction in the complexity of the model [16].

9 Final Examination Day

During the collegial discussion, the 1:500 scale models were placed within the shared context maquette in order to have an immediate confrontation with the built context. The 1:200 scale model, the graphic drawings and the carnet de voyage, were placed in close proximity to the shared maquette to allow a constant relationship between the different representations of the same artefact.

The physical models presented allowed for a full understanding of the design proposals and, through Augmented Reality tools, virtual elements and information were integrated into the real environment (Fig. 8). The physical models, paper documentation, digital models and related elaborations produced demonstrated a good mastery of the representation techniques illustrated in the classroom.

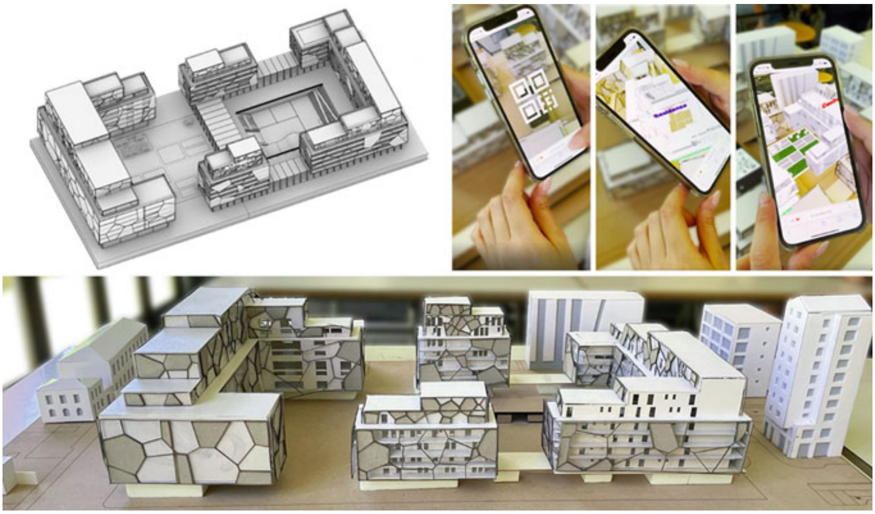

Fig. 8 The final exam: virtual model, AR experience and physical model (Authors: students; Photos and editing: F. Ronco)

10 Conclusion

The first ideas undergo a process that allows the architect to analyze, revise and refine them until the project, now consolidated, is ready to be delivered. Within this operational flow, models are indispensable tools for investigating and presenting the formation and development of ideas in all the three dimensions. The advent of digital has certainly opened up the range of opportunities available to our students, sometimes to the detriment of physical modelling. This approach continues to hold undoubted advantages, such as the ability to express materials, shapes and colors in an accessible and very direct way, allowing the three-dimensional experience to be perceived without having to imagine it, while at the same time identifying and controlling spatial problems. In this regard, the proposed workshop set itself the goal of becoming familiar with established and emerging manufacturing systems and processes. Using recent visualization technologies, from computer vision to augmented reality, students explored ways to produce aesthetics for architecture capable of uniting analogue and digital worlds.

The use of different methods of communication is therefore a stimulus for students to investigate ideas: different methods and techniques of representation induce very different conceptual processes and inspire more design ideas.

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AR-Bicycle: Smart AR Component Recognition to Support Bicycle's Second Life

Michele Russo and Flaminia Cavallari

1 Introduction

The mass products industry has seen an exponential increase in the last few decades in disposable items that can provide a low-cost answer to growing consumer needs. The extension of this concept over a long time leads to the use of products composed by not durable components until they break down, then to the immediate replacement of the whole creation. This behavior is typical of social development in many countries, dominated by two main pillars: time and money. These two aspects shape citizen lifestyles, fueling consumerism and affecting climate change. Multiple factors, including waste pollution, contribute to the increase in the latter. The lack of human foresight, more focused on the present living, although foreseeing the future and the consequences for the Earth, underlies the actual situation. Using products with shorter lifespans reflects the desire to have ever-new items suited to the momentary living condition [1]. This attitude unconditionally fuels the collection, management, and disposal of ever more significant amounts of waste, profoundly affecting the pollution of the Earth.

One attitude that opposes this trend is the circular economy. The ability to identify different forms of reuse of the same product extends the life of the object or its components, reducing the impact of pollution [2]. Numerous web videos shared on the main dedicated channels define an invaluable experiential database that promotes practices on products in public and private contexts. They encourage do-it-yourself

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behavior, fixing an object, prolonging the product's life, and opposing the consumerist trend. This attitude has a very positive impact on the environment and boosts our self-esteem about the ability to solve practical problems.

What is the role of technology in this debate? We live in the contradiction of being surrounded by technology that gives access to infinite resources. However, this resource does not enhance our ability to do anything. Using smartphones, cameras, and image recognition algorithms allows identifying every product worldwide, suggesting all the information related to the object and how to obtain it. This information is often limited to global development, offering how to acquire new or better-performing ones. This kind of information is perfectly consistent with the consumerist attitude described earlier. However, this knowledge system only supplies specific information about the single components, the working system, and how to fix them if they break down.

The research presented in this contribution focuses on using Augmented Reality (AR) as a vital tool for implementing this process, contextualizing this information in the real world, and framing the application of digital technology to fix a failed product. For many reasons, the family of products tested in the research is bicycles. On the one hand, it represents a growing vehicle in the post-pandemic period for the low impact on the environment and the independence of public or private transportation [3]. The latter is also strongly conditioned by the cost of gasoline. Alongside ecological and economic reasons, this product is composed almost exclusively of mechanical parts with simple working systems suitable for fixing activities [4].

The research aims to propose an instrument to gain maintenance and repair work anywhere, anytime, contextualizing information in the real environment and filling the gaps that research and tutorial media often present. With the help of advanced representation tools, such as AR, the APP can recognize the bicycle object (generic) and individual components (Point of Interest—PoI), linking each to a different information system that facilitates its repair or replacement. The specific service aims to promote and encourage ongoing and autonomous product maintenance. Instead, the overall purpose of the research is to reflect on the role of AR in the Industrial Design domain for the specific repair activity.

2 AR & Object Recognition in Product Design: Pros and Cons

The use of digital models and current advanced visualization technologies is rapidly expanding in the Product Design domain. The role of the digital model understood as a virtual prefiguration of the final project output, assumes a pivotal role in the design pipeline Thanks to AR [5, 6], interactive virtual visualization of the 3D model in the real environment enables rapid verification of the use of the model [7], supporting the creative process, accelerating time-to-market, and adding new dimensions to the manufacturer-consumer relationship [8]. Moreover, AR and prototyping processes can gain even more potential by integrating the virtual model's simulation capabilities with the physical prototype [9]. This trend toward complete digitization of the process encourages the introduction of emerging technologies on which Industry 4.0 is based.

Augmented Reality has endless applications in Industrial Design [10–12]. The user can experience a choice while remaining in the virtual world, accessing the different options in front of them, and contextualizing what is happening in the real world. Such technology profoundly affects the evaluation process in the design process [13] and the final product visualization [14], directing product selection. For this reason, AR is beginning to play an essential role in the e-commerce domain, such as Amazon or Ikea, in which the visualization of products in AR allows one to arrive at a more focused and informed choice [15].

Although the trend in using new technologies by both users and manufacturers is growing, there is still evidence of a clear gap in knowledge between the easy use and the complex definition of AR. This gap is emphasized by numerous applications related primarily to communicating straightforward content. These are extremely simple to use at the primary level but often do not allow for the introduction of aspects of interaction with the model, presenting themselves as black boxes for the user. On the other hand, the only way to develop complex AR applications comes through specific programs, such as Unreal Engine (https://www.unrealengine.com) and Unity3D (https://unity.com), which have enormous potential but discount complexity in startup usage. Thus, we are in this paradoxical condition whereby the demand and interest for AR, even in the industrial domain, are very high. However, there is currently no possibility of answering this question adequately. The situation is generated by the request of a few overspecialized figures who should handle the communication, graphics, IT, and programming aspects. By having few such trained people, the risk is to unbalance the definition of AR projects more on the graphical side, reducing interactions, or on the IT side, with low care in graphics and usability.

Within the AR domain, some aspects are fascinating but challenging. One of these concerns is the possibility of enabling AR visualization with 3D markers by recognizing physical objects in space. This mode is extremely useful in the Design domain since it can tie any virtual product to specific parts of an environment, body, or other products. The main advantage is that recognition moves from the plane to the space; therefore, it is no longer constrained to specific viewpoints from which to observe a target but has greater activation freedom. Furthermore, it is possible to tie different information to the same subject, depending on the point of view, also initiating possible analysis paths on feature recurrence. These advantages certainly meet one of the primary conditions of AR application. Besides, this potential is particularly useful in Product Design, where it is undoubtedly necessary to thoroughly analyze objects from all points of view to understand morphological complexity in space.

However, the geometric complexity aspect, defined by the set of multiple primitive shapes and their relation, is crucial in the shape recognition process. Simple geometries are not helpful in recognition because they can be easily confused. Besides, manufactured symmetries or parts repetition can cause an AR tracking error. Finally, the target generation process is not simple, as it requires constructing a virtual model that conforms to the real one to be recognized by the camera. This virtual model can be reality-based, built because of 3D survey data, or a parametric model defined through an interpretive process. Thus, AR based on tracking in space is more complex than AR in the plane. The research presented here addresses the generation of this type of AR.

3 Experimental Background

The experiment's boundary conditions are essential to understanding the project's purpose. First, the general external conditions must be assessed. As reported in the research introduction, most societies in developed countries today are characterized by marked consumerism, which leads, among other consequences, to producing enormous amounts of waste, posing the cogent problem of disposal and recycling. On the other hand, in recent years, issues related to environmental protection have become a worldwide priority. They are particularly felt by the younger generations, who are very sensitive to waste and the subject of the second life of products [16].

A second aspect concerns the social habit of throwing away a product immediately as soon as a part breaks. The motto "Rather than repair it, buy a new one" is repeated continuously within family units, partly fueled by that prevailing consumerism and partly by the supposed lack of competence to fix the product. Indeed, this attitude fosters a non-virtuous circle in which "the less I repair, the less I can repair", supported by most companies to sell more products. It often costs less to buy a new product than to repair it, regardless of the time spent repairing it, arriving at the straightforward conclusion of the lack of advantage in fixing items. Instead, this is a crucial point: a change in perspective that saving time is not the only yardstick for the quality of life. Its use, for example, in rediscovering the do-it-yourself activity has the twofold advantage of having positive consequences on the environment, limiting the disposable process, and on our self-esteem, rediscovering the ability to make and fix. Technology can help us in this transition, although it must be channeled correctly for the specific purpose. Infinite resources can cause a sense of scattering and an inability to select the one best suited to our needs. Having upstream a system that allows us to filter them, proposing only those specific to solve a given task, feeds the sense of doing no longer alone (Fig. 1).

4 AR's Role in the Product-Fixing Process

How can technology and AR interfere with the process?

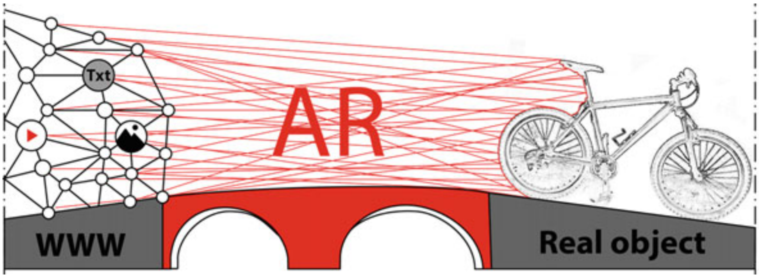

Fig. 1 Outline summarizing the role of AR in the project: a bridge between the vast networks of information contained in the web but decontextualized from reality and the reality itself. AR can generate a new link between container and content for a greater understanding (Image: M. Russo, F. Cavallari)

We know that to limit excessive consumerism, we can rely on several strategies related to the production process:

- Encouraging the second life of objects, changing their owners according to changing needs.
- Recycling all components to have 0 impacts on the surrounding environment.
- Extending the life of products as much as possible by learning how to maintain them accurately.
- Repairing products when they break down.

The connection between different elements and the schematization of complex systems for assembly and disassembly is a topic explored in depth by some research [17]. Here, however, it is essential to emphasize a fundamental point related to the use of AR in this area [18, 19]. By focusing on the repair aspect of products, AR technologies can be leveraged for component identification by introducing specific information to understand the physical operation of the individual component and the whole system [20]. There must be recognizability of elements by the camera, so the ability to repeat similar features or break down complex products into recognizable components benefits the use of AR. Mechanical parts occupy this domain, as they often present systems with more straightforward operations, visible and composed of easily replaceable components.

In contrast, products characterized by electronic components present difficulty given the lack of geometric modularity of shapes. Conversely, the latter also presents lower efficiency and consumption in product life, showing a shorter use time. In summary, mechanical objects exhibit greater ease of repair and allow for longer product life (Fig. 2).

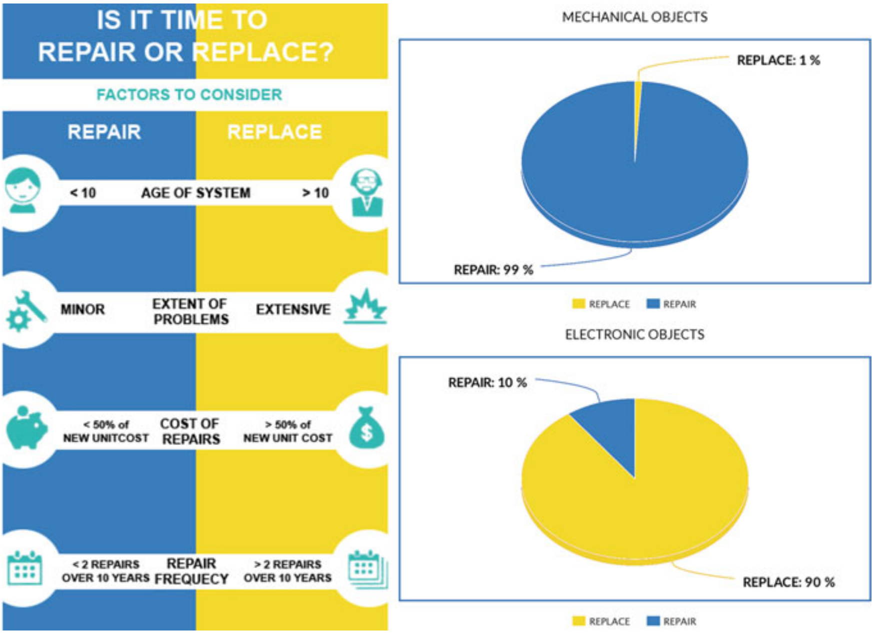

Fig. 2 Left diagram comparing repair and replacement activity. Right quantitative analysis of these two activities in mechanical and electronic products. *Source* https://www.onehourheatandair.com; Images composition and editing: M. Russo, F. Cavallari

5 The Bicycle Case Study

The experiment examines a product suitable with all the boundary conditions listed in the preceding paragraphs: the bicycle. Primarily, it is a product used globally that has seen a significant increase in use in recent years. It is considered an environmentally friendly transport able to move around without expense by covering large distances. The massive use of this product in some cities activates profound urban and social transformation processes, foreshadowing alternative mobility while reducing the emissions of public and private transportation [21]. In addition, the bicycle is a simple product from a mechanical point of view. It has a linear operation structure based on action-reaction with mechanical elements of the simplified form (except for the gearbox). Finally, most of the components that characterize a bicycle can be found in the global market for a replacement, with a wide range of alternatives that can be adapted to the specific case.

The target audience for this project is people aged 22–35. It is because Millennials are currently the most interested in environmental issues, but they are also digital natives; therefore, they do not present any limitations in using technology and being able to handle digital processes and all kinds of devices well.

At the design level, what are the variables involved? The system is defined by two actors: a device on the one hand and a bicycle on the other. Therefore, the variables belong to both and the connection between them. The first actor, the device, contains different elements involved in the process: the type of camera and the graphics processor. Besides, the operating conditions (indoor or outdoor), focusing distance, material reflections, and the AR algorithm that supports the overlay process between digital content and the real context must be considered. The second actor of the system is the bicycle. Its type and model involve variation in shape, number of components, and proportions between details and the general product. As will be observed below, all these factors play a role in recognizing the features of individual components. For this reason, starting with a market analysis of the main types of bicycles present was necessary to eliminate exceptional cases and analyze the leading families. Seven were identified at the end of this phase: City Bike, Commuter Bike, BMX, Cruiser Bike, Mountain Bike, Enduro Bike, and Folding Bike (Fig. 3).

Finally, a key role is determined by how many points of interest (PoIs) may be activated and bonded to the bicycle product. Their number depends mainly on the reading level you want to assign to the product and the scale of intervention.

6 Methodology and Results

The project is based on two process steps: modeling and visualization (Fig. 4). The methodological process thus involves an initial phase of analyzing images and modeling geometric shapes, preliminary to a series of very delicate design choices. Specifically, the most important one is to define a less adherent shape to a specific type of bicycle to develop an application that covers different kinds. It requires the definition of an average shape that considers the distribution of the shapes and skeleton of the structure. Conversely, the second phase is geared toward building a recognition system in space, which can activate and link multimedia content by framing the product with the camera from any viewpoint. Finally, the methodology includes a testing phase, applying the recognition process to different types of products to validate or not the process.

6.1 Image Analysis and Modeling

A geometric-comparative analysis of the main types of bicycles precedes the 3D modeling stage. To do this, we started with a representative image for every single type of bicycle family, shown as frontally as possible, reducing perspective distortions. Every picture was analyzed, translating the main structure of the bicycle into lines and identifying with dots essential joints with interchangeable elements (PoI). The qualitative evaluation and definition of the basic geometries were done by placing the average line that passes between the single components of the bicycle (Fig. 5). This abstraction in simplified models was significant for two reasons. On the one hand, moving away from the specific case study, defining a geometric scheme that is

Fig. 3 Types of bicycles examined in the experiment (Images composition and editing: M. Russo, F. Cavallari)

detached from the purely metric aspect (which would require a detailed survey and a definition of measurements with known tolerances) to define representative models of that class. In this way, the simplification considers all the minor formal variations within the same typological category in the first instance.

Furthermore, this makes it possible to homogenize the different classes, a prerequisite for comparing the families analyzed. This comparison predicted an overlap between the seven categories (Fig. 6). In this activity, it was necessary to identify a standard reference system. Since there are no invariant points in all the classes, the one, which sees the minor variations, was recognized for mechanical and functional

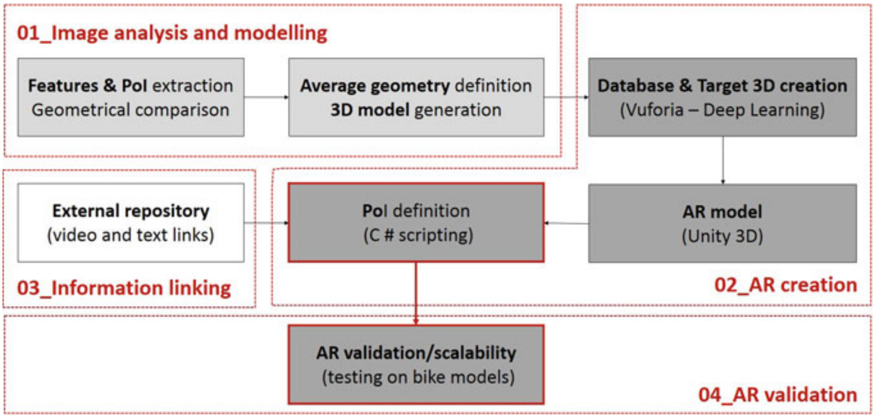

Fig. 4 Methodological process applied in research (Image: M. Russo, F. Cavallari)

reasons: the axe of the front wheel. Since these are scalable geometric schemes, each scheme has been scaled by reporting the distance between the centers of the two coherent wheels. However, this operation, formally incorrect (we will discuss it later), allowed us to start a comparison between the models. From this planned comparison, it is evident that there are areas of influence, understood as coherent areas within which the position of the joints varies inside the bicycles. For example, the pedals and gear shifter present a small area due in part to the constraint of the two-wheel axes and the fact that almost all bicycles have the same distance ratio between this and the centers of the two wheels, in line with these two.

From a dimensional point of view, the distance between the centers of the two wheels changes significantly only in the Mountain Bike and the City Bike. On the other hand, other parts, such as the saddle or handlebars, present considerable space position variability. Finally, the significant variability of the diameter of the wheels should be highlighted, a decisive but strongly characterizing aspect of the different models.

The construction of the average model, i.e., a geometric scheme that tends to define an average of the seven analyzed, started from the definition of guidelines passing through the individual parts of the structure. It considered not only the position of the forms but also their distribution in space (weighted evaluation). Once the intersection between these lines was defined, the definition of the PoIs also followed the same principle. That PoIs characteristic of defined classes but not present in the others have not been entered (Fig. 6).

By taking average measurements in the section between the different parts, this basic geometric structure has allowed the reconstruction of a bicycle shape that best approximates the seven classes analyzed. Besides, this study made it possible to discriminate between certain types of bicycles with too high geometric variations. This complex geometric analysis is not only preparatory to the construction of a model which is as flexible as possible, i.e., which allows a trans-class application.

Fig. 5 Geometric frame construction of the seven bicycle classes (Image: M. Russo, F. Cavallari)

Nevertheless, it lays the foundations for a critical evaluation in the experimental phase, analyzing which classes work better or worse and knowing the weight of the variables. The primary geometries were reconstructed within the Blender program. The geometries were defined following the choice of the number of interest points activated during AR (Fig. 7).

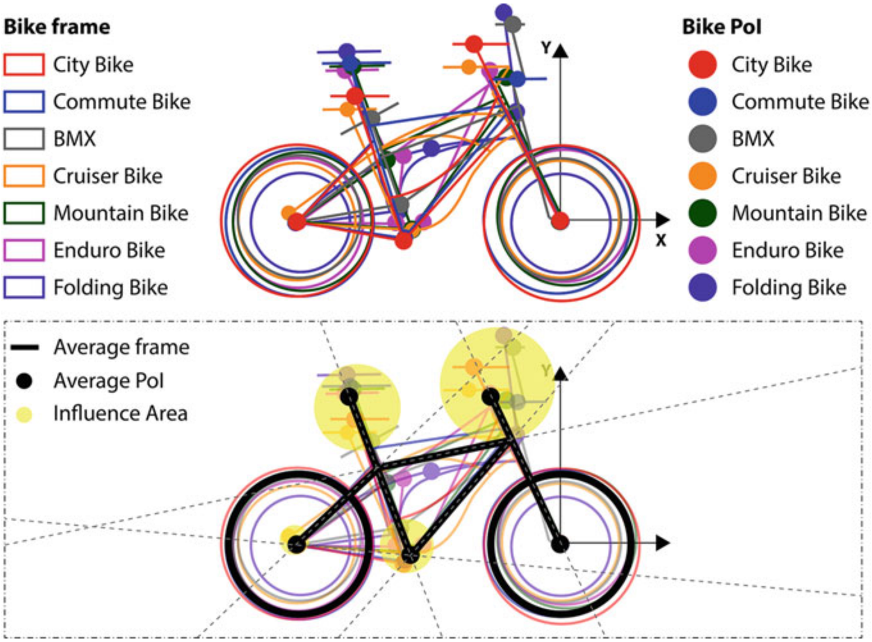

Fig. 6 Geometric comparison among the seven bike classes (top), construction of the average geometry with PoIs, and sizing of component influence areas (bottom) (Image: M. Russo, F. Cavallari)

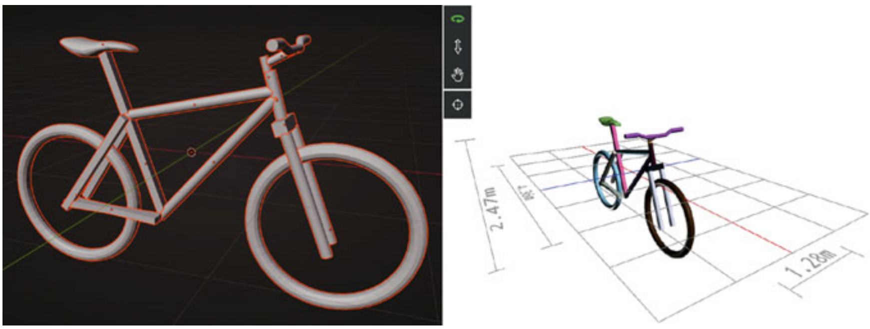

Fig. 7 Average 3D model reconstructed in Blender (left) and the same model within the Vuforia MTG platform (right) (Modeling: M. Russo, F. Cavallari)

6.2 AR Creation and Validation

The second step foresaw the visualization phase. It was carried out within the Unity3D program. The choice fell on this program only for greater information portability on Android systems, which are the ones on which the application was tested. In addition, Unity3D has an AR module (https://unity.com/unity/features/arfoundation) that allows users to create applications for portable and wearable AR devices.

This module supports device tracking, raycasting, gesture recognition, face tracking, meshing, and point cloud detection on different platforms. Thanks to the established partnership with Vuforia, 2D and 3D targets can be generated. The construction of the 3D target is done within the dedicated Model Target Generator (MTG) module. This module allows the management of model ingestion, verifying the scale unit and the tracking mode (Fig. 7). The latter is vital since some basic parameters must be defined for target recognition. These include the type of model (whether a generic model, a highly reflective model, or a model from survey data) and the viewpoints. The latter can be placed within a predetermined path or be free in space without constraints on alignment between the virtual camera and the model. The only limitation can be imposed whether the model is visible from all viewpoints or involves a ground plane, constraining the view only above that plane. This second choice, which allows maximum freedom in the visualization of the model, requires a training process for the program, which goes on to build a database of possible views.

Once these parameters are defined, training begins by activating the Training Model Target module within the Vuforia Cloud. Through the application of Deep Learning algorithms, a trained Advanced Model Target Database is created and imported within Unity3D, recognizing the 3D model and all its components. To insert PoIs, a small command line in C Sharp language (C #) is inserted to enable hotspots to which different multimedia content can be connected.

In the last phase, a service APP was initially designed to support the entire process, hosting both the Augmented Reality and multimedia content access function and the location of service points in the territory (Fig. 8). In a B-test version, the APP involves free user registration and profiling to customize the service better. Then it is necessary to register the type of bicycle owned, being able to access initial content on the guide related to the specific product. The APP can then connect, via AR, the existing bike with the information contained on the Web, improving the knowledge of the single components. This stage opens the dual path of arranging the different parts through viewing ad hoc videos and replacing the components. This last phase, like the repair, can occur online or by connecting to local physical services.

For this reason, the last part of the application allows geolocation and the possibility of mapping nearby stores (using existing services such as Google Maps). The idea of relying as a final step on a service that advertises local stores and small or large workshops is related to the possibility of being promoted by a network of businesses in the area and those online to sell spare parts.

The final phase of the research is devoted to the APP's testing phase on different products to check its level of scalability. The current study focused on using two similar smartphones, the Samsung A3 (13 Mpix, 4128 $\times$ 3096 pixels, f/2.4) and the Samsung S4 (13 Mpix, 4128 $\times$ 3096 pixels, f/2.2). The final phase of the research is devoted to the app's testing phase on different products to check its level of scalability. Having built the recognition model on an average shape, the APP makes it possible to recognize all those types of bicycles that fall within a certain metric tolerance

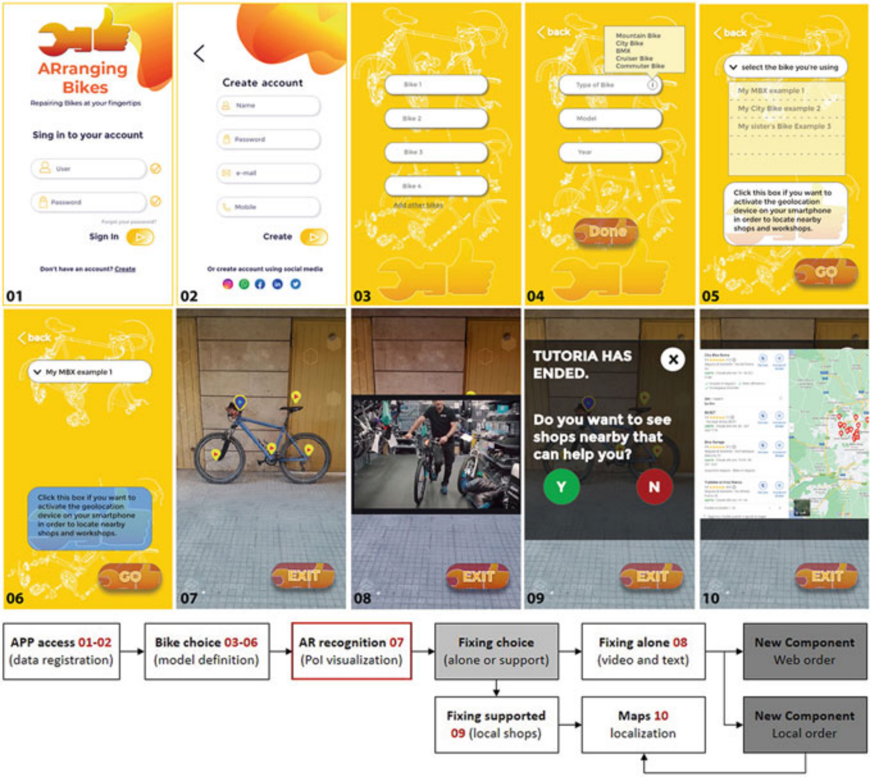

Fig. 8 APP development through the sequence of main screens and steps, from user profiling to smartphone geolocation. A block diagram tracing the hierarchical structure of the APP and sequential steps are shown below (Image: M. Russo, F. Cavallari)

while excluding those with entirely different shape or size ratios. It is the case for BMX and folding bikes, whose dimensions and aspect ratio between the wheels and the bicycle frame are too different from the 3D model to CAD. The comparison geometric scheme shows that these two families are not recognized for two reasons. The BMX is a bicycle that presents the most different structure, with more significant variability in height between the position of the saddle and the handlebars as well as the highest position of the pedals and the gears. It leads it to be the typology with the structure that most distances itself from the elaborate medium form.

On the other hand, the folding bike has the distinctive characteristics of a minimum diameter of the wheels and a strongly contracted distance between the wheels' centers, allowing it to be folded into a package. This peculiarity leads the components to a position in space utterly different from the average geometric model. The application gave very positive response feedback, particularly on Mountain Bikes and City Bikes (Fig. 9).

Fig. 9 Images of different real bikes and scaled models (right) and feature recognition and interactive visualization of PoIs (Photos and images: M. Russo, F. Cavallari)

7 Conclusion and Future Steps

The research aims to deepen the role of AR in Product Design concerning extending product life. In particular, the article highlights how important it is to change the paradigm of product use from the disposable to the use and fix mode. It entails a change of mindset, first of all at the societal level, thinking on the one hand about the new role of the product that can find a second life or be fixed before being shelved. In addition, this has a direct positive consequence in safeguarding the planet by counteracting the ever-increasing trash. Finally, the ability to fix products also has a positive effect on a personal level, as it nurtures our partly lost ability to work with our hands and our self-esteem in being able to solve problems. In all of this, technology can come to our aid, thanks to the immense amount of information on the Web and the ability to access it at any time. This vast amount of data can be optimized if contextualized in the environment and on the specific object we need to fix. Augmented Reality assumes precisely, in this case, the role of a bridge between information on the Web and reality, that is, as a tool to contextualize these large masses of information in real life, simplifying access and fueling the desire to solve problems. The case study of the research is the bicycle, a widely consumed and rapidly rising product following the pandemic period. Primarily highlighted in the study is the role of the 3D model as a tool to access a system of information helpful in understanding the actual product. It is easier when mechanical components define it. The association of the 3D model and AR allows for increased knowledge of the existing, being able to intervene in the accommodation of failed mechanisms or components. It also provides the following:

- A better understanding of how products work.
- Gaining a greater awareness of the objects we use.
- Increasing the product value.
- Fostering the potential interchangeability of components.

Crucial in experimentation is the type of 3D model to be used, i.e., a simplified and interpreted model versus a 3D model that adheres to reality (reality-based). The former, used in the research, allows feature recognition to be extended to different types of products; conversely, it does not ensure the recognition of a specific one. On the other hand, a 3D model obtained from surveying provides recognition of the particular product but needs to be more generalizable. It would be necessary to import 3D models corresponding to all products to solve this dilemma, introducing all possible variables. However, since some of these differ slightly, it is necessary to check for possible interference between similar models. Indeed, this research focuses on arriving at a balanced choice that preserves the metrological aspects of the survey and the morphological ones dictated by the product type.

Finally, as far as the research perspective is concerned, some next steps are noted. The first is the possibility of more generalization of shape recognition, expanding the use of the APP to most types (or providing for differentiated patterns according to the geometric classes they belong to). A second point concerns experimentation with a more significant number of devices. It is crucial to validate the use of AR using devices with different performances, to check possible bottlenecks or models with which AR works better. We also point out that the application is designed only for the OS. Android, limiting its use. Finally, there is a need for a testing phase by both users (bicycle owners) and companies/spare parts shops/mechanics to assess the functionality and ideal number of PoIs to be applied for each model. Overall, the positive response to this application of AR to encourage product recycling opens the door to a new form of knowledge, which contextualizes already existing information, having a direct positive social and environmental consequence.

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3D Outputs for an Archeological Site: The Priene Theater

Elisabetta Caterina Giovannini, Andrea Tomalini, Jacopo Bono, and Edoardo Pristeri

1 Introduction

The paper presents a methodological process from the acquisition to the digital dissemination of a partially existing archaeological record. The extensive documentation includes numerous previous studies that postulated different reconstructive hypotheses for the Priene temple over time. The acquisition campaign involved an integrated survey: the UAV acquisition was carried out by specialized personnel. In contrast, the photogrammetric acquisition campaign in the field was part of the educational experience offered by the international summer school. One of its objectives is to establish a yearly interdisciplinary summer program project based on architecture and archaeology in the Aydin region of Turkey. The international summer school was organized with invitations: the workgroup was composed of diverse teams: academics, young professionals, researchers, and a small number of students coming from different universities, cooperating for an extensive digital survey of the archaeological site, a research project on the formation process of the city, and a set of experimental design proposals for a Priene Museum (Fig. 1).

The acquisition phase, with dissemination purposes, led to the development of a 3D digital asset of fragments and diverse point clouds. The collected items allowed

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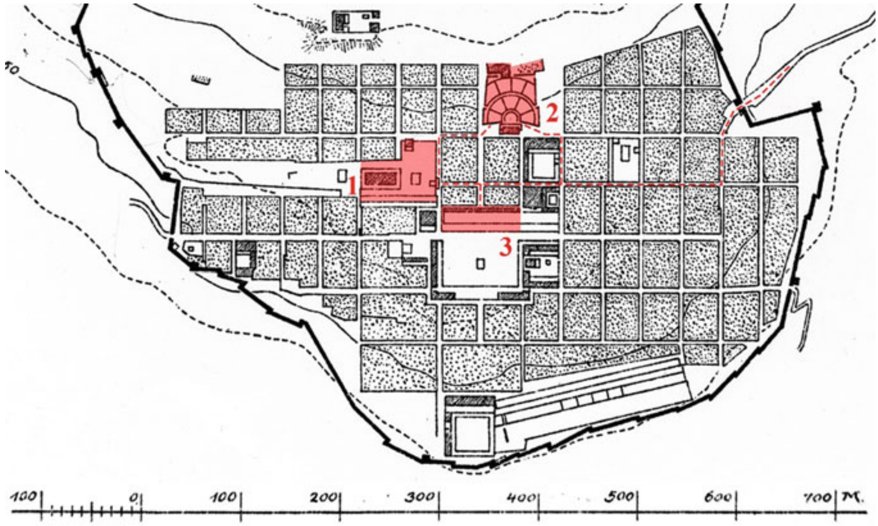

Fig. 1 Portion of the Plan of Priene, in *Griechische Stadeanlagen* [2], with the locations investigated during the Summer School and the digital acquisition campaign. Path and places analyzed: (1) Temple of Athena Polias, (2) Theatre, (3) North hall of the Agorà (Editing: E. C. Giovannini)

the group to hypothesize a virtual reconstruction of the temple using previous studies and historical documentation as data from the digital acquisition.

The 3D models obtained are of two types. The first one, resulting from the photogrammetric acquisition, reproduces the archeological site as it is today.

The second one, resulting from critical interpretations of historical documentation and previous studies, proposes a hypothetical virtual reconstruction of the theatre, including no more extant architectural elements. Both 3D models were re-used for dissemination purposes through the use of open and web-based tools.

Technologies, such as Virtual Reality and Augmented Reality, today allow for remote fruition, increasing the accessibility of places through devices and smartphones. On the one hand, the immersive fruition and use of virtual reality platforms enable the management of different levels of visualization of knowledge. On the other hand, the platforms' limitations emphasize the need for lightweight and metrically less accurate models in favor of a more reasonable and accessible web fruition. This is demanded, especially in contexts where a wifi network is challenging to access.

1.1 Virtual Archeology and Digital Applications in Cultural Heritage

In recent years, there has been a development and proliferation of technologies related to remote sensing and visualization of 3D models through portable devices. These potentials have been harnessed to expand the usability, accessibility, and new knowledge of Historical-Cultural Heritage. The digitization processes have a leading role in the democratization and interdisciplinary knowledge in Digital Cultural Heritage (DCH). The term was used for the first time by UNESCO (2003) in the *Charter on the Preservation of the Digital Heritage*, understood as a unique resource of human knowledge and expression. It embraces cultural, educational, scientific, and administrative resources, as well as technical, legal, medical, and other information created digitally or converted into digital from existing analog resources. When resources are born digital, there is no other format than the digital object [3].

The DCH is based on two topics that are closely related to each other. The first pertains to the digital acquisition of data thanks to the use of new technologies and tools. This process is related to the field of surveying and photogrammetry. The digitization process is also associated with the field of Digital Humanities with the aim of making accessible libraries, archives and historical documentation.

Virtual Archeology is a term introduced in 1990 by archaeologist and computer scientist Paul Reilly to describe computer-based simulations in archaeological excavations [4]. Nowadays, the term can be referred to studies and research intending to create a three-dimensional reconstructive model of an archaeological site. Purposes and outputs can vary depending on the representation scale, details, and available documentation. In the face of these new frontiers introduced by digitization processes in the field of cultural heritage, it has been necessary, over time, to introduce international guidelines and regulations: the London Charter (2009) and the Seville Charter (2012) [5, 6]. Both Charters have their foundations in UNESCO's Charter on the Preservation of Digital Heritage (2003), which recognizes "resources in information and expression are increasingly being produced, disseminated, obtained and preserved in digital form, thus creating a new heritage—the digital heritage" [3].

The London Charter attempts to respond to the spread of digital representations by identifying the principles underlying the principal methodologies and applications adopted in Cultural Heritage research and communication—about intellectual integrity, reliability, documentation, sustainability, and accessibility. The Seville Charter, which turns out to be an implementation of the previous one, explicitly refers to the field of Archaeology [7]. Since the 2000s, Archaeology has recognized and developed its horizons in the technological area, producing multiple branches: virtual archaeology, computer archaeology, computational archaeology, and archaeometry.

This research pursues the themes of Virtual Archaeology within the context of DCH, understood as a discipline that attempts to combine the scientific quality of the data with the capacity for knowledge transmission. The dissemination outcomes of the projects concern visual expedients such as 3D models, augmented reality (AR), and virtual reality (VR) that allow closing the gap between scholars and the large public [8]. Methodological-technical criticalities between adopted solutions can be stated as follows.

- 3D models. Three-dimensional modeling in archaeology needs specific knowledge of historical and archival documentation that should be critically analyzed and interpreted. The 3D model assumes the role of mediator between the surveyed form (when available) attesting to today's appearance and the original form eventually wholly lost. The main issues concerning 3D models are the reconstruction processes' transparency and their visualization [9]. How the 3D model is created is strictly related to the final purpose of the reconstruction: research or large public. The process involves diverse layers of knowledge, including the level of details, uncertainty, accuracy, and semantics [10–12]. Sometimes research in virtual reconstruction processes is related to paradata and metadata for 3D modeling purposes [13, 14].

- Virtual reality (VR). The purpose of virtual reality is to simulate a real environment through electronic technologies. The experience, for users, consists of the impression that they are immersed in that environment. Until now, virtual reality has mainly privileged sight and hearing. Using these two senses, however, it is possible to achieve almost total immersion by using special helmets that allow the wearer to receive only the inputs from the simulator. VR is used in the cultural heritage sector for virtual tours and virtual museums [15–17]. An essential aspect of virtual reality is that it also allows the interaction of multiple people moving within a single virtual environment while being tens of thousands of kilometers away. Thus, virtual social applications are the new frontiers of virtual reality. They were developed for teleconferences or conference calls to 'bring together' people who work miles apart [18, 19]. During the pandemic COVID emergence, social virtual environments (SVE) have been used in both the edutainment [20] and cultural heritage sector [21].
- Augmented reality (AR). Tom Caudell and David Mizell coined the term to refer to a visualization system that involved an overlay of visual effects on top of the real view [22]. AR has increasingly strengthened its relationship with the archaeological world. This development has been possible due to the improved sensor technology of mobile devices, the ease of their interfaces, and the relative cost-effectiveness [23]. A recent European study entitled *Augmented Reality in Heritage Apps: Current Trends in Europe* emphasizes the importance that AR has gained in the field of Cultural Heritage (CH) with the purpose of restitution, dissemination, and usability of 3D content.

1.2 A Layered Story: The Priene Theatre

Priene, built in the fourth century, is located in the southwestern province of Aydin in Turkey. The city is situated on the slopes of Mount Mycale on the loops of the Meander River and is organized into four levels. The city was abandoned in the thirteenth century. This allowed the preservation of the site until the eighteenth-nineteenth century.

The Theater of Priene is considered a typical example of a Hellenistic theater due to the reduced modifications it underwent in the Roman period, unlike most Greek theaters in Anatolia. The archaeological site is framed by the urban system based on a rectangular grid (Fig. 1). The city was discovered in 1673 by English merchants, and it has subsequently attracted numerous archaeologists from Germany who have carried out and performed multiple scientific excavations [24–28]. Carl Humann carried out the first excavations in 1894 with the permission of the Ottoman authorities. Between 1895 and 1899, excavations were carried out by archaeologists Theodor Wiegand and Hans Schrader, who focused on the ancient part of the city [29]. From 1911 to 1912, the archaeological campaign was carried out by Armin von Gerkan, who conducted detailed studies of the theater [30]. This study used their published drawings as a reference for the 3D reconstructive hypothesis (Figs. 2, 4 and 5). During the period of the two world wars, excavations were suspended and then resumed by numerous scholars: Wolfgang Muller-Wiener (1977–1982), Wolf Koenigs (1990), Wulf Raeck (2013), Hasibe Akat (since 2014). Between 1992 and 1998, architect Jens Misiakiewicz elaborated a restoration and maintenance intervention of the ruins, leading to today's definition of the theater. The intervention carried out included: removing minor damage, the relocation of elements by their nature recognizable and framed within the context, and better legibility of the architecture of the proscenium to ensure its overall image and stability [31].

The theater comprises two main parts and sub-parts: the stage area and the cavea.

- The stage. An area for staging musical performances and concerts, and also orators and representatives for holding town assemblies or *ekklesiae*. The place for actors

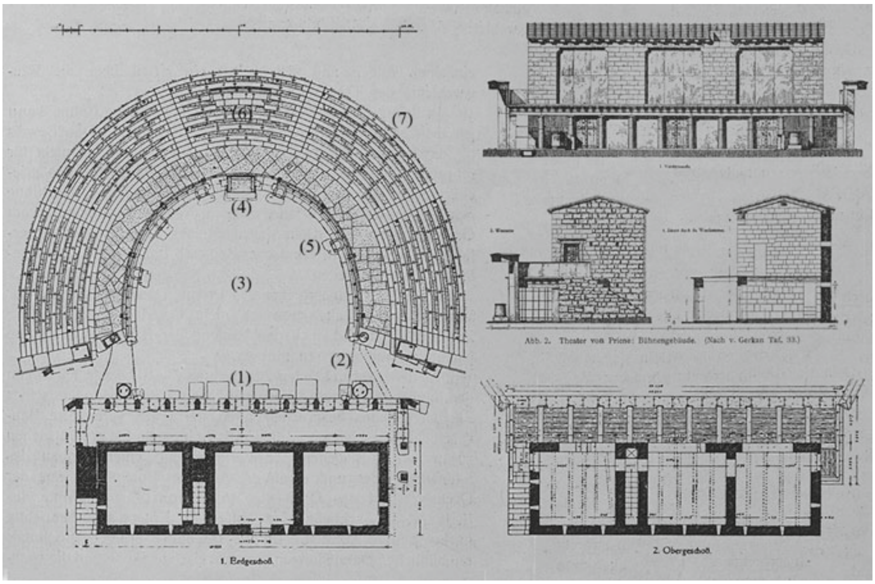

Fig. 2 Hypothetical reconstructive drawings from *Das Theater von Priene und die griechische Bühne* [32]. On the left: ground floor (bottom) and theater plan (top): (1) *proscenium*, (2) *parodoi*—secondary entrances, (3) *orchestra*, (4) altar of Dionysus, (5) *prohedria*, (6) *theatron*, (7) *diazoma*. On the right, from the top: main facade of the proscenium, lateral facade with stairs to the first floor and transversal section, plan of the first floor (Editing: J. Bono)

and musicians. The stage apparatus is the element of the theatre that has undergone the most transformations over time. This occurs due to the change in playing performance since the second half of the second century when the action moved above the *proscenium*.

- *Proskenion or proscenium*. The architectural element is interspersed with eleven openings framed by doric half-columns. The semi-colonnade supports an entablature decorated with metopes and triglyphs. The ends were closed by pillars. Openings were eventually closed by wooden panels covered with stucco or paintings that composed the scenography. At the ends were the secondary entrances or *parodoi* characterized by a marble trilithic system. *Parodoi* could be closed by the presence of metallic bars. Nearby the entrances, there were several sculptures. Fragments of their bases and epigraphs on the depicted subjects are still in place today.
- *The orchestra*. The place where the dramatic action took place with a semicircular shape. The orchestra was separated from the *theatron* by a low wall. The wall was also used as backrest for the first row of seats or *prohedria*. The *prohedria* was reserved for the society's representative figures and housed, in the middle, an altar dedicated to Dionysus, the god of wine-making and ecstasy, whose festivals were the driving force behind the development of Greek Theater. Within it, there can be found five stone thrones with backs and decorations in the shape of lion's paws and scrolls on the sides.
- The *theatron*. This element was made over the slope of Mount Mycale's flank, divided by a *diazoma* into two sections. The lower part, is semicircular and composed of twenty-two bleachers. The upper part, has twenty-five bleachers and a trapezoidal shape. Because of the orography of the terrain, it has retaining side walls to the east and west ends. Each part, in its structure, was divided respectively in the lower part into five vertical sections and in the upper part into four sections. *Klimakes* allow accessibility to all parts of the *theatron*. Corresponding to the central axis of the altar of Dionysus and five rows away, there were additional seats for the significant representatives of the society (Figs. 2 and 6).

2 Methodology

The proposed workflow faces the main phases of the 3D virtual reconstruction process. From the data acquisition to the data visualization of the digital asset enriched by historical documentation re-used to three-dimensional modeling of the theater, the data were collected and modified according to diverse visualization purposes using the latest web-based technologies.

The developed solution encounters the need of a diverse target audience: a specialized public with a 3D virtual reconstruction resource-based and scientifically accurate; a large public with a VR environment accessible on-site and remotely for an immersive fruition of the archeological site.

2.1 Data Acquisition

The purpose of the digital acquisition is to have a point cloud of the archeological site, as it is today, to be used as a reference for the hypothetical virtual reconstruction of the theater. To pursue this goal and optimize fieldwork time, it was decided to generate a model using a photogrammetric acquisition technique. At the photo-modeling stage, a free-net adjustment was made with subsequent scale assignment by applying the least-squares method on three known distances, measured with the help of a metric token.

Using elements of known length is an inexpensive, quick and well-established procedure, both in the orientation of the photogrammetric block of industrial complexes [33], and in the survey of archaeological heritage [34].

Correctly sizing the supports taken as reference they must be proportionate to the object to be surveyed and the distance of the taking images are the fundamentals of this technique. The scientific community recognizes that generating point clouds from photogrammetric blocks provides excellent results even when the starting dataset is not a set of images acquired with a calibrated photogrammetric camera [35]. The method used has already been tested and found suitable for the survey of the theater. The acquisition was made in the vicinity of the elements taken as dimensional reference. Studies show that despite the economy of the process, even at greater distances from the reference element, the accuracy is approximately a few centimeters [36].

In particular, the measurements were acquired, with the help of a laser distance meter, of: diameter of the orchestra (13.50 m); length and height of the skene (20.97 m; 2.70 m); and the distance is a corner of the altar and the base of the third, sixth, seventh (the two central) and tenth columns of the skene (14.90 m; 14.00 m; 12.60 m; 13.70 m) (Fig. 3). Photogrammetric shots were taken using a Sony Alpha 6000 camera equipped with a 23.5 x 15.6 mm sensor. The dataset was supplemented with aerial images taken with a DJI Mavic Mini drone (equipped with a 1/2.3-inch CMOS sensor) and other terrestrial images taken with an iPhone13Pro (the latter were used to capture some details for the theater seats. This type of device, equipped with a 1/1.65″ sensor, was owned by the students who participated in the digital acquisition).

There are mainly two photogrammetric blocks: the first concerning the acquisition of the skene and the second aimed at the rest of the structure.

To acquire the external elevation of the skene, four paths were carried out with axes parallel to the elevation, one at a greater distance (±4 m) which was able to acquire the entire height of the structure, three closer together (±2 m). To acquire the internal elevations of the skene, three paths with parallel axes were carried out for each elevation at a close distance (±2 m), each strip was concentrated on a different strip (lower, middle and upper part of the elevations) and the two the outer ones served to reveal the roof and the floor of the skene. Around the columns, shots were taken with converging axes to acquire the capitals and bases of the same in greater detail. Given the tools used and the maximum gripping distance of 5 m, it is possible to state that the GSD value varies from 0.08 to 0.02 (cm/px).

To acquire the remaining part of the theatre, the team positioned themselves at different heights of the steps (respectively on the first, fifth and tenth steps). Subsequently, the team moved in synchrony, the operator in the upper tier began to acquire the images and the others followed him successively, so that the operator below did not appear in the images of those who stood on the upper steps, and the first capture path was carried out by converging the axes of the chambers in an imaginary axis central to the orchestra. Subsequently, other routes were created that followed the steps of the terraces from the orchestra. Further shots were taken from the skene towards the steps following the prospectus of the skene in parallel. In this case, given the variety of the machine body used and the complexity of the structure (the inclined steps) it is complex to return a single univocal GSD value. Finally, with the support of the drone, two acquisitions at an altitude, with respect to the orchestra, of 15 m and two at an altitude of 20 m. Guaranteeing a GSD of between 0.09 and 0.11 (cm/px). Considerable attention has been paid to ensure that all these shots have, compared to the previous shot, a good overlap, never less than 40%.

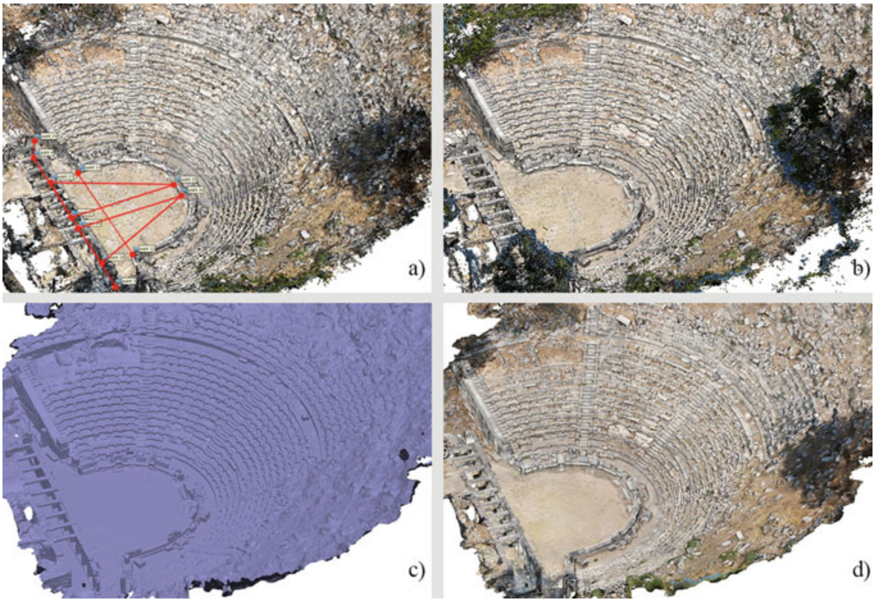

Fig. 3 Data processing for 3D model of the theater using photogrammetric acquisition. **a** dense cloud with measured distance points; **b** dense cloud; **c** model solid; **d** model textured (Post-processing: A. Tomalini; Editing: E. C. Giovannini)

2.2 Data Interpretation and Representation: 3D Reconstruction

A hypothetical virtual reconstruction of the theater was made following the survey data acquisition and previous studies. Hypothetical reconstructive choices were made based on the collected iconographic and bibliographic sources [29–32]. The importance given to the sources was given according to the source's varying level of accuracy and uncertainty [37] analyzing the type of information available (Table 1).

The photogrammetric point cloud was segmented into the main elements that make up the theater. The process of classification and segmentation into smaller parts was manual.

A non-automated three-dimensional modeling process was adopted for the virtual reconstruction of the theater. Point cloud and raster images of the bibliographic

Table 1 Comparison: resources used and information available (Author: E. C. Giovannini)

Resource	Dimensions	Plans	Section	Facades
Point cloud	•	•	•	
Dörpfeld (1924)	*Unreadable*	•		•
Wiegand (1904)	•	•	•	

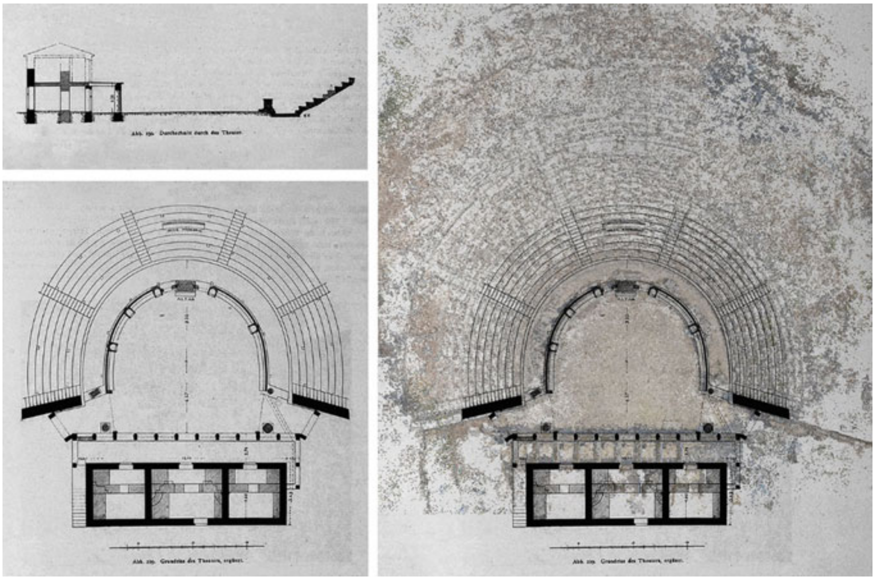

Fig. 4 Comparison between sources collected. On the left, the plan and section from *Das Theater* [38]. On the right, superimposition between the point cloud and historical documentation (Editing: E. C. Giovannini)

sources were imported into Rhinoceroceros 3D modeling software and placed in projective correspondence. The comparison process was continuous during the reconstruction activity (Fig. 6).

Different modeling choices were made for each of the previously classified portions of the theater: *orchestra, proskenion, skene,* bleachers, *diazoma*, *klimakes*, and *theatron.* Thanks to the archaeological evidence, relocated and repositioned during the last restoration conducted in 1992–98, it was possible to reconstruct the correct outline of the orchestra. Regarding the planimetric drawing, there are no significant differences between the photogrammetric data and illustrations in Wiegand (1904) (Fig. 4).

The *proskenion* was integrated during the 1992–1998 restoration campaign. The later combined portions are distinguishable because they have different levels of

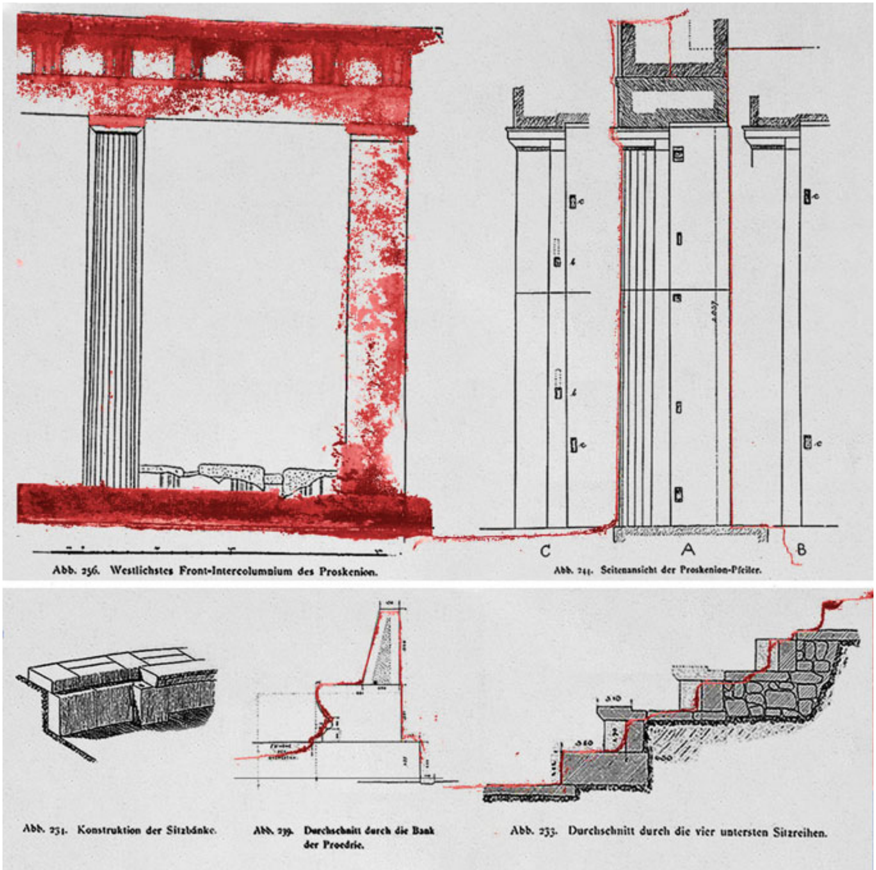

Fig. 5 Superimposition of the profile obtained from the point cloud with the collection of details inside *Das Theater* [38] (Editing: J. Bono)

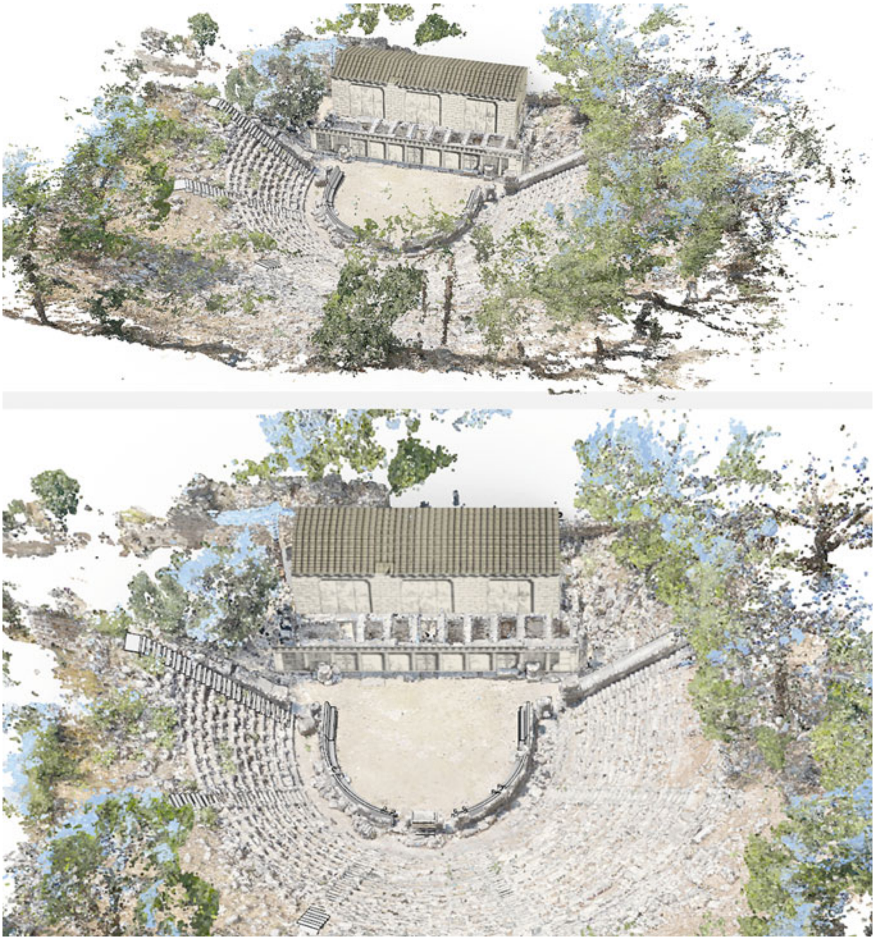

Fig. 6 Illustrative 3D model of theatre immersed within the point cloud. The model was scaled according to the digital acquisition and textured with drawings from *Das Theater von Priene und die griechische Bühne* [32] (Editing: J. Bono)

degradation and other construction techniques. The bibliography and the digital acquisition information match without significant dissimilarities.

The *skene* portion was modeled using published studies conducted in less recent times. The interior elements were redrawn from the latter because only its outer perimeter could be digitized during the acquisition campaign.

The bleachers are the element with the highest level of detail within the point cloud. The gripping mode ensured that the metric datum was returned uniformly enough to distinguish each stone block. In contrast with the point cloud, the profile drawing of the bleacher section has some significant differences. Connecting the outer vertices of the seats of the bleachers from the iconographic sources and relating this line to the ground line has a smaller slope than the line obtained by redrawing the bleachers obtained from the point cloud. For the reconstruction of this portion, the bleachers profile (Fig. 5) reported by Wiegand (1904) was redrawn, and the heights were set by going to approximating the photogrammetric point cloud.

The same procedure was followed for the visible part of *diazoma*.

The sections of the *klimakes* and *theatron* were challenging to read from the point cloud. As one ascends the hillside, the step blocks are increasingly hidden and emerge marginally from the vegetation and soil accumulated over the centuries. The right and left sides are different. In the steps on the right side, it was possible to develop a consistent reconstructive hypothesis thanks to the data from the left portion. Further investigation is needed in reconstructive modeling for the *klimakes*, and *theatron* portions, as the data to date do not allow for a critically corroborated virtual reconstruction.

2.3 Data Visualization: Low-Cost Virtual and Immersive Reality

Archaeological, cultural heritage, or more simply archaeological heritage, is a subcategory of the world's cultural heritage. It is distinguished from other types of heritage by the historical, aesthetic, and symbolic values possessed by the archaeological assets of which it consists.

Archaeological sites are places where tourists and non-specialist visitors go to explore and see the memories of places partially disappeared. An archaeological site is a place where evidence of past activity is preserved and investigated by diverse disciplines, including archaeology.

The enhancement of ruins is a topic debated in architecture only recently. From the postwar period until the early 1990s, there was a general situation in which urban and suburban archaeological sites remained excluded from people's lives.

Ruins and excavated artifacts are generally only the subjects of recovery aimed at restoration and preservation, excluding their valorization. The archeological areas sometimes, in fact, lose their testimonial value of the past ending up in a state of degradation and abandonment. When this does not happen, archaeological valorization activities can have a wide and varied case history of in situ interventions. Priene, because of the fragmentary nature of the finds and the extent of the open space, the places of most significant interest are provided with an information panel (Fig. 7).

The covid emergency highlighted the need for the cultural and archaeological heritage sector to make heritage accessible online. The available data were thus reused for the creation of a virtual environment. Sketchfab is one of the most popular online 3D repositories [39]. The platform allows annotation features to help users understand and contextualize the 3D artifacts. In the platform, it is also possible to

Fig. 7 Illustrative panels are placed at the Archeological site's entrance (left) and near the right entry of the Priene theater (right) (Photos: E. C. Giovannini)

Table 2 Transformation of the digital asset (Post-processing: E. C. Giovannini)

	Original	Cleaned	Simplified
N. vertices	21,831,522	9,548,285	403,473
N. faces	43,646,219	19,078,538	799,999
Model: .obj	5.55 GB	2.33 GB	94.4 MB
Texture: .jpg	15,192 × 15,192	15,192 × 15,192	15,192 × 15,192

add sound, animation, ground shadows, and hi-res textures. Despite the potentialities of the platform, in the case of cultural heritage and archeological sectors, representing and visualizing elements at the architectural scale is challenging. SketchFab is generally used to create digital galleries of objects or collections. The complexity of architectural/archeological heritage 3D models is the main bottleneck of the process from digital acquisition to digital fruition of the asset. Within the PRO version of the account, it is possible to upload a 200 MB maximum file size per model, including the textures.

From the original photogrammetric model, the 3D was first cleaned by removing vegetation elements and then simplified (Fig. 8). The retopologization of the original model was performed using MeshLab and its Quadratic edge collapse decimation (with texture) filter [40] to obtain a suitable textured model to be uploaded on the web (Table 2). Online was set up the point of view to navigate the model in VR and annotations with links to other digital galleries developed during the International Summer School (Figs. 9 and 10).

2.4 Data Visualization: Augmented Reality Potentialities

Despite the efforts to explore and test different methodologies to create an AR application, the tests conducted were not sufficient to produce a fully functional product.

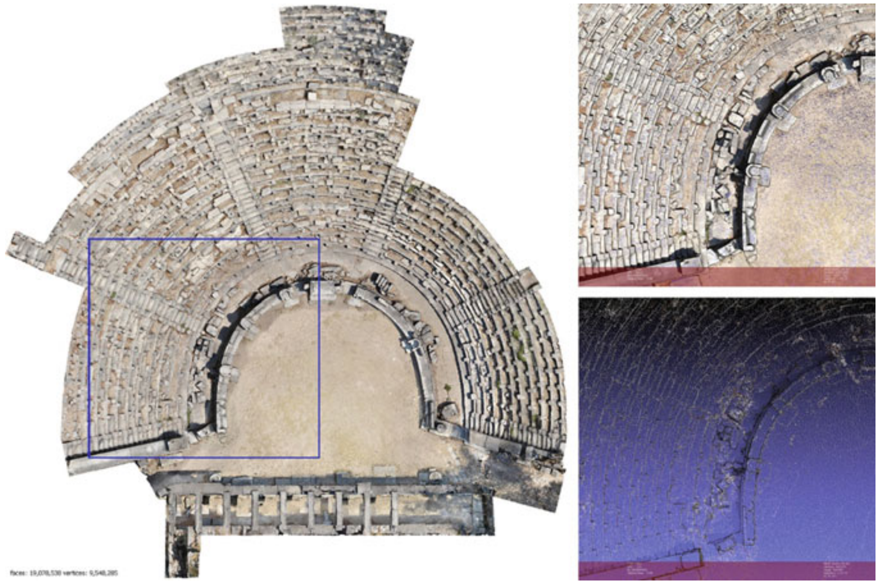

Fig. 8 MetaShape interface shows the cleaned 3D model obtained after removing vegetation elements (left). On the right, MeshLab interface showing the original pointcloud (top) and simplified pointcloud (bottom) (Post-processing and editing: E. C. Giovannini)

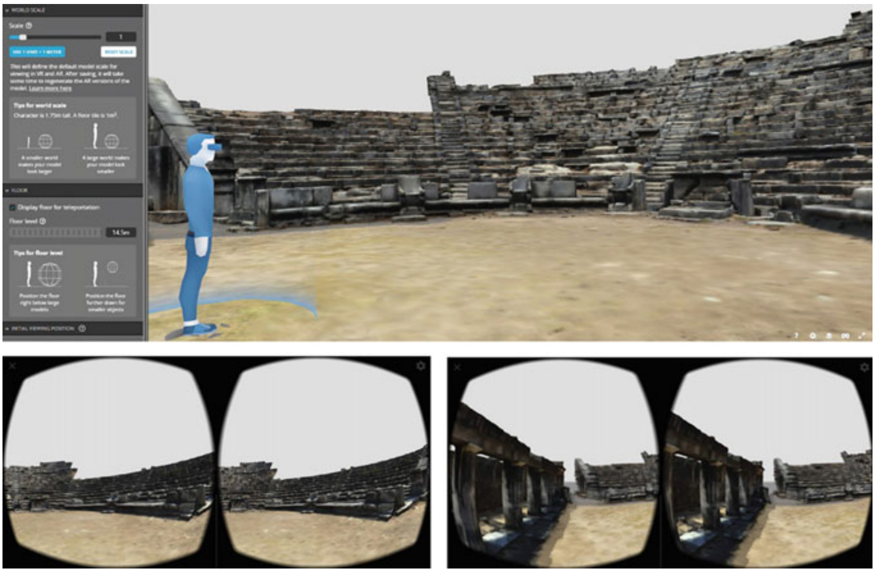

Fig. 9 Desktop user interface for setting up the Virtual Reality fruition (top). Two different points of view using the VR tool experience on mobile device (bottom) (Post-processing and editing: E. C. Giovannini)

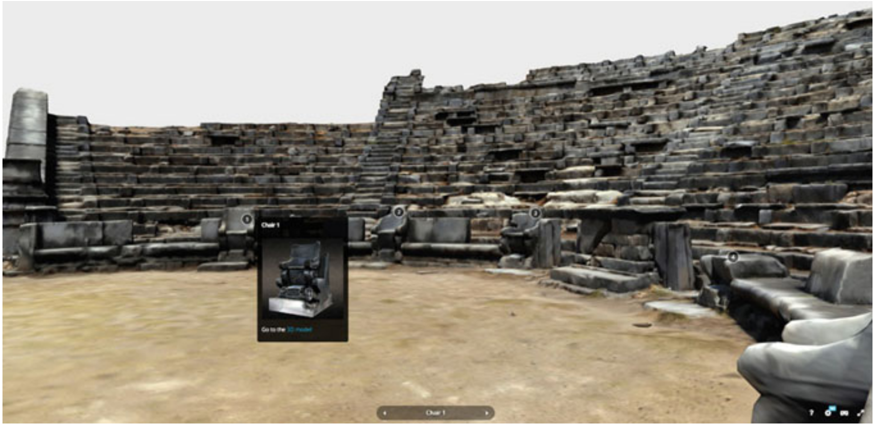

Fig. 10 VR experience of the Priene theater with annotations (Post-processing and editing: E. C. Giovannini)

The focus of this text is to explain the methodology used, but no concrete results can be shown due to the limitations faced. The inability to revisit the site for further data collection hindered the opportunity for more in-depth testing and further development of this application.

Initially, the group investigated some applications that can be installed on android devices, such as GAMMA AR, vGIS AR, and VisualLive. These applications were developed for monitoring construction sites through augmented reality. The limitations of these applications are the system's low customization and the inability to load complex geometries. Although it is already possible to associate annotations to the model, this can be simplified, and their visualization needs to be more suitable for an edutainment purpose.

Other applications such as MyWebAR.com and AR.js—Augmented Reality on the Web have the advantage of running directly in the device's browser. This approach is particularly advantageous but more complex to enrich the model with information.

For these reasons, in order to create an AR application that overlays the model of the virtual reconstruction of the theater on top of its ruins, the research team set out to explore the following technologies.

- Google Maps API. Google Maps API can be used to obtain the user's geographic location and use it to place the georeferenced 3D model. Google Maps API can also create markers on the map that indicate specific locations, such as the user's location or the location of a place of interest.
- ARCore. ARCore is a Google augmented reality platform that allows users to create AR experiences on Android devices. ARCore can insert the 3D model into a video stream originated by the device's camera and position it relative to the user's geographic location. ARCore also has the advantage of being a cross-platform framework, available on iOS, Android, and the Web.

In order to use these technologies together, the group tested the integration in a test app to test an early version of a geo-referenced AR experience. The Google Maps API in this first demo was used to obtain the user's geographic location. Arcore was used to display a simple 3D model in the camera view and position it according to the geographic location. A 3D model, following the reconstruction phase, must be exported to an ARCore-compatible format, such as gITF, to be displayed. The advantage of this format is that it is easy to include georeferencing data.

ARCore also has the advantage over other competing frameworks in providing depth estimation capabilities. This technology makes it possible to calculate the distance between the mobile device and objects in the surrounding environment. Virtual objects can interact with the real environment and achieve greater visual depth due to the occlusion effect of the objects already present on the inserted 3D model. With this capability, creating more realistic AR experiences is possible. However, it is important to note that the current 3D model is too heavy for mobile devices, and further work is needed to optimize it for a smoother user experience. Unfortunately, due to the constraints mentioned earlier, such as the impossibility of revisiting the site, the development of a fully functional AR application remains a challenge, and further research and testing are required to achieve the desired results.

3 Conclusions

The research, part of a broader project that concerns the collaboration between diverse Universities and institutions, has investigated the different aspects of digital acquisition and visualization of an archaeological site. The purpose is to increase the narration, fruition, and dissemination of a heritage site that gradually transformed and partially disappeared. The research tries to define a possible operational process beyond the apparent limits that this type of modeling constitutes when applied to a fragmented archeological area. Another challenge was modeling a virtual reconstruction hypothesis for an archeological building: the theater of Priene. Finally, the group investigated opportunities and future developments for VR and AR solutions. In this context, the study explores the potentialities and limits of using VR tools in Sketchfab for creating an interactive and immersive digital model.

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Although the contribution was conceived jointly, E. C. Giovannini is author of paragraphs 1, 2, 2.3, 3; A. Tomalini of paragraphs 2.1; J. Bono of paragraphs 1.1, 1.2. Paragraph 2.2 was written jointly by A. Tomalini and J. Bono. Paragraph 2.4 was written jointly by A. Tomalini and E. Pristeri.

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Immersive Ro(o)me. A Virtual Reconstruction of Rome in 1750

Tommaso Empler, Adriana Caldarone, and Alexandra Fusinetti

1 Introduction

1.1 Edutainment and Serious Game: Visual Storytelling, Game Play, Interactions

Practice of digital technologies to enhance and communicate cultural heritage is widely recognized as a possible and valid tool, not only to reach a wider audience, but also to make the transmission of information clearer and more effective.

In recent times, the structure of cultural communication towards users has evolved in a more playful and interactive direction, a turn certainly facilitated and supported by the fast technological development in which information and communication technologies have played a fundamental role. Their consolidated effectiveness in disseminating information through mainly visual communication models (online/offline, static/dynamic, reconstruction, or simulation, etc.) has allowed the development of new communicative methods capable of engaging and exciting the public. The synergy between these different modalities is notably successful precisely because the visual aspect is predominant: thanks to it, it is possible to contextualize the work, integrate information at multiple levels, and make it accordingly more understandable to those observing it [1].

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ICTs allow for digital access to cultural heritage, and two modes of information access can be identified: passive and active. In the first case, the heritage is digitized, reconstructed (using, for example, integrated survey operations and subsequent data processing), and made available online to visitors. Such experiences, if well-constructed, can stimulate the user's curiosity to visit the physical place or work, but to a non-specialized audience, proposals of this type can be sterile, uninvolved, and less accessible from a cognitive point of view. On the contrary, the active approach places the user at the center of the experience, providing for the creation of diverse content, adapted to different media, and using storytelling as a communicative strategy to convey content. In this way, leveraging the emotional variable that the story can generate, the user engages in a functional learning state for the transmission of content. The use of these methodologies intervenes in situations where it is more complicated to engage the public or to disseminate information to multiple levels of users, with the aim of making it more accessible.

The language of videogames is among these new communication systems and, thanks also to the use of a storytelling mode known as Visual Storytelling, and the use of images as an expressive means, it is increasingly establishing itself as a valid tool for the communication of cultural heritage.

Games of this type are defined as Serious (or Cultural) Games and are developed with learning purposes, in which the concept of Learning-by-doing is adapted using the language of the game. The high degree of involvement translates into an effective and enjoyable learning experience.

Involvement is due to several factors, such as the development of a story, the graphic representation of the game environment, elements of competitiveness, usability, and interactions. Learning is structured by organizing content in simplified forms inserted within the game narrative.

Graphic setting is among the fundamental elements within the framework of the transmission of content: the representation of cultural artifacts, whether it be a faithful digital representation or a hypothetical reconstruction, facilitates its correct interpretation. Thanks to this predominance of the visual aspect, it is possible to contextualize the work, integrate information at multiple levels, and accordingly make it more understandable to those observing it.

Visual medium is, in fact, a much more effective form of communication, from a cognitive point of view, than purely linguistic communication, especially if written [2]. This research presents the methodology used to define a Serious Game set in Rome in 1750.

The reconstruction of the architectural context of the period, carried out scientifically through analysis and comparison of various iconographic sources and the current state of the urban fabric, has generated a three-dimensional model of the neighborhoods of the historic center of Rome, within which various narrative proposals have been developed. The model thus allows access to an interactive experience that recreates a virtual environment freely explorable by the user.

1.2 Vision Hierarchy and Visual Hierarchy: A Scenario Construction

The aim of the current research, as previously announced, is to communicate and disseminate the architectural, artistic, and expressive context of the social and cultural events in Rome during the second half of the eighteenth century. The starting point is the reconstruction of the site according to an approach that involves a careful analysis of sources (documentary and iconographic) to translate relevant historical and architectural elements into a three-dimensional setting. Depending on the requirements, the construction of the space is developed through a process in which writing, level design, game design, imagination, and project purpose create urban clusters that project users into places that are always partially the result of fantasy, even when they recall real spaces.

Urban space, in fact, becomes a main character in the gaming scenario, also because it acts as a medium between human beings and the virtual environment. Urban spaces, like every space, are built from different overlapping and interconnected layers, where architecture, society, human and political history, geology, and many other factors shape the city scenario.

Video game environments are artificial representations of real spaces that must appear natural or at least familiar to those who interact with them. For the exploration of virtual spaces to be experienced as real, in addition to historical reliability, the three-dimensional representation of the scenario in which the player moves assumes a fundamental role, also for the purpose of recognizing the space in which they are inserted.

In general, the recognition of a space involves reassembling the different stimuli coming from the surrounding environment into a spatial continuum: the physicality of elements, odors, and sounds can help the user determine the size of spaces and distances and build mental cognitive maps. Visual perception plays a fundamental role in this, creating mental reference schemes based on hierarchies, which help users in spatial orientation.

However, the neural model in virtual reality is substantially different from the real one [3], so in addressing the issue of navigation in virtual spaces that must be experienced as real spaces, it is necessary to consider how spatial perception operates.

According to the well-known Gestalt psychology, perception does not consider the individual parts that make up the observation field, but rather its entirety, and the overall image is grasped by the mind as an organized set of signs [4]. From this it follows that the reading of a place, in order to represent and model it in its formal aspects, is a semantic and analytical operation: the elements that compose it assume their own meaning in relation to the others in terms of position, balance, shape, and configuration, as predicted by the visual perception theories of Arnheim [5]. On the other hand, according to Arnheim, who analyzes the power of architectural form, urban space is not only the result of solid and void but arises from the interrelationship between them [6]. However, the element that provides value and character to a space is not only to be found in solid or void and their relation, but in the observer. In fact, humans perceive urban fabric through a personal attribution of meaning, through a system of relationships between the user and the scene.

The perception that the user has of urban space is linked to their movement and orientation, and the entire configuration is acquired as a structured set of elements to which a value is assigned based on relations of size, position, and direction. The vision hierarchy can therefore be defined as the ability of an observer to look at objects and hierarchize information according to spatial or dimensional relationships: for example, an object of greater size is the most important, dominant, and in the foreground.

In the composition of a virtual scenario of an urban space, it is necessary to consider this process of hierarchization of elements, attributing greater or lesser relevance to the objects represented according to the same laws that govern vision hierarchy. In order to translate the architectural context of eighteenth century Rome into a three-dimensional setting, it is necessary to deal with this mode of information processing by users. To this end, a visual hierarchy process has been implemented, which organizes the three-dimensional model according to a reading order that depends on the relevance of the object being represented.

In particular, three categories of elements that make up the scene have been identified, namely primary, secondary, and tertiary elements. Primary elements are architectural and urban components that emerge within the fabric of the city by virtue of their form or size, or whose importance derives from the function they assume within the context. They are mostly main squares, churches, and noble palaces, iconic and representative objects for the recognizability of places that structure the urban context as a whole and are generally functional for orientation. Secondary elements are objects that perceptually and visually compose the urban morphology, whose architectural typology is similar throughout the urban fabric or divided by neighborhoods. They too are fundamental for the composition of the urban fabric, but they are less important for defining points of reference for orientation in the cityscape. Finally, tertiary elements are mostly architectural and decorative objects that characterize the urban scene, such as fountains, obelisks, statues, and artistic elements that contribute to delineating the features of the city center and characterize it. They are not fundamental for the structuring of space but are essential for orientation.

The syntax of the representation, adopted in the construction of the scenario, essentially involves the concomitance of symbolic and iconic elements, according to which iconic elements are virtual objects related to real objects by virtue of a similarity character. This mode was used for primary and tertiary elements. Symbolic elements, on the other hand, are not based on similarity, but the relationship with the real object is established in purely conventional terms. In fact, secondary elements belong to a symbolic category of palaces.

A mode was also adopted that provides for a deepening in modeling according to certain levels of detail, higher for iconic elements and lower for symbolic ones, according to a sort of perceptual gradient.

All these techniques, already used in the representation of Rome employed by vedutisti and engravers from the second half of the seventeenth century (Fig. 1), allow for a method that is independent from the identity of a place: the hierarchy

Fig. 1 Giovanni Battista Falda. Map of Rome from 1667. The three churches depicted in this excerpt (primary elements) are represented in iconic way; the buildings comprising the urban context (secondary elements) are instead symbolic and share common characteristics and variations in height, width, and number of openings. The obelisk constitutes the tertiary element that does not contribute to the composition of the fabric but is of fundamental importance for the recognizability of the place (*Source* Info.roma.it)

of elements, although the representation must express the intrinsic characteristics of each space, allows for the existence of criteria and invariants that constitute the basis for adequate design and communication.

The model thus becomes a carrier of physical-geographic and perceptual values. It follows that visual hierarchy imitates vision hierarchy, becomes the syntax for reading a virtual space, and proves to be an appropriate tool for communicating real places in order to achieve greater understanding by users.

2 State-of-the-Art

2.1 Video Games for Culture

Video games for culture have an important development in Italy since 2010, when a synergy for the dissemination of serious games with educational and cultural contents begins through initiatives by video game developers and research institutes. In this direction, can be mentioned a series of initiatives, such as: SeriGamex 2014 conference, organized by the Department of History, Representation and Restoration of Architecture, Sapienza University of Rome and by Mimos, the association which in Italy deals with spreading the culture of simulation and virtual reality; workshop Videogames, Research and Cultural Heritage as part of the Rome VideoGameLab event at Cinecittà (Rome) in 2018, organized by the Department of Human and Social

Sciences, Cultural Heritage (DSU) of the CNR and by CNR ITABC (today ISPC). A milestone in this direction is the book *Videogames, Ricerca, Patrimonio Culturale*, edited in 2020 by Sofia Pescarin [7], published by CNR, VideoGameLab Cinecittà and MIBACT Directorate of Museums. Contributions and research are collected in the direction of production, communication and design, research, museums and schools.

3 Virtual Reconstruction of Rome in 1750

3.1 Game Design Document

The Game Design Document (GDD) describes the main components of the game design project to be developed and is a constantly updated document [8].

It has a structure divided into: High Level Concept Design; Product Design; Detailed & Game Systems Design.

The High-Level Concept Design contains general information about the game, such as:

- The working title, which should communicate the gameplay and style of the game.
- The concept statement, in which the game is expressed with one or two sentences at most, which illustrate the theme and why it is fun.
- Genre(s), a single genre is clearer but often less interesting. Genre combinations can be risky. Beware of tired genres.
- Target audience, relevant motivations and interests; potential age, gender, etc. of players.
- Unique selling points, what sets the game apart? How is it different from all other games?

The Product Design is articulated in:

- Player Experience and Game POV (Point of View), who is the player? What is the setting? What is the fantasy that the game allows the player to have? What emotions do you want the player to feel? What keeps the player engaged throughout the game?
- Visual and Audio Style, what is the look and feel of the game? How does this support the player's required experience? What concept art or reference graphics can be shown to give an idea of the game?
- Game World Fiction, a brief description of the game world and any narrative relevant to the player (how it is presented to the player).
- Monetization, how does the game allow for earning money? Premium purchase? How can it be integrated into the design?

- Platform, Technology, and Scope, PC or mobile? Tabletop or phone? 2D or 3D? Unity or JavaScript? How long to set up, and how large should the team be? How long to play for the first time? How long to complete the game? Major risks?

The Detailed & Game Systems Design includes:

- Core Loops, how do game objects and player actions form loops? Why is it engaging? How does this support the players' goals? What emerging results can be expected? If there is F2P (Free To Play), where are the monetization points?
- Objectives and Progression, how does the player move in the game, literally and figuratively, from the tutorial to the end? What are the short- and long-term goals (explicit or implicit)? How do these support the game concept, style and player fantasy?
- Game System, what systems are necessary to realize the game? Which ones are internal (simulation, etc.) and which ones do players interact with?
- Interactivity, how are different types of interactivities used? (Action/Feedback, ST Cog, LT Cog, Emotional, Social, Cultural) What does the player do moment to moment? How does the player move in the world? How do physical force/combat/work, etc. work? A clear and professionally designed schema of the game's main UX (User Experience) is useful.

In addition to what is established by a Game Design Document in general, it is necessary to structure and elaborate historical-artistic information that will be disseminated during the interaction phase, closely connected with an effective level of modeling, in order to make the reconstruction believable and adherent to what was present in reality during the historical period being reconstructed.

Therefore, it was decided to proceed by identifying two different objectives but correlated with each other: educational objectives and game objectives. As for the objectives and the storytelling approach, it was decided to divide the city into Rioni (districts) and build independent narrative and goals on each one, in an approach based on multiple levels of gameplay (Fig. 2).

In addition, in each chapter, the main characters that are played by the player and the non-playable characters who take on the role of guide during the development of the plot, were established (Fig. 3).

Last, but not least, is the drafting of a storyboard and a mood board: the first is a graphic representation, in form of drawn sequences, of the scenes that are chronologically ordered, possibly also identifying the different frames and/or levels of gameplay (Fig. 4); the second is a visual representation that consists of a set of images, words, and materials and aims to trace an inspiration map to clarify the points to follow and respect the work objectives (Fig. 5).

In the video game, each user becomes the protagonist of the story and influences it. Depending on the choices made, the game's ending changes. This method helps to connect with the story and facilitates better conveyance of the messages.

Fig. 2 Expected cover for the game level in the III Colonna Rione. The protagonist of the game, Alice Alberici, is a young forger. During the game, Alice must reproduce some works by famous authors that depict scenes of daily life and historical buildings, scouting out the places of inspiration for these works in order to be able to faithfully reproduce them (Editing: T. Empler, A. Caldarone and A. Fusinetti)

Fig. 3 On the left and center, **a** and **b**, preparatory sketches for the main character identified for district III Column. On the right, **c**, digital modeling of the character (Editing: T. Empler, A. Caldarone and A. Fusinetti)

3.2 Composition of Virtual Scenery

The process of reconstruction and composition of the scene involved an organization into several fundamental phases:

- Historical research and data analysis, during which, to understand the juxtaposition in plan of all elements, we started from the Nolli's Map and some images taken from engravings or paintings of the time, referring to the three-dimensional composition of objects.

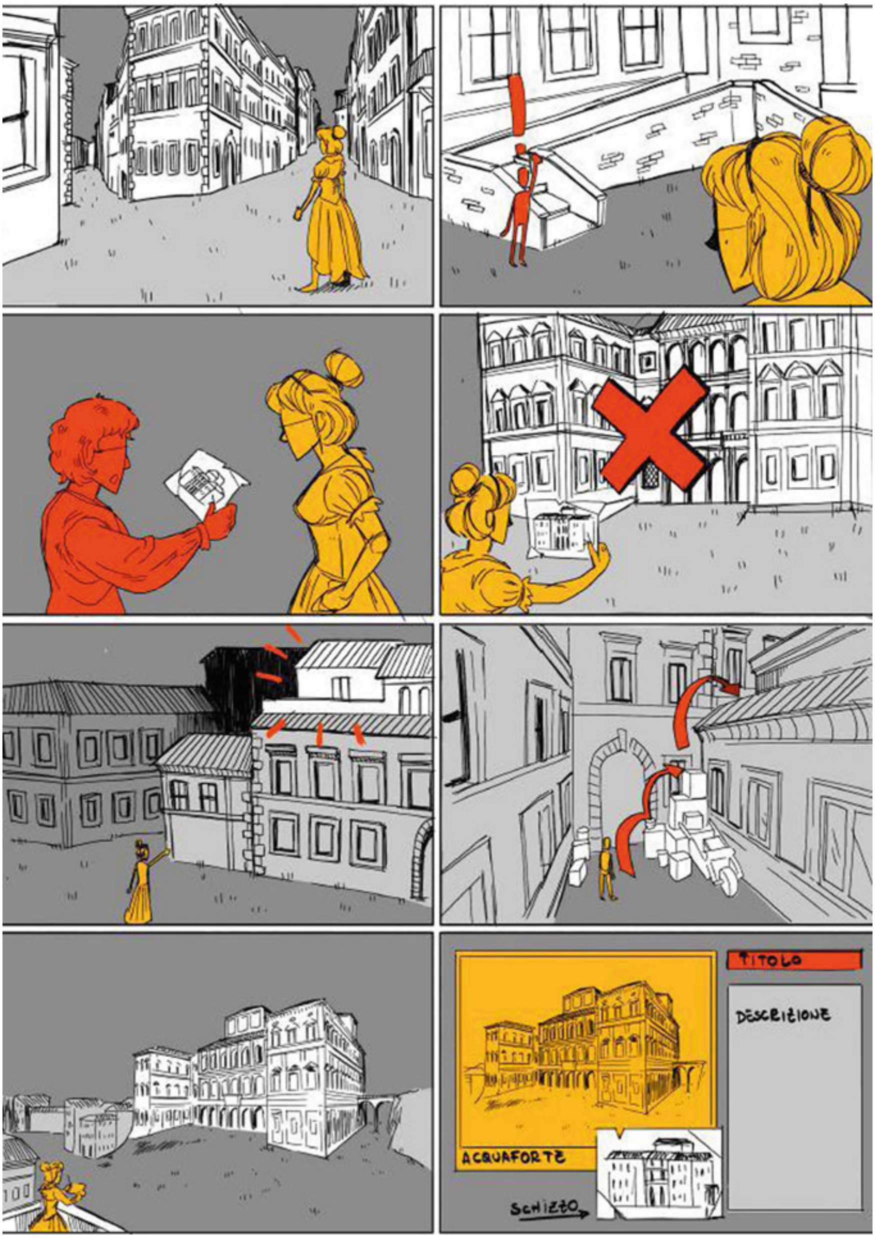

Fig. 4 Example of a storyboard designed for the level of Rione III Colonna (Editing: T. Empler, A. Caldarone and A. Fusinetti)

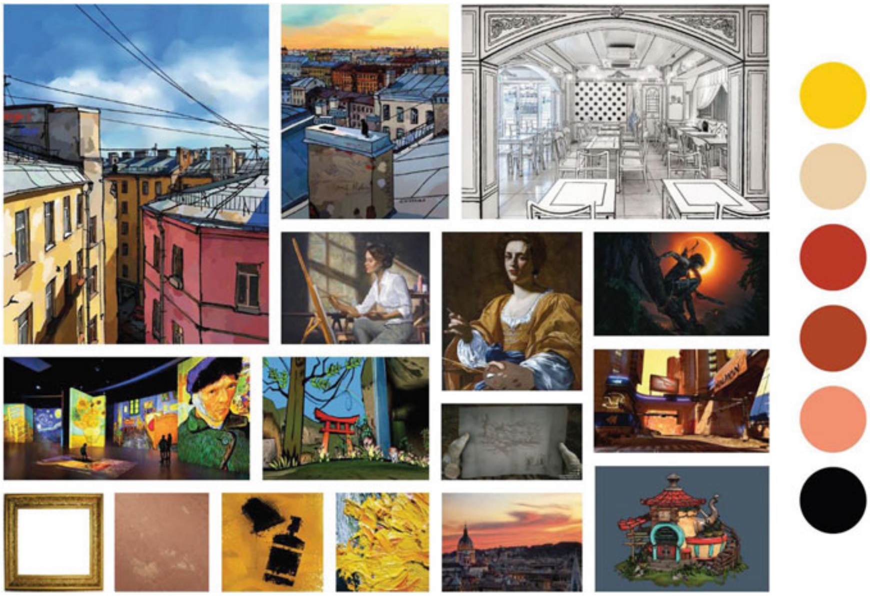

Fig. 5 Example of moodboard designed for the level of Rione III Colonna (Editing: T. Empler, A. Caldarone and A. Fusinetti)

- Identification of significant historical and architectural elements and classification into primary, secondary, and tertiary elements.
- Modeling of the elements.
- Combination of the elements and composition of urban spaces.
- Modeling of the terrain topography.
- Texturing.

During the first phase, it was considered that the three-dimensional spaces must not only be characterized by a correct proportion between the objects that make-up the scene, geometric reliability, and recognizability of places, but above all by historical reliability. For this reason, a superimposed reading of information and data derived from direct and indirect documentary sources was carried out. The articulated framework of the urban history of Rome from the mid-sixteenth century to the mid-eighteenth century, a time of profound renewal and remarkable urban growth, was developed. Cartographic documents were analyzed in multiple aspects, and the Nolli Map of Rome from 1748, on which the entire cartographic and planimetric basis was set, the views of Rome by Giuseppe Falda, Piranesi, and Giuseppe Vasi, and the plans of Rome by Greuter were consulted. Some spaces and buildings, present in the engravings and still existing today in their original configurations, were compared with what is still visible today thanks to instrumental surveying and massive acquisitions.

In the second phase, based on the observations expressed in the preceding paragraphs, the urban scenario is broken down into its primary, secondary, and tertiary elements (Figs. 6, 7 and 8).

Regarding secondary elements, further analyses and decompositions were carried out: first, a morpho-typology or characteristic class of each neighborhood was identified. Based on each typology, an abacus of elements (roofs, chimneys, windows, frames, and recurring decorative elements), modeled as parametric objects, was created to adapt to different sizes. Once the metric references, the footprint of the buildings, and the hypothetical heights were identified, the elevations were created

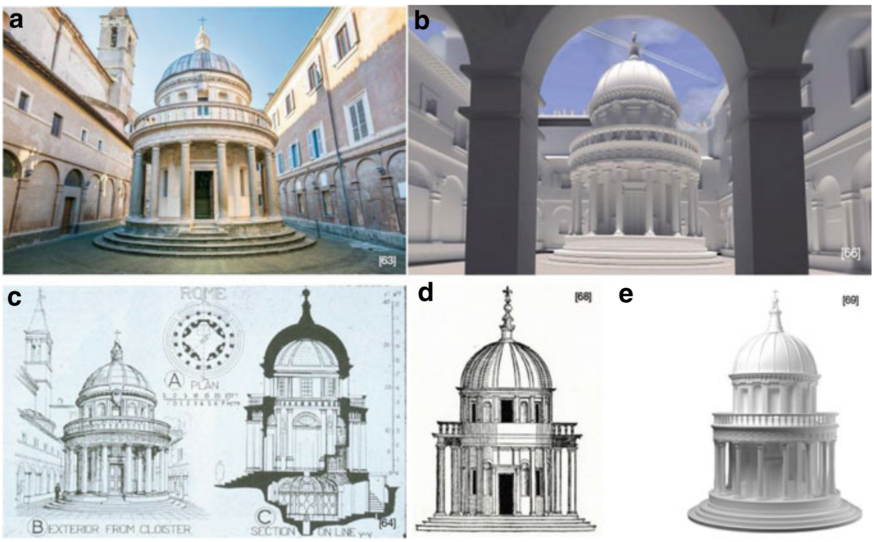

Fig. 6 In the top left corner of **a** is the elevation of Bramante in its current configuration; in the bottom left corner, **b**, and in the center, **c**, are plans, elevations, and sections in an anonymous drawing dated 1850; in the bottom right corner, **d**, is the model of the primary element; in the top right corner, **e**, is the reconstruction inserted into its context (Editing: T. Empler, A. Caldarone and A. Fusinetti)

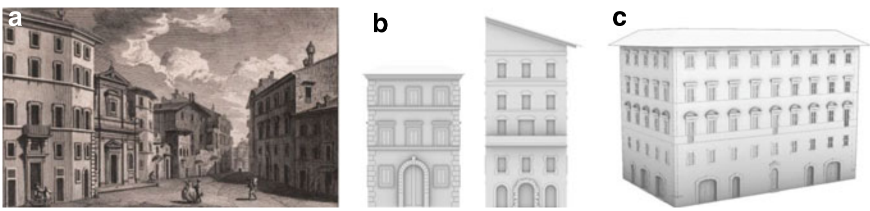

Fig. 7 On the left, **a**, there is an etching by Giuseppe Vasi (1756) of the area of S. Tommaso in Parione; in the center and on the right, **b**, there is a modeling of some secondary elements distinguished by quarters to form architectural classes and types (Editing: T. Empler, A. Caldarone and A. Fusinetti)

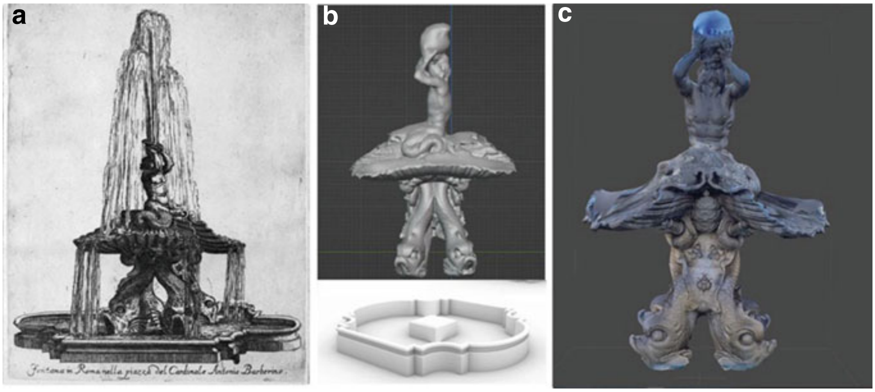

Fig. 8 On the left, **a**, an etching by Berriere Dominique (ca. 1649); in the center, **b**, a mesh modeling of the Triton fountain; on the right, **c**, the result of photogrammetric surveying (Editing: T. Empler, A. Caldarone and A. Fusinetti)

and the parametric objects were combined to form classes of buildings, divided into different types. Finally, to obtain the most diverse context possible, the aggregative laws that led to the urban form of 18th-century Rome were analyzed and parametrically combined with the classes of buildings, following predetermined algorithms and geometry, in order to simulate a random distribution (Fig. 9). Through this method, the structure of solids and voids is represented, assembling the urban layout that defines blocks, streets, alleys, and squares. The thus-shaped model is suitable for representing space by providing an ordered sequence of places organized so that they can be viewed from different perspectives, relating their elements through a montage mechanism.

After composing the scene, corresponding planimetrically to the Nolli map, the product is imported into a suitable game engine program, within which it is possible to link satellite elevation data for terrain modeling, referring to the current state. The terrain morphology is then further explored through the interpretation of historical registers and maps, allowing a current interpretation of the data from the eighteenth century, and modeling the resulting morphology (Fig. 10).

However, the model must not only be capable of expressing the coherence of a descriptive process of the form or material values of a place, but also of translating the essence of a city into a concrete spatial context.

The in-depth study of perception represents the starting point for a subsequent approach that aims to translate into a model the immaterial components necessary for identifying a precise urban reality.

For this reason, a careful study of lights, textures, colors, and elements of scene enrichment (Figs. 11 and 12) has been carried out, considering them as visible embodiments of identity values: all these elements combined, are able to reproduce an intangible reality attributable to the place itself.

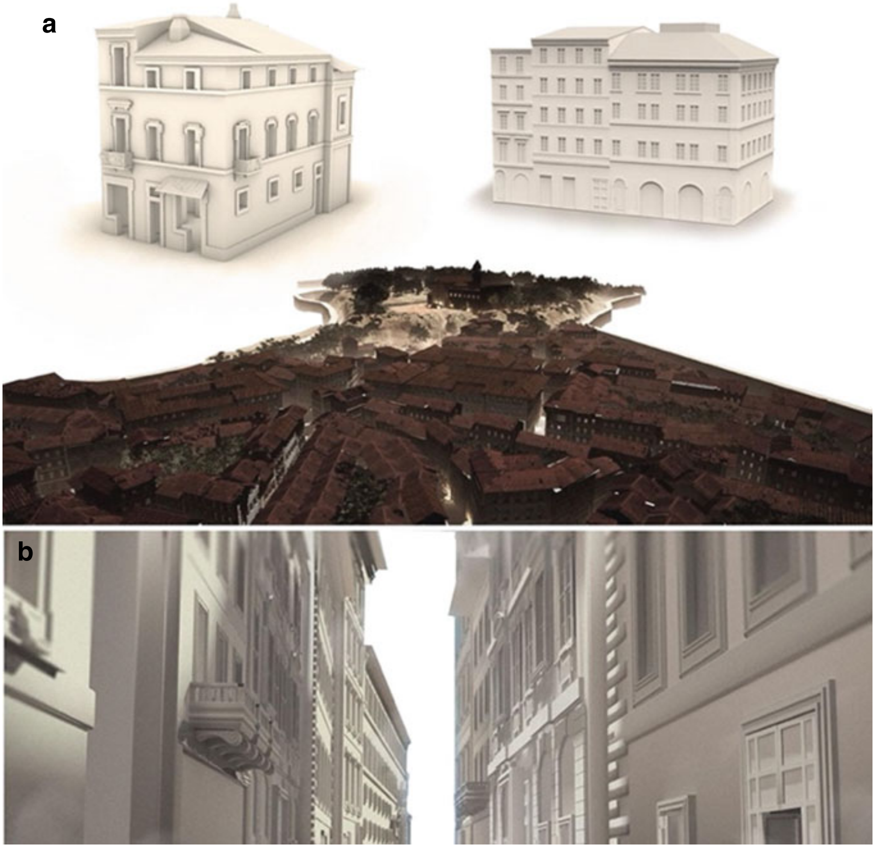

Fig. 9 Above, in **a**, two examples of parametric combination of constituent types of secondary elements are shown, forming classes of buildings. In the center, in **b**, an aerial view of the overall composition is presented. Below, in **c**, a perspective view of the model is shown (Editing: T. Empler, A. Caldarone and A. Fusinetti)

3.3 Interaction Development

In his famous book *Homo Ludens*, Huizinga describes the act of play as the foundation of all social organization, the basis for the development of civilization, capable of providing the tools for interpreting reality, experiencing it and, consequently, learning its dynamics [9].

Through action, according to the concept of Learning by doing, play is thus configured as the first form of learning that humans experience. However, the assimilation of information depends on the level of involvement and therefore the more an individual is actively involved in learning, through the use of their perceptive and cognitive abilities, the greater the effectiveness of the learning itself.

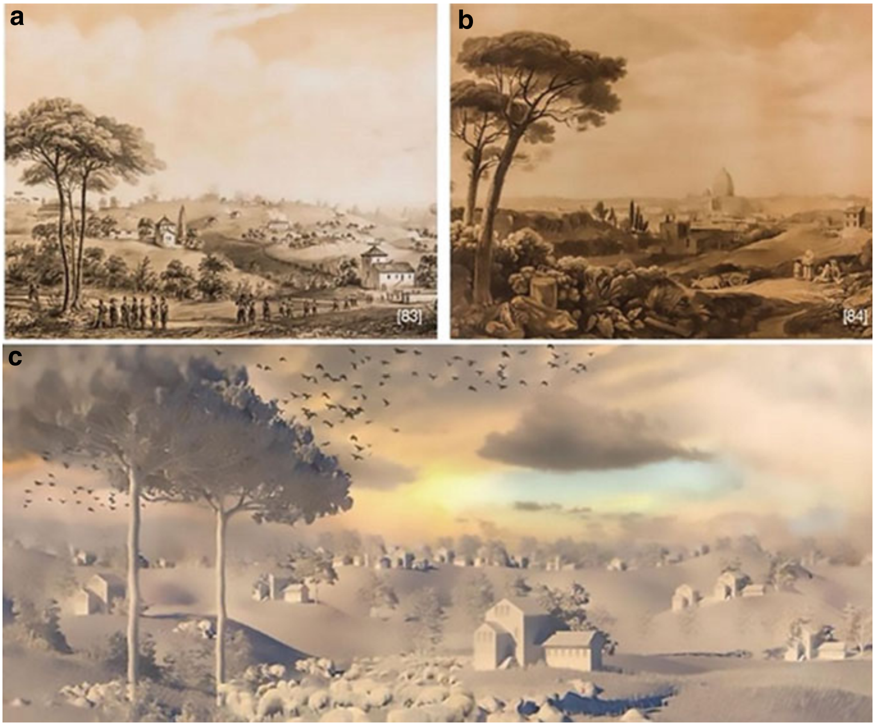

Fig. 10 In the upper left, in **a**, an illustrated table by Huges Charles Antoine Vertray (1851) is shown, while in the upper right, in **b**, an illustrated table of the panorama of Rome between the Gianicolo and Villa Borghese by G. R. Lewis and A. Wilson (1840) is presented. In the lower part, in **c**, the result of the modeling of the terrain's orography is shown (Editing: T. Empler, A. Caldarone and A. Fusinetti)

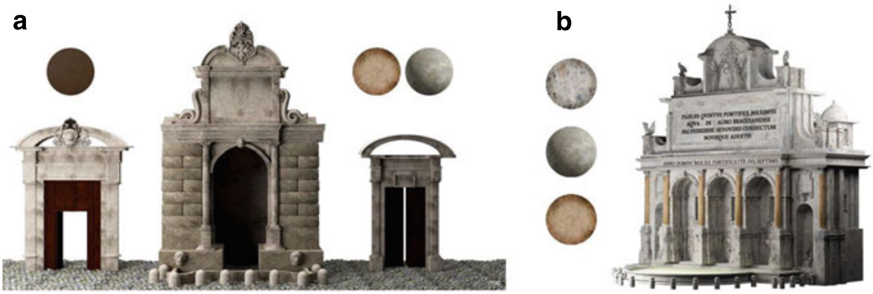

Fig. 11 On the left, **a**, texture tests on tertiary elements and architectural components; on the right, **b**, texturing on a primary element (Editing: T. Empler, A. Caldarone and A. Fusinetti)

Fig. 12 Tests of texturing and evening lights on secondary elements (Editing: T. Empler, A. Caldarone and A. Fusinetti)

In the field of cultural communication, the use of gaming as a method of divulgation of content has long been used mainly within museums, and in recent times, thanks to the increased accessibility of digital technologies, they have also begun to offer video-game content to their audiences.

These institutions leverage the concept of Edutainment, which indicates an educational approach that is also capable of entertaining and involving those who use it and is based on an interactive narrative in which the user becomes the protagonist of his own gaming experience, capable of activating learning processes.

The research methodology illustrated here starts from these considerations to propose to the user a digital world that is populated with information with high cultural content structured within a role-playing game and accessible through exploration and interaction with it.

Once the modeling of the primary, secondary and tertiary elements is done, we proceed with their import into the Unreal game engine.

The terrain is modeled directly within the game engine, through the use of plugins that allow the download of satellite elevation data, and the three-dimensional models of the various reconstructed wards are placed on it.

To avoid a tiresome exploration of the digital model it is necessary to introduce elements within the game experience that can stimulate the player's attention and increase his involvement in the story by predisposing him to assimilate the educational content conveyed by the game itself.

Therefore, the interactive element is developed through the introduction of characters that populate the environment or the inclusion of objects, to be searched for and collected, that allow the development of the story and whose feedback, returned to the user, is crucial for learning.

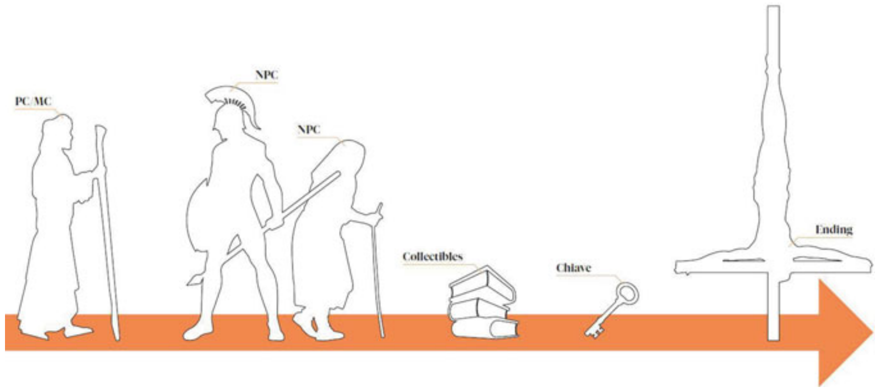

Fig. 13 Preparatory graphical schematic of Gameplay: the game is based on the exploration of an open world map in which different types of interaction can take place. The main character can interact with characters of the people or soldiers to obtain information and collectibles, as well as the Key of St. Peter (game objective). This element allows for the discovery of the truth about the martyrdom of the Saint (Editing: T. Empler, A. Caldarone and A. Fusinetti)

The modes of interaction can be varied, but in general they always remain linked to the development of the narrative, such as:

- Exploring the world and collecting objects to acquire points.
- Talking with certain characters to gain useful information.
- Participating in secondary mini-games within the main story, such as quizzes.

Dialogues, research, collection, and games in fact allow for understanding the plot, actively participating in quests, and acquiring information about the reconstructed environment (Figs. 13 and 14).

In order to communicate cultural content relating to Rome in 1750, it is therefore of fundamental importance, in addition to the scenario, a Human Machine Interface (HMI) system to benefit from the flow of information. In fact, it has now been demonstrated that the application of HMI to play contexts for education renews the perceptive processes of learning thanks to the elaboration of responses to significant visual stimuli, according to the Learning-by-doing process. This determines a renewed interest and an emotional involvement (engagement) of the users in the dissemination processes.

The graphical interface allows the player to understand the flow of information and support him in the decisions to be taken during the game, using visual and audio messages and making the contents more accessible.

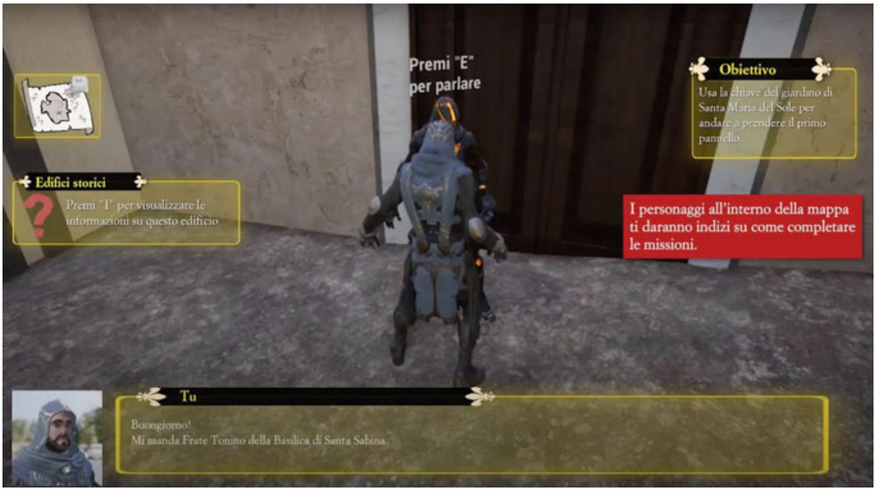

Fig. 14 Example of interaction with one of the characters in the game, useful for obtaining information to continue with the story (Editing: T. Empler, A. Caldarone and A. Fusinetti)

4 Conclusion

Engaging new generations in the dissemination of artistic and architectural heritage is an action that has been gaining strong momentum.

At the same time, video games and virtual reconstructions more generally are proving to be effective tools for education and learning.

Serious games have emerged as transversal elements: through engaging gameplay, reliable information dissemination, historical three-dimensional reconstructions, visual storytelling, visual identity and branding, they bring young people closer to cultural heritage, stimulating learning.

The 3D reconstruction of the city of Rome in the 1700s allows for outputs in various directions, including reconstructing a time bubble of Rome, disseminating the historical evolution of the city by implementing reconstruction epochs, including narrative anecdotes and curiosities that deviate from canonical history while remaining faithful to scientific rigor.

As a future scenario it is possible to identify machine learning (likened to artificial intelligence), which allows, based on the algorithms already applied, to improve the reconstructed Rome. In fact, it is possible to create real procedural environments, in which each element of the scenario is used to make an ever-changing environment.

This is possible thanks to inputs and instructions that may concern aggregative laws of the eighteenth-century urban fabric of Rome, which are provided directly to the gaming application.

It is important to note that, in a historical moment in which the exchange of messages, content, and information occurs on a virtual plane, a moment in which the enjoyment of heritage takes place in an apparent space, the 3D reconstruction of Rome in the 1700s (available through gaming modes) succeeds in valorizing an intangible aspect by communicating a place distant in time and space.

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Measuring the Quality of Architecture. Serious Games and Perceptual Analysis Applied to Digital Reconstructions of Perugia Fontivegge Station Drawing Evolution

Fabio Bianconi, Marco Filippucci, Filippo Cornacchini, and Chiara Mommi

1 Introduction

The goal of the research is the study of architectural space in its relationship with the person and in the quest for its reasons.

On the one hand, the research wants to search for the origin and originality of a place, and on the other hand, it wants to test new ways of reading the impact of the environment on the person [1]. The two issues, which are intertwined in methodology and not in results, both implicitly place the image at the center, using the seduction of images [2] for the value of vision [3, 4], responsible for more than 50 percent of our sensations [5]. The focus is placed on the interaction between humans and the environment because of even implicit response to perceived stimuli [6–8], in the quest to investigate how a place, for better or worse, without ever being neutral, marks our existence and actions [9]. Thus, the goal is the survey of perception [10–14], related however to project [15].

The central theme for research development is to understand the possible role of digital simulations for the analysis of reality. The mathematization of space, inherent

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in the process of digital representation, is the ideal context for the development of quantitative and qualitative analyses of the impact of an environment on those who perceive it; consequently, the analysis of experiences in virtual reality represents a valid approach for the extraction of formal relationships from the various elements. The purpose of the research is to estimate interaction, a path that is intended to be ensured through the geometric and dynamic construction of the intersection of visual cones with the experienced space. Therefore, the experiences of interactions allow the identification of the poles that capture one's attention, with a clear design transformation perspective of the space. The most important information that can be obtained from a VR experience is the accuracy of the 3D coordinates (x, y, z) of the user at any time during the session, along with the orientation/rotation of the head of the person being tested. The combination of this data, combined with the knowledge of the position of the pupil detected with specific lenses attached to the viewer, is a valuable method of capturing the user's vision and obtaining a heat map of the areas of greatest attention [16, 17].

The aim is thus to bring out what is immaterial [14, 18–21], but based on a real materiality of human interaction, always concrete, with space, which is also not random. To represent the interaction of vision and paths of exploration is to somehow understand how places affect behavior, deriving legible and interpretable data. The basis of the investigation is the creation of a kind of digital twin [22], through which processes related to simulating the environment [23, 24] and interacting with the user [23, 25], who is nevertheless free to explore [17, 26], can be repurposed. Using this virtual environment analysis can be developed [27] to study the qualities of places [28], allowing the inclusion of what is not present. Generally, this process is aimed at testing the impact of new solutions, with the advantage of not having to test them in reality but only simulate them. Such an approach in an innovative way wants to understand the relationship between the existing and what is not there anyway such as the past. For these reasons, the study, in comparing the present and the past, aims to highlight the influences between two successive projects for the same place, in a path that nevertheless links to the design and images that survive the evolution of time [29]. Such a study makes it possible to analyze the quality of spaces [30], that are linked to a clear function of orientation and thus to their legibility [31, 32], analyses that are always strategic in the survey of perception [28, 33–36] and in any case central to the pole spaces of transportation such as the station.

2 Case Study

The study was applied in the Perugia Fontivegge station by making a comparison between the current state and the original mid-nineteenth century project, which was never realized.

Since the beginning of their development, the creation of railroad tracks has been a strong element of modernization of the territory and transformation of the city [37–39]. In Italy there was a late development compared to the European scene, beginning the planning of railroads following the creation of the Italian state [40]. The purpose was to connect the major urban centers, unifying the territory from north to south. For this reason, the city of Perugia was taken as the country's hypothetical railroad node, mainly in plans between 1845 and 1856 [41, 42]. It was in this context that architect Antonio Cipolla's first station project was designed [43].

The initial design was characterized by a modestly sized but richly detailed and majestic railway body, given also to the presence of the train tunnel, an iron and glass structure that served as a cover between the machine shed to the main body. Due to the unfavorable orography, Perugia's railroad centrality projects were redirected to Foligno [43], thus leading to the dismissal of all the railway projects that had already been carried out. The railway arrived in Perugia in 1866 with a new project, presumably by the same architect, with a more anonymous design related to the serial types found in railway manuals [44]. Making an initial comparison between the two stations, it can be seen that the dimensions are about half the size of the existing building. The new station retains some elements of the designer's initial idea, which still remains the genesis of the urban space and architecture of this pole. There are similarities especially in the atrium, where in both cases it draws on drawings and indications found in railway manuals [41] (Figs. 1 and 2).

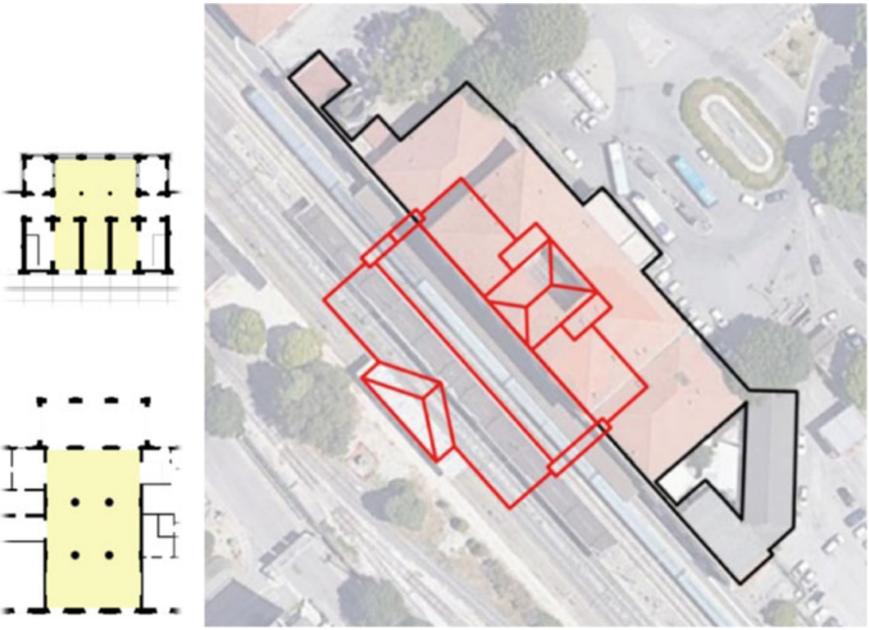

Fig. 1 Floorplans of the two stations compared (Editing: C. Mommi)

Fig. 2 Photo and render of the two stations compared (Photo and modelling: C. Mommi)

3 Materials and Methods

The research is based on the validation of results, already demonstrated, between the analysis of perception in the real and in the virtual, taking up a methodology of the related investigation [35]. The goal is to create two game levels, one per scenario, in which all the user's movements in space, head rotations, and pupil movements are recorded through special lenses installed inside the Head Mounted Display (HMD) visor.

During the registration, an algorithm projects the visual cone into the scene by going to increment a counter associated with the points acquired during discretization whenever it comes into contact with them. Two more levels are created to develop the actual processing of the data and the subsequent representation of the information collected through a three-dimensional heat map, which can visually communicate the results of the analysis performed previously.

3.1 Virtual Representation of Both Models

Regarding the station area in its current state, a digital twin of the zone has been realized, going to create an interrogable and interoperable model, with special attention and higher level of detail in the intermodal interchange area that includes the Fontivegge station (Figs. 3 and 4).

In parallel, the historical reconstruction of the first nineteenth-century design hypothesis, according to the drawings of architect Antonio Cipolla, was simulated and reconstructed according to a philological process. Initially, the original design

Fig. 3 Digital twin of the station area that can be used for the analyses (Modelling: C. Mommi, M. Seccaroni)

Fig. 4 Reconstruction of the station of Perugia Fontivegge to date (Modelling: C. Mommi)

Fig. 5 Digital reconstruction of the station designed by architect Antonio Cipolla (Modelling: C. Mommi)

plans preserved at the Academy of San Luca in Rome were scanned and digitally reproduced, and then the three-dimensional model was created [2] (Fig. 5).

Starting from the 3D meshes, models are generated that can be navigated and explored in all of their parts through an immersive experience, which realizes a bidirectional connection between digital and physical systems [45–47]. The two spaces show some ideational connections in the forms, especially in the entrance atrium, a common part of both versions examined. This leads the present research to make the comparison of the two stations in that area, driven moreover by the spatial and perceptual cardinality that the entrance lobby represents for the railway building typology, thus going to analyze the building's calling card, the visitor's first impact with the interior architecture, decorations, and orientation.

The two three-dimensional models were realized by mesh modelling with a level of detail that does not aim for photorealism, but is at a medium to high level, with the goal of making the scenery recognizable and easily navigable, without affecting the fluidity of the experience.

3.2 Generative Surface Discretization Algorithm

Starting from the three-dimensional models of the two scenarios, an initial phase of discretizing the geometries was necessary. Using Rhinoceros and Grasshopper, a network of equidistant control points is obtained that subdivides the meshes and allows attributes and values to be assigned to the points in the scene. The script subdivides the surfaces according to a step that can vary as needed, with an approximation that can handle those cases in which it is not possible to divide some geometries by always considering the same length (Fig. 6). The output of this algorithm is a CSV

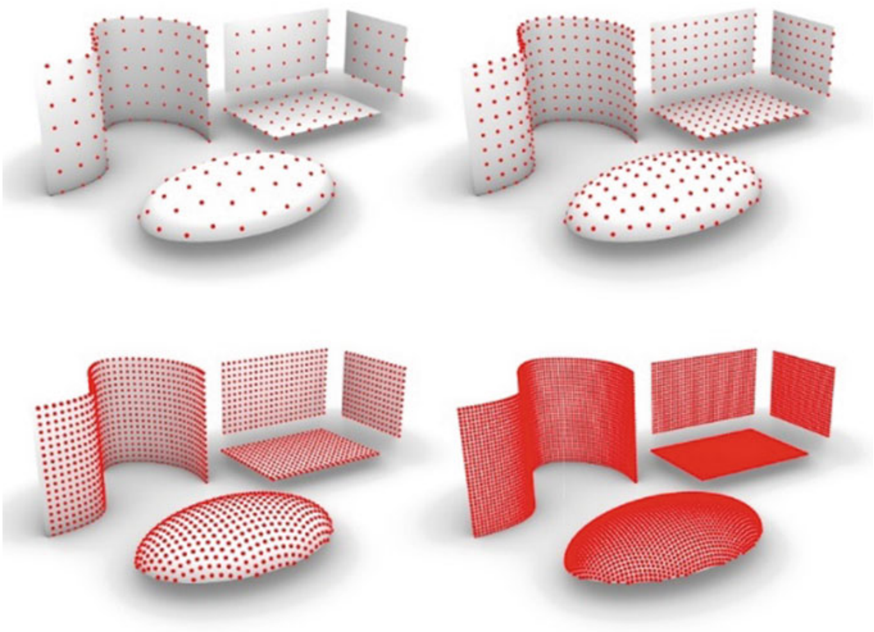

Fig. 6 Discretization of surfaces by equidistant points (Editing: F. Cornacchini)

format file containing the list of identified points formatted so that Unity can use it within its scenarios.

3.3 Importing and Level Design

Unity was identified as the game engine to create the interactive scenarios. Three-dimensional models were imported through FBX file format and placed, then, into the game scene (Fig. 7). Next, materials were assigned to the objects in the scene and lights were set. As for the materials, simple shaders were made using the Universal Render Pipeline (URP), which is a rendering engine template that allows satisfactory graphics rendering without heavily affecting the execution performance. The scene lighting was realized using a fully real-time GI (Global Illumination). This is made possible by the low number of vertices contained in the templates and avoids the time-consuming process of baking lightmaps.

Fig. 7 Three-dimensional model of Fontivegge Station (Modelling: C. Mommi)

3.4 Programming Interactivity and Virtual Reality

Initially, a simple scenario selection interface was built, which automatically configures the scene appropriately, thanks to specific functions activated by buttons. Next, the part of the code necessary to achieve interactivity, that relating to the user's movements within the virtual scene, either through mouse and keyboard or through a head mounted display, in this case an HTC VIVE, was realized (Fig. 8). This head mounted display has 6DOF locomotion capabilities in 3 by 3 meters range and the two external tracking stations can track it. With this technology, users can move freely and look around, interacting with the VR environment via the two hand controllers. The horizontal FOV of the HTC VIVE is 110°, while the peripheral vision of the human eye is 60° for the near peripheral, 120° for the mid-peripheral and 220° including the far peripheral area.

3.5 Programming the Level of Exploration

Regarding the programming of immersive virtual experiences and the related data processing, two game levels were created for each scenario to be analyzed (Fig. 8), completely identical in geometries but with different and complementary functions:

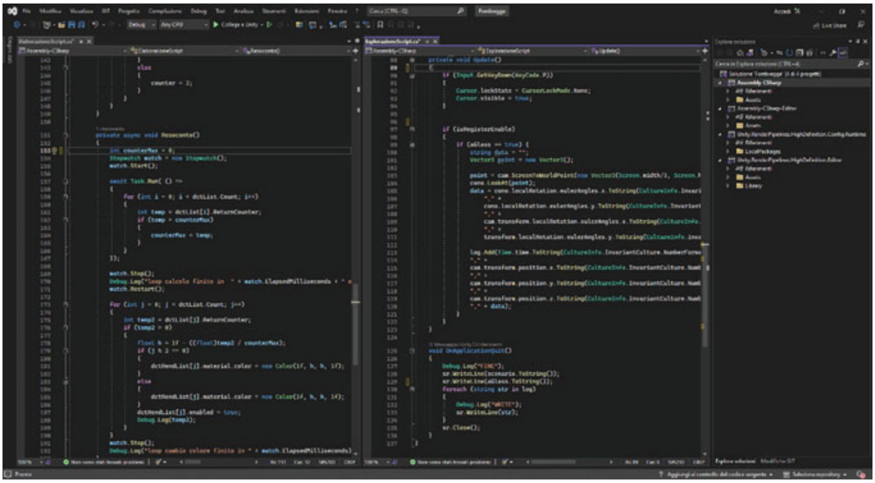

Fig. 8 Code for the relative functions of the exploration and processing levels (Script: F. Cornacchini)

the first level (Exploration) was created to enable the virtual experience for users by selecting the appropriate scenario through the aforementioned interface. With the second level (Processing), on the other hand, the processing of the data collected during the exploration proceeds. This separation was necessary because the possible simultaneity of the immersive experience and information processing would have caused the execution of a large number of operations for each frame of the visualization, leading to significant slowdown even on PCs with high computing power (Fig. 9).

Regarding the Exploration level, when the experience begins the function for the appearance of the interface for scenario selection through two buttons, one for each possibility, is immediately activated. Pressing one of the available buttons will activate the linked function that introduces the user inside the selected scenario.

This starts the 3D rendering of the camera corresponding to the user's view and activates navigation through HMD controllers or mouse and keyboard inputs. The user has, now, the freedom to move freely in the scenario and to rotate the tilt of his view (Fig. 10). At the same time, the recording of the visitor's interaction with the scene begins: at each frame, in fact, a function is executed that records on a list of variables the same Cartesian coordinates relating to the user's position in the scene, the three rotation coordinates that identify the angle of the camera and, therefore, of the view, and a time reference of the moment when the data are collected.

From this point on, recording will occur automatically until, through an input, the immersive experience is stopped. Stopping playback triggers the final function of saving the collected data to a text file in csv format in a folder on the PC selected by the user at an early stage of algorithm configuration.

Fig. 9 Game level of each scenario: the current one at the top and the historic one at the bottom (Modelling: C. Mommi and F. Cornacchini)

3.6 Programming the Processing Level

The logic of the second level, called Processing, begins with a phase of configuring the visual cone to be used in the data analysis phase. In the settings, in fact, it is possible to customize several parameters related to the shape of the cone that will be projected, including the aperture angle and height, which determine the depth of the field of view, in relation to the hypothetical speed of the user. As processing begins, then, an algorithm collects this information and applies it to the geometry of the cone to resize it.

Next, the algorithm retrieves the exported csv file from Grasshopper and, for each indicated point, instantiates a small sphere in the scene that will serve to intercept the projection of the visual cone. The individual spheres, in fact, were associated with

Fig. 10 Immersive test example (Photo: C. Mommi, F. Cornacchini)

a small script capable of recognizing collisions with the geometry of the cone and storing in a special variable the times when contact with it occurred.

The next step is to retrieve and process the csv file processed in the previous layer, i.e., the one with the records related to the user experience: the algorithm is configured to read the records from the file and, for each row, project the cone from the recorded x, y and z point and orient it according to the rotation coordinates. By repeating this procedure for all the annotated coordinates related to each frame of the immersive experience, the control spheres are able to record the number of overlaps with the cone and thus how many times the virtual visitor's eye has intercepted the specific portion of the 3D model. Three-dimensional rendering is disabled at this stage, as it would have caused an increase in the number of computations and thus an unnecessary use of computing power. The algorithm, however, through control messages, informs the operator about the operations being processed, describing the stages in progress and, through a counter of the calculations performed, compares the total number of operations.

Once the analysis procedures are finished, the layer logic proceeds with the coloring part of the created spheres. To do this, the sphere with the greatest number of intercepts is identified and a color scale is created that assigns the selected full color (e.g., red) to that sphere, while for the others the coloring is gradually tending toward white, again in relation to the number of contacts recorded. Spheres that have not registered contacts are completely hidden so as not to make the model too heavy, both from the point of view of rendering processing and aesthetics.

When the processing part is finished, the algorithm restarts the rendering of the scene so that the results can be analyzed graphically. In addition, the programming generates two opposite orthogonal axonometries (Fig. 11). A csv file is saved, derived from the one containing the coordinates of the sphere insertion points, to which the value of the reciprocal counter is added for each. In this way, it will be possible to view the results of the various processing in the subsequent steps, simply by selecting one

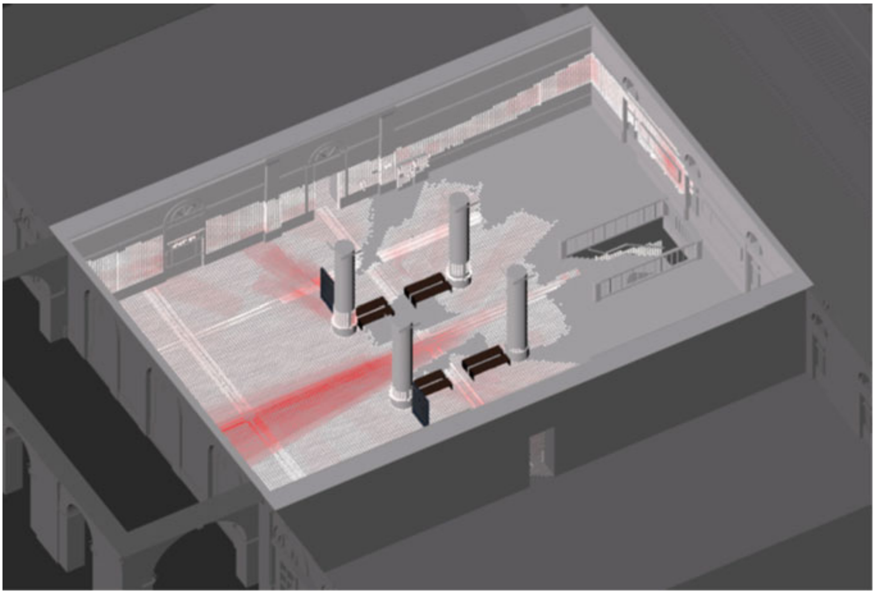

Fig. 11 Axonometric representation of the results in the current state of the station atrium (Modelling: C. Mommi, F. Cornacchini)

of these files at the beginning of the procedure. In addition, the navigation functions are activated, which allow you to freely move the camera in the scene to view the results from the necessary viewpoint.

4 Results

After completing the analysis, processing and representation of the data, the output of the whole process is obtained, which is a series of heat maps that provide a clear and intuitive visualization of the points of greatest interest and most observed by users (Fig. 12).

The representations produced by experimenting with the two scenarios are similar and partially superimposable due to the fact that the geometries of the analysed areas show similarities due to the ideational connections of the forms. In fact, the railway building typology presents standardizations in the distribution of spaces, resulting from railway manuals that spread in the late nineteenth century and influenced the design of numerous Italian stations.

Comparing the heat maps, in fact, there are remarkable points of similarity, such as the four central columns that identify the tripartition of the space and the arches, repeated in different sizes but always with the same shape and proportion.

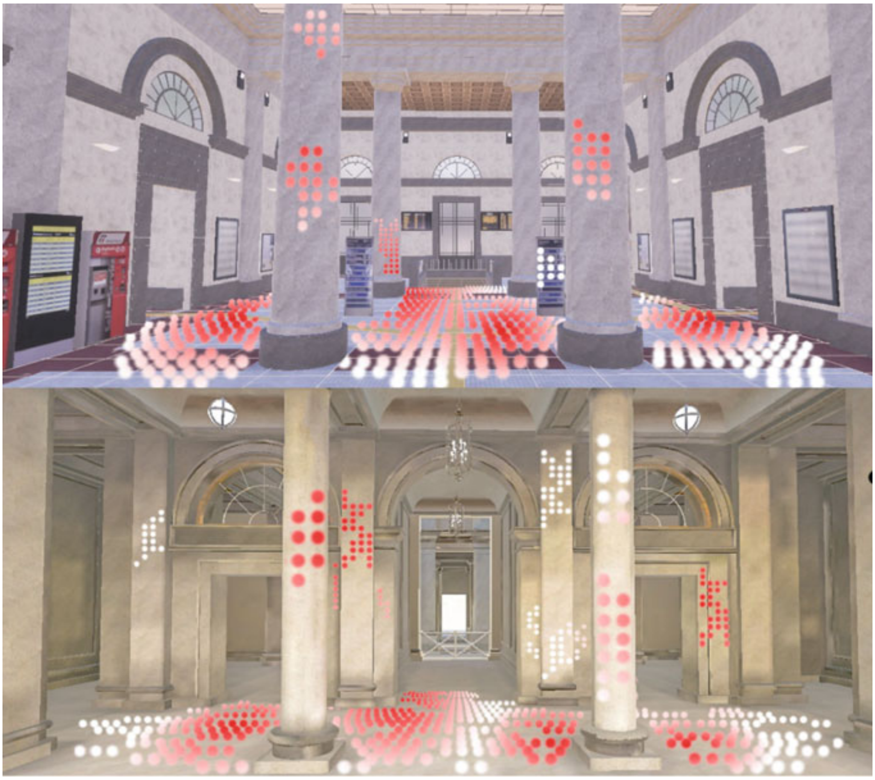

Fig. 12 Three-dimensional representation of the analysis results: the current one at the top and the historic one at the bottom (Modelling: C. Mommi, F. Cornacchini)

However, while the maps are similar, they also show some significant differences that reflect the peculiarities of each individual area and allow for further analysis.

For example, an important difference, is found in the central part of the atrium, that is the part that connects the switching area to the tracks. In the historical case, the user's gaze is drawn to the central part, marked by the three arches that allow a direct view of the tracks and the railway shed. In the actual state, the tripartition in the final part of the atrium remains, but the eye is attracted to the underpass that inserts itself between the user and the exit route to the tracks, ideally posing as a barrier between the user and his final destination.

5 Potential Future Development

The present research highlights the similarity between the space represented by the original design, which is the space of the past, with the current version of the same building, the modern configuration of Perugia Station. The similarities observed in the results of the conducted analyses are confirmed by the common characteristics of the two different versions of the building, leading, instead, to contrasting results only in those portions of the building where there is a divergence of form. A future development of the present research could be represented by a path of comparison between a digital twin related to a current scenario and a future project related to the same space, so that data related to the quality of the hypothesized forms can be captured in advance. In fact, this research path provides the opportunity to analyse a space and its forms in order to understand whether it is able to fulfil the mission for which it was designed. The study of user behavior within an unbuilt space opens up new scenarios for design optimization, all the way to true co-design through the involvement of the end users of the place.

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Parametric Architecture and Perception. Luigi Moretti's Prophecy About the Role of Digital Representation

Fabio Bianconi and Marco Filippucci

1 Luigi Moretti's Vision of Parametric Architecture

In 1960, Luigi Moretti [1, 2], a great master of Italian rationalist architecture, presented at the XII Milan Triennale his famous Exhibition of Parametric Architecture and Operational Research in Urbanism, signed by the IRMoU, Institute of Mathematical and Operational Research in Urbanism, which he had set up in 1957 [3].

Luigi Moretti is an undisputed genius: the issues reported here and the very marriage of architecture and parametricism that is shown today with all its revolutionary charge. As stated in presentation of the same, "the Exhibition illustrates with graphs, models and applications in action, a new approach to the study of the problems of architecture and Urbanism. This approach, which is identified in the need to apply specific logical and mathematical methods to the two disciplines, had its origin and impulse from those enunciations of concepts and examples that until 1942 architect Luigi Moretti formulated under the name of parametric architecture and which are illustrated here for the first time" [4].

Already between 1939 and 1942, involved in a design proposal for the Olympic Stadium in Rome and the grand theater planned for EUR [2], he called in his refined writings for the birth of a new language for architectural thought [5], aimed at using mathematics to support architecture. With insistent firmness, he called for mathematical calculation procedures to enter structurally into the design process, hoping for and experimenting with the use of computers [6]. Moretti himself, would write in one of his famous correspondence that "the parameters and their interrelationships thus

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become the expression, the code, of the new architectural language, the structure, in the original and rigorous sense of the word, deficient in the forms that those functions fulfill. To the determination of parameters and their inter-relationships, the most up-to-date techniques and instruments of scientific thought must be called upon to assist; particularly logic-mathematics, operations research and computers, especially the latter for the possibility they give of expressing in self-correcting cyclic series the probable solutions of parameter values and their relations. To the development of this approach and to the new method and theory specified in its schemes and verified in its first, and I would say exciting, results I gave the name Parametric Architecture" [4]. This research finds the celebrated contribution of the great Italian mathematician Bruno de Finetti [7], in a work carried out with an interdisciplinary research group that is embodied in the plastic forms and conceptual designs brought to the exhibition, abstractions placed between the representation of space and the space of representation, in a formal and functional research that does not recuse plasticity and is nonetheless directed by a scientific humanism [8], where parametric forms arise in relation to the centrality of the person. The models on display at the exhibition synthesized the investigations of parametric architecture in the form of stadiums for soccer, for swimming, for tennis, and in a movie theater. The computer used, an IBM 610, allowed for changing conditions, parameters, thus achieving multiple conformations. The manifest goal is "the determination in a surrounding of a field of the optimal spatial distribution of information of the phenomena taking place in that field, where a field is defined as an area or portion of space with assigned boundaries. Thus, are born the curves of visual equiappetability, the result of mathematical equations transcribed into geometric forms, sought to respond in a manner most responsive to the functions called upon to perform" [4]. Visibility, defined with the W parameter, is marked by three classes of parameters:

- Parameters inherent in the object of information (game).
- Parameters inherent in the type of information (visual).
- Parameters inherent in the characters of the specific class of information with respect to the subject (viewer).

The simplified assumptions set forth impose whole field visibility, placing attention in specific areas of interest and defining visual desirability as a function of the distance to the center of the field and the angle under which the area of interest is viewed.

Taking the soccer field as an example, to express visibility (W) for the soccer stadium, the function chosen by Moretti and De Finetti equation (1) is as follows:

$$W = x^{k(y)} e^{-k(y)x}$$

$$\text{Together with: } k(y) = 3.5y^2 - 2.5y + 1.5$$

$$x = \frac{\rho}{\rho(\vartheta)};\ y = \frac{2\vartheta}{\pi} \tag{1}$$

The visibility values, derived from Moretti's proposed equations, are dimensionless, drawing parametric curves in space to quantitatively measure the function of the spectacle that must be fulfilled. In the parameter W it is possible to read the interpretation of the proposed vision, defined by an ascending function to a maximum value then declining at the horizon, tending to infinity. Thus, considering the parameter x as a normalized distance, the behavior of the function tends in some way to emulate the progress of human vision. There will be a distance x that it is possible to see with higher quality, then moving away and closer to this value, the quality will decree. The other parameters are corrective parameters, and the curves obtained here are defined in the yz plane, and then rotated around an axis to realize the shape search. Only later, after defining the formulas, is the quotation mark z inserted: this condition leaves doubts about interpretive congruity, partly because it is given a substantial impossibility to represent even the mechanism of vision in such a synthetic way [4].

The forms represented show themselves in their sinuosity, abstract and elegant, the expression of a fascinating relationship between architecture and mathematics, between form and function, space and vision [5, 9, 10]. Moretti, bewitched by the classical, a master of rational forms, an expert in the Baroque, linked to futurism, a man of technique and art, a theorist and pragmatist, thus finds an innovative spatial language, synthesis and vision that anticipates contemporary themes, anticipating almost prophetically the digital processes of parametric architecture.

2 Perception in Stadium Design

The relationship between perception and stadiums is at the heart of the function of such environments, the performance they must provide, and therefore their design. The governing body of European soccer, UEFA, has prepared in this regard the UEFA Guide to Quality Stadiums [11], where it introduced the C-value, used to design and optimize contemporary stadiums. Based on the model hypothesized by John Scott Russell, in 1838 [12], which determines the placement of auditorium seating according to a curve characterized by the same acoustics and vision, isodomic and isoacoustics, then applied by Adler and Sullivan in 1889 in the design of the Auditorium Building in Chicago [13]. The c-value refers to the visual axis and distance from the field, but also to the height of the seat rise relative to the row in front and the depth of each row of seats [14]. The formula Eq. (2) referred to is as follows:

$$N = \frac{(R + C)(D + T)}{D} - R \tag{2}$$

where:

- D horizontal distance from eye point to focal point;
- N mast height;
- R vertical height at the focal point;

T width of the row of seats.

Thus, this is a formula that seeks to define a perceptual value as a function of geometric character conditions, where to obtain a good C value, the distance from the viewer's eye level to the apparent contour of the head of the viewer seated in front should be between 120 mm (ideal) and 90 mm (acceptable).

Applied in different contemporary stadiums design [15, 16], reality the simplified proposal protracted by UEFA is not a harbinger of a careful analysis of visual phenomena, relating neither interpretations on the visual phenomenon, nor the complexity of space, analyzed only through a two-dimensional section without any indication of the field of vision, the position in the stadium, the dynamism of the spectator's experience in moving his eyes and head according to the sports marked precisely by dynamism. For these reasons, in stadium design are sued other integrative or alternative methods those combine different analysis, as shows φ-value, combination of different factors as C-value, distance, angle, seat location (https://www.fenwickiribarren.com/en/fi-factor/), or A-value, based on a computational simulation which takes into account static and dynamic binocular field of view considering the problem of view quality in a 3D domain considering the nature of human visibility [17].

3 Experiments in Parametric Architecture and Perception

As pointed out, the thesis proposed by de Finetti and Moretti on the interpretation of visual phenomenon is based on simplified assumptions about the interpretation of vision [18]. Even the criteria proposed by FIFA have important approximations on the phenomenon of vision. It is on this topic that a real line of research is developed, as a foundation for our culture, which is dominated by vision and image [19, 20]. Analyzing the impact of what is perceived opens up multiple questions, ranging from landscape evaluations [21], impacted in their substance by reductivist exemplifications and vulnerable to the possible manipulation of images [22], to more substantive considerations of the value of places to the person, by virtue of sensations conveyed substantially by the eye [23].

The studies developed over the years by the writers have found in the centrality of the representational approach the tools and processes to address multiple issues related to the generation of form through the logic of computational design [24, 25] and in the perception studies [26, 27]. This approach has been supported by teaching, always at the center of the activity, where, through exercises but above all dissertations, multiple experiences have arisen and research paths have been traced that have allowed the exploration of the potential of these processes and of generative representation, developed mainly in the environment of Rhinoceros, NURBS modeler, through Grasshopper, Visual Aid for Scripting to which is linked a community of developers that continuously enriches its potential.

This approach is linked to a real strand of architectural research that is linked to masters such as Frank Gehry, Peter Eisenman and Zaha Hadid [28, 29], just to mark the most famous names, theorized by Patrick Schumacher as parametricism [30, 31]. Beyond conceptualizations and formal stigmatizations [32, 33], the fourth digital revolution that has invested design culture [34, 35] finds in the value of information and the consequential parameterization the reasons for the current value of the model expressed by its representation in both, the BIM [36] and the generative design approach [37–39], the abstraction of relationships inherent in parameterization is proposed for its ability to manage complexity, requiring the digital to do its statutory task of being able to do the calculations. The new descriptive geometry inherent in the definition of topological relations [40] drives design heuristics, replacing the canonical form-checking paths, marked by the verification of proposed hypotheses, with form-finding processes, the search for even multi-objective for the best solutions.

The cases presented show a different way of setting up design, with the form that can derive from the function that the space must provide, and the digital taking on the task of comparing the different parameters placed in play and identifying solutions according to different objectives for the best [41, 42]. It should be noted that the computational design, that is thus developed, implicitly proposes the hypothesis that design is a discipline, and not (predominantly) an art, by advocating the thesis of a stochastic result, which nonetheless arises from the design, is based on the representative model that selects, synthesizes and interprets information through a combinatorial calculation capable of offering solutions, thus fully implementing the vocation proper to Computer Aid Design. This approach finds multiple fields of application, among which prevail structural and energy optimization research, in any case linked to cost optimization, but also performance of a perceptual nature such as those hypothesized by Moretti for his stages.

In this context, we want to highlight in particular the first transcription of the formulas proposed by Moretti for his stadium (Fig. 1). This path, promoted for his dissertation in 2010 by Stefano Andreani [43], who later became a professor at Harvard University and today CEO of Oblyk studio, first led to parametrically re-transcribing Moretti's and de Finetti's formulas into digital through Grasshopper, and then testing the first 3D printing processes, as well as evolving such forms into compositional experiments. The translation to the prodromes of parametric modeling allowed for analysis of the many issues related to the seriality of generative procedural logics (Fig. 2). Model reconstruction then highlighted the incongruity of De Finetti's function for a continuous reading of space, designed with a serial and gradual process in mind.

Ten years later, this approach was followed as the premise of Luisa Vitali's dissertation, which focused on perception in stadiums, a work awarded a scholarship by the Order of Engineers of the Province of Perugia. Starting from the replication of Moretti's logics, as a function of a different interpretation of the visual phenomenon protracted in spatiality, new models of stadiums were realized through formfinding processes, based on genetic algorithms (Galapagos) (Fig. 3). Through this path it was

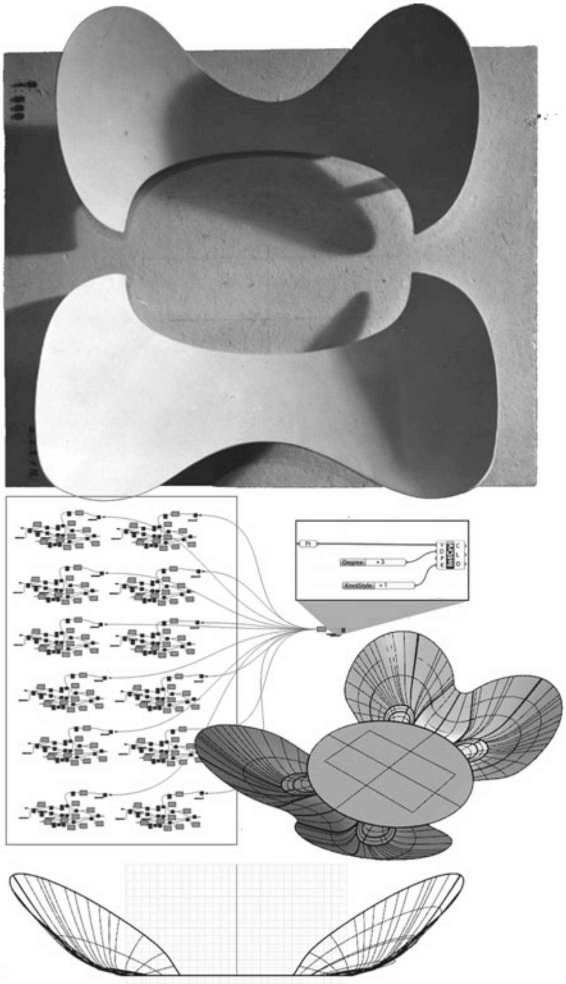

Fig. 1 Luigi Moretti algorithms transcription using Visual Aid for scripting (Grasshopper) (Representation: L. Vitali)

possible to first reconstruct de Finetti's original forms, then go on to study the subject in function of a more lendable interpretation of the visual phenomenon. Thus, the form of a study generated through perceptual form-finding processes was studied as a function of the most accurate interpretation of the visual phenomenon, using genetic algorithms (Galapagos) to maximize the quality of vision. The goals required of the computational calculation involve optimizing the spatial conditions for which a spectator seated from the stands can see with the highest quality, by placing the 18° angle of the parafoveal zone the optimal zenithal aperture that creates a wide conoid in the azimuth of 300°, considering that the spectator can turn the head left and right to look at the two penalty areas. This approach can lead to extending the same process, with

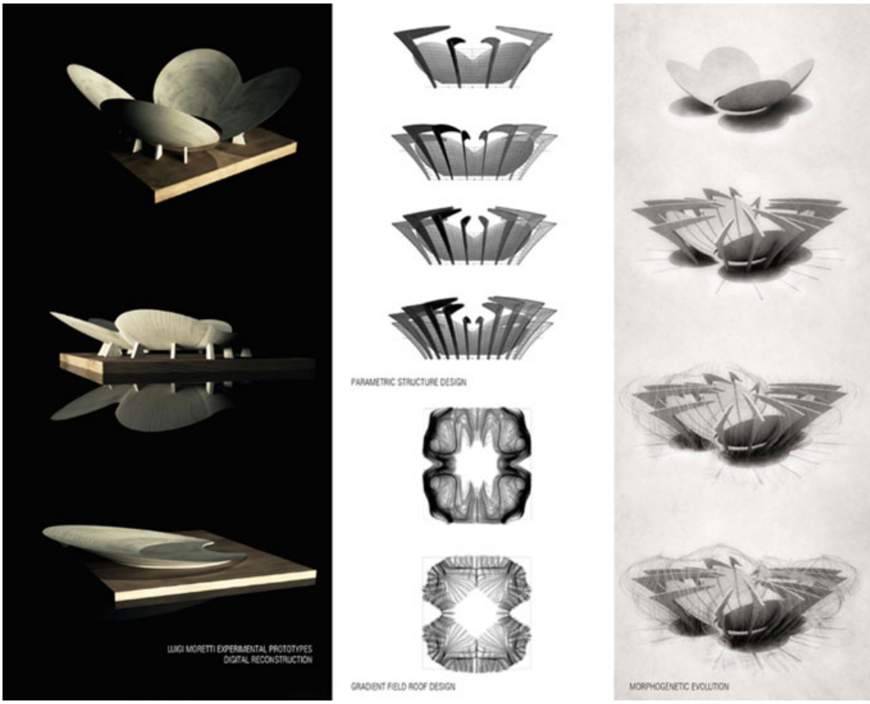

Fig. 2 Parametric reinterpretation of Luigi Moretti stadiums (Representation: S. Andreani)

some adjustments, to different architectural types, just as Moretti already proposed, associating the same logic of optimization to identify determined spatial forms of places intended for the spectacle of events, seeking confined environments but also open spaces or dynamic paths (Fig. 4).

In parallel, studies on the interpretation of the relationship between vision and form were developed with Alessandro Buffi through the generative use of specific Grasshopper (Toro) add-ons for optimization through still genetic algorithms (Fig. 5): it is possible to analyze and find the for the best solutions related not only to C-value, but also to A-value, which measures the percentage of the projected field area in the cone of vision in relation to the obstruction of the spectators seated in front, thus extending the vision into three-dimensional space, and E-value, which analyzes spectator comfort, in terms of the twist between the direction defined by the seat and the center of the field and horizontal and vertical angles at the boundaries of the playing area. This approach has led to the search for multi-objective form-finding solutions, related to the values proposed by FIFA, optimized results similar to Luigi Moretti forms (Fig. 6).

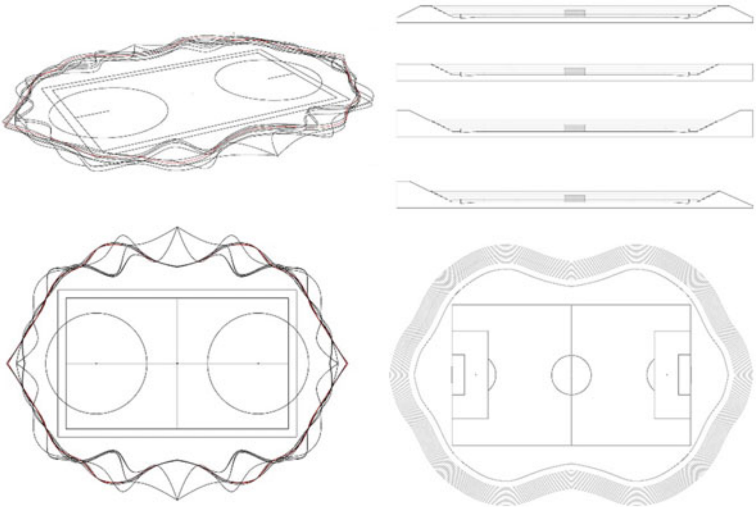

Fig. 3 Parametric reinterpretation of Luigi Moretti approach using different criteria (Representation: L. Vitali)

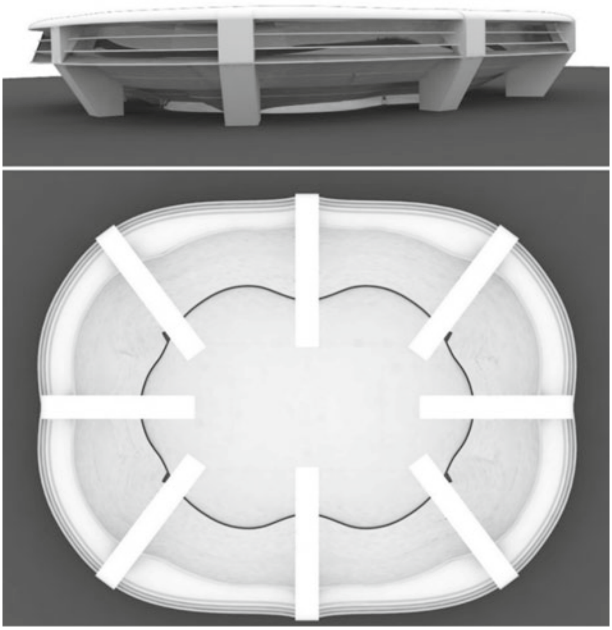

Fig. 4 Form finding and perceptual optimization in Luisa Vitali's stadium morphogenesis (Representation: L. Vitali)

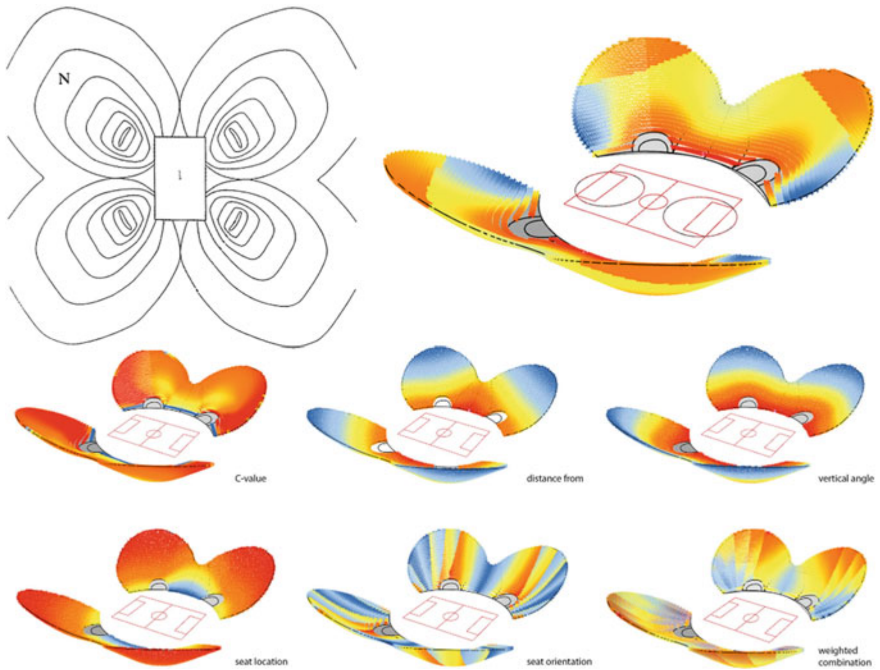

Fig. 5 Luigi Moretti forms analysed using generative tools (Toro add-on for Grasshopper) (Representation: A. Buffi)

The latest experimentation implemented on the topic was developed through Davide Quaglia's dissertation, which analyzed Renato Curi's stadium in Perugia by comparing the different analytical standards of C-value, A-value as well as φ-value, an extension of C-value that considers more elements connoting perceptual quality (Fig. 7). This comparative analysis shows the variation in the interpretation of the visual quality of the different parameters, analyzing the quality of one of the most felt places by the community, with a view to placing these values as the foundation for the project. Also in this context, it was generated a design proposal for a stadium that stems from perceptual optimization. Of note is the recent decision to proceed with the construction of a new stadium, a hypothesis that is supported by the research data that point to a low quality of vision, in any case one that cannot be resolved by improving interventions according to existing spatial constraints.

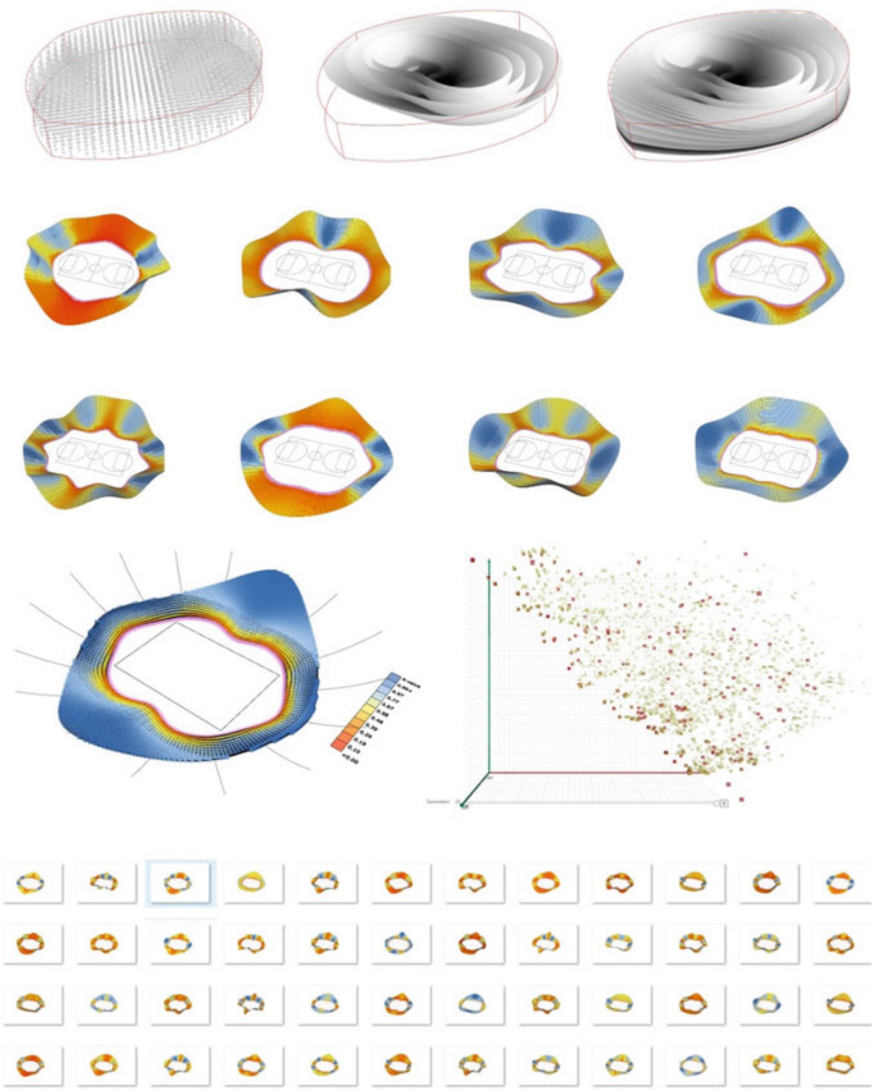

Fig. 6 Variety of design solutions emerged from the genetic algorithms (Representation: A. Buffi)

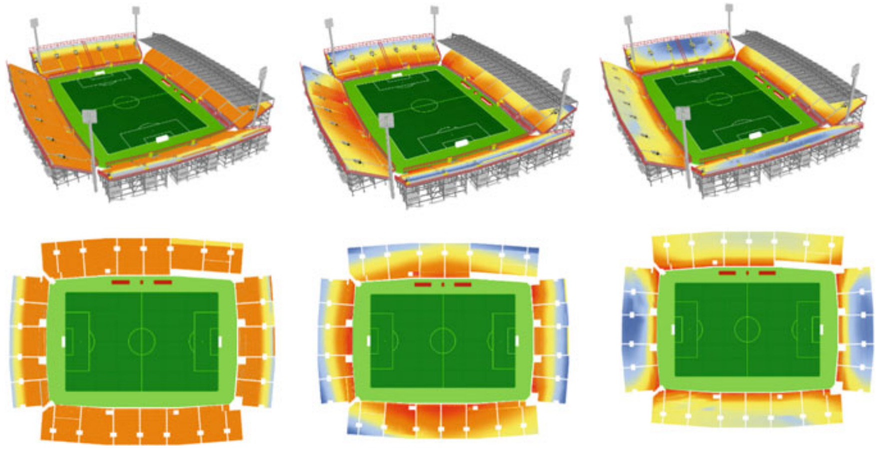

Fig. 7 C-value–A-value–φ-value in Perugia Stadium (Representation: D. Quaglia)

4 Conclusion

As Moretti himself writes, "in the theory of A.P. there is always present, subdued, that degree of culture and universality that is connected with the noble name of architect, which allows one to master its instrumentation… In the mental procedures of the A.P. it can be said that a double dose of intuition and imagination will be needed: one to glimpse, identify and set quantizable parameters and their relations; another to organically complete the globality of forms by closing the caesuras that leave the quantizable parameters" [4].

Luigi Moretti, since the 1930s, has been trying to define a new way of doing architecture, investigating results related to a new relationship between medium and message, both related to the experimentation of a new architectural language. Morphological research contrasted with the need for data, to ensure a quality that resulted from the application of methods from mathematics and logical analysis of fundamental structures. This study, rediscovered with the use of generative tools, has conceptualized criteria and languages that correspond to the aesthetic demands of the project on form, to which architecture must always respond.

The metaprojectual characters of this result can then be highlighted, which, as with Moretti's model, are the consequences of the objective, of the demands from the project. The contemporary reinterpretation of Moretti presented, does not intend to question the results of the original approach also if there is similarities with digital formfinding solutions. The central focus is to highlight the revolutionary vision that, even in the rejection of those results, is determined by the evolution of the tools. It is the analysis that brings out the data, which are transformed into information to build a form-finding process that seeks the most presentable solutions. CAD exercises its role of helping to design, a place where calculations and parameter combinations that vary according to the ranges imposed by the project converge in forms. The critical philology determined by a transcription exercise, brings out general characteristics of the generative approach, which apart from a connatural eclecticism about the potential of the tools, reveals the concrete convenience of artificial intelligence, or at least an intelligence with augmented computational capacity, which is used to support architectural choices. Metaprojectual solutions are thus offered, with design computation, however, presented as a frontier of the present, integrated in reality also with the logic of BIM, whose boundaries are open to the designer to horizons to be discovered.

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City's Drums: The Case of Catania

Matteo Pennisi

1 Catania Upside-Down

The aim of this contribution is not to delve into the city of Catania itself but to highlight its peculiar way of stratifying itself over time, a hidden but decisive feature in its history and central to the research. Catania is an unusual city because of the presence of Etna, both a blessing and a curse for this city, on the one hand a constant threat and on the other a source of water that descends from the summit down into the valley. Etna introduces into the stratification of this city a speed that is quite unusual and unknown to most urban centers. Normally every city increases its thickness over time through a slow sedimentation carried out by man based on a direct proportionality: in a long time, much matter is stratified and in a short time little is stratified. This slow process leads to an orderly succession of the city's layers, whereby a well-known relationship is obtained: greater depth in the soil corresponds to greater temporal anteriority and vice versa. In Catania it often happens that the slow stratification of man is upset by the unpredictable action of the volcano enormously more rapid and boundless. It is a peculiar characteristic of Etna to act according to even faster timescales than human ones, a singular behavior for a geological body, the meaning of which is commonly understood as synonymous with long timescales. Cataclysms due to Etna make Catania a rare example of inverse proportionality between time and matter, which results in a disordered succession of strata whereby it happens that the most recent elevation lies below the oldest.

The most emblematic example in Catania's history is the lava flow of 1669, the one that most affected the city and disrupted settlement conditions more than any other (Fig. 1). In that year a river of lava, spewing from various ephemeral vents at about 800 m a.s.l., reached Catania skirting the walls with a lava front so high that it

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Fig. 1 Catania and the eruption of Mount Etna in 1669, 1669–1678 (Author: W. Schellinks)

managed in some places to overrun them and in others to knock them down. In the three months that the lava besieges the city, it raises the ground elevation by more than a dozen meters: in a very short time an enormous amount of matter is stratified. To get an idea of the extent of the phenomenon, it is effective to proceed with a simple proportion: let us ideally assume that, in common cases, the slow sedimentation of a city proceeds by increasing by 1 mm per year: the lava flow stratifies 10 m of soil in three months: transposing space into time we would have that in 3 months 10,000 years have fallen in the form of lava.

For these reasons, Catania is chosen as the case study for the research, a paradigm of an extraordinarily stratified city.

2 City as an Interlocking of Drums

Just as the columns of classical temples are built by superposition of interlocking drums, so the city takes shape over time. The current doctoral research is concerned with the layering of the city, the vertical growth on itself, and how the underneath, the archaeological substrate, forces the shape of the above, the city we live in: "the present is built on the past, as the past on the times that preceded it" [2]. The suggestion of the classical column's drums is the guiding light of research that intends to produce an advancement in the way the shape of the city is read and represented. A new way of representing the *forma urbis*, which is also possible today thanks to the tools of digital representation, no longer to be understood only in its last visible layer, as the rapid exploration within urban iconography has shown us, but rather as an overlapping of drums in space and time. It is now widespread knowledge that the urban space we inhabit is only the most superficial layer of an invisible layering of multiple overlapping cities. Taking this into account, the question underlying the research is: how do we draw this extraordinary construction? What representative tools are most appropriate to clarify a constructive principle that has always shaped the city?

Ph.D. research has recently entered the period of experimentation in the enterprise envisaged by the pathway at the Digital Atom S.r.l, a company involved in computer graphics, in particular virtual and augmented reality. In a first phase, the work aimed to translate the orthogonal drawings developed so far into three-dimensional models; in a second phase, it is intended to elaborate a mode of reading in VR potentially available to the user. It is important that the representational method can achieve a communicative capacity such that it can be of interest even to non-insiders. The translation into 3D, evidently, is not limited to a neutral transposition of the drawings processed so far. The shift from two-dimensional to three-dimensional representation allows for a shift in thinking: from an idea of overlaying by layers to one of constructing by interlocking drums through ancient fragments.

Another extremely important point on the basis of the representation is the purpose to renounce hypothetical reconstructions of traces that are no longer present today as much as possible: every element that constitutes these drawings is *present*, understood in a double meaning. First, *present* in the sense of existing, only physically existing fragments of reality in the contemporary city that can be detected and dated are considered. Moreover, *present* is to be understood as contemporary, the city is all contemporary with itself. On the one hand, it is clear that not all the artifacts that constitute the city have the same age, on the other hand, it is incontrovertible to say that they all coexist in the same city. The idea that the city is a complex construction in which several different times coexist in a single present is placed on the basis of the drawings that the research wants to elaborate. Drawing the past not through hypothetical reconstructions but through the dislocation in space–time of fragments that are all contemporary.

The shape of the city is thus broken down into several drums that constitute it, framing a period of about 15,000 years described by the only existing and detectable city fragments. In these drawings, it was chosen to take into account only the fortified perimeter, as a synecdoche capable of identifying the shape of the city, and to the main axes of the eighteenth-century reconstruction. Finally, it is worth noting the ability of the ancient fragments that although infinitely small compared to the size of the entire city manage to force the shape of its future developments (Fig. 2).

2.1 The Sedimentary Basement

The sedimentary basement is the virgin soil prior to lava flows, an area characterized by a sequence of oblong sandy-clay ravines furrowed by streams and wetlands. The exceptionality of Catania makes it possible to draw the morphological condition of 15,000 years ago from a survey of the existing. Each lava flow at the moment it covers the soil it encounters makes a cast of it by petrifying it, embedding the condition it submerges. The modeling of the sedimentary layer was obtained by inverting a recent survey showing the thicknesses of the lava soil. The depth of the lava corresponds to the cast of the original soil, so the inversion of this relief allows the morphology of the submerged soil to be represented. This layer is the negative of a scientific relief

Fig. 2 The drums of the *forma urbis* of Catania, 2023 (Author: M. Pennisi)

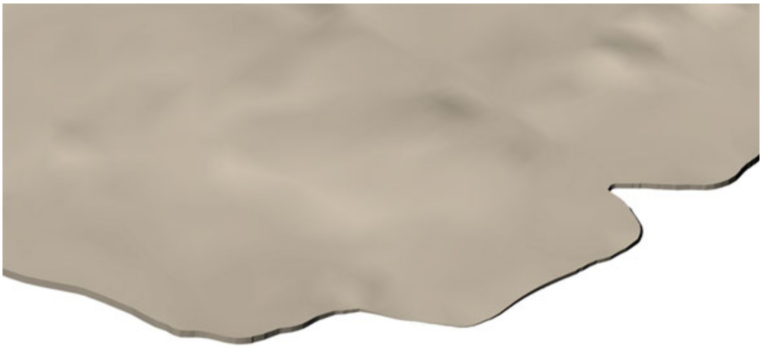

Fig. 3 The sedimentary basement, 2023 (Author: M. Pennisi)

and identifies the geo-morphological condition of thousands of years ago, or rather, thousands of years under the city (Fig. 3).

2.2 The Barriera Del Bosco Lava

The Barriera del Bosco lava of 12,000–5000 B.C. is the first flow to occupy the ground on which the city will rise by creeping between the gullies covering them almost entirely. It is on this flow that the first forms of settlement appear in Prehistory, being with this the first sign of Etna in the constitution of the urban settlements (Fig. 4).

Fig. 4 The Barriera del Bosco lava, 2023 (Author: M. Pennisi)

Fig. 5 The Larmisi—S. Giovanni Galermo lava, 2023 (Author: M. Pennisi)

2.3 The Larmisi—S. Giovanni Galermo Lava

The Larmisi—S. Giovanni Galermo lava of 5500–2600 B.C. is the second flow that structures the city's soil. From the east, the flow squeezes the sedimentary soil in a vise so tightly that it is reduced to a thin flap besieged between the two flows. This is the first time in history that in this portion of the territory the lava reaches the sea, distorting the formerly sandy coastline and now consisting of a high rocky cliff. The perimeter of the flows was obtained from the most recent geological maps (Fig. 5).

2.4 The Greek-Roman-Medieval-Renaissance City

The sign of the walls synthesizes the human stratification due to the overlapping of several cities. The Greeks are the first to settle in this southern offshoot of the volcanic soil, finding a favorable site with a small harbor, excellent southeastern exposure, and a suitable elevation for the city's acropolis. It is likely that it was the Greeks who built the first city wall, consisting of a simple fence of considerable thickness, first defining a form that would remain virtually unchanged for the next 2500 years. In the years that followed, the Roman, medieval and Renaissance cities were layered on top of the signs defined by the Greeks. The shape of the walls and thus of the city is not distorted over time, only quadrangular towers are added in the medieval city and modern-style ramparts in the Renaissance city (Fig. 6).

Fig. 6 The Greek-Roman-medieval-Renaissance city, 2023 (Author: M. Pennisi)

2.5 The Lava of 1669

As previously exposed, the lava flow of 1669 is one of the most destructive and important eruptions in Etna's history such that it changed Etna's eruptive behavior in the years to follow. The flow invades the city going over and destroying only two sections of the walls. It is curious to note how walls built against men proved to be fundamental only against nature, defending the city from a destruction that would most likely have come in their absence. The lava flow approaching the walls imprints the artificial sign of fortifications on the lava front by imprinting an anthropic form on the natural one (Fig. 7).

2.6 The Plebiscito Street

Just after the end of the eruption, a ring road was carved into the still-hot lava to surround the city from the outside, the Gallazzo Street (present-day the Plebiscito Street), the city's first ring road. The road firstly reconnects the areas of the city that remained isolated by the lava eruption and secondly allows the annual procession of St. Agatha around the city. The road derives its shape from the shape of the lava front in turn shaped by the walls (Fig. 8).

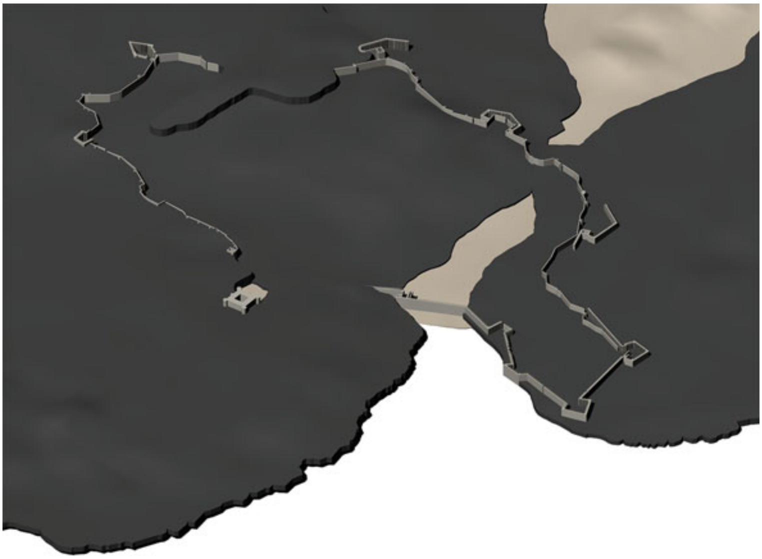

Fig. 7 The lava of 1669, 2023 (Author: M. Pennisi)

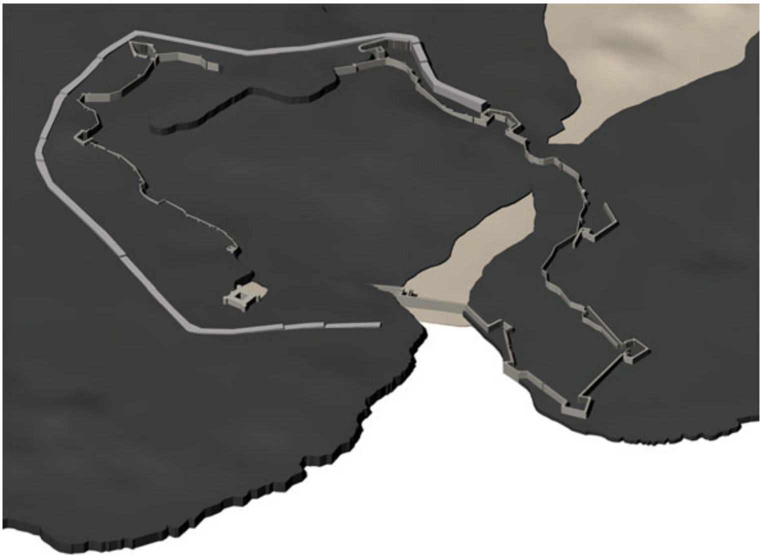

Fig. 8 The Plebiscito Street, 2023 (Author: M. Pennisi)

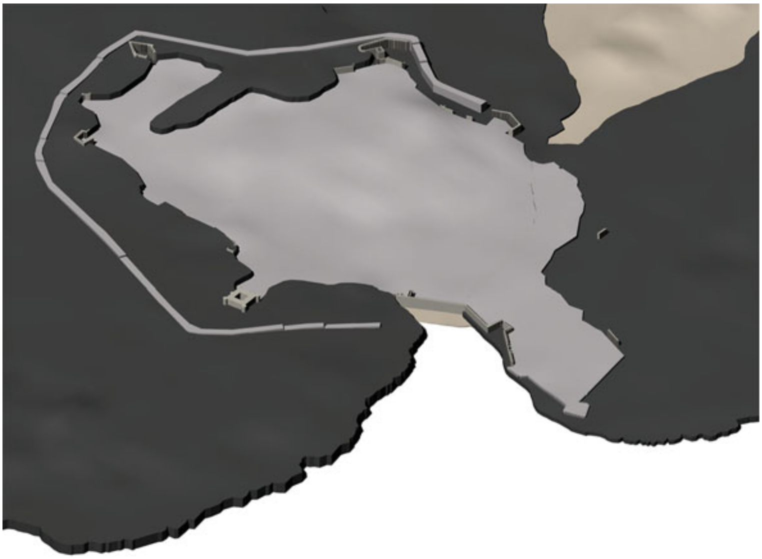

Fig. 9 The 1693 earthquake, 2023 (Author: M. Pennisi)

2.7 The 1693 Earthquake

A few years later another extra-ordinary event struck the city of Catania: the strongest earthquake ever recorded on Italian soil. Numerous cities and towns throughout eastern Sicily are razed to the ground, including Catania, the city that suffers the greatest destruction. The earthquake entails two important consequences: it breaks the continuity of the fortified enclosure, reducing it to a few scattered fragments, and it raises the elevation of the city with a layer varying from 2 to 7 m made up of the rubble of the antecedent cities (hypothetical removal would have been unthinkable given that almost all the buildings had collapsed). These two phenomena formed the basis for the subsequent reconstruction that would affect the city (Fig. 9).

2.8 The Eighteenth-Century City

The eighteenth-century city is reconstructed with principles completely at odds with the characteristics of the pre-earthquake city, a modern city consisting of wide straight streets unlike the previous narrow winding paths. The destruction of the continuity of the fortified perimeter and the leveling between *intra-moenia* and *extra-moenia* cities make the eighteenth-century city entirely independent at the sign of the walls, an unprecedented case of eighteenth-century town planning at least certainly in Europe. Of the main pre-earthquake streets, the only one that is reconfirmed is the Plebiscito

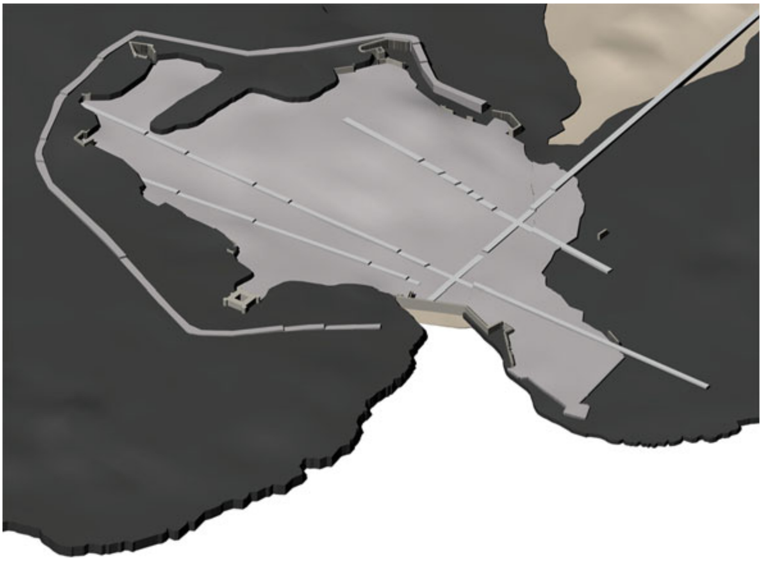

Fig. 10 The eighteenth-century city, 2023 (Author: M. Pennisi)

Street: it was, evidently, already a sign afferent to an idea of a modern city. Two cataclysms of such proportions shake any city to its foundations, entailing, as in fact happened in other Sicilian cities hit by the earthquake, especially due to their relocation, the loss of the millenary form that had distinguished them. Catania, unlike the other cities, was hit about 25 years earlier by the flow, and it is only because of this event that the city was able to maintain a foothold in the multi-thousand-year-old *forma urbis* that had defined it since Greek times. Summarizing: the shape of the Plebiscito Street is given by the 1669 lava front that is the cast of the walls that trace the edge of the elevation of the Barriera del Bosco lava that is given by the shape of the sedimentary basement. The Plebiscite Street keeps the city anchored to its own sediment, its own original reasons, the surface projection of the submerged primeval soil (Fig. 10).

3 The VR Experience: The Interactive *Forma Urbis*

"What has been seen so far in architecture showed a conception that basically did not exceed the second dimension, as in painting. The three dimensions did not constitute a simultaneous whole, but were seen successively. They were, in fact, a plan, a profile and a section: they were surfaces, in short, and only a very rapid succession of two-dimensional surfaces could approach a three-dimensional view" [1].

The planned period of experimentation of the research course is still in progress, so the results presented here are not to be understood as definitive but as intermediate steps still to be refined. However, the overall sense of the experience being elaborated emerges from the frames proposed here. Starting from a shift of thought, the research wants to make a shift of representation: the idea of the city understood no longer as a two-dimensional plane of the only visible layer but as an assemblage of drums interlocked in space and time. An idea representable today thanks to the possibilities given to us by the new methods of representation.

Virtual reality is an opportunity to allow for a decomposition and reconstruction of the city according to the previously explained drums. The user is offered the opportunity to grasp the relationships between the below and the above, between the past and the present. The study of historical cartography, the most up-to-date geological maps, and underground surveys has led to a reliable reconstruction of the city's drums, which the user is confronted with as soon as he or she enters the virtual space (Fig. 11). At the beginning of the experience, as user, I am below the drums and on the surface of the sea. The sea is the neutral surface ready to receive the arrival of the drums (Fig. 12). When I select the desired element with the pointer, it will slowly begin to descend vertically until it reaches its position (Fig. 13). Similarly, the other drums can also be made to fall by letting them interlock on the previous one. When finished, a complex construction will appear in which each element is directly determined by the one immediately next to it. The aim is to appreciate a new way of seeing the shape of the city not as an already given surface but as a syntactic process of several mutually dependent elements. It thus becomes evident that even the most superficial drum is related to the deepest one: the city as a construction of matter in space and time (Fig. 14).

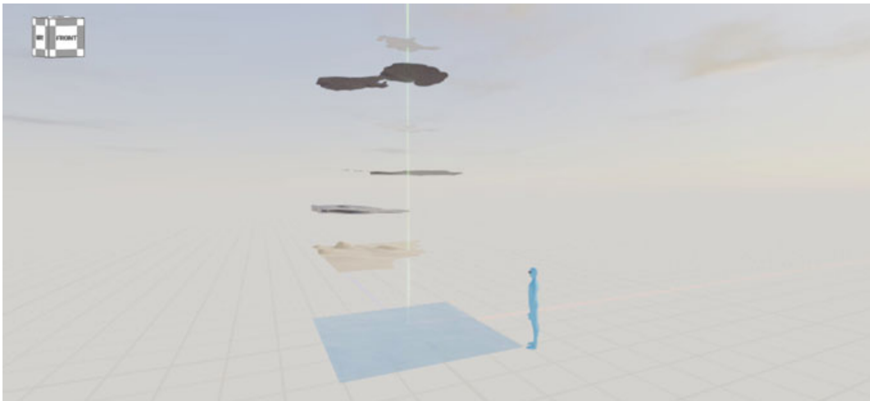

Fig. 11 Frame from Eyecad VR Studio, 2023 (Author: M. Pennisi)

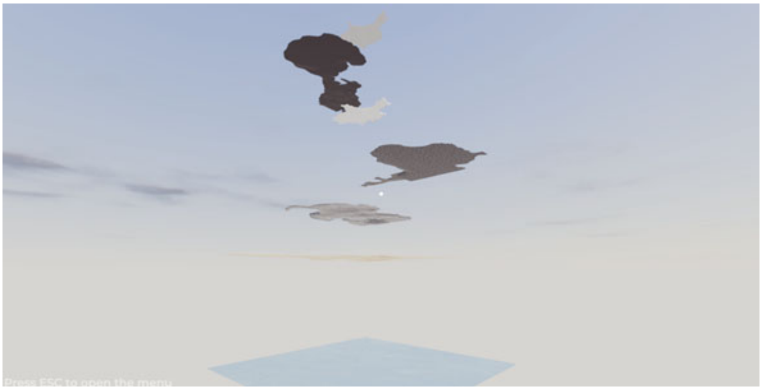

Fig. 12 User's point of view (Frame from the VR experience on Eyecad VR Studio, 2023) (Author: M. Pennisi)

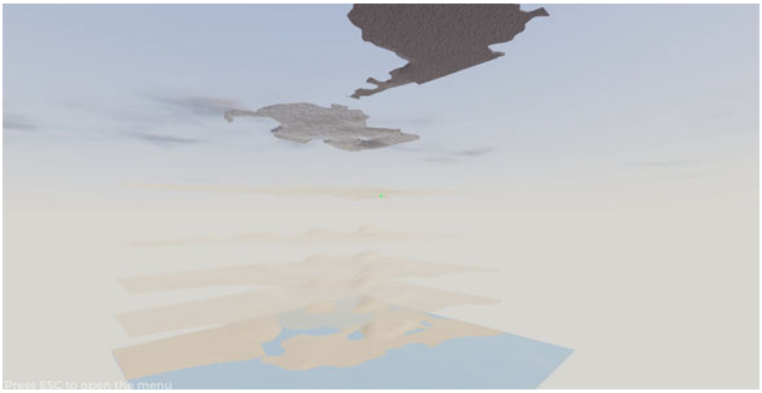

Fig. 13 Interaction with the drum (Frame from the VR experience on Eyecad VR Studio), 2023 (Author: M. Pennisi)

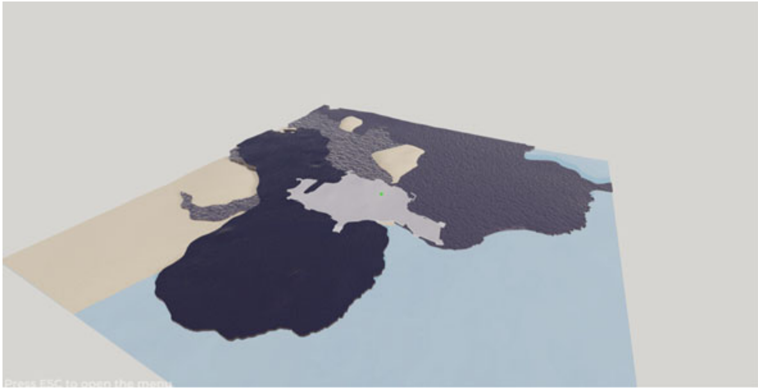

Fig. 14 End of overlapping (Frame from the VR experience on Eyecad VR Studio), 2023 (Author: M. Pennisi)

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AR&AI and Building Monitoring

Dataspace: Predictive Survey as a Tool for a Data Driven Design for Public Space

Massimiliano Campi, Marika Falcone, and Giacomo Santoro

1 Introduction

The decision-making process based on the interrogation and prediction of Big Data is a research topic that has animated the interest of many fields of investigation in recent decades. Among these, the architectural field has also participated in this widespread interest involving, in particular, the disciplines of Drawing and Representation. In this context, technological progress has transformed the way of knowing and investigating architecture with research approaches characterized by a multidisciplinary vision. The use of these new technologies has in fact developed new ways of thinking about architecture while representing, at the same time, a key factor in the process of analogy-digital transition still underway. In this mixture of physical and digital fits the theme of city models that follow development strategies based on Artificial Intelligence and Internet of Things applications that allow for the processing and analysis of the enormous volume of data they generate. The definitions attributed to these cities are different: from wired city [1] to cyber city [2], from digital city [3] to intelligent city [4] up to the more recent and well-known ones of smart city [5], sentient city [6] and senseable city [7]. Each of these terms has been coined to explore the relationship between Big Data and the city itself, analysing the effects that information and communication technologies produce on urban form and public space. It is from this assumption that this contribution aims to analyse the quality

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of public space by defining, through survey techniques, a three-dimensional model in which to simulate a series of heterogeneous data collected through field surveys. The aim is to define a future sensors system to support a design based on real data and, therefore, a prototype of a forecasting model. Topics that are trendy in the predictive survey that associates morpho-metric information with a continuous flow of heterogeneous data obtaining what is commonly called Digital Twin. In this vision, the survey is understood, in its broadest sense, as a modification of the reality of the subject that reflects the research attitude of the group. The limitations of 2020 have certainly changed our lives for better or for worse. The Covid-19 pandemic has highlighted the weaknesses of the places we live in, and the introduction of the concept of social distancing has forced mankind to think about public space in a different way. What has changed in the use of spaces in our cities? Can we make the most of it in everyday life? The aim of this thesis work is to understand the quality of public space by defining—through survey and representation methodologies—a three-dimensional model in which to simulate a series of heterogeneous data collected through field surveys. The aim is to imagine a future sensor system to support a design based on real data. The scope of this work is potentially enormous. From maintenance, through restoration, urban redevelopment, construction from scratch—but also the simple monitoring of spaces or interactive management. The application possibilities are many. This model, however, needs to be fed by a huge amount of data, so often, to date, there are not even collection tools. The output of this thesis wants to be the definition of a method, understanding which tools are currently available and which ones would be needed to collect these data and put them into a coherent and usable system [8]. On the basis of the premises mentioned above, the methodology used saw the identification and distinction of four operational phases. The first phase concerned the analysis of the sources, linked to the necessity to understand how the urban context of our cities has been influenced, during history, by pandemic events and which kind of lessons have been learnt on the way. The second concerned the direct knowledge of the public space through the acquisition of morphometric data. In this case, the investigation campaign was conducted using image-based technologies, with the combined and integrated use of LiDAR techniques. The third phase concerned the creation of a digital model on which a series of interpretations were developed. Instead, the fourth phase was dedicated to the design and implementation of the model with a simulation of methodology (Fig. 1).

2 Analysis

Humankind is not new to pandemics, and Covid-19 will not be the last event of this kind. The concept of pandemic (from the ancient Greek *pándēmos*, what affects all people, public, general) is of recent introduction, used in the modern age to indicate the exposure of the entire world population to a common disease [9]. The spread of these diseases on a global scale has been the consequence of a progressive process of globalization which has made possible the contagion between different

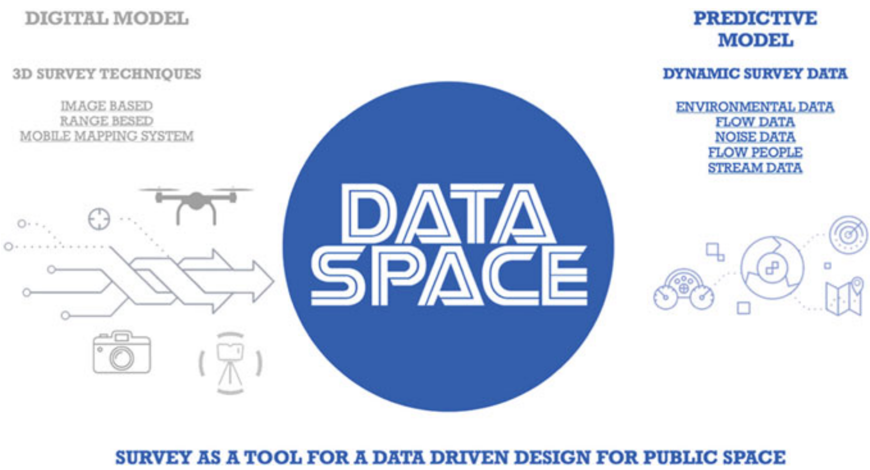

Fig. 1 From digital model to predictive model for public space. *Editing* arch. M. Falcone and arch. G. Santoro

peoples; the story is scattered with examples which have brought suffering, death, even the disappearance of entire civilizations [10]. Some diseases have struck rapidly, others have acted in lethal waves over the years but all, for better or for worse, have profoundly changed the social fabric and the urban layout of our cities. Covid-19 could be again—as it happened before—a watershed for rethinking our cities to make them ready for the challenges of the future [11]. A barrier to the risks deriving from pandemic and epidemic events can be found within some tools developed in recent years at a global level. The UN 2030 Agenda for Sustainable Development outlines, among other things, the 17 Sustainable Development Goals. From the fight against poverty, through the protection of the environment and the development of clean energy sources, the objectives recognize an important role for health (objective 3) and the development of safe and sustainable cities (objective 11). These goals go hand in hand: today half of humanity, 3.5 billion people, live in cities and by 2030, almost 60% of the world's population will live in urban areas. This transformation will lead mankind to face new challenges (Figs. 2 and 3).

2.1 State of Art

In a global context in which 63% of the global mortality rate is linked to chronic diseases, many of which are linked to risks from urban environments, what can we do to make cities not places where we get sick but active organisms that cure and are adapted to the historical context to avoid the risk of new pandemics? First through maximizing the use of data. Making decisions based on scientific evidence, collecting both historical data and real-time data streams regarding the environment,

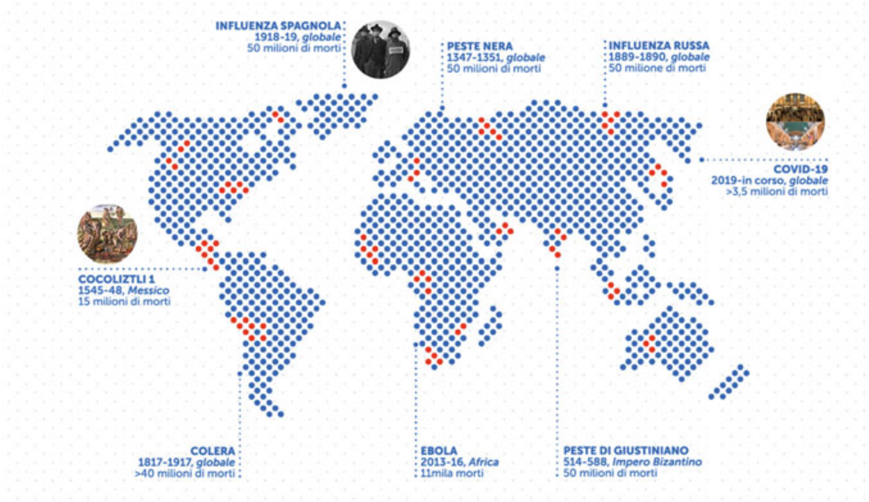

Fig. 2 Pandemic and epidemic events in the history. *Editing* arch. G. Santoro

Fig. 3 The 17 goals of United Nation (on the left). Healthy and unhealthy urban space (on the right). *Editing* arch. G. Santoro

Fig. 4 The project of Norman Foster in Trafalgar Square, London. *Editing* arch. G. Santoro

health, can help establish an even closer link between the built environment and the well-being of citizens. The use of data in the field of architecture, therefore of the survey and understanding of city spaces, is not new and examples in this sense already exist from the beginning of the 2000s. In fact, at the end of the 90s, the British architect Norman Foster's studio was commissioned to define a masterplan called World Squares for All for the improvement of the public space of Trafalgar Square, considered insecure and unpleasant. The definition of the project was supported by a series of analyses on space carried out by the Space Syntax studio: in particular, both pedestrian and vehicular traffic flows were analysed, through observation periods which led to the definition of a highly developed analysis model for the era. The collected data helped to define a new design of the square, still existing and widely appreciated. Although this project was a forerunner in the use of data to support design, the data used was far lower than what it would be possible to do today; despite the mass of heterogeneous data of our day—designing using data is an approach that has never become canonical. In recent years, the greatest contribution to this research field has been made by the Senseable City Lab of MIT in Boston, led by the Italian architect Carlo Ratti. With more than 50 research projects developed, the Senseable City Lab stands as an ambitious experimenter in the field of data use, maintaining a multidisciplinary approach that relies not only on architecture or urban planning, but also on physics, biology and sociology. Notable projects include the recent Desirable Streets, for which thousands of pedestrian trajectories—obtained from the GPS signals of mobile phones—were used to build a desirability index of Boston streets (Fig. 4).

2.2 *The Use of Data and the Importance of Survey*

But how to collect this data? The extraction of knowledge from Big Data and their use for the improvement of decision-making are subordinate to the definition of processes that allow to efficiently manage and transform datasets that grow rapidly in volume and variety. In addition to the variety of formats and structures, Big Data also has a variety of sources. In particular, we are talking about human generated data (those coming from the internet, social networks, blogs, etc.) and machine generated (extracted through the use of technological sensors). The acquisition, for both types, can take place both using specific software and by accessing the APIs made available by the web services, relying in any case on technologies present in everyday life. The combined use of everyday data flows from these technologies—equipped with low-cost sensors—and data taken with field investigations, can help build an unprecedented analysis framework. The key to all of this is survey. Through digital representation procedures and tools, it is nowadays possible to support the interpretation of data; understanding the structure of cities, its buildings and activities helps to understand how urban space works and could work better, according to the maxim of “if you can’t measure it, you can’t manage it”. Digital photogrammetry (in particular, Close-range Photogrammetry) has been the most suitable tool to pursue these objectives. An accurate urban survey allows to obtain dimensional data, geometric proportions of the spaces, analysis of the materials, favouring a typological, structural and functional knowledge of the building (Fig. 5).

The accessibility of technologies, through the use of reality-based sensors, and specifically of image-based techniques, can allow the reconstruction of accurate three-dimensional models that can recreate, with the implementation of data, digital twins of the context taken into consideration, within which to hypothesize possible transformation scenarios through predictive analysis. The Digital Twin, for the definition of which survey and representation play a fundamental role, is constituted as an interactive digital container, within which is possible to pour a series of heterogeneous data fundamental to the management, conservation and monitoring of the urban context [12]. The city, after all, is a complex system in which a great deal

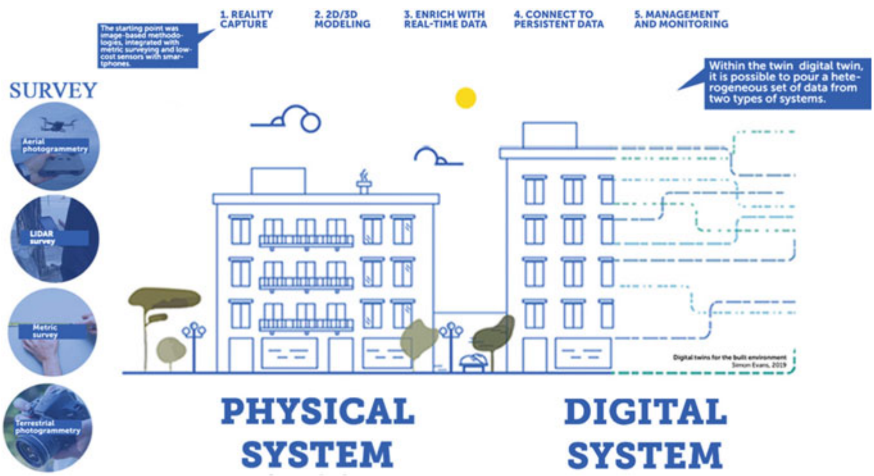

Fig. 5 The technologies of 3D survey and the definition of digital twin. *Editing* arch. G. Santoro

of information and data is generated and used to determine its characteristics. In the examined case study, the data are the result of a mixed digital-physical system: the smartphone, considered as a low-cost sensor, acts as a data collection element linked to environmental (noise, tree species) and/or dimensional factors, also thanks to the development of increasingly performing integrated cameras; field surveys, on the other hand, serve to integrate data for which there is no specific instrumentation [13].

2.3 Public Space

The assessment of the public space fits within this framework. Public space plays a fundamental role within the city. During the 2020 lockdowns, forced indoors, we realized how important it was, coming to find alternative solutions to replace it and when it was finally possible to go out, the decision to go out or stay at home was strongly influenced by how the city is designed, due to social distancing restrictions. The pandemic has presented itself as an opportunity: an opportunity resulting from the need to rethink the spaces that we collectively live in every day, based on real data [14]. How can we experience these spaces and respect such restrictions if cities are not designed for the purpose? The theme of public space rests on very solid theoretical foundations. Only in recent years, innovative methods started to develop in the urban environment and the city dwellers have started to become the protagonists within the urban public space. An approach that focuses on the search for a relationship between the environment and the human perception of spaces is the one supported by the theories of Reijndorp and Hajer in the book in search of the new public domain. Based on an analysis of the cultural structure of the city, the authors believe that the value of the public domain is conditioned by the intensity, diversity, overlapping and the interaction between uses and users. But an impactful role in this research was given by two personalities: first Jane Jacobs and later Jan Gehl, who concentrated their studies on improving public life, reorienting the design of cities towards a more humane scale and rejecting the policies undertaken until that moment.

In *The Death and Life of Great American Cities*, Jane Jacobs details the quality of urban life and the liveliness of the city, highlighting the limits of modernist planning, regarding the separation of the uses of the city and the emphasis on the individuality of buildings, which would put an end to urban space and life in the city, making it lifeless and deprived of people. Jane Jacobs' observations, activism and writings have had a significant impact on generations of architects, planners, politicians and activists. Jacobs saw cities as an integrated system with its own logic and dynamics, capable of changing over time according to the way it is used, promoting higher density in cities, smaller city blocks, small businesses and mixed uses [15]. Jan Gehl fits into the tracks traced by Jane Jacobs and the two would often confront each other in the years to come. Graduated in 1960, he undertook a change of pace in his profession when he married a psychologist and became interested in the borderland between architecture and the social sciences, in what people did in public spaces and how the shape of

Fig. 6 Architect Jan Gehl and the 12 criteria of Public Space. *Editing* arch. G. Santoro

those spaces influenced the life of the people who used them. For a short time in the 1960s he moved to Italy to study its squares: how they worked, why they worked, what worked, which didn't. These early studies converged in the book Life Between Buildings and in the development of 12 criteria for defining quality public space. These criteria are a tool for understanding how public spaces are experienced by their users. They are used to evaluate whether the different characteristics of a public space are protective, comfortable and pleasant for the people who spend time there. The thinking behind these three categories is as follows: (1) without basic protection from cars, noise, rain, and wind, people will generally avoid spending time in a space; (2) without features that make walking, using a wheelchair, standing, sitting, seeing and conversing comfortable, a place will not invite people to stay; (3) large public spaces tend to offer positive aesthetic and sensory experiences, take advantage of the local climate and provide human-scale elements so that visitors do not feel lost in their surroundings [16]. The approach for using this tool, and others developed by Gehl and used in the analysis phase, is based on the observation and perception of spaces (Fig. 6).

3 Survey

3.1 Case Study

The application of this process had to be done, obviously, on a case study. The decision to use a specific site within a district of our hometown (Salerno, Italy), was not dictated by a simple obligation due to travel restrictions: the city is known for being "mountainously marine", as defined by the Salerno poet Alfonso Gatto, squeezed between the mountain and the sea with a population density far higher than the already high one of the region in which it is located. A context with such a high population density was an indispensable prerequisite to be sure of finding the right mix of characteristics in a few square meters of space.

From the choice of the city we moved on to a neighborhood scale. Usually, this type of analysis can be carried out on a larger scale (neighborhood), medium (a block) or small (a public place). The choice fell on the latter scale as it allows us to understand how the space works and is used. Once in the public space, are people invited by the street furniture, landscaping and planning to stay and enjoy it? A robust set of tools that measure public life and public space can help answer these questions and enable urban planners and decision-makers to set higher standards for public life. Thanks to the use of data from social network locations, we were able to identify the most popular public spaces. This was possible by searching a series of squares and extracting the number of user registrations, for an indefinite period of time. This led to selecting, among the various neighborhoods, Pastena as a case study. The choice was also confirmed by a qualitative observation born from a spontaneous planning during the 1900s, at present it seems to express the concept of liveliness better than other areas, a term that can be considered a sort of benchmark of evaluation which includes all the characteristics that qualify the public space. In particular, in Piazza Caduti Civili di Brescia, the place with the highest number of location registrations on social media, there are elements—such as the diversity and mix of activities and the presence of pedestrian and vehicular traffic—useful for making multiple assessments (Fig. 7).

Fig. 7 The focus on the *Piazza Caduti di Brescia* in Salerno. *Editing* arch. G. Santoro

3.2 Survey Process

Once the location of the case study was determined, an indirect survey campaign was conducted with a terrestrial and aerial photogrammetric approach using a Nikon D3100 digital camera and a DJI Mini 2 drone.

During the shooting phases, 1111 frames were recorded, in which it was guaranteed an image overlap of approximately 60%. In relation to the conformation of the spaces, it was decided to set the focal length to 24 mm with shooting with parallel axes. The acquisition of the spaces of the square, on the other hand, was carried out through a video taken with a drone, from which the frames were extracted using the 3DF Zephyr application. Subsequently, the processing of the images was carried out with the Agisoft—Metashape structure from motion application where medium quality parameters were set in all phases of the work. After the alignment phases, the dense cloud of 93,807,336 points was extracted. With the recognition of homologous points, it was possible to obtain, with dense image matching algorithms, the textured polygonal model, consisting of a triangular mesh of 6,699,696 faces. Finally, the orthophoto used for the critical interpretation phases was elaborated from the texturized model. From the orthophotos was then extracted the elevations of the buildings (Fig. 8).

From the export of the polygonal model, better known as a mesh, the three-dimensional modeling process began which was performed directly in the 3D CAD environment, and specifically in the Rhinoceros software, exploiting the use of NURBS modeling (Non-Uniform Rational B -splines).

The street furniture was also analyzed and was carried out with the support of a classic photogrammetric process, compared with a survey with LiDAR technology, using an iPhone 12 PRO which integrated this type of sensor. LiDAR—(acronym for

Fig. 8 The survey techniques used. *Editing* arch. G. Santoro

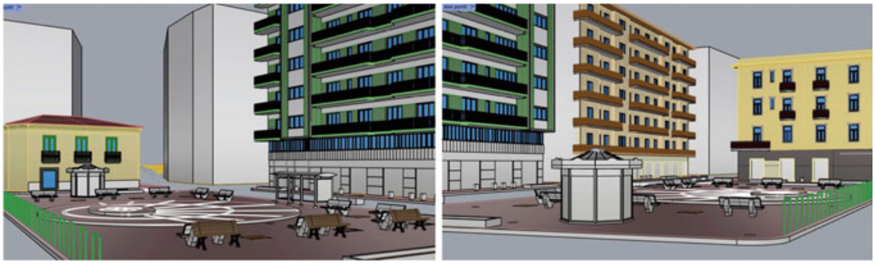

Fig. 9 The reconstruction of 3D model with rhinoceros. *Editing* arch. G. Santoro

Light Detection and Ranging or Laser Imaging Detection and Ranging) is a remote sensing technique that allows to determine the distance of an object or a surface using a laser pulse—it has been used for years in the field of survey but through large machinery (Fig. 9).

The introduction of a version of reduced dimensions, in a device possibly within everyone's reach, opens the door to a greater use of this instrument in the field of surveying. The two extrapolated point clouds were compared using the CloudCompare application to understand the actual accuracy of the data. Once the clouds were aligned using the ALIGN command—using the homologous points of the objects (in this case the markers) it was possible to calculate the distances between them.

This made it possible to understand that the maximum distance between the two clouds, in most of the model, is less than a centimeter. Decisive factor to positively evaluate the accuracy of the LiDAR sensor in the field of urban and architectural survey Both the urban context and the furniture elements, thereby, have been digitally rebuild—both as 2D and 3D outputs—to analyse them and start the interpretation phase.

3.3 Interpretation

The 12 quality criteria for public space elaborated by Jan Gehl have made it possible to define a framework in which to move for the collection and interpretation of data useful for understanding the space. In particular, proceeded to an analysis of the elements that contribute to the definition of the public space: the facades of the buildings—to be considered as a scenography of the public space—with qualitative analyses and the square and surrounding sidewalks with both qualitative and quantitative analyses.

These analyses determined outputs that are both objective and subjective, but which together can contribute to the definition of the characteristics of the space. By definition, a square is an enclosed place. The buildings that surround it help to define its characteristics and the perception by those who live around it. For this reason, all the characteristics that define them contribute to making public space a pleasant place.

The study of materials and colors plays a fundamental role in this understanding, having a strong psychological impact. It is also a question of scale; the study of heights makes it possible to highlight the scale characteristics of the buildings and their relationship with the surrounding space. According to Gehl's research, contact between the building and the streets is possible below five floors (or 13.5 m), beyond this limit, contact with the urban space is quickly lost. This comes from the way human vision develops, which allows us to see primarily horizontally, with limited upward and downward angles. Low-rise buildings, therefore, conform to the human sensory apparatus unlike tall buildings. Our horizontal field of vision indicates that when we stand along the facades of buildings, only the ground floors can offer us interest and intensity. If the ground floors are full of variations and details, our walks in the city will be full of experiences. In a good urban neighborhood, the ground floors of buildings work symbiotically with the surrounding sidewalks and public spaces. Together they provide a continuous network of active, safe, comfortable and engaging paths and experiences, creating a sort of funnel between the private sphere (the apartments) and the public sphere (the square and the sidewalks). It is no coincidence that Gehl defines different types of ground floor, evaluated based on their qualities and the experiences they can offer. The ground floors surrounding Piazza Caduti Civili di Brescia, although characterized by small businesses and largely with high visual permeability between inside and outside—and therefore comparable to lively ground floors—could fall into the monotonous category due to the presence of repetitive commercial activities which contribute little to the quality of the public space. In terms of materials, the square is characterized by porphyry and gneiss bolognini, materials not of local origin but imported from Northern Italy (Fig. 10).

The concept of the visual field also applies to the square space; In City for People, Jan Gehl describes the field of social vision by inscribing it within a radius of 100 m. This distance allows observers to stand in a corner and have a general view of what is happening in the square and, approaching 60–70 m, to recognize the faces of the people who frequent it. This relationship is reflected in the size of most of the old squares of European cities which rarely exceed a width of 100 m and an overall size of 10,000 m^2. A close look at the invitations to participate in public life reveals a relationship between public life and public space. If there's no place to sit, people will not sit down. If there is no tree canopy to manage high temperatures or create visuals of interest, walking will be less pleasant and therefore less prevalent. Without inclusive programming, some people will never find a reason to spend time in the public space. This data layer helps uncover the relationships between the built environment and a place's ability to foster social mixing.

The tools developed by Gehl over the last 50 years make it possible to understand and analyse the behaviour of people in public spaces. These observational analyses help to understand if spaces work, what doesn't work and what could work better, defining an essential basis for any future projects that could take this data into account to design public spaces of quality. The analyses were carried out after choosing an observation point from which to write down all the necessary data, during a weekday and a holiday in the time slot between 8 in the morning and 18 in the evening, with observation times lasting 20 min. The cross-use of the tools developed by Gehl

Fig. 10. 2D representation with metric, material and colorimetric data. *Editing* arch. G. Santoro

People Moving Count, Stationary Activity Mapping and Gender + Age Tally has made it possible to collect a varied number of data relating to the type of user and their reasons for using the places, highlighting how the square is a place frequented mainly by elderly people who spend long periods of time socializing.

This socialization is more frequent when the seatings are placed in such a way as to favour conversation. It is no coincidence that the architect Ralph Erskin spoke of Talkscape, a systematic way of conceiving the conversation space, introducing in all his projects two corner benches with a small table in front, so that people could both talk and use the table. These observations were enriched with environmental analyses in relation to the noise level of the places and the presence of urban green areas. Trees generate shade and contribute to creating a pleasant microclimate, but the choice of the correct types can bring even more benefits: greater biodiversity, barrier from vehicular traffic, less maintenance; In the case study of Piazza Caduti Civili di Brescia, the prevalent presence of Mediterranean pines certainly contributes to create pleasant, shaded areas, but this specie cannot be considered suitable for an urban context due to its invasive root system. Furthermore, since it is a tall tree, it cannot offer the benefit of acting as a filter—both visual and aerial—between the public space and the driveway. Noise, in fact, is another factor of vital importance.

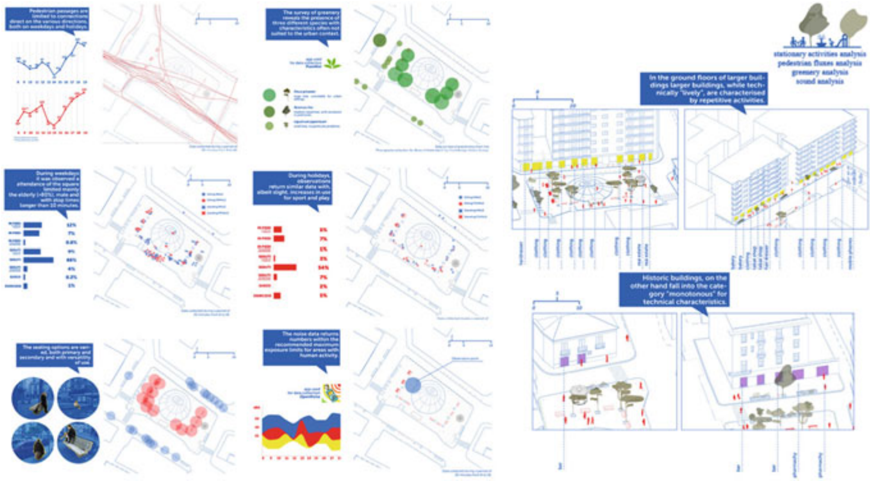

Fig. 11 Qualitative analysis. *Editing* arch. G. Santoro

According to Gehl, the cities where it is simple and pleasant to meet are those which offer good opportunities to hear, see and speak. These are fundamental aspects for human relationships but often the high noise levels due to car traffic and the high concentration of people and activities make them difficult. According to studies, the optimal background noise level should not exceed 60 dB; with levels equal to or lower than this it is possible to have a conversation between individuals while maintaining a distance that does not violate the personal space of others. In the case study, the noise levels recorded can be considered normal, with less than a few isolated peaks. These analyses helped to draw some conclusions: the square is mainly seen as a place of passage, the square lacks attractive elements that favor a greater variety of users (by gender and age) and the lack of continuity with the surrounding pedestrian areas reduces the perception of safety for the little ones. These conclusions could, ideally, be a starting point for a redesign of the space in order to meet quality criteria in the future (Fig. 11).

4 Simulation

The last phase of the work consisted of the simulation phase in which the data collected through field surveys became the starting point for the embryonic development of the digital twin. Although at this stage it has already been possible to draw some conclusions based on the observed data deriving from the physical system (which would allow the introduction of redevelopment interventions of public space), the implementation of an advanced sensor system would allow to have a much richer and more reliable pool of information and data to be merged into a database to support the decision-making process. To evaluate the potential of this system, a scenario of the current Piazza Caduti in Brescia in the year 2030 was simulated with the help of the TwinMotion application. Inside the scene, a series of above-ground sensors were virtually installed: audio control units, solar panels, cameras, thermal imaging cameras, data streams from mobile phones, satellite data, etc. that would monitor the physical changes of the case under consideration with a new level of knowledge of the problems related to urban space. The simulated model is nothing more than a predictive model, according to which surveying and Artificial Intelligence take on a key role. In this field of investigation, Machine Learning and Data Mining techniques applied to three-dimensional mappings allow to obtain data on traffic, air quality, neighborhood as well as possible scenarios to be adopted at an architectural and urban level. For example, the analysis of cameras or thermal imaging cameras would make it possible to monitor the movement of pedestrians and passing vehicles as well as to detect the use of public space by different stakeholders at different times of the day. As the performance of these sensors improves, so does our understanding of environments. In fact, in recent times, the technological evolution that has been achieved in the field of the Internet of Things has made possible the integration of reality-based and AI technologies. The relationship that is established between these two realities opens up new operational scenarios, supporting architects, designers and planners to design responsive urban environments [17] (Fig. 12).

However, there are various gaps against which it is necessary to codify a methodological process of investigation aimed, on the one hand, at the continuous acquisition of heterogeneous data obtained from sensors useful for training AI algorithms, on the other, at the management and systematization of information, through the structuring of a database for storage and prediction of phenomena in progress.

5 Conclusions

The virtual monitoring/management experience conducted for this contribution showed the results of survey methodology based on the analysis of urban space. In this context, the dynamics of the management and design of these spaces were addressed, starting from the three-dimensional survey, the digitization processes, and the integration of the various information. The possible benefits of this operational workflow today concern multiple fields of investigation such as maintenance, restoration, urban regeneration, and this is a great strength. Starting from this assumption, the course of study was articulated along two lines: from qualitative and quantitative analysis derived from the survey to the simulation of heterogeneous data. The goal was to prefigure a sensor that uses low-cost sensors and AI to structure a forecast model.

Fig. 12 Simulation of 3D data and definition of sensor. *Editing* arch. G. Santoro

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Monitoring Systems Design with Real Time Interactive 3D and Artificial Intelligence

Valeria Cera and Antonio Origlia

1 Introduction

The paper presents the topic of Environmental Artificial Intelligence, a naming used to indicate Artificial Intelligence approaches, based on the use of natural language, applied to architecture to support the design and operation of systems to control the progress of degenerative states through simulations in a digital environment i.e., employing real-time interactive 3D models.

This is a field of research that the group of the Department of Architecture of the University of Naples Federico II, coordinated by Prof. M. Campi and A. di Luggo, in collaboration with the group of the Department of Electrical Engineering and Information Technology, coordinated by Prof. F. Cutugno, is developing in several ways.

The issue of monitoring the manifestations of decay affecting the built environment, in its most superficial to structural components, is now one of the main topics of experimentation in the scientific community. In fact, the concept of Preventive Conservation, i.e., the tendency to study processes that are able to inform on the state of health of the heritage and monitor it over time, acquiring—through the use of various types of sensors—useful data to guide the diagnostic investigation in a non-invasive manner [1–4], has been affirmed in the last five years. In this sense, interesting are the potentials that, through some research, are emerging with respect

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to the use of AI approaches in tracking the prediction of future damage so as to anticipate interventions [5–7].

This is the context for the research presented, which is distinguished by 2 specific aspects: (1) the use of semantic maps to prioritize conservation actions and thus return information on the severity of the damage detected, weighted against the real urgency of intervention; (2) the use of 3D, interactive real-time applications integrated with natural language-based AI systems to, on the one hand, optimize the installation of the monitoring system through digital simulations of its operation; and on the other hand, inform users of the detection of a potentially dangerous change by interacting with them through verbal communication. To this end, the study is organized into 3 macro-actions: (i) Multiscalar digitization and hetero-informative characterization of the semantically annotated cultural heritage artifact; (ii) Design of the remote monitoring system and digital simulation of its operation through integration with AI modules; and (iii) Testing of the infrastructure and scenario simulations for in situ implementation and to guide preventive conservation actions (Fig. 1).

The first and second phases of the project will be explicated here: the objective is the design of the installation of sensors (in this case, RGB chambers) for the monitoring and verification of an AI system that signals, by dialoguing with an expert user, the progress of degenerative states that are evaluated as potentially dangerous and automatically detected. The actions were conducted on the case study of the Cathedral of Padula, a church datable around the ninth-tenth centuries, affected by phenomena of both plaster detachment and surface deposition of frescoes at the intrados of the vaulted systems, for which cognitive actions have been initiated as early as 2019.

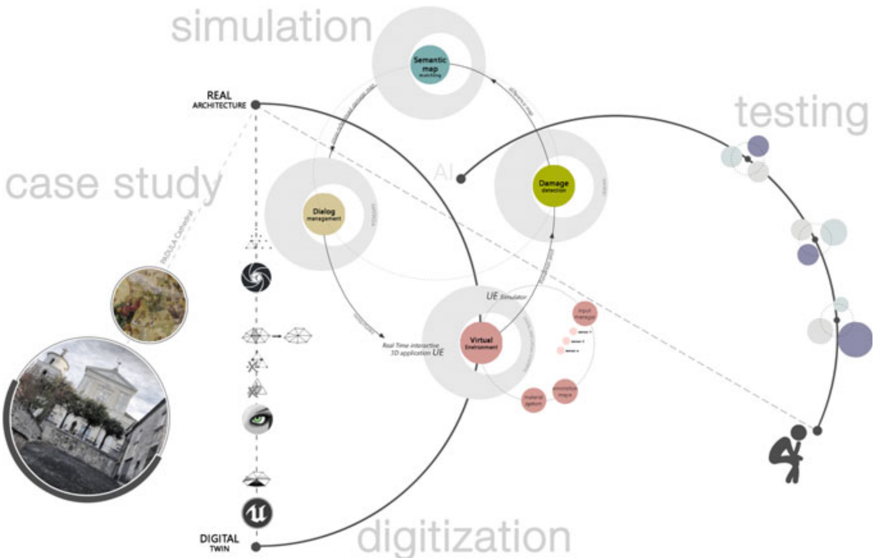

Fig. 1 Research workflow. *Image* V. Cera, A. Origlia

2 Modeling and Characterization of the Digital Environment

To pursue the research objective, it was decided to take advantage of the potential offered by 3D modeling and digital environments to conduct simulations by exploiting real-time interactive 3D models. To be able to test the infrastructure of the control system, the digital environment must be characterized from an informational point of view so as to provide the system with the necessary data to determine the state of preservation of the investigated artifact at a time T0, the initial time of the observation process, and a comparison term for the detection of anomalies. Finally, to support the detection of any progress of phenomena judged to be damaging, semantic annotation of the three-dimensional information model is essential for the reporting of problems that have been evaluated and indicated as such to the user interfacing with the system, based on a hierarchical order of importance.

2.1 Multiscalar Digitization

The first action of the research involved the digitization of the case study.

Evidently, in order to set up a digital environment in which to plan the architecture of a remote control system of the variables and related parameters that influence the state of preservation of the examined artifact, the digitization actions were oriented to the construction of its multiscalar representation. In fact, by articulating the acquisition processes from the macro to the micro scale, it is possible to achieve the construction of a restitutive digital replica of the real architectural configuration of the studied asset, in its most detailed characteristics. This condition is necessary for the arrangement of monitoring systems that, aspiring to inform on the negative evolution of degenerative states, must be based on a particularly large and specified body of information. To meet these objectives, the survey campaign was declined into 3 operational phases: (i) range-based survey with a phase-modulation sensor to acquire a general point cloud of the church; (ii) range-based survey with an optical triangulation system to refine the geometric datum for specific portions; (iii) detailed image-based survey to refine the colorimetric datum.

(i) A TLS Faro Focus3D X330 was employed to survey the entire religious complex by making an orderly and constant acquisition network evenly distributed in the space of the cathedral. Therefore, with a maximum controlled distance between range maps of about 10 m, 37 scans characterized by an average point discretization of 6 mm/10 m, considered suitable for digitizing an interior full of carved decorations and ornaments, were made (Fig. 2a). The individual point clouds were aligned in the proprietary FAROScene software, with the well-known best-fitting procedures of geometric primitives—such as planes and spheres—corresponding to the specific targets used in the capture phase. The tension recorded at the end of the procedure was on the order of a millimeter, with no alignment errors. The final registration

Fig. 2 Data acquisition schemes with TLS (**a**) and hand-held scanners (**b**). *Image* V. Cera, A. Origlia

returned an overall cloud of 240,000,000 points with origin expressed in a local reference system, coincident with that of station No. 1, assumed as the basis for roto-translation of the range maps.

(ii) Having set up a general restitutive model of the morpho-metric specificities of the cathedral, the information base was deepened—in terms of accuracy and metric-formal precision—for those elements particularly significant for its architectural characterization such as: the pulpit, the stoup, the tabernacle and the sculptural collections. Therefore, the previous model was integrated with acquisitions using a portable optical triangulation scanner, the FARO Freestyle3D. Given the dimensions of the elements involved in the detail digitization, it was possible to manage the data recording in a single scan returning a single, complete point cloud for each object. Acquisition was conducted by following a nearly helical trajectory with the sensor, with circular movements around the individual artifact, maintaining a distance from it of about 0.50 m (Fig. 2b). In the trajectory, the hand-held scanner was oriented perpendicular to the lie of the dominant planes (for objects distinguished by flat facades) by integrating the capture with acquisitions at different angles of incidence. The goal was to compose point clouds as void-free as possible.

Due to the colorimetric characteristics of the digitized artifacts, which are connoted by non-homogeneous chromatics, it was not necessary to use targets during the scans. In fact, the variability of colors easily allowed the acquisition system to maintain stable tracking by taking advantage of texture diversity. All data acquisition and processing were performed with the proprietary applications: Scene Capture (for acquisition only) and Scene Process (for post-processing). As is well known, point cloud reconstruction is done in real-time and is based on the detection of common points used for the correlation of successive images. No reconstruction errors or gaps were recorded during acquisition but, before saving and exporting the recorded cloud, the raw data were post-processed to improve the quality of the result by filtering the point cloud so as to reduce noise as well as optimizing the scan trajectory.

(iii) Referring to the quality of the colorimetric datum of the surface texture, the collection of survey data was refined with an image-based activity conducted both for the sculptural and architectural elements mentioned in the previous point, and for the fresco cycle of the vaulted systems. Wanting to set up a control system referring to the progress of decay phenomena that, at present, affect the surface layer of the frescoed walls, as previously reported, the color data becomes a key component to be recorded. Any changes in its parameters can, in fact, be indicative of the presence of ongoing events that need attention. Employing a CanonEos1300D SLR camera set with a focal length of 18 mm, the photographic dataset related to the pulpit, stoup, tabernacle, some minor altars, and sculptural collections was collected. Adopting parallel axis shooting techniques combined with that of converging axes, shots were recorded using a telescopic pole for the taller architectural elements. As will be clarified in the next subsection, the collection of frames for the pictorial cycle at the intrados of the vaulted systems was conducted, however, at the same time as the recording of thermal images. In this way, it was possible to collect digital documentation that was already partially integrated and overlaid for subsequent interrogation and manipulation. Once again, the SLR was used with which the shots were acquired at different heights: for an initial collection of data, the camera was placed on a tripod at approximately 1.70 m above the floor level of the church, with a distance of about 11 m from the frescoes of the vault and about 15.50 m for those of the dome; the subsequent shooting was carried out with the help of a scaffold on which it was possible to take acquisitions with a height from the ground of 10.30 m and, therefore, closer to the deteriorated surfaces, with a distance of about 2.80 m from the walls (Fig. 3a). The choice of focal length was commensurate with the characteristics of the field of view of the sensors used for the subsequent capture of information on the thermal state of the surfaces. Therefore, respecting the usual overlap percentage between successive images of 60%, the following were captured: 35 photos for each fresco of the nave vault and 25 for the dome, from the height of the scaffold; 23 photos for the paintings of the vault and 14 for those decorating the dome, from the ground.

The datasets collected in the 3 operational phases described so far were integrated with each other to obtain a single 3-dimensional model, through processing in the RealityCapture application.

Specifically, the range maps of the TLS, previously aligned and registered in the proprietary software, were imported into RC in.ptx format, setting as 'Draft' the relationship between the scans to be imported so as to employ, in subsequent steps, the initial registration as a starting point to be refined. Information on the intensity of the scans was acquired at the same time as the colorimetric indications. A similar procedure was performed for the clouds from the triangulation scanner. Next, the frames captured with the passive sensor were imported.

Next, all datasets were subjected to an initial joint alignment process for automatic computation of their position and orientation in the scene. The integrated point cloud thus obtained was, then, subjected to triangulation for the generation of a polygonal

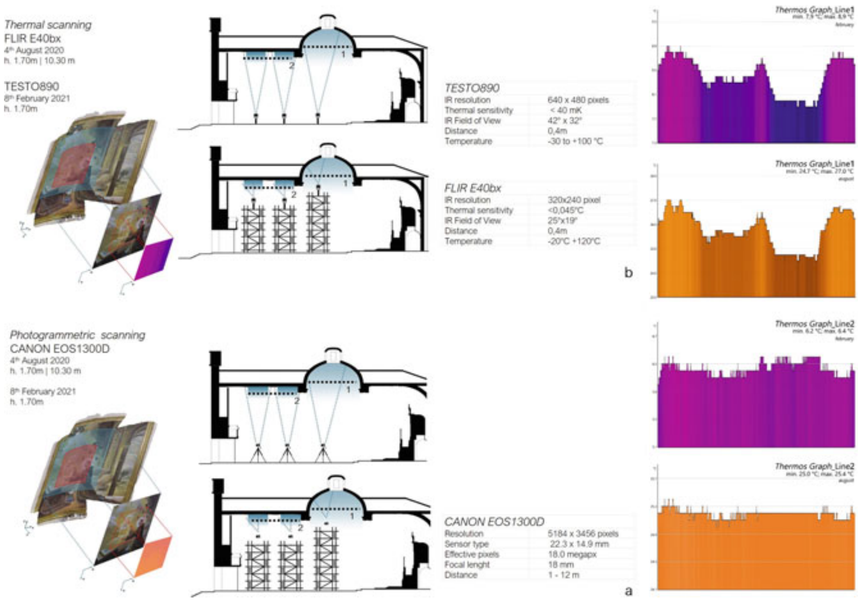

Fig. 3 Data acquisition with photogrammetric technique (**a**) and with thermal cameras (**b**). Diagrams related to the thermal state of the frescoes (**c**). *Image* V. Cera, A. Origlia

mesh model. Having defined the spatial reconstruction region by excluding some spurious points near the church windows from the calculation, the computational parameters were specified. Considering the huge amount of data collected, a slightly undersampled point cloud was chosen to be triangulated. The density of the cloud was filtered by establishing a minimum distance between two successive points of 0.002 m and requiring that points with an intensity below 0.03 be discarded because they were considered inaccurate. From the streamlined data, the polygonal surface was generated, choosing laser scans as the information to be considered for reconstruction and instructing the application to take into account in the process only those images taken covering areas not recorded with the active optical sensors. This choice was motivated by the desire to obtain a triangular mesh distinguished by as accurate and precise a geometry as possible.

Once edited, the mesh was textured by setting the texture information calculation method to 'multi-band' for the highest quality output. In order to achieve an effective representation of the visual qualities of the architecture, both images acquired from the camera embedded in the laser scanner and photos taken with the external camera were specified as input resources, with priority given to the latter for areas of greatest interest for research purposes. The downscale of the images for the coloring process was set to 2, to speed up the process, but without enabling the intuitive fill function for the parts not perfectly covered by a camera or scan so as not to alter the colorimetric data. For texturing, the maximum texture resolution was set at 16,384 × 16,384, and an image reduction before texturing of 2. At the conclusion of the whole process, the model was imported into Unreal Engine 5 software, which was chosen for the simulation of the monitoring system and integration with AI modules, as will be discussed below.

2.2 Informative Characterization of the Digital Environment: State of Conservation at Time T0

In order to simulate and subsequently validate the operation of the control system, prior to its installation in situ, the reconstructed digital environment must be characterized from an informational point of view. That is, it is necessary to collect a body of data that allows to establish the state of preservation of the investigated artifact at a time that can be defined as T0, or the initial time of observation, which will be referred to for the evaluation of the progress of decay phenomena. It is evident that in the multiplicity of factors, elements, aspects, resources that characterize an architecture (consider the technological, structural, energetic as well as historical and engineering aspects), only a few have been considered here (surface thermal state, microclimate humidity value, material, and color components) functional to the type of investigation hypothesized and related to the alteration phenomena that motivated the study. Therefore, the extension of the information base was divided into 4 actions, performed for the areas that at the beginning of the research showed the presence of pathological states (cover frescoes): (i) acquisition and analysis of infrared images using a thermal imaging camera to determine the thermal state of the deteriorated surfaces; (ii) cataloguing and mapping of materials by visual survey and manipulation of reflectance maps; (iii) cataloguing of color parameters associated with the materials; (iv) cataloguing and mapping of the degradation phenomena already in progress, characterized both qualitatively and quantitatively with the study of geometric deviation and direct investigation.

(i) The determination of the thermal state of the deteriorated surfaces was carried out from the recording of infrared images by thermal imaging camera, collected at 2 different times, summer and winter seasons. This was used to get initial information on the thermal distribution of the surface layers related to the variation of the cycle of seasons.

The first thermal survey campaign took place in summer, in August 2020. Using a FLIR MR77 hygrometer, ambient temperature, and relative humidity values of 24.3 °C and 66%, respectively, were recorded. Using a FLIR E40bx thermal imaging camera, thermograms were acquired with a resolution of 320 × 240 pixels, taking into account the tabular value of the emissivity coded for the material of the dome frescoes i.e. ochre lime plaster, average between dark and light colors, e = 0.97.

The second thermal data collection was carried out in the winter period, in February 2021, using a TESTO890 thermal imaging camera to capture images with a resolution—extended—of 1280 × 960 pixels. As anticipated in the previous subsection, for each thermal shot, a photograph was also recorded in the visible field with the reflex camera in order to have a single discrete 3D model in which for each point at the position in space results aggregated also the temperature value. To do this, thermograms were acquired at the station points and at the same elevation as described for the photogrammetric survey (Fig. 3b). Their integrated processing was carried out, as extensively discussed in [8], within the 3DF Zephyr software, taking advantage of the coincidence of the optical centers of the two sensors in the data capture phase.

Based on the analysis of the thermal imaging data, basically 2 differentiated physical conditions were noted: one related to the frescoes of the nave vault, and the other related to the paintings of the dome. The thermography of the vault paintings revealed a substantial homogeneity of the thermal state between the points affected by the plaster detachment and those still intact (homogeneous thermal distribution around 25.3 °C for the August shot and 6.3 °C for the February shot). This data suggested that although moisture infiltration had been there and had caused plaster detachment in the past, at the time of the two shoots the area was dry showing no change in temperature.

Because of the time interval between the two acquisitions and the unchanged qualitative situation of the thermal behavior, the degradation phenomenon could therefore be considered arrested, at the current situation.

Opposite was the thermal condition of the dome frescoes: in both summer and winter periods, the thermographic analysis made clear the presence of cold areas, with a temperature 1° or 2° lower, depending on the season considered, than the surrounding areas. In this case, the insistence of a pathological condition of high humidity emerged in 4 segments descending toward the drum starting from the lantern.

In August, the coldest areas recorded a temperature of 24.7 °C, despite the surrounding temperature distribution attested to 27.0 °C. In winter, the temperatures recorded for the areas mentioned earlier were 7.9 °C and 8.9 °C, respectively (Fig. 3c).

Such thermally characterized areas, cross-referenced with images in the visible range, appeared to overlap with the visually damaged portions. What is more, a further significant fact is that these 4 cooler portions were, at the time of analysis, found to be much more extensive than the diseased areas. Therefore, thanks to the data from the thermal imaging camera, the presence of moisture was highlighted that was not visible on the surface and, therefore, to be monitored to obviate the manifestation of further deterioration phenomena involving plaster detachments in larger areas. For that matter, the persistence of this thermal behavior in the two different recordings in different seasons of the year showed the persistence of the conditions triggering the manifestations of degradation.

(ii) The cataloguing and mapping of the main materials that constitute the facies of the studied artifact followed the indications contained in the Italian standard UNI 3972:1981 for the graphic representation of architectural materials. Through direct

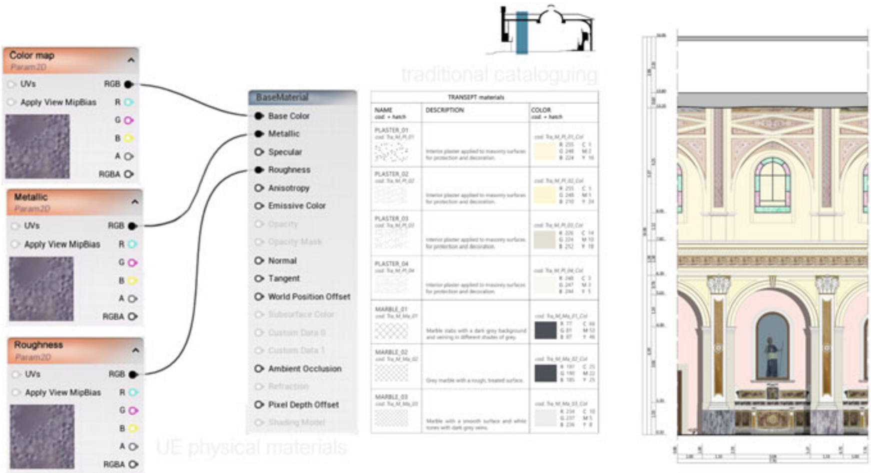

Fig. 4 Example of the scheduling and mapping of materials and colors and their use in Unreal Engine 5. *Image* V. Cera, A. Origlia

observation and comparison with historical archival sources, the materials were catalogued in traditional type paper sheets that, at the same time, were used for the definition of the specific Physical Materials parameters applied to the model in UE5 (Fig. 4).

These were mostly polychrome marbles, stucco, plasters with different finishes, walnut wood for some prominent elements such as the inlaid choir, and glass in various colors.

In order to accomplish the most accurate material scheduling possible at this stage of the research, the reflectance maps recorded with the TLS were also manipulated, so as to extract additional descriptors useful for the material composition of the artifact. It should be noted that this type of activity was possible where the TLS stations were planned taking into account from the beginning the variables most influential on the reflectance data.

Keeping the focus on the painted representations of coverage, the related hue intensity images were examined by evaluating the changes in reflectance in relation to the wavelength of the emitted pulse type. As argued in [9], by varying the percentage range of the observation from a full 1–100 range to smaller, detailed ranges with 5–10 percentage point shots, the following resources were extracted:—for the dome, the recorded reflectance variations, ranging from 30–35% to 62–75%, were completely consistent with the behavior of the lime plaster with chromatics of blue (30%), natural (60%), yellow ochre (70%), and red ochre (65%);—for the vault frescoes, similar reflections were made in relation to the reflectance values with a variation between 33 and 60% (Fig. 5).

(iii) As indirectly emerged from the description of the manipulation of reflectance maps, the cataloged materials were also associated with a sampling of their respective colors. The color survey, at this cognitive stage, was carried out by the computer

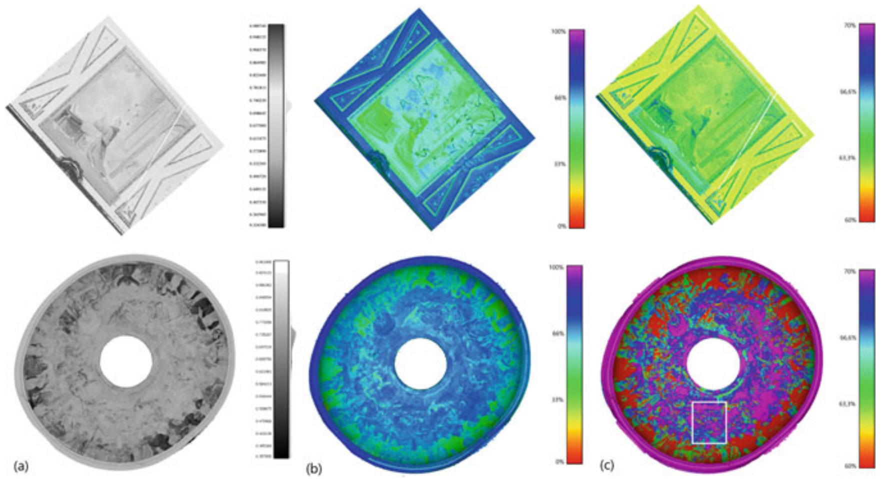

Fig. 5 Manipulation of the reflectance maps obtained with the TLS survey (**a**, **b**). By varying the range of the percentage value **c**. *Image* V. Cera, A. Origlia

method, employing a recognition system based on the comparison of images in the visible range with a computerized color catalog. The sampling covered both the general materials of the architecture examined as a whole and the colors proper to the frescoes. Hence, by way of example, we report a great chromatic variety of the marbles used in a variety of shades, from red to ochre, blue to black. Each color was expressed in both the additive RGB and subtractive CMY color models (Fig. 4).

(iv) By cross-referencing, finally, the materials cataloguing, the results of reflectance mapping, and the study of thermal states, it was possible to set up a map of the phenomena of alteration and degradation that punctually affect the investigated pictorial layers. Using the normative indications of UNI11182:2006 as a reference for cataloguing, the perceived phenomena were traced back to: the lacuna (subtractive phenomenon of material) for the vault, affected only by the loss of surface coloration; and the efflorescence (additive phenomenon of material) for the dome, affected by the manifestation of overlapping patinas. For each of them, an initial quantitative estimate of the surface extent of the affected areas was provided, to get an idea of the relevance and scale of the ongoing phenomena. Regarding, on the other hand, the quantification of the volume of material lost or deposited, an attempt was made to obtain values by exploiting some mathematical algorithms, such as RANSAC in Cloud Compare, and by computing the maximum displacement, positive and negative, of the 3D model with respect to primitive geometric solids. However, it was not possible to arrive at a noteworthy result where portions with millesimal thickness variations are involved.

Hence, at this stage, we stopped at calculating only the surface extent of damage.

2.3 Semantic Annotation of the Digital Environment for a Hierarchy of Phenomena to be Monitored

All the resources collected so far have been associated with the model constituting the digital setting of the research experiment using a semantic labeling approach. Specifically, the model was segmented into semantically relevant macro- and micro-elements by employing an annotation system using 2D maps related to 3D space, already codified in [10]. For the identification of concepts in the domain of interest, we referred to the Art and Architecture Thesaurus, implemented in the semantic tree with historical treatises and specific manuals on sacred architecture. The architecture was then segmented through the annotation maps with respect to both its components considered in the horizontal development of the architectural space and in the vertical one. The following were then identified: facade, hall, triumphal arch, transept, triumphal arch, chancel, apse (horizontal decomposition); I order, II order, roof (vertical decomposition). Proceeding from the most general to the most detailed components, the most significant elements of the artifact were progressively annotated, taking advantage of the potential offered by the thesaurus in terms of inference between concepts (Fig. 6).

Finally, the macro- and micro-elements were hierarchized, again through the use of semantic maps, according to the state of degradation found. In this way, it is possible to have an initial indication of the most sensitive areas and therefore to be monitored with greater attention and priority interest.

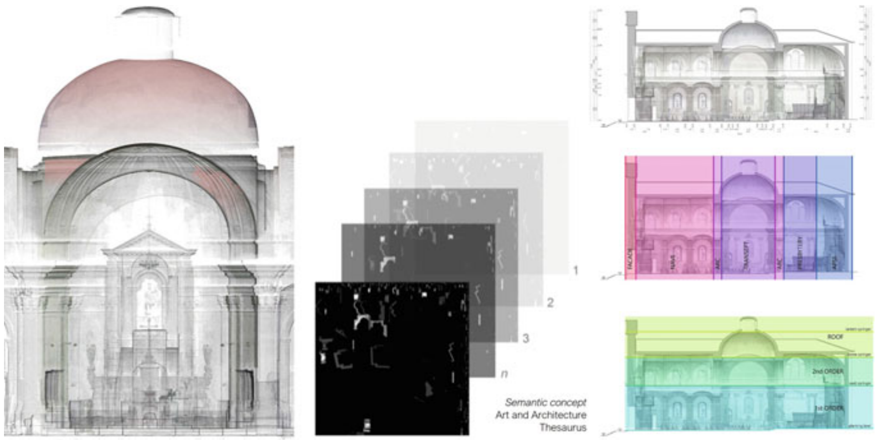

Fig. 6 Example of the semantic annotation using maps. *Image* V. Cera, A. Origlia

3 Design and Simulation of the Integrated Monitoring System with AI

The Unreal Engine 5 has introduced, with respect to its previous version, a number of improvements that further push its applications in the architecture field. First of all, the introduction of the Nanite engine for geometry virtualization allows the use of extremely detailed meshes without the need of introducing approximations through the use of Normal Maps or Ambient Occlusion. Also, the introduction of the Lumen Global Illumination system makes the technology for photorealistic rendering in real time accessible in many different situations. This is ideal for the field of architectural survey, where the output of photogrammetric and/or laser scanning procedures produces 3D models characterized by a high degree of polygons. In this work, we take advantage of these new technologies to generate a stream of video data from the engine and inform a monitoring system during its development phase. This has the advantage of avoiding time consuming and costly tests on-site and allows testing the basic technology in the lab using realistic data. An example of the rendered architecture in Unreal is shown in Fig. 7.

First of all, the Unreal Engine supports complex simulations of a wide range of camera lenses for image rendering, so that the behavior of RBG monitoring sensors can be approximated this way. Figure 8 shows a Cinematic Camera placed in the 3D environment to simulate a monitoring sensor pointed towards a fresco together with a selection of the parameters allowing to change the effect of lenses, ISO, aperture, etc.…

Fig. 7 A view of the imported 3D model of the considered case. No decimation approach was used but the rendering speed keeps running at 60 FPS using Nanite virtualized geometry. *Image* V. Cera, A. Origlia

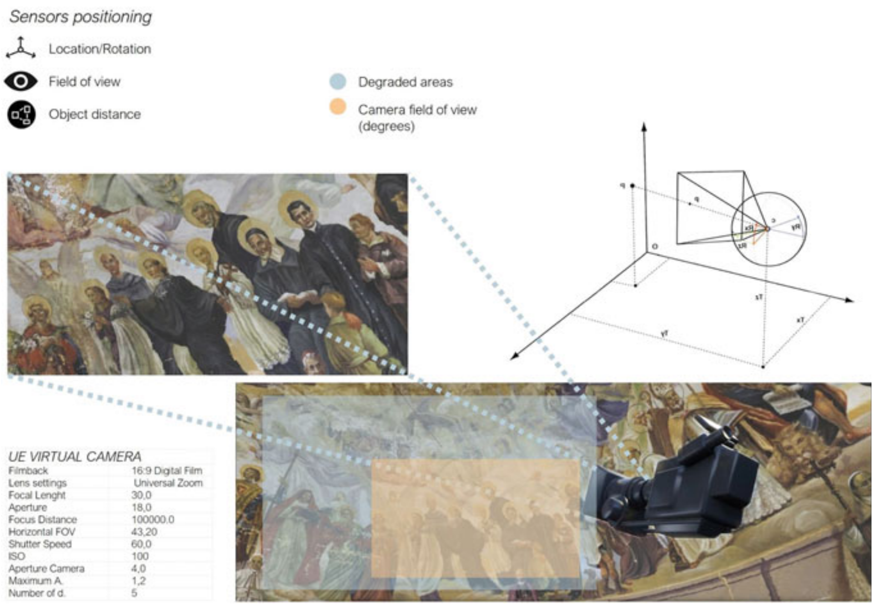

Fig. 8 A Cinematic Camera in the Unreal Engine 5. *Image* V. Cera, A. Origlia

The Unreal Engine 5 has also consolidated the production-ready version of the Pixel Streaming technology, which allows remote clients (e.g., browsers) to connect to a server running the Unreal Engine application and receive a rendered stream of frames. While this technology also supports interaction between the remote user and the application, in this case we will focus on Unreal acting as an environmental simulator for remote Artificial Intelligence systems for architectural monitoring. The architecture of a Pixel Streaming application is shown in Fig. 9.

The 3D environment equipped with simulated camera sensors can be used to stream images containing simulated damage localized on different areas of the model.

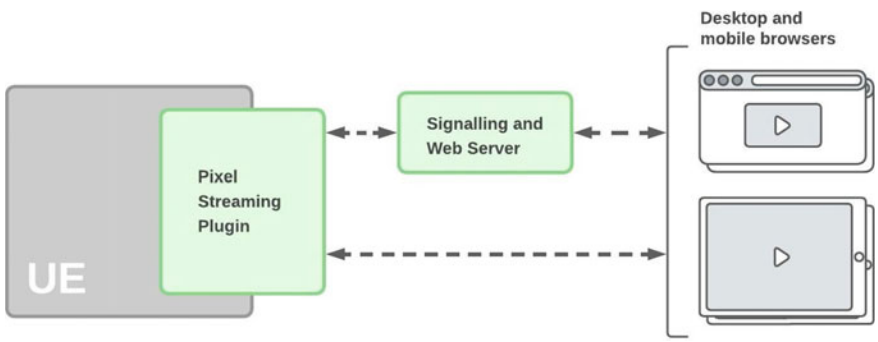

Fig. 9 The pixel streaming architecture provided by the unreal engine. *Image* V. Cera, A. Origlia

This is achieved, in this work, using Decals, which are designed to project patterns over textured surfaces to add details and dynamic changes guided by the application state. We consider a library of Decals containing a wide variety of damage patterns and we focus on the stains subset, consisting of 62 stain patterns including, for example, paint, moss, and grunges, of which some examples are shown in Figs. 10 and 11.

A dedicated shader has, then, be used to control the amount of damage projected by each Decal actor in terms of strength (transparency) and extension. To simulate stain extensions, the corresponding parameter is linked to a Gaussian mask filtering the projection over the scanned texture. The control panel of the Decal material is shown in Fig. 12a while the effect of a Decal projecting a damage pattern over a scanned surface is shown in Fig. 12b. Different levels of damage extension, controlled with the corresponding slider, are shown in Fig. 13.

Data generated using Pixel Streaming from the Unreal simulation can be used to train and test machine learning algorithms aimed at performing anomaly detection

Fig. 10 Grunge maps for stain patterns used in decals (normals included). *Image* V. Cera, A. Origlia

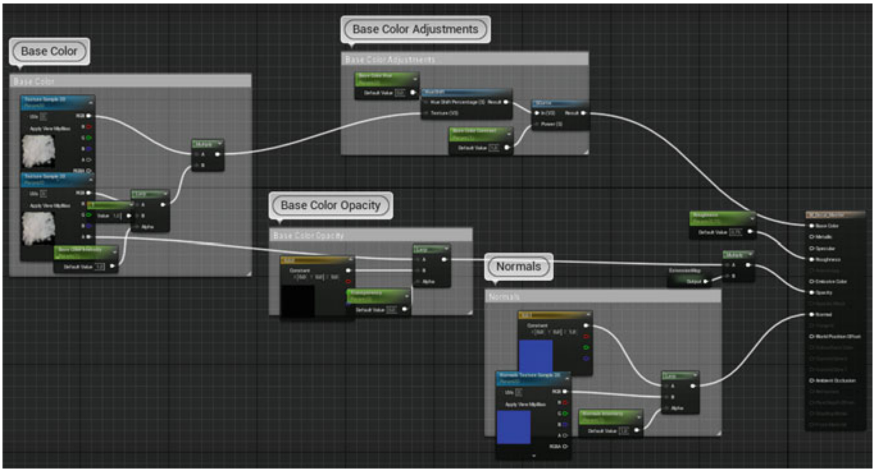

Fig. 11 The master material blueprint controlling the parameterized decals. *Image* V. Cera, A. Origlia

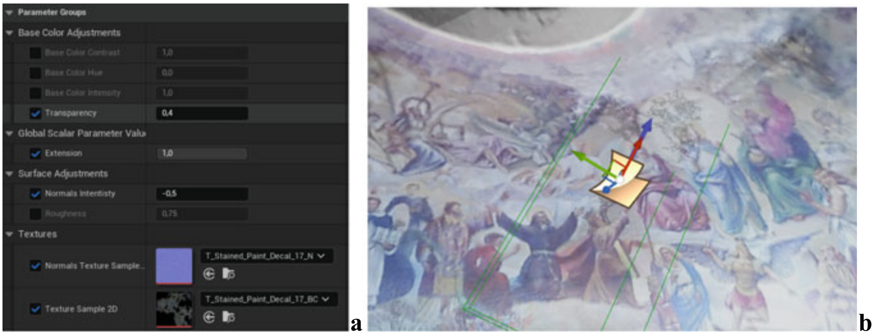

Fig. 12 The configuration panel of the Decal simulating stains. In particular, the Transparency and the Extension sliders allow to control the amount and the extension of the projected stain (**a**). A damage Decal projecting a stain pattern over the 3D model (**b**). *Image* V. Cera, A. Origlia

Fig. 13 Two levels of stain extension controlling the damage Decal. A Gaussian mask is used to approximate a radial extension of the damage. *Image* V. Cera, A. Origlia

or damage recognition. This effectively implements a simulation in which a remote data processing server using machine learning provides information to a monitoring system designed to cross-reference the position of detected anomalies with the information provided by the semantic maps. Specifically, once an anomaly is detected, a difference operation between reference images of the normal situation and the anomalous image localizes the problem with respect to the 3D model. The proposed strategy represents, in general, a methodological proposal to build synthetic datasets to train machine learning algorithms in the damage recognition task. Since real data representing different kinds of damage and containing pre and post-incident representations of architectural artifacts are not easily collectable and/or accessible, this proposal represents a way to rapidly build damage simulations over existing 3D datasets.

Depending on the extent of the damage and on its position, for example, with respect to works of art or structurally relevant areas, a Real Time Interactive 3D (RTI3D) application can be driven to generate an error message in natural language and report the position of the damage. To implement this kind of application, also including data coming from external sources, typically organized in a graph database, the Framework for Advanced Natural Tools and Applications with Social Interactive Agents (FANTASIA) [11, 12] is used. FANTASIA is an open-source plugin for the Unreal Engine developed to support the creation of Embodied Conversational Agents (ECAs) and, in general, RTI3D applications. FANTASIA aims at supporting the academic community, mainly, in conducting Human–Machine Interaction studies but can also be used for more industrially oriented applications (e.g., automatic kiosks, Virtual Assistants, etc.…). The framework consists of a series of components that, currently, allow Unreal to access (a) the Azure Automatic Speech Recognition service, (b) The Azure Natural Language Understanding Service, (c) The Azure Text-To-Speech service, (d) The Amazon Text-To-Speech service, (e) The Neo4j Graph Database, (f) The AGRuM library for Bayesian Networks. The FANTASIA architecture is shown in Fig. 14.

Being centered around the Unreal Engine, FANTASIA can be directly connected to the outcome of remote analysis processes performed using machine learning techniques to guide the behavior of artificial conversational agents in Unreal. These can either be embodied or not and can make use of Natural Language Processing techniques made available by the connection with services provided, for example, by Amazon and Microsoft. The interaction control systems FANTASIA allows to implement are based on a combination of Behaviour Trees, for task prioritization, Bayesian Networks, for decision making, and Graph queries, for deductive reasoning.

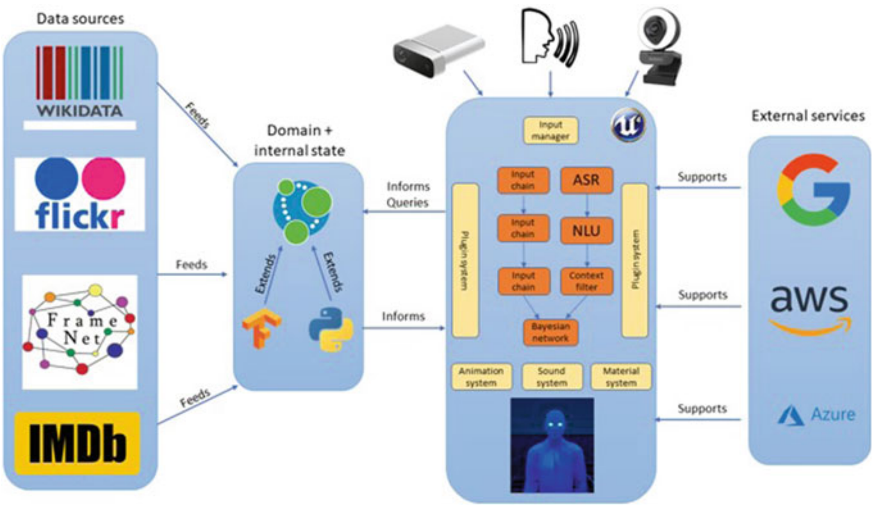

Fig. 14 The FANTASIA architecture. *Image* V. Cera, A. Origlia

4 Conclusions

We have presented a simulation environment for the design and test of monitoring applications leveraging on the novel technologies brought in by the Unreal Engine 5, on our methodology for semantic data annotation and on a framework for the development of interactive applications powered by Artificial Intelligence. We have shown how we imported a large set of data in the engine without the need of decimation procedures and how we simulated damage over the scanned geometry to be captured by virtual cameras configured in such a way as to simulated real lenses. The video stream produced inside the engine can be sent to remote processing applications to perform anomaly detection and, in general, machine learning tasks that inform interactive applications developed using FANTASIA, a module designed to support the development of RTI3D applications integrating AI for Natural Language Processing.

With this infrastructure in place, future work will consist of simulating different kinds of damage and their evolution. Also, using the Unreal Engine photorealistic rendering capabilities, we will explore the possibility to generate synthetic datasets to train monitoring approaches based on machine learning and, in general, on AI.

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Preliminary Study on Architectural Skin Design Method Driven by Neural Style Transfer

Lu Xu, Guiye Lin, and Andrea Giordano

1 Introduction

The development of the times and the advancement of technology have given architectural design the ability to carry more environmental information content. The development of digital technology has opened up perspectives and methods of viewing the physical and social structure of the world, helping people to reconstruct a way of recognition that goes further than individual perception [1]. Architectural design will no longer be based solely on qualitative criteria, but will increasingly turn to scientific methods to establish and interpret the quantitative impact of morphological design on the functional requirements of buildings, and thus promote the quantitative integration of design thinking with the objective physical environment [2]. With this trend, computational design methods have emerged. How to effectively integrate computational design theory into engineering design practice and develop it into a design tool with high confidence and feasibility is a common issue in the field of architecture today.

The rhythm of the skin of a building in different materials or arrangements conveys different images of the building in the city. The knowledge and understanding of the skin of a building have also taken on different meanings in different contexts at different times, and the functions carried by the skin have been constantly changing. In the past, the building skin has always existed as a structural, functional or spatial

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appendage, performing a protective function and suggesting the functional, structural and technical composition of each historical period. With the development of technology and new materials, the architectural skin has gradually separated from the traditional load-bearing structure and become an independent building construction system, becoming more free and versatile in its functional and formal expression, and participating in architectural design in a more active way [3]. The skin of a building is the most intuitive way for people to know the building, and it allows the building to convey spiritual meaning of the building through its material elements such as materials, colors, and forms, as well as the construction of the abstract elements implied by the interface as a whole [4]. With the advent of the information age, society as a whole has undergone profound changes, and the connotations carried by the building skin have gradually become more complex and diverse, and people pay more attention to the building skin than ever before, and some buildings have increasingly strong demands for the expression of historical culture, local traditions, technical features, and individual styles. The design of the building skin began to adapt to the uncertainty, complexity, and uniqueness of architectural design, and to pay more attention to the expression of the skin at the spiritual level on the basis of satisfaction of the functional needs of users [5].

In recent years as the architectural works of some architects such as Herzog, de Meuron, Peter Zumthor and Koolhaas have taken the world by popular fame. Eventually, the publication of David Leatherbarrow's *Surface Architecture* brought the idea of architectural skin and its positioning in the overall architectural design to unprecedented attention. In fact, the concept of architectural skin has existed in various forms since the birth of architecture. The concept of parametric design emerged in the middle of the last century, while its appearance in the field of architectural design was probably after 1960 [6]. Traditional architectural design ideas have been greatly impacted by the emergence of parametric design. The emergence of parametric design has overturned the existing architectural forms and expanded new ones [7]. The morphological changes in the field of contemporary architecture gradually evolved into a general pursuit of dynamic continuous nonlinear forms supported by digital technology.

Nowadays, many architects pursue irregular curves as a way of creation, and many bionic architectures, non-linear architecture, and biomorphic architectural forms gradually appear in people's view. With the continuous progress of computer technology, more and more design software has been written, including many involving parametric design, and it is with the wind of the development of this parametric software that parametric design has come into rapid development [8]. These groundbreaking methods have overturned existing architectural forms and opened up new areas of architectural form. The design of the building skin is a very important part of the overall architectural concept design, and cannot be ignored in any way for the overall effect of the plan [9]. With the application of parametric design in building skin design, the forms of building skins are becoming more and more diversified and complex. If each building skin design plan needs to be modeled before the architect can evaluate it, a lot of time will be spent on building the model. In order to improve efficiency, artificial intelligence algorithms can be used to generate different building skin forms and filter them before building the model [10].

Style transfer is a computer vision technique that converts the style of one image to the style of another image without changing the content of the image. It can be used to create artwork, to change the appearance of an image, or to convert the style of one image to another style for a different effect [11]. Due to the rapid development of artificial neural networks, Gatys et al. made a great research contribution to image style transfer and innovatively used a neural network-based method for image style transfer [12]. It is also shown that the neural network can extract the basic content information and style feature information of the image well, and use this neural network to process the higher level feature information of the image independently, which can perform image style transfer efficiently and thus achieve better artistic results [13]. This algorithm fills some problems of the previous algorithm, it is more effective in extracting style features, reduces the distortion of image content after style transformation, and also improves the transformation of edge detail content and reduces the loss of detail content. Subsequent scholars have worked on improving the neural style transfer algorithm to improve its computational efficiency or propose some improved algorithms for converting the artistic styles of images [14]. Figure 1 shows the image representations of Gatys et al.'s convolutional neural network [15].

Neural networks are a class of algorithms from the field of machine learning, which are inspired by research on artificial neural networks [16]. The core idea of the algorithm is to extract higher-level feature information from the raw data information

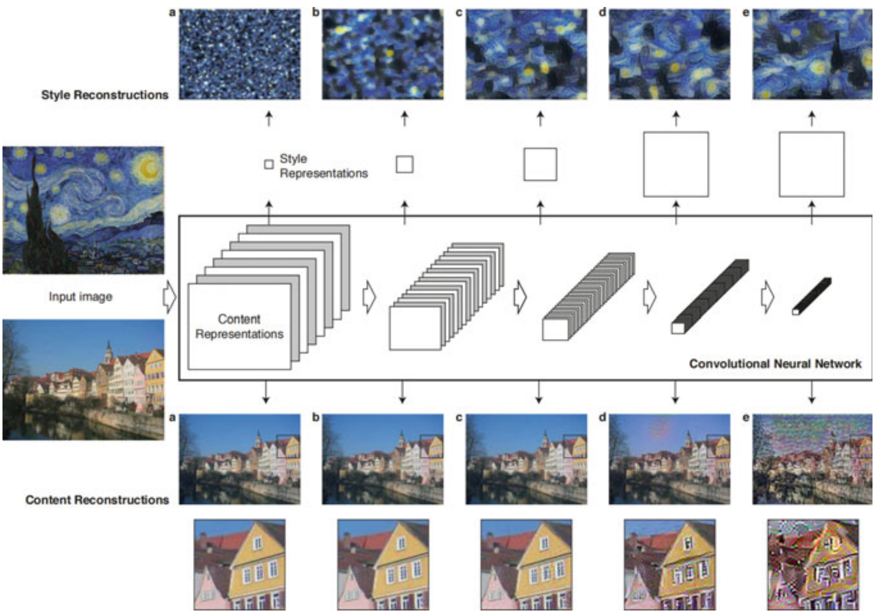

Fig. 1 Image representations in a convolutional neural network. [15] *Source* Gatys et al.

input [17]. For example, in intelligent computer image processing, lower-level feature information can recognize concepts such as the edges of an image, while higher-level feature information can recognize human-related concepts such as numbers, letters, or faces [18]. Traditional image style transfer techniques tend to treat style transfer as a generalized problem and task, i.e., by synthesizing the texture features of an image. Specifically, the texture features in a style image are obtained and transferred to the content image [19]. With this approach to reconstructing design styles, it uses a pre-trained image model that can stylize the input design data and thus generate new design solutions. It is also an AI-assisted algorithm that designers can conveniently use to support their search for inspiration [20].

2 Methodology

There are four types of style migration based on neural networks. Gatys et al. pioneered the neural network-based style transfer method. This approach uses VGG networks to extract texture features of style images and structural features of content images [12]. To solve the time-consuming problem, researchers want to build reusable models to achieve real-time style transfer, resulting in three types of methods, which are Per-Style-Per-Model Fast Neural Method, Multiple-Style-Per-Model Fast Neural Method, and Arbitrary-Style-Per-Model Fast Neural Method [21]. Johnson first proposed a style transfer model using perceptual loss instead of Gatys' style loss style transfer network model [22]. The implementation of this method is simple, which is to obtain a forward feedback migration network single style by pre-training. Using this pre-trained model, the input content image can be converted to that style in real-time. Based on the idea of the Per-Style-Per-Model, there are various methods to achieve further optimization of the visual quality of style transfer, such as texture synthesis and stylization in the feed-forward network and style transfer for multiple stroke patterns using the self-attention mechanism [23].

Since the Per-Style-Per-Model uses a large number of variables, it is not appropriate to continue training other styles on this model to achieve multiple styles in Per-Style. In addition, the Per-Style-Per-Model is updated for the parameters itself, and it does not adjust accordingly for multiple style training. Dumoulin's based on the Per-Style-Per-Model approach finds that scaling and shifting parameters can achieve similar transfer effects, which saves a large number of model parameters and reduces the risk of over-fitting the model to a single style, allowing the model to be applied after training to multiple styles with similar texture styles after training [24].

After this algorithm, researchers have proposed a series of approaches, and a more typical and effective arbitrary style model is the Adaptive Instance Normalization. This model combines some previous approaches, such as style swapping, and uses a large number of styles and content graphs to train the model, which eventually achieves real-time generation of stylized images of arbitrary styles, and performs well in most styles [25]. However, the multi-style model is constrained by the number of styles contained in the training set, and cannot deal well with styles that are not in the training samples, and this model also cannot recognize more complex style texture patterns well, and can only do a certain degree of style transfer [26].

In general, Gatys' method generates stylized images with optimal results, but the time-consuming problem makes it inconvenient to operate in some real-time application scenarios, and this method is also mainly used in this work. The proposed three Offline Model Optimisation processes could satisfy the demand of real-time applications to a certain extent, and greatly improve the speed of style transfer [27]. Although the visual quality of transfer results is slightly inferior, its speed advantage and flexibility make it have a wider application and research prospect.

3 Application of Neural Style Transfer in Architectural Skin Design

The approach of neural style transfer in architectural skin design is to convert one style into another style by using deep learning techniques. The purpose is to improve the diversity of architectural skin design, to make it more artistic and aesthetic. And this method helps architects to deeply the design in the following. It uses deep learning technology to simulate the appearance and structure of the architectural skin to achieve a more flexible and diverse design [7]. The application of style migration in architectural design can help architects draw inspiration from one style and transform it into another. For example, architects can incorporate elements of modernism into classical architecture to create a new architectural style. Mixing different architectural elements from past architectural styles in architectural design to form a new style with some uniqueness within the existing architectural style.

In addition, style transfer can help architects better understand and grasp the architectural features of different styles to better realize the design concept. Before proceeding with neural style transfer, typical architectural features, such as curved, arch or columnar structures, stonework or details, and decorations, need to be analyzed. Record the building materials and analyze the color and cultural background of the style [28]. After identifying the elements you want to integrate then think about what modern materials to use, such as metal, concrete, glass or plastic; which new cultural elements to integrate, such as contemporary lifestyles or artistic concepts. Finally, the style transfer is realized, using the materials and details of the style as a basis to combine with another element to produce a new skin design style [29]. The architect then develops a new architectural design based on the skin, taking into account the actual environment.

This work combines the approach of Gatys et al. Figure 2 shows the workflow diagram. Gatys' Neural Style method is the base algorithm for image style transfer. The method uses the feature space of 16 convolutional layers and 5 pooling layers of a 19-layer VGG convolutional network [30]. To generate a highly effective style transfer image, the method defines two loss functions: content loss, which requires the output image to be extremely similar to the input content image in terms of content

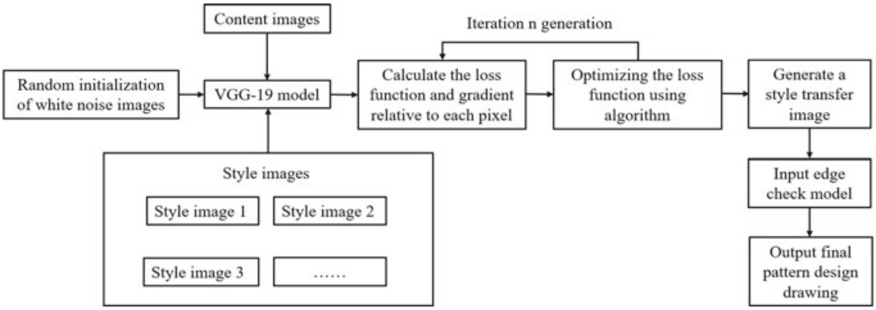

Fig. 2 Scheme of style transfer images based on CNN. *Editing* Lu Xu, Guiye Lin, Andrea Giordano

details; and style loss, which requires the output image to be extremely similar to the style image in terms of style [31]. Calculate the loss between the output image, content image and style image, I is the input content image, S is the style image and O is the output image. Then the content loss function is:

$$L_{\text{content}}^{k} = \frac{1}{2P_k B_k} \sum_{ij} (F_k[O] - F_k[I])_{ij}^{2} \tag{1}$$

where L is the total number of convolutional layers, k denotes the k-layer convolutional layer of the deep convolutional neural network. and $F_k[O]$ and $F_k[I]$ are their corresponding feature representations in the layers. In each layer, there are P_k filters and each filter has a vectorized feature mapping of dimension B_k. The method uses the Gram matrix to represent the stylistic features of the image [32]. Where is the inner product between the vectorized feature mappings in the first layer:

$$G_{ij}^{k} = \sum_{m} F_{im}^{k} F_{jm}^{k} \tag{2}$$

And the style loss function is:

$$L_{\text{style}}^{k} = \frac{1}{2I_k^2} \sum_{ij} (G_k[O] - G_k[S])_{ij}^{2} \tag{3}$$

The final minimized total loss function is obtained as:

$$L_{\text{total}} = \sum_{k=1}^{L} \alpha_k L_{\text{content}}^{k} + W \sum_{k=1}^{L} \beta_k L_{\text{style}}^{k} \tag{4}$$

where α_k and β_k are the weighting factors for content and style reconstruction, and W is the weight to balance the two weights of content and style.

The image style transfer algorithm in this paper first introduces semantic segmentation and Matting algorithm to segment the content and style images, then uses pre-trained VGG-19 convolutional neural network for feature mining, and finally generates images [33]. Python 3.7.1 is used in combination with the pytorch deep learning framework, and the computing platform is an 8-core i7 processor with GPU acceleration using a GTX1060 graphics card. The method in this paper uses pre-trained VGG-19 as a feature extractor [34]. Five groups of buildings are selected as content maps in this work, which are Chinese ancient architecture, modernist architecture, modernist architecture in Shan-shui City style, modern residential, and Shanghai city skyline. Five more groups of buildings were selected as style maps, which are Notre Dame de Paris, Chinese landscape painting, House of bones, traditional European building, and science fiction movie still. In the processing procedure of style migration for the five groups of photos, when the number of iterations increases, the stylized degree of migrated images also deepens, when the number of iterations is greater than 50, the edge contours will gradually distort and color blocks will appear in some areas of the buildings; when the number of iterations is 20–40, the visual effect and the evaluation index do not differ much. From the perspective of saving computational resources and time, 20 iterations were finally chosen for this study [35].

4 Results and Discussion

As can be seen from Fig. 3, this paper has performed effective style transfer for the images, and a total of five models were trained in this paper, all of which were effective in transferring the styles of the images. After designing different architectural skins by using neural style transfer, the obtained images have significant changes in style. In the first group of traditional Chinese building, the images obtained through the style transfer of Notre Dame de Paris show a different style, and the stone element makes the ancient Chinese building of wood material reflect another context. For the architects if only the material changes may not be enough to achieve the design intent, if by adding elements such as arch roll and rose windows may be more stylistic transfer. So this approach can provide a reference and imagination for the architects when doing the skin design. The images obtained through the stylistic transfer of Chinese landscape painting in the second group of modernist buildings have a more obvious oriental character. If the architects want to obtain a new Chinese style, then this method can better provide them with a more efficient conceptual choice. The third group is the work of architect Ma Yansong with the Shan-shui City style, which has a more complex architectural skin after the style migration of the House of bones, so not all buildings are suitable for Gaudi's architectural style. Through such style transfer, the architect can quickly identify what style and skin the building is suitable for, and save a lot of modeling time. For example, the third group of style migration provides the architect with a clear choice of whether to integrate the two styles. The fourth group is a modern residence with European style after style migration through European architecture, which provides a quicker communication platform for developers and architects. The residential style with obvious characteristics can be screened quickly. The fifth group is Shanghai city skyline formed by the style migration of science fiction photos with science fiction characteristics of the city. Although this is unrealistic for urban design, it is very experimental and provides a possibility of theme design for urban design, not necessarily science fiction style, and can be used to provide more choices for planners and architects [36].

These five groups of images are not enough in terms of design depth and cannot be directly used as the result of architects. The main role is to inspire architects to thinking about how to design architectural skins from different views in different aspects of dimensions. The application of artificial intelligence in architectural design is not only style transfer, but also generative design, urban model prediction and spatial layout [13]. These aspects all interact with each other, for example, style transfer can intervene in the form of the skin of the building model in generative design, which allows the architect to adjust the design scheme at any time. This work

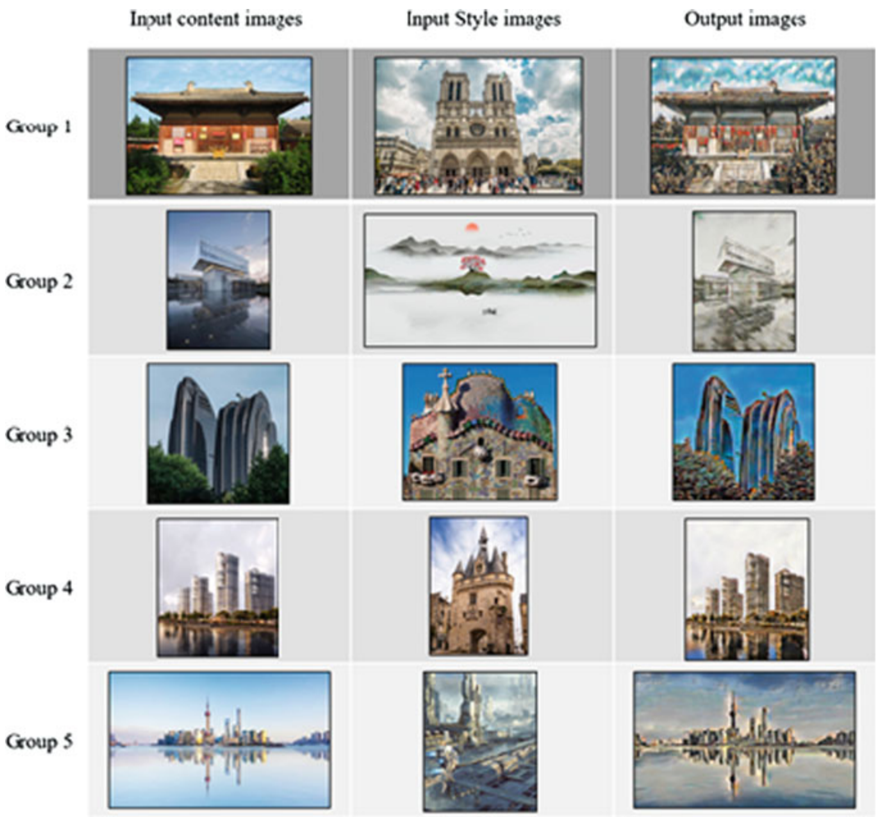

Fig. 3 Comparison diagram of five groups of style transfer images. *Editing* L. Xu, G. Lin and A. Giordano

does not go far enough in the computer algorithm to simply style transfer the content map and style map, providing the knowledge of whether style transfer can be used to assist in the design of the skin. The important thing is to provide a design idea, especially to provide some inspiration for the conceptual design phase of architecture. Under the influence of AI technology, it is believed that designers will reach a higher level of design intelligence and design thinking, be more decisive and creative, and become better organizers, decision makers, and creators of architectural projects [14]. The overall level of architectural design will continue to improve, thus simplifying the original complex architectural design or exploring a new architectural model to suit different kinds of buildings [37].

5 Conclusion

The practical work demands in architectural design and the development of intelligent technologies have together led to a revolutionary transformation in design methods. The integration of computational thinking into the creation of architectural solutions is an important way to address the complexity of contemporary architectural engineering design problems. In this work, five groups of buildings with different styles are matched, and images with different levels of different effects are obtained through style transfer. A preliminary discussion on the inevitability and degree of implementation of computational thinking into architectural skin design from a practical perspective is developed. Some are more in line with the creative needs of architects, while others can quickly negative the results of a certain style migration. Regardless of the conclusion, neural style transfer has influenced architects to a certain point. This type of thinking is highly efficient and scientific, and can be an ideal tool for meeting the needs of architectural design intentions, providing a scientifically robust design strategy for program implementation.

However, as an effective design tool, computational design such as neural style transfer needs to be expanded in terms of its methodological connotation and process construction to meet the needs of more diverse architectural concepts in the future. For example: combining the platforms of ChatGPT and Midjourney to assist architectural design; comparing the effects of different algorithms on skin design and architectural generative design to select an efficient method; enriching the applicable design aspects of computational thinking to expand its application scope; enhancing the interconnection between design modules to form a more complete computational design flow and improve the workflow systematization It also establishes the mechanisms of multi-criteria decision analysis and computational design result determination to enhance the rationality of designer's evaluation, etc. It is reasonable to believe that along with the continuous iteration of design practice and application research, computational design will bring more innovative design ideas for architects and provide more scientific and efficient technical support to achieve future design needs.

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Artificial Intelligence and Virtual Reality in the Simulation of Human Behavior During Evacuations

Giorgio Buratti and Michela Rossi

1 Introduction

A widespread belief assumes that reality coincides with tangible, material objects. Since Plato's cave myth, the issue has been debated in philosophical and scientific circles, often leading to reductive theories that relegate virtual entities to non-existent. Instead, the etymon of the term virtual, from the Latin *virtus*, with the meaning of force but also capacity or faculty, leads back to the concept of possibility, that is, of unexpressed potential far from opposing the real, representing a diverse mode of existing [1]. Such a meaning nowadays seems more suited to the interpretation of those phenomena related to the technological and social evolution that is leading to the advent of the Metaverse, an advancement of the Internet that transcends the concepts of hypertextual and multimedia using simulated three-dimensional environments in which the fruition of meanings and interaction with objects and other users is mediated by virtual, augmented or mixed reality technologies.

Of all media, drawing is the one that has stood out most as a mediator between the potential level and the physical world, helping humans materialize their ideas or reproduce, dematerializing what exists in the real world. The digitization of the process has over the years redefined the question of the greater or lesser verisimilitude of a representation by arriving at the modelling of parallel virtual worlds, which not only constantly interact with and orient material reality, but are capable of such precise simulations that they become predictive. Simulation, from *simĭlis* (similar, make like), introduces the temporal dimension into the representation, thus

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foreshadowing the dynamic evolution of a system or process from given initial conditions. Whether it is a virtual space of the Metaverse based on VR/AR technology or an application dedicated to a specific context, simulations require processing an abnormal amount of heterogeneous data to function effectively. Thus, various forms of AI capable of detecting, classifying and describing the data needed to make the comportment of entities and objects in virtual spaces verisimilar have evolved in parallel with the constitution of digital worlds. Video game development was the first field of managing such an articulated process through dedicated work platforms known as game engines, software capable of integrating heterogeneous data and optimizing the workflow. Originating in the creation of video games, these tools are also finding wide use in research and/or design, fields united by the need to visualize phenomena in real time with the support of robust computational simulation processes.

2 AI and Videogames

Traditionally, the relationship between artificial intelligence and video games has always been very close and used to make plausible elements that must respond to the rules of a particular digital context. At the dawn of the computer science discipline, Turing himself theorized for his celebrated test a game aimed at establishing the intelligence of an artificial application. The development of AIs capable of interacting by play with human beings dates back to the early 1970s, with programs capable of interpreting the rules of checkers, chess or go. In 1996, news of IBM's challenge to then-world chess champion Garry Kasparov to confront the AI created for the occasion, Deep Blue, was widely circulated. Deep Blue was the first computer to win a chess match against a reigning World Champion, Garry Kasparov, with a tournament time cadence. Deep Blue's strength came mainly from its extraordinary computational power, capable of calculating 200 million positions per second. Its evaluation functions were initially written in a general form, with many parameters to be defined (e.g., how important a safe position for the king is compared to a spatial advantage in the center of the chessboard, etc.). The system then determined the optimal values for these parameters by analyzing thousands of sample games. Today, high-level AIs based on neural networks in a few hours learning to play chess at grandmaster levels, although made for entirely different purposes. These experiments, based more on computer computing power than anything else, laid the groundwork for Automated Game Understanding, a field of study that applies AI tools to video games, developing systems that can perform specific actions without them being preprogrammed. Creatures, realized by Grand S. in 1997, a video game that turned out to be a commercial success, is an excellent example of the potential of an intelligent virtual environment. In Creatures, the player hides small, furry creatures called Norns in the virtual world of Albia (Fig. 1), teaching them how to talk, feed and protect themselves against predatory Grendels. Lively and curious Norn move autonomously in a two-dimensional world, interacting with it, evolving their behavior according to rewards and punishments set by the player.

Fig. 1 Some evolved Norns and the virtual world of Albia where they are born, interact and die. *Source* English Wikipedia

Each Norn then develops its behavioral range that characterizes how it approaches the virtual world. This astonishing learning ability is due to a network of 1,000 neurons and 5000 synapses that characterizes the Norns as Artificial intelligent life, enabling each agent to grossly recognize sounds, objects and environments and transmit characteristics and knowledge to successive generations, resulting in increasingly unpredictable behaviors. Creatures is today recognized as an essential experience in advancing research on intelligent virtual spaces, systems in which specific actions occur without being explicitly programmed. Although research has made considerable progress since the day it was commercialized, this videogame was among the first applications to highlight fundamental dynamics in any artificial agent's relationship with the virtual environment in which it acts. The relationship between VR and user, depending on the technology used [2], is usually visual and involves those perceptual aspects related to shapes, textures, brightness, and level of detail that contribute to the creation of signification. The other entities in the virtual environment interact only in terms of occlusion concerning the user's view. If, however, we introduce more complex entities, such as an intelligent agent, the interaction between objects, characters, and the virtual environment increases significantly. Agents must see and identify each other for any exchange to occur, as well as detect state changes occurring in the simulated virtual space, avoiding unwanted collisions with other objects, whether they are stationary, such as trees, buildings and furniture, or moving. For this recognition to occur, it is necessary for the algorithm that describes the behavior, analyze the inputs and decides on the outputs after examining them and based on what is happening on the screen at that instant. This difference distinguishes an AI from an ordinary program [3]. The problem is that to be applied to the analysis of any phenomenon, an AI requires the training time necessary to implement on a statistical basis the prediction of a datum from those it has, a process that, depending on the complexity of the application system, can take several months. The advantage of many game engines is that they have special libraries for AI, with effective tools, especially in finding the most efficient paths for agents. In fact, the protagonists of the games, characters, animals or vehicles, must move according to specific objectives and be able to identify the optimal routes from start to finish while also taking into account virtual geography. The agent must be able to understand the difference inherent in walking in tall grass rather than in a driveway or if they are in the presence of water rather than on the ground.

These computer applications free programmers from redesigning recurring features each time, allowing them to focus on game dynamics and the characterization of environments and characters. Years of development, supported by the substantial funding that has marked the evolution of the market, have enabled the creation of advanced models that robustly reproduce dynamic systems [4]. Considering, for example, a human body as a set of rigid structures joined by a system of constraints that define its degree of freedom, the motion in the virtual world will be the result of a continuous system of thousands of animations that these constraints admit while avoiding those that not correctly describe the action of a human body (e.g., a skull rotating 360°). These tools will be used in the next chapter to describe the behavior of virtual agents in fire situations.

3 Simulating Evacuation

The term simulation refers to creating a real word model that allows for evaluating and predicting the dynamic unfolding of a series of events consequential to the imposition of predetermined boundary conditions word. Typically, the designer defines the project's purpose, specifies the safety objectives he intends to ensure and translates them into quantitative performance thresholds. After that, using analytical or numerical modelling tools, it describes or calculates the effects of the design hazard scenarios on the assumed design solution for the activity. If the impact thus calculated preserve an adequate margin of safety concerning the previously established performance thresholds, then the analyzed design solution is considered acceptable. The use of simulation models has steadily increased over the years because of the constant attention paid by the countries' legislative bodies [5] that require building, plant and management measures to ensure the highest possible level of safety. Narrating the historical evolution of different evacuation models transcends the scope of this paper, which will only report how there has been a tendency to move from a simplified type of analysis to more advanced models over the years. Simplified evacuation analysis is based, fundamentally, on a so-called macroscopic type of behavior modelling, which predicts how a flow of people can be roughly described by approaches borrowed from fluid dynamics. Instead, advanced evacuation analysis uses so-called agent-based models (in a mesoscopic or microscopic framework). Agent-based approaches model the dynamics of each pedestrian (an agent) and allow control of each agent in terms of properties and behavior. Consequently, agent-based methods allow consideration of population heterogeneity and obtain information about the state of each pedestrian person at each instant of the simulation. It is evident that the creation of virtual reality agents for human behavior in the event of fire poses several challenges from the standpoint of model development and requires a multidisciplinary approach to the topic that considers physics, applied psychology, sociology, and computer science [6, 7]. Be that as it may, to represent the decision-making process employed in evacuation, the model must incorporate an appropriate method of simulating the behavior of exposed people. The theory adopted in this experiment finds its roots in the studies of behavioral dynamics conducted in the early 1950s by Von Neumann and Morgenstern [8] to those of Coleman [9] and Bartholomew [10]. According to these studies, agent motion can be obtained as an emergent property based on a set of global/local rules or differential equations (usually based on Newtonian forces) defined by the model developers. The experimentation conducted here is based on the more recent Helbing and Molnár [11] social force model, derived from the previous ones, which considers how an individual's behavior is triggered by external stimuli, which can change trajectory, speed and acceleration. Basically, the reference social force modelling describes the dynamics of each agent as that of a rigid body with three degrees of freedom, i.e. two planar translations and one rotation. The following rigid body dynamics laws govern the dynamics of each agent:

$$\begin{cases} m_i \cdot \ddot{\mathbf{x}}_i(t) = \mathbf{F}_i^g(t) \\ I_{z,i} \cdot \ddot{\phi}_i(t) = T_i^g(t) \end{cases}$$

where m_i (kg) is the mass of the ith agent, $\mathbf{x}_i$(t) (m) is its instantaneous two-dimensional position vector, $\mathbf{F}^g{}_i$ (t) (N) is the global immediate force vector acting on the ith agent, $I_{z,i}$ (kg · m^2) is the agent moment of inertia, φ_i *(t)* (rad) is the instantaneous orientation angle, $T^g{}_i$ (t) (N · m) is the instantaneous torque acting on the agent, and dots indicate differentiation with respect to time. The way each agent interacts with the environment to achieve its goal is governed by its properties and parameters. Most of these parameters are fixed and the same for all agents. Other parameters, however, such as walking speeds (flat, uphill, and downhill), response time, and choice of an escape route, are specified as random variables with associated distributions in a move to reproduce the heterogeneity of the population according to physical type [12]. The simulation presented here was implemented through the Unreal 4 game engine, which, like all game engines, is not designed for exhaustive tridimensional modelling.

Therefore, the optimal workflow involved:

(1) Optimal modelling of the building or space to be studied using dedicated three-dimensional modelling software, in this case, Rhinoceros, and then importing the model into the UNREAL environment. The correctness of the geometric description of the model must be verified after conversion to interchange format (FBX) or following a dedicated Datasmith conversion algorithm.
(2) Use available virtual models to which the motion-related settings have been applied. UE4 already provides some functions related to collision physics among the available tools. Capsulecomponent, for example, determines an area within which specific behaviors are triggered depending on interaction with elements in the scene. However, many settings, such as the speed of movement, have been modified depending on the purpose of the simulation (Fig. 2).
(3) For other objects, such as furniture, which is part of the scene, a basic physics must also be set up that defines their nature and prevents moving elements from interpenetrating them. The Nav Mesh Bounds Volume algorithm allows the AI to read the obstacles along the path based on the objects to which Collision physics has been applicated, and that reside within this volume. The generated wall surface will be parallel to the normal of the staged characters at an angle less than the established angle, always less than 90°. Therefore, all elements perpendicular to the horizontal plane will be interpreted as obstacles. This process will determine the space within which the AI can move and on which it will calculate the path to the desired direction.

4 Conclusion

The experimental model obtained is very simplified, considering that the agents can only recognize the nearest exit and choose the optimal path while avoiding obstacles. These determinants need to be more comprehensive to fully describe how information is conveyed and align individuals with mass behavior in an emergency, even though behaviors in an emergency still need to be fully understood and quantified by modern research. Nevertheless, it is already possible to note how, as variables change, such as the fire's ignition position, the agents' behavior changes, allowing specific considerations to be drawn on the evacuation route. Having used the Unreal 4 game engine as a development environment has brought some unprecedented advantages:

- Integration of rigid body motion equations and contact addressing can leverage the PhysX-integrated physics engine [13]. The physics engine offers numerous possibilities to define agents' behavior with precise formulations, greatly simplifying the work.
- The environment allows the direct import and rendering of geometries described by generic 3D meshes. Once the agent behavior has been implemented, it is possible to test different architectural types quickly.

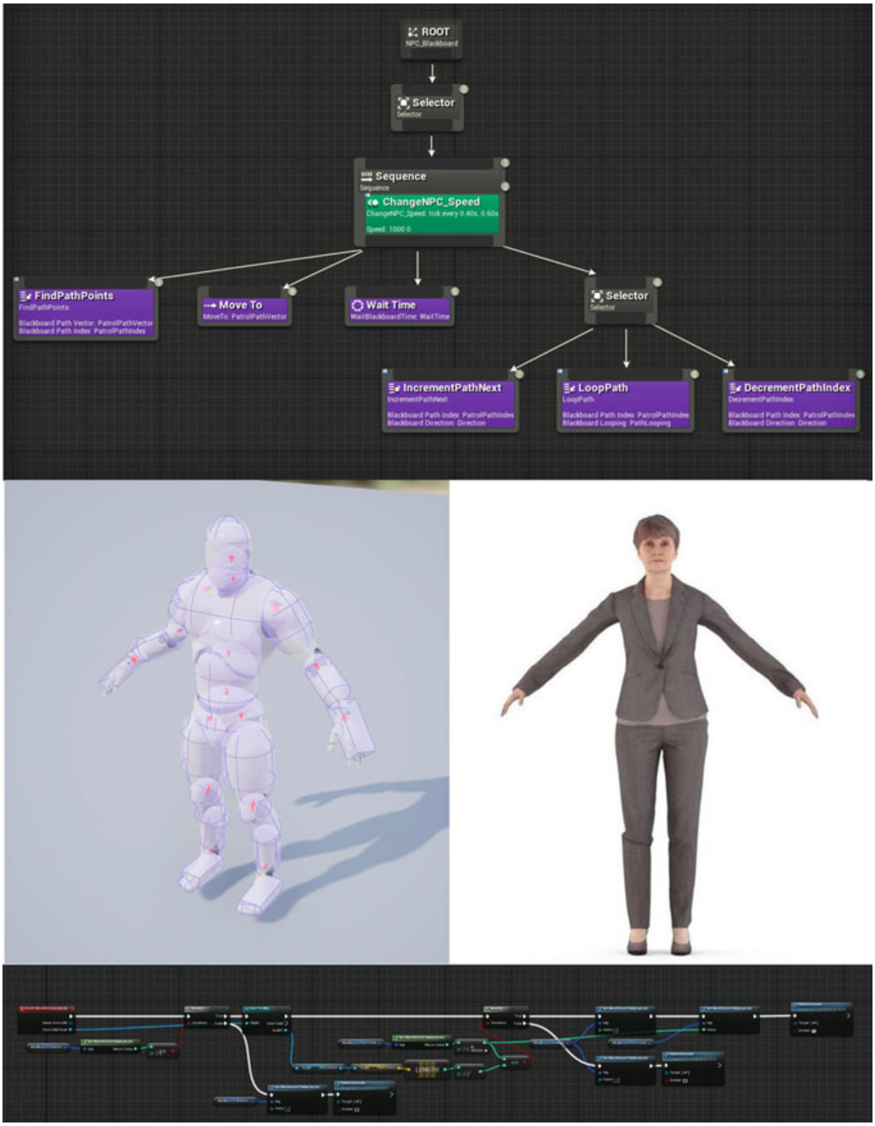

Fig. 2 Construction of the physical-anthropometric and AI characteristics of one of the virtual agents used in the test. Note the visual interface (a graph whose elements are interconnected according to a node logic) based on the Object Oriented Programming paradigm. *Editing* G. Buratti

- Most simulation systems available today require a calculation time and subsequently propose a movie showing the agents' behavior. Therefore, every time a change is made, a recalculation is necessary. Within Unreal 4, the simulation in progress can be viewed in real-time, with the immediate possibility of visualizing the result of any changes (Fig. 3).
- Many tools are available to develop the interactivity of virtual reality, offering the possibility to add sound and light effects, increasing the simulation's prediction. Furthermore, taking first-person control of an agent is possible, thus immersing oneself in the simulation to experience the virtual space and interact with other agents. This possibility is extremely promising for supporting decision-making processes and for training purposes [14].

Future development will improve the robustness and performance of simulation to achieve as realistic a description of human behavior as possible. In particular, the complex organizational capabilities of people under evacuation conditions must be investigated. The social force models used in this study are based on relatively

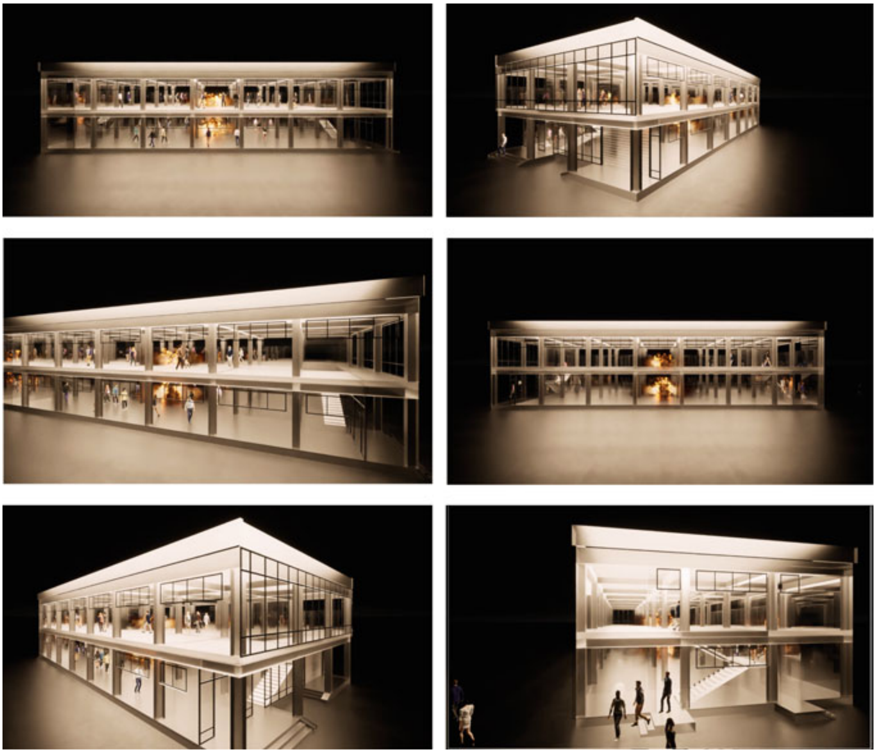

Fig. 3 Simulation at work: the different agents leave the burning building. Depending on their characteristics, they will follow various trajectories with dissimilar speeds, taking different times to reach safety. *Editing* G. Buratti

simple short-range interactions between agents that do not reflect the fact that, during an evacuation, human behavior can also be influenced by the evacuees' level of knowledge of the situation about spatial topology, density conditions, or that both immediate and estimated future needs can be considered.

These estimates can not only be based on a short-term assessment but can also be made in the long term and used to adjust the speed or choose the route to be followed. In particular, possible experiments with human interaction may pave the way for evacuation models' calibration and validation through virtual reality [15]. Consider that, due to the nature of the subject, it is hardly possible to test what happens in an emergency evacuation. The data available are mainly a posteriori, resulting from the analysis following the emergency event. Virtual reality is the most applicable and economical method that could enable studying catastrophic events [16]. Real-time human participation could be crucial for training in simulated hazard situations and have important design implications due to an improved perception of processes and the possibility for the planner to participate virtually and actively in the evacuation.

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Documentation Procedures for Rescue Archaeology Through Information Systems and 3D Databases

Sandro Parrinello and Giulia Porcheddu

1 Memory and Digital Archives in Archaeology

Storage and process the memory related to cultural heritage is one of the main challenges of digital archival [1], considering the significant transformation of the documentation methodologies also applied in the disciplines of archaeology [2]. These changes raise questions about how to actively access and use the documentation produced on archaeological sites. The issues are not only technical (heterogeneous data and different formats), but also cultural [3]. The digitization of archaeological memory involves cultural aspects whose implications are intensified by the destruction produced by the archaeological investigation [4]: the exploration involves the destruction of what is discovered and, if not efficiently documented, the loss of memory. The challenge, therefore, concerns the documentation and archiving process itself: how to process digital replicas of archaeological remains, which information should be recorded and how, and according to which structure the data should be organized [5].

The destructive actions involving an archaeological excavation demands specific considerations about digital documentation and surveying systems. Conventionally, when dealing with archaeological excavation, the survey describes just the last phase uncovered [6]. It is, therefore, easy to lose the traces (at least the morphological ones) of the portions removed and not properly documented. Today, increasingly high-performance tools—integrated survey methodologies[7–11] as well as photogrammetry and modelling [12–15]—provide the ability to capture the consecutive steps

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of the archaeological investigation in a reduced time, allowing to accurately register the succession of volumes and surfaces representing the stratigraphic levels [16]. The survey database is thus configured as a digital replica that can convey the complexity of the site by introducing into the documentation process the fourth dimension: the time [17]. The overlap of different excavation phases, either through point clouds or three-dimensional models, helps to display the evolution of the archaeological investigation and retrace the temporal sequence of the research.

While survey outputs ensure the metric and morphological knowledge of the site, the core of archaeological analysis is the stratigraphic investigation. This documentation is achieved through matrices (Harris Matrix [18]) and archaeological sheets. Archaeological sheets are developed by the Central Institute for Catalogue and Documentation (I.C.C.D.), which, based on early experiments in the 1970s, drafted different types of paper sheets in order to standardize the description of archaeological excavation [19]. In this way, such paperwork can describe the stratigraphic units, as well as the artifacts and different types of finds unearthed along with the architectural structures.

With the integration of such data, the information corpus then becomes more complex. The different formats and datasets make a synthesis process extremely challenging, especially from a management perspective. This large amount of dataset often flows in repositories and paper archives, making their interconnection a problematic task. The digital support of informatized systems can certainly solve the issue by curbing the loss of information and simplifying the data access, however archive digitization only partially covered the stratigraphic one [20]. While there has been some efforts to provide official website [21] for archaeological records (of site, area, finds), the filling in of stratigraphic unit sheets is still a paperwork to be done in situ [22].

The digitization and archiving of survey documents within a tight timeframe, although apparently not an urgent need for planned excavations, becomes a crucial issue for rescue archaeology. Rescue archaeology refers to those archaeological protection activities ordered by the Superintendency and specifically related to public works [23]. These activities are performed mostly by archaeologists in the role of private technical professionals. Although this type of excavation does not require any modified investigation techniques, the archaeologist's work on the site is affected by the research context. The amount of data to quickly catalogue, combined with the site's vulnerability, require a certain organizational effort and clarity of method [23]. The archaeological remains are threatened by the action of nature and even more by human activity: the choice of what to protect turns out to be a rather complex task that sometimes, in an attempt to meet the different demands involved, ends up sacrificing the persistence of the evidence. This fragility then requires careful documentation to transmit the archaeological memory of the place. Such documentation must necessarily be sorted according to specific structures that will allow for the analysis and interpretation of archaeological remains, thus facilitating the reading of records even if the evidence is not preserved [24]. For this reason, the data storage hierarchy must reflect the intricate network of relationships within the excavation layers and permit the collection and description of those imperceptible inequalities that testify to humankind's journey through history (Fig. 1).

If we also consider that, excluding funding for planned excavations, rescue excavations constitute one of the main field activities of the Superintendencies [25], then such documentation becomes an opportunity to study and forecast archaeological preexistences on the territory [26].

In the last decades, numerous research projects have experimented with the integration of archaeological databases into Geographic Information Systems (GIS), in an attempt to promote a system that would allow for both the preventive protection of such pre-existences and the documentation and archiving of sites of archaeological interest. Since the 1990s, GIS has been used to provide an answer to the inventory and management of existing excavations. However, the leap from the map of existing excavations to the map of the singular excavation, with its specificities, is still hard to achieve. Even if two-dimensional maps exist, they have issues concerning their

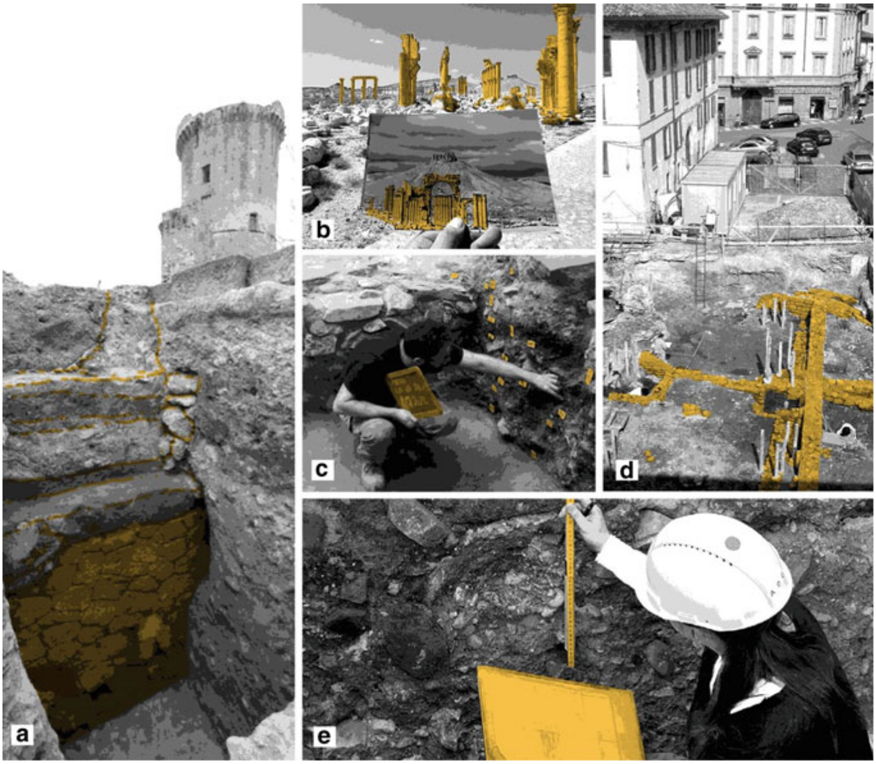

Fig. 1 Issues in archaeological documentation: **a** Data density requires specific methods for cataloging and archiving data; **b** The precariousness of sites imposes digitization of memory; **c** The quality of the survey can be improved using information systems; **d** The short timeframe of rescue archaeology needs expeditious methods of documentation; **e** Data quality can be improved by digital acquisition. *Editing* S. Parrinello and G. Porcheddu

updating, and in any case, they hardly ever fully describe the three-dimensional spatiality of an excavation. On the other hand, the absence of a three-dimensional map is understandable. The reasons lie in the heterogeneity of the data produced by digital surveying [27] and the difficulty of managing large amounts of data through networked systems. So cataloging processes, from digital acquisition to data transmission, must cope with the absence of an effective unified protocol that follows progressive technological innovations [28].

The existing two-dimensional GIS can just roughly represent the complexity of the archaeological analysis; indeed, it fails to display the stratigraphic reading (other than in the format of attachments). Since single stratigraphic unit analysis is useless-stratigraphic units can only be understood and analyzed in relation to their context—the identification of mutual dependencies between different work phases allows the understanding of the overlapping of layers and the succession of the temporal actions [29]. The 2D standard GIS representation proves unsuitable for this level of detail because archaeological traces are marked as points on the ground rather than as volumes or areas provided with their depositional and stratigraphic context [30]. The complexity of excavation systems cannot be represented and understood through a bi-dimensional simplification of the geometries but only by reading the interdependence of all its parts.

The idea of integrating highly descriptive models into the stratigraphic database has led to the development of three-dimensional information systems. The main advantage is the possibility to relate different types of data, select information, and organize its contents, but above all, interact and use archaeological data within a realistic three-dimensional visualization of the object. 3D models are the visual representation of numeric and alphanumeric data, constituting an intuitive information system interface. In this way, such three-dimensional media provide easy access to complex data structures and constant orientation for the user to navigate a large amount of heterogeneous information [31].

Aiming to contribute to the research in archaeological archiving and representation, the project presented—on the former Santa Margherita Institute case study in Pavia—focuses on elaborating a three-dimensional information system that collects the data emerging from the rescue excavation. The three-dimensional archive is built through a methodology that aims to report the key features for in situ recording and classification of the stratigraphic archive through 3D models processed from integrated surveys.

2 The Archaeological Area of the Former Santa Margherita Institute

The former Santa Margherita institute (Pavia, Italy) (Fig. 2) represents an emblematic case for the analysis of urban morphology. The archaeological excavations concern a remarkably extensive area whose stratified layers date back to the Roman period.

Moreover, archaeological sites located in urban centers always bear traces of the evolution of the built environment, revealing the transformations that chronicle the city's history [32]. The large complex is the result of the evolution of the first built core, which is still visible today, i.e., the noble tower of the Sacco family (1458).

Over the centuries, the favorable location within the city's medieval walls and proximity to the Ticino River led to a process of urban coalescence through the addition and construction of later-built areas. These transformations, which can be retraced from available cartography (from 1458 to 1886), emerged during archaeological activities ordered by the Superintendency in 2010.

The complex was the site of a project aimed to convert it from a hospital to a residential facility, requiring the construction of an underground parking lot in the outer courtyard. During construction excavations, the discovery of a medieval settlement prompted the rescue archaeological investigations intrinsically linked to the construction works, which were abruptly stopped in 2010; the resulting following decade of disuse compromised the conservation state of the remains exposed to the

Fig. 2 Photographs of the former Santa Margherita Institute. In color: Drone and ground photographs of the current state of the complex (Editing: authors). In black and white: Early 1990s photographs (Surveys: Eng. Calvi, Pavia Civic Museums, Chiolini Archives)

weather and only partially documented. In 2021, a company interested in its restoration purchased the crumbling building. This initiative fostered the beginning of a new archaeological documentation campaign aimed at investigating the underground area through preventive assays.

The need to safeguard the memory of the undocumented evidence and the necessity to digitally record the excavation at different stages of investigation led the company GEA Archaeology (responsible for rescue archaeology activities on site) to seek the technical support of the experimental laboratory DAda-LAB of the Department of Civil Engineering and Architecture of the University of Pavia. In this critical context, such research meets documentation requirements by exploiting digital media to achieve heterogeneous and multilevel databases suitable for archaeological investigation. Under these assumptions, the issues related to excavations conducted in emergencies have prompted specific interventions, providing an opportunity to experiment with a methodological protocol for archiving archaeological data in situ. The need to digitally acquire stratigraphies that would have otherwise been lost—within a tight timeframe and with high morphometric reliability—constrained the methodological choices aimed at the research objectives.

The three-dimensional database was developed from an extensive survey of the entire complex, combined with an integrated detailed survey of the excavation areas (Fig. 3a); so as to carefully record the stratigraphy of the excavation along with its transformation and to pursue the construction of a dynamic documentation of the archaeological site [33]. The extensive survey, carried out in March 2022, was conducted through TLS equipment (FARO Cam 2 Focus S150), integrating a GPS device to obtain data to georeference the global point cloud. The detailed survey—carried out through TLS, close-range photogrammetry (Canon EOS 77D), and UAV (DJI Mavic mini 2) for larger portions of the excavation—covered both undocumented assays (following the abandonment of the construction site) and new assays (ordered by the Archeological Superintendent's Office) as propaedeutic action to the construction work. As a result, ten Excavation Areas (AS) were identified (Fig. 3b), distributed mainly within the open spaces pertaining to the complex. For these areas, detailed acquisition campaigns started to follow the investigation simultaneously, documenting the sequences of excavation phases. The assays south of the inner courtyard exhibited a highly articulated depositional and stratigraphic configuration, which required numerous survey campaigns (from February 2022 to August 2022, documenting 14 excavation phases).

The experimentation in the setting up of the information system was carried out on the evidence that emerged in this area, in order to test the incorporation of a large dataset in a limited portion of the three-dimensional environment.

The main challenge in digitally capturing these surfaces of the excavation arises from the necessity to document an ever-changing space. Acquiring voids and surfaces that consistently change in both space and shape requires careful planning of survey activities from the earliest stages. For this reason, fixed targets were placed since the extensive survey campaign started to ensure the consistent presence of reference points within the overall database. This preliminary action allowed the digital recording of the excavated areas for each subsequent investigation phase, making it

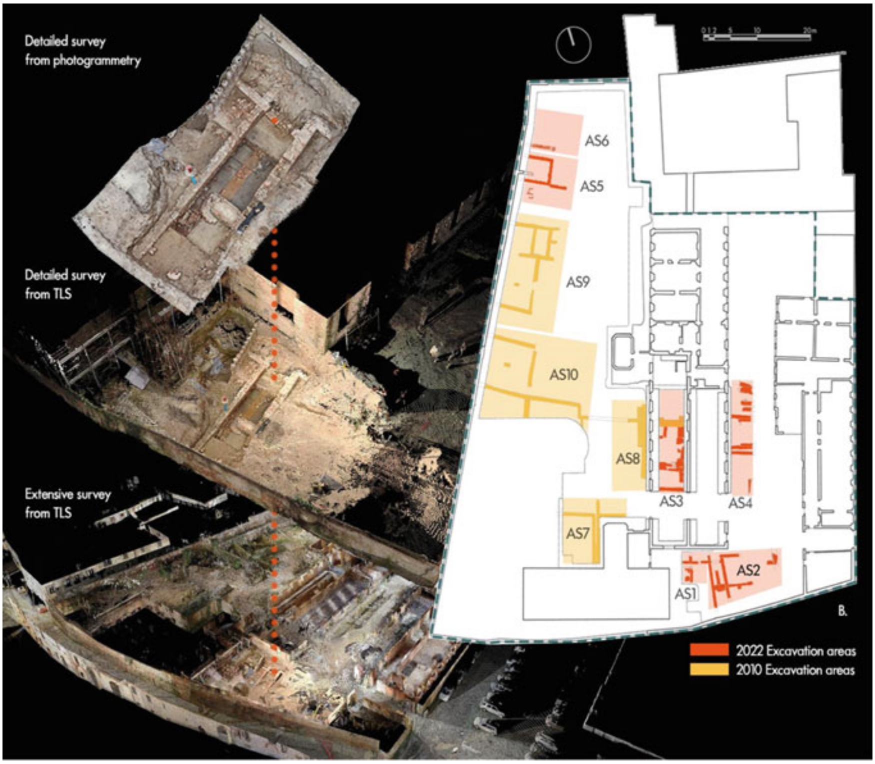

Fig. 3 **a** Subdivision of excavation areas within the complex; **b** Structure of the survey and database. *Editing* S. Parrinello and G. Porcheddu

possible to capture not only the stratigraphic units present in situ but also to record the evolution and development of the investigation itself.

It was then possible to align the TLS point clouds with the photogrammetric ones, generating a highly reliable general three-dimensional database. This database was used to produce drawings to support the stratigraphic investigation. Overlaying the point cloud corresponding to each excavation phase made it possible to extract plans and sections (Fig. 4) to read the stratigraphy of the excavation and reconstruct the temporal succession of the deposit and masonry units. From the general TLS point cloud, supplemented with the GPS data, it was possible to georeference each stratigraphic unit in relation to the context.

The accurate placement of the units confirmed previous considerations that emerged on-site and were difficult to verify just by means of a direct survey. On the other hand, photogrammetric models (Fig. 5a)—processed through SfM photogrammetry techniques (Fig. 5b), scaled, and referenced according to coordinates from point clouds—provides colorimetric data closer to the real object. This feature highlighted the contrasts and irregularities that differentiate a stratigraphic unit from contiguous ones and matched selected portions of the model to the classification

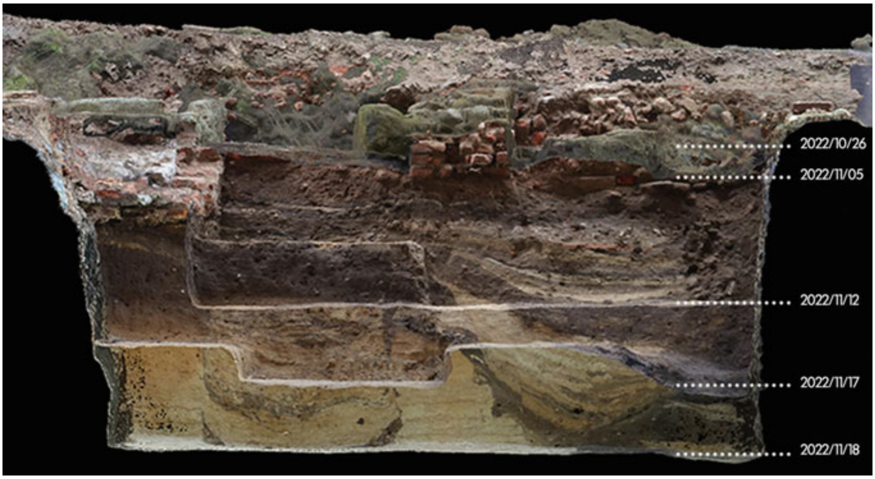

Fig. 4 Section of the point cloud related to the northern sector of the AS4 excavation area. The point clouds (related to different survey campaigns) are aligned and overlapped, allowing to reconstruct of the sequence of the archaeological investigations. *Editing* S. Parrinello and G. Porcheddu

made by archaeologists in situ. Such outputs make it possible to retrace the investigation stages, clarify doubts and ambiguities that emerged during the analyses, and compare the on-site archeological documentation with the data produced by the research activities. This comparison confirmed the practical functionality of the proposed acquisition methodology, ensuring the preservation of the digital memory of the site.

3 Protocols for Integrated Management of Archaeological Data

Despite the advantages offered by digital acquisition, comprehensive excavation documentation cannot be achieved solely by using the models resulting from the survey. In a traditional pipeline, the recording of the excavation stratigraphy relies on the compilation of standard archaeological sheets (Fig. 6) used to collect data through textual descriptors.

Because of the structure of the sheet, which requires writing down detailed definitions, the digitization of information does not fit the tight timeframe; therefore, it is normally done *ex-post*. Data acquired in situ are archived through experimental or official platforms or, more simply, through text and spreadsheets. Such procedures certainly allow the preservation of digital data. However, the formats themselves are destined to a certain degree of obsolescence and they do not allow for proper analyses as they do not incorporate relational database systems.

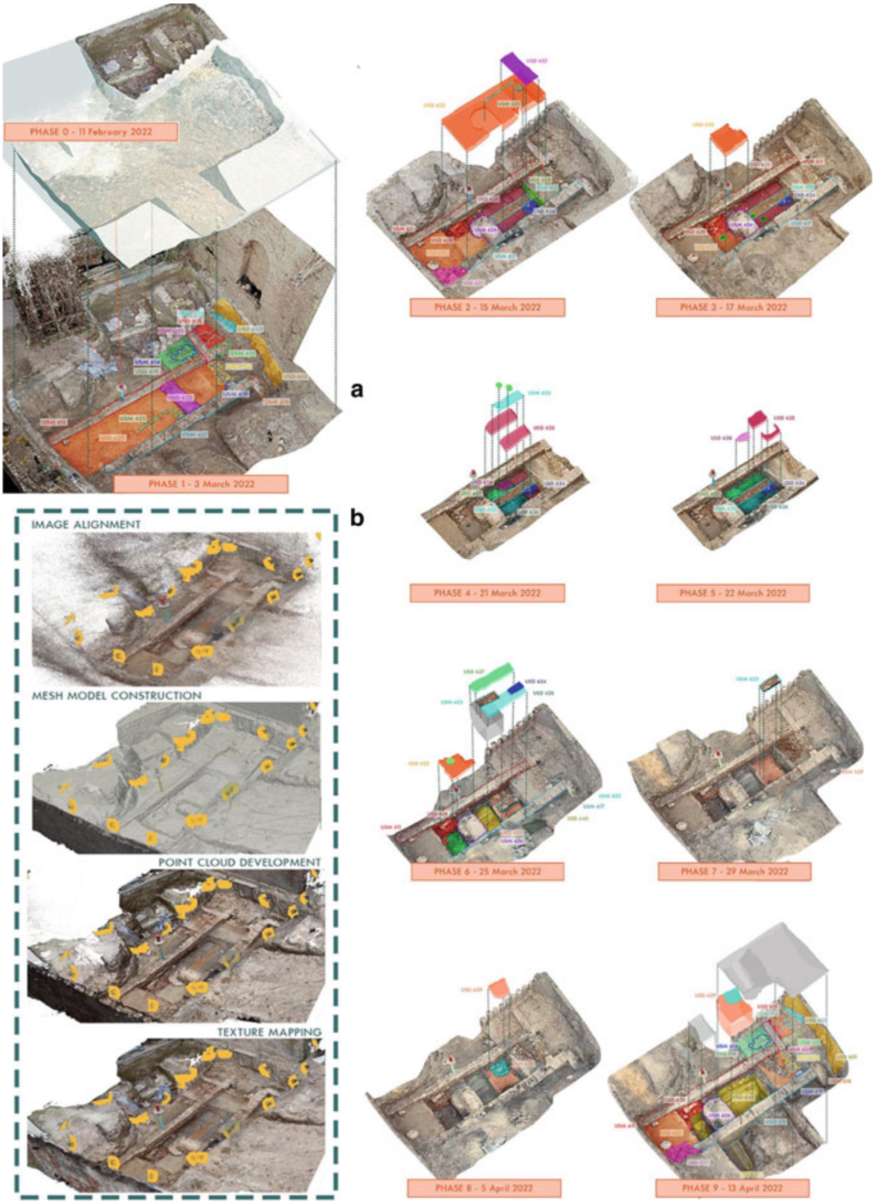

Fig. 5 A photogrammetric model was processed for each excavation phase, subsequently proceeding to identify the stratigraphic units classified on site. **a** Textured photogrammetric models for each excavation phase with stratigraphic units highlighted (AS2 area); **b** Processing of photogrammetric models on Agisoft Metashape software. *Editing* S. Parrinello and G. Porcheddu

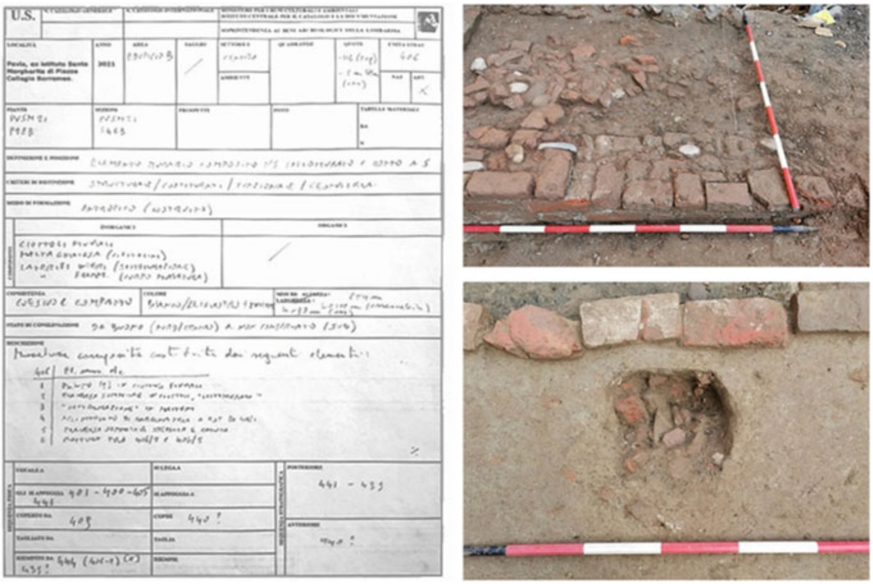

Fig. 6 On-site documentation of stratigraphic units through manual compilation of ministerial sheets (left), photographs (right), and personal notes. *Editing* S. Parrinello and G. Porcheddu

Following the archaeologist's *modus operandi* during the recording and classification phases, it emerged that the primary objective should concern the on-site digitization of stratigraphic unit (U.S.) sheets. The procedures of census and sheet compilation take a long time and are not suited to the dynamism of rescue excavations. Furthermore, it requires a certain degree of impartiality and attention by the operator [34]. The result is that such sheets are often filled out only after the excavation is concluded, by consulting photographs and personal notes, thus undermining the accuracy and objectivity of the documentation.

In order to meet the need for expeditious documentation that would allow for populating the database directly on-site, it was decided to introduce tablet [35–37]: Apple Ipad 11 Pro was employed during the field trial.

These user-friendly and lightweight devices are able to produce extensive documentation in terms of photographs, diagrams, drawings, schemas, matrices, and three-dimensional models that can be incorporated into the forms. It was, therefore, necessary to implement and rethink the ministerial sheets to incorporate the new types of information within the stratigraphic archives and guarantee the object-description relationship to avoid data loss. The digital records were designed within the FileMaker Pro Advanced software, which is associated with the FileMaker Go iOS application for on site compilation through Ipad. The simple and intuitive interface facilitates and speeds up the compilation of in situ records through multiple-choice textual fields, drop-down menus, and container fields for photographs, images, and three-dimensional models (generated via Ipad through Lidar applications available for both iOS and Android, such as Policam and 3D Scanner).

In order to be able to segment the ministerial sheet offering detailed descriptors, two different types of sheets were designed: the sheet for masonry stratigraphic units (U.S.M.) and the sheet for soil deposit stratigraphic units (U.S.D.) (Fig. 7). This subdivision made it possible to include, depending on the type of stratigraphic unit, specific lists of attributes to execute search queries within the information system. In addition, this experimentation provided the opportunity to rethink the open and generic descriptors in the ministerial sheets that do not fit an objective description and homogeneous analysis of collected data.

These sheets become new digital tools, way more complex than storage media: a proper system for recording, documenting, and interpreting archaeological excavations.

An interface must be defined to query an information system and to display the data and the thematic analyses resulting from the search queries [38]. Within this content-container relationship framework, the implementation of the three-dimensional models derived from digital acquisitions allows the addition of morphological, dimensional, and colorimetric information to the stratigraphic archive through a visually effective and intuitive representation.

The distinctive feature of a GIS applied to a 3D environment embodies the possibility of containing, visualizing, managing, and analyzing spatial and nonspatial information using as a support tool the two-dimensional entities rearranged in three-dimensional structures [39]. Such 2D entities, i.e., the surfaces of the excavation phases recorded during the several acquisition campaigns, must be semantized and assembled according to the subdivision into stratigraphic units made during the field census to represent the container of information related to it entirely. In this way, one-to-one correspondence between the model and stratigraphic unit can be established, allowing the explanation of the interactions that characterize the information system.

In order to integrate the three-dimensional models within a georeferenced space, a workflow for modeling stratigraphic units was developed, keeping in mind the issues related to model implementation.

A few simplifications were implemented in order to make the platform user-friendly. By decimating the photogrammetric mesh models (Fig. 8), it was possible to reduce the file size, also ensuring a reliable representation of the stratigraphic units thanks to the high-quality texture [40].

Moreover, it is crucial to ensure the last phase representation for each stratigraphic unit. Indeed, any excavation phase leads to the removal of some stratigraphic units or to the highlighting of new portions of other ones. In parallel with the fieldwork, it was necessary to semantize the surfaces related to the same stratigraphic unit operating on each corresponding model, by carrying out cleaning, overlapping, and hole-filling operations (Fig. 8) on the mesh surfaces. Eventually, it is possible to obtain three-dimensional non-manifold volumes representing the stratigraphic units recorded at their final stage.

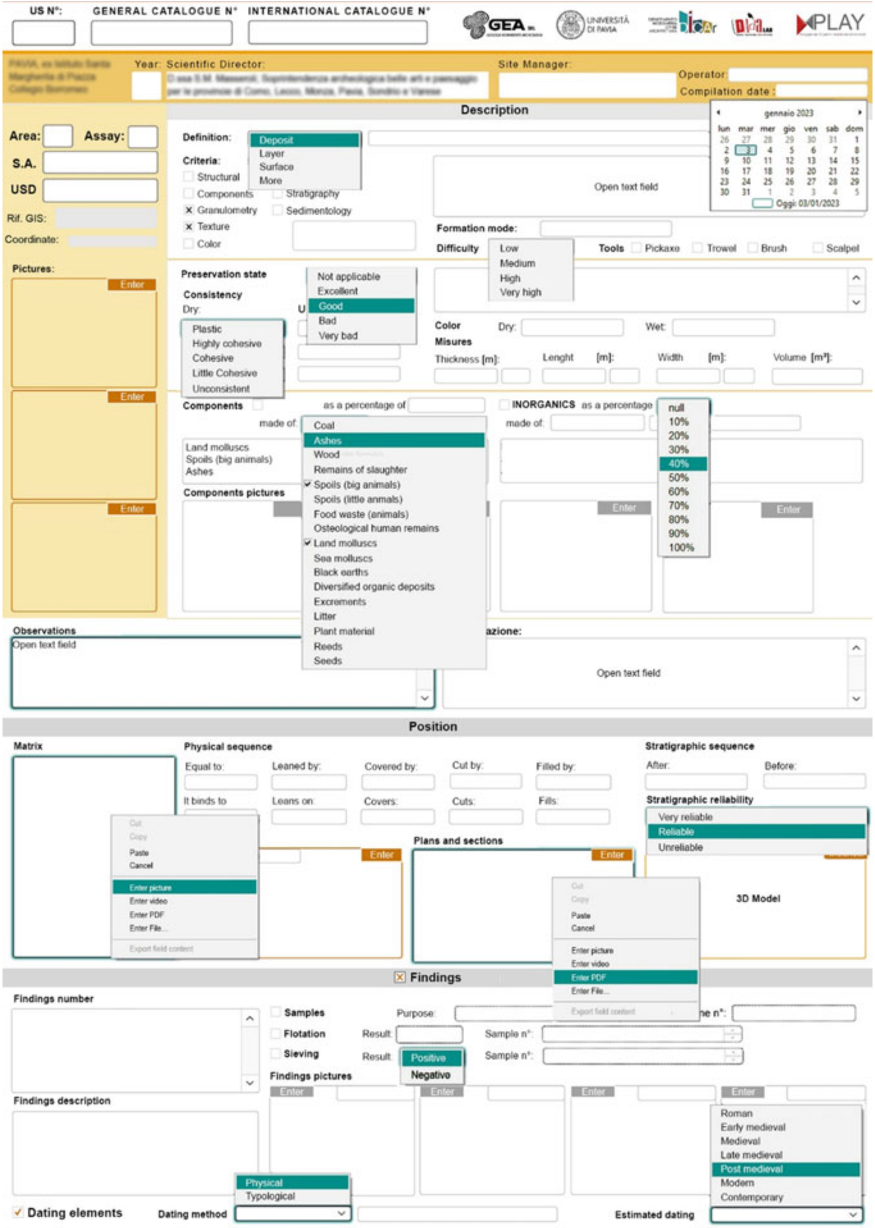

Fig. 7 U.S.D. sheet (for Deposit Stratigraphic Units) and how to interact and fill in through Ipad. *Editing* S. Parrinello and G. Porcheddu

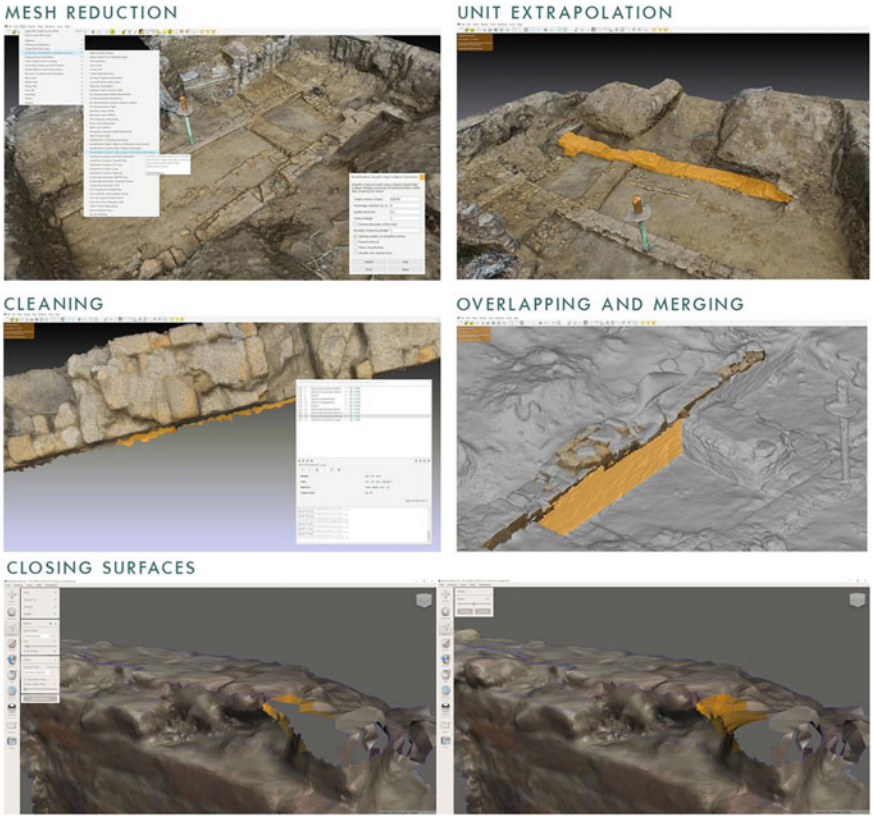

Fig. 8 Decimation, extrapolation, cleaning, and overlay operations performed on the photogrammetric models, representing the excavation stages, to obtain individual three-dimensional models of the stratigraphic units. *Editing* S. Parrinello and G. Porcheddu

These three-dimensional structures were then rearranged according to a logic that enables the visualization of the excavation phases using layers (Fig. 9). All the stratigraphic units were initially associated with layer 0; subsequently, at any layer, the corresponding excavated unit was removed.

By operating on the layers, it is possible to display the fourth dimension of the archaeological excavation, thus, materializing the temporality of the archaeological process according to the given sequences of investigation steps.

In order to define a dialogue between the three-dimensional database and the stratigraphic archive, the data must be appropriately named to set a 1:1 relationship between models and stratigraphic unit sheets [41]. The sheets were exported in schedules (.xlsx format) organized according to rows—corresponding to the individual census sheet—and columns—describing the fields (text, number and other data container). Each stratigraphic unit (soil deposit or masonry) sheet is uniquely defined by the field “U.S. Code” placed in the first column. Once each unit has been

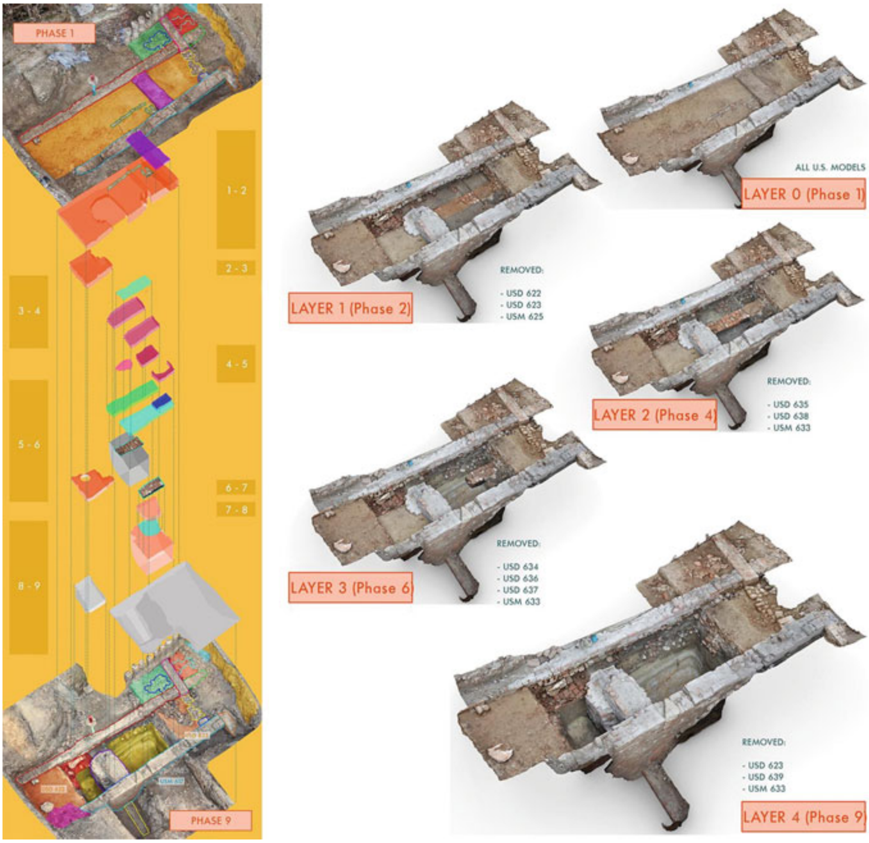

Fig. 9 Rearrangement of stratigraphic unit models according to layers belonging to the documented excavation phases of AS2 area. *Editing* S. Parrinello and G. Porcheddu

carefully encoded according to the nomenclature assigned on-site, the corresponding three-dimensional model has been named, exported, and organized according to layers of excavation phases, to be later imported within the GIS (data entry was tested both on ArcGIS Pro and ArcScene software).

Through the attribute table, the one-to-one correspondence—that is established between the "Name" of the three-dimensional models and "U.S. Code" of the tables—enables the content-container relationship that makes the information system queryable.

4 Results and Conclusions

In addition to showing the temporal variations through the management of the excavation layers (Fig. 10a), the GIS will also allow querying the U.S. according to selected parameters (Fig. 10b), or filtering multiple attributes displayed in the form of thematic maps (Fig. 10c).

The temporal visualization allows the information system to work as a digital excavation journal capable of retracing the investigation according to following stages of excavation. In addition, this tool provides the opportunity to clarify doubts raised during the analysis, and to review considerations and interpretations on the stratigraphic units even when the physical asset is no longer available.

On the other hand, upon directly querying the specific U.S., the user will have access to the information and metadata recorded during in situ filing phase. Furthermore, the possibility of storing the stratigraphic unit forms (in PDF format) within the information system allows a more effective and intuitive representation of the attached multimedia if compared to XLXS spreadsheet.

The essential advantage is the possibility to query multiple stratigraphic units simultaneously according to fields and lists of associated values. The information related to any field in the archival database is displayed through three-dimensional maps according to color-range scales. All entities belonging to the same classes will be simultaneously associated with a color code identifying a particular property.

The graphical synthesis offered by thematic maps thus allows an intuitive and immediate visualization of the number of entities corresponding to a given parameter,

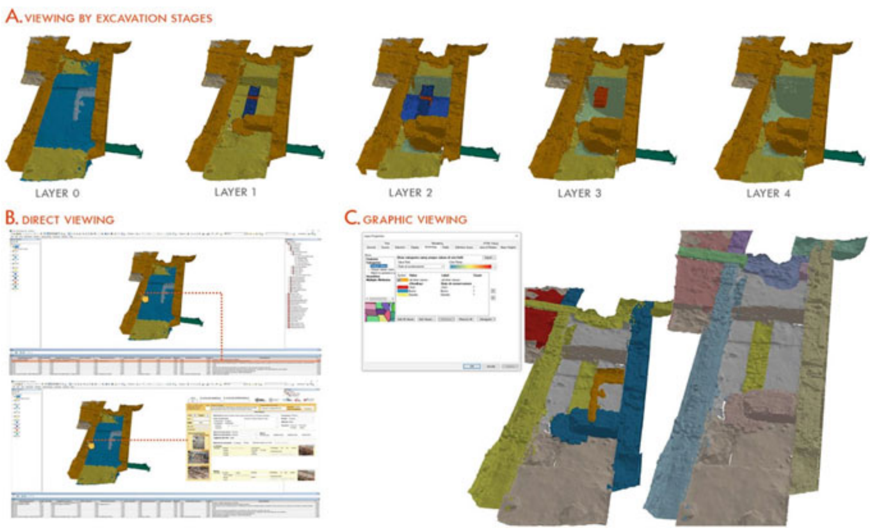

Fig. 10 Visualization and query features of the GIS system. *Editing* S. Parrinello and G. Porcheddu

thereby becoming a powerful tool for chronological and functional analysis of the archaeological excavation.

In this way, three-dimensional GIS systems stand out as advanced tools of great potential for archaeological applications [42]. The ability to relate different databases typologies and to manage and visualise this data allows for accurate and error-free analysis. In the field of rescue archaeology, this possibility becomes of crucial importance, as the physical space of the excavation can be destroyed, and with it the historical memory of the site.

The information system then becomes the keeper of the memory of the place: the intent to curb data loss during an archaeological excavation is promoted through the use of digital containers, 3D models, which facilitate a smoother visual orientation for data reading. This framework, which helps the dialogue between heterogeneous databases, acts as a bridge between the past and the future. The stratigraphic analysis, which allows to unravel the past of an archaeological site, is connected to the present through survey actions, documenting the stages of the investigation, and is all the same joined to the future as planning, management and valorisation actions can born through this system.

Aiming at a uniform and comprehensive management of urban archaeology, present and past, the developed methodology could then be tested and applied to a wider territorial area, developing a digital information system that allows for the control, visualization and interaction of information at multiple levels: from the detail scale, to the site scale, to the urban scale. In a future development perspective, these information systems should belong to a single web GIS system, creating not only a digital twin of the excavation activities, but a widespread map of all the excavations in progress, being able to record, through the control of the timeline, the actual evolution of the excavation campaigns and the materials found in them.

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Hybrid AI-Based Annotations of the Urban Walls of Pisa for Stratigraphic Analyses

Valeria Croce, Marco Giorgio Bevilacqua, Gabriella Caroti, and Andrea Piemonte

1 Introduction

In recent years, Artificial Intelligence (AI) techniques have been successfully applied to ease the interpretation of architectural heritage [1–3], but their application to the field of fortified heritage remains underexplored. In order to ensure such tools as an effective support in documentation, enhancement and preservation studies, proper sharing and transfer of information between different types of digital models are key issues [4, 5].

This work proposes the use of AI-derived Supervised Machine Learning (ML) techniques for the semantic classification of the walls of Pisa, aimed at supporting stratigraphic analysis, as well as alteration and degradation mapping. The observation and surveying of the still existing structures are related to some significant historical events that have affected the medieval city walls, from the construction to the reinforcement interventions underwent between the twelfth and the sixteenth century. Then, the results of stratigraphic analyses are translated from images to 3D photogrammetric models, in order to preserve the acquired information when shifting to another type of digital representation. The preliminary results of the classification

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of lithotypes herein presented are evaluated in terms of performance of the predictive model in making correct predictions, as well as in terms of comparison between semi-automated and automated annotation times.

The presented methodology is tested over a collection of relevant sections of the city walls, in which the visual analysis of the fortified structures yields the narrative of the historical events: the track between Torre Santa Maria and Porta murata di Santo Stefano, the walls in Tersanaia, and the track between Porta Calcesana and Canto alle Piagge are identified as specific case studies for the research.

The work presented is part of the broader context of a Ph.D. thesis that focuses on different ways of storing, retrieving and transferring semantic annotations within different types of digital representations.

2 State-of-the-Art

Through the annotation process, it is possible to provide a digital representation with essential information relating to the knowledge and analysis of an architectural object. Information could concern, e.g., the mapping of deterioration [6], materials [7] and the identification of architectural components [8]: depending on the type of medium to be annotated, a distinction is made today between 2D annotation systems such as SiCAR [9] or Geographic Information Systems (annotation is performed over photographs or drawings), 3D systems such as Neptune IS [10] and CulTO [11] (annotation is realized over mesh models or point clouds), or hybrid 2D/3D annotation systems. More specifically, this last category includes those systems, such as the web-based platform Aioli [12], which are based on the simultaneous enrichment of several digital representations, as images and 3D models, starting from the reconstruction of the mutual relationships between them.

Hybrid annotations might provide a powerful tool for stratigraphic analyses in archaeology and architectural conservation, to enable the rapid and accurate identification, over digital 2D and 3D representations, of the various layers of material and construction techniques used in historic buildings. Moreover, the growing availability of Machine Learning tools to ease the interpretation of digital data paves the way for the search of new, semi-automated annotation tools, allowing to rapidly analyze (annotate) complex structures and artefacts and offering a new level of insight to the past [13]. In detail, starting from a certain amount of training data and from the extraction of a suitable set of features, ML algorithms as the Random Forest [14] and Convolutional Neural Networks [15] have been applied to historical architecture, e.g., to boost the identification and classification of different layers of materials and pigments of urban walls [3], to assist the recognition of stone pavement patterns [16], to tackle image reassembly with wide space between fragments [17] or again to compare the different states of conservation of frescoes in time [18]. The RF is a widely used supervised learning techniques for classification tasks: when applied to surveying data in the architectural heritage domain, it outperformed other existing ML approaches—in terms of computing and processing time trade-offs [19].

Referring to the case of complex masonry structures, however, the multimodal enrichment of different types of representations derived from the survey, also obtained from more automatic classification processes, could improve the reading of stratigraphic units and the understanding of the evolution of masonry layers.

3 Urban Walls of Pisa

The urban walls of Pisa constitute a complex and articulated defense system, whose first installation dates back to 1154 under the consulate of Cocco Griffi.

Built by adapting to the natural elements that surrounded or crossed the city, the walls had a perimeter of over six thousand meters, with embankments, towers and ramparts, to which new bastions and a fortified citadel were added between the fifteenth and sixteenth centuries, during the Florentine occupation [20–22].

The methodology proposed herein was tested on two significant stretches, selected for their characteristics of stratigraphic evolution, the latter closely connected to the historical events pertaining to these portions of the walls.

The tracts covered by the study are (Fig. 1):

- The curtain wall that runs north of the city, in the oldest section of the wall layout, starting from the Torre Santa Maria and proceeding eastwards, along the ancient course of the river Auser, reaches the Porta murata di Santo Stefano. This portion of the urban walls has an average height of 11 m and an average thickness of 2.20 m. The lower sections of the wall, built in greyish limestone from the quarries of San Giuliano (Calcare di San Giuliano), were all completed by 1161; the intermediate sections were built without any solution of continuity with the lower sections, from 1161 to 1261; the last layers, with squared ashlars in sedimentary breccia di Asciano, refer to an elevation project of the walls dating back to the fourteenth century, the period to which most of the crenellations can be traced [23].

Fig. 1 Relevant sections of the urban walls of Pisa considered: the track between Porta Santa Maria and Porta murata di Santo Stefano (on the left); the track in Tersanaia (on the right) (*Photos* V. Croce, M. G. Bevilacqua, G. Caroti and A. Piemonte)

- The walls in Tersanaia, i.e. that portion of the Pisan walls that encloses the quadrangular area that gathered, in ancient times, ship-building activities (Tersana). The city walls in this section, between the Torre Sant'Agnese and the Porta Degazia di Ponte, encircled a protected space intended for the shipyard activities dispersed along the riverbed. In the lower layers of the walls, the breccia di Asciano is used, while in the upper layers there is evidence of later revetments, as the rows of merlons are incorporated into the elevation wall.

4 Methodology

With a view to testing and validating the application of classification techniques to support stratigraphic investigations, in this work we focus on the case study of the walls of Pisa, in order to investigate whether the semantic classification system based on supervised ML might effectively represent a useful cognitive tool in the extensive mapping of wall textures, to assist morphological studies and analyses of lithotypes.

The methodology is structured as follows (Fig. 2):

(1) Data acquisition phase. Over a dataset of images, appropriately acquired on-site, a photogrammetric model is first processed by reconstruction of the camera orientation parameters. In the dense cloud resulting from the photogrammetric survey, each point is assigned an RGB color value.

(2) ML-based classification. Purpose of this second step is to annotate the entire image set in 2D, adding semantic information on materials patterns and/or on the detection of different construction layers. In detail, a supervised ML algorithm, the RF, is initially trained by annotating layers of information over a small portion of one single image. This input data, together with the extraction of appropriate colorimetric features from the input photographs, allows the entire image set to be classified into stratigraphic layers, by batch processing (i.e., without further training). The quality of the classification process can be finally assessed by comparing the predicted results with ground-truth (i.e., manually annotated) values, on a validation image set.

(3) Propagation of semantic annotations. With ML-based classification, the information on lithotypes can be transferred from a single, manually annotated image to the whole set of photos of the photogrammetric dataset. At a final stage, by retrieval of the projective relationships linking 2D and 3D data, this semantic annotation information is even transferred from the images to the 3D photogrammetric model, in order to guarantee proper data archival and retrieval. To this purpose, the relationship between 3D coordinates and images is preserved, but the original images are replaced with the annotated ones in order to change the color information of the dense cloud (the so-called colorized dense cloud process), as well as in order to generate the texture of the mesh model. In other terms, the 3D coordinates of the points remain unchanged, while the color of the 3D model is modified according to the classification result.

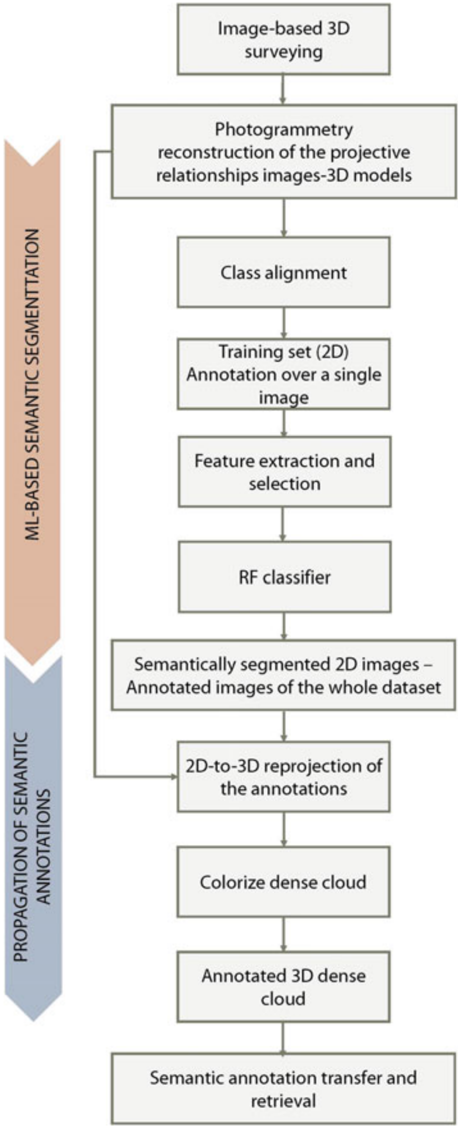

Fig. 2 Workflow of the proposed approach (*Editing* V. Croce, M. G. Bevilacqua, G. Caroti and A. Piemonte)

The continuous 2D–3D reprojection operation allows semantic enrichment of both types of representations and avoids scattering or possible alteration of semantic data on stratigraphic analyses.

5 Results and Discussion

For the two case studies considered, a preliminary photogrammetric survey is performed, starting from a set of images suitably acquired on site (Fig. 3). The 3D point cloud and the related image data are used as input information.

As for the Terzanaia section, Fig. 4 illustrates the classes identified for the training: a lower level of breccia di Asciano, a second level of heterogeneous and re-used lithic material, and a third level of crenellation, interspersed with the presence of loop-holes. Vegetation infestation is highlighted in green on this section of the walls.

The semantic segmentation of Fig. 4, performed from the manual annotation of some wall portions on this image, is used to extend the annotation information to the entire dataset. In this way, a semi-automatically annotated image set is first obtained; then, the classification information is transferred from the whole set of images to the 3D point cloud by back projection (Figs. 5, 6).

The results of the validation of this approach on the Tersanaia section are promising: on the basis of the training data, the RF was able to correctly identify the different phases of superelevation that interested this section of the wall. In detail, in addition to the layers of breccia di Asciano and heterogeneous lithic material, the class of the crenellation (merlatura) clearly reveals the distinction between a first layer of crenellation corresponding to the reinforcement works carried out in 1394 and a second, higher layer, relating to a later reinforcement carried out by the Florentines during their first domination over Pisa, dated back to the fifteenth century. An estimate of the performance of the RF algorithm in the automatic recognition of lithotype component classes can be derived from the comparison between real and predicted data. Figure 7 shows the comparison between the initial images in RGB colour, the images obtained by automatic classification and those obtained by manual annotation with ground truth labels (class colors refer to the legend of previous Figs. 5, 6).

With regard to the oldest section of wall, the one between the Torre di Santa Maria and the Porta murata di Santo Stefano, the results are satisfactory, albeit less reliable than in the previous case. This specific section of wall is indeed characterized by two initial layers of greyish limestone from San Giuliano (calcare di San Giuliano): a first stratum featuring better-worked stones and more precise joints, and a second stratum with blocks that are less homogeneous in quality and slightly larger on average.

Although being derived from different workmanship types, the two layers appear homogeneous in terms of colorimetric characteristics, which means that the transition from one lithotype to the other cannot be clearly recognized and distinguished (Figs. 8, 9). The same pattern recognition problem is found in the highest section of the wall, in the band of pinkish-grey sedimentary breccia di Asciano: this upper part of sedimentary elevation, culminating in the final layer of brick crenellations, is related to a later elevation project of the walls [21].

Automatic classification is, in this second case, complicated by the use of colorimetric features, so that those areas of the image that show less variation from a radiometric point of view are not classified correctly. To overcome this problem, might

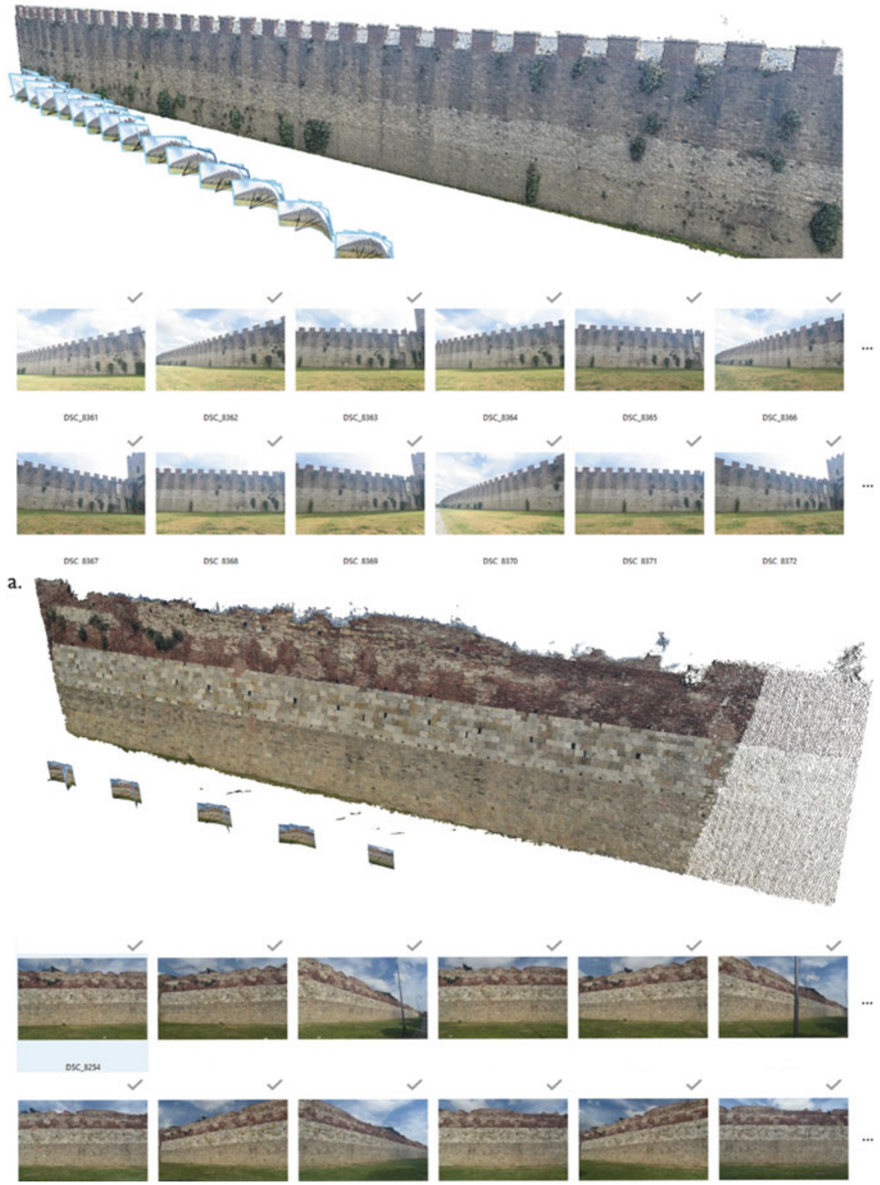

Fig. 3 Portions of the reconstructed 3D models with related images: the track between Porta Santa Maria and Porta murata di Santo Stefano (above); the track in Tersanaia (below) (*Editing* V. Croce, M. G. Bevilacqua, G. Caroti and A. Piemonte)

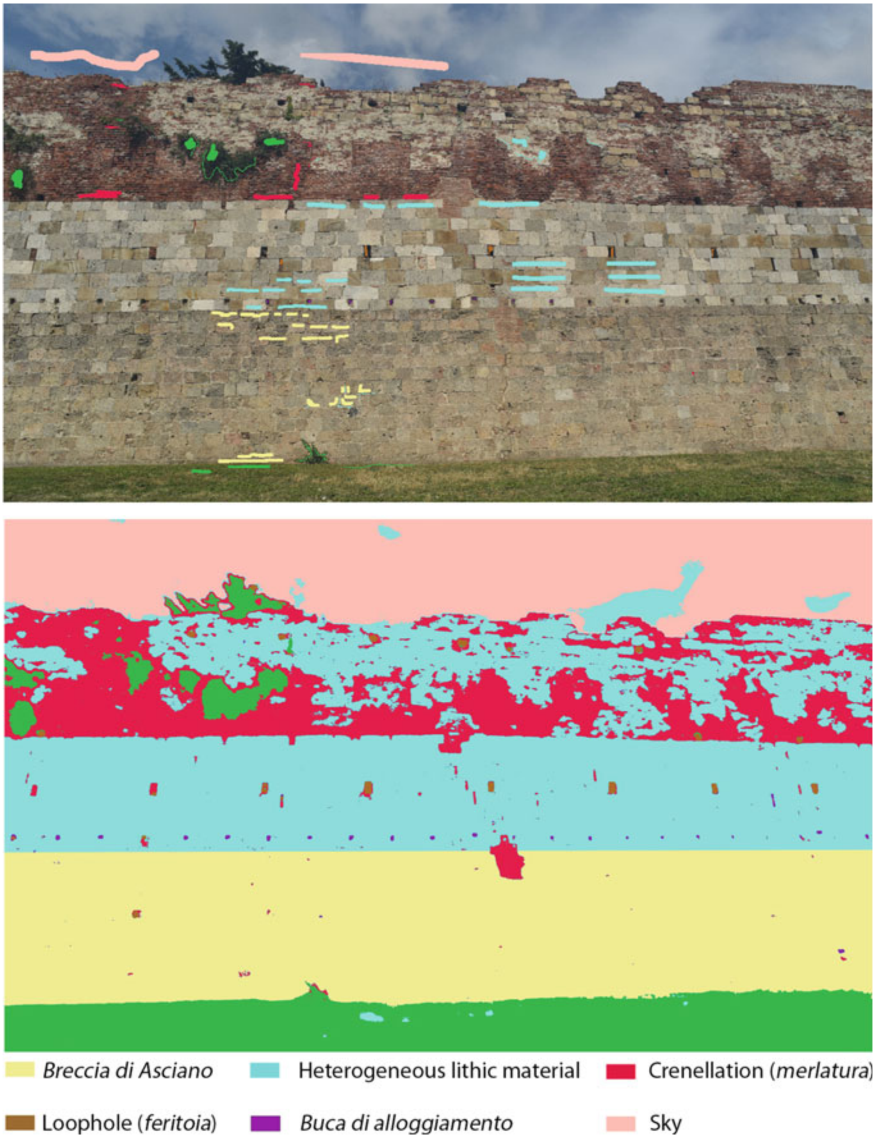

Fig. 4 Manual annotation of a single image (above) and related classification result obtained via the RF (below) for the track in Tersanaia (*Editing* V. Croce, M. G. Bevilacqua, G. Caroti and A. Piemonte)

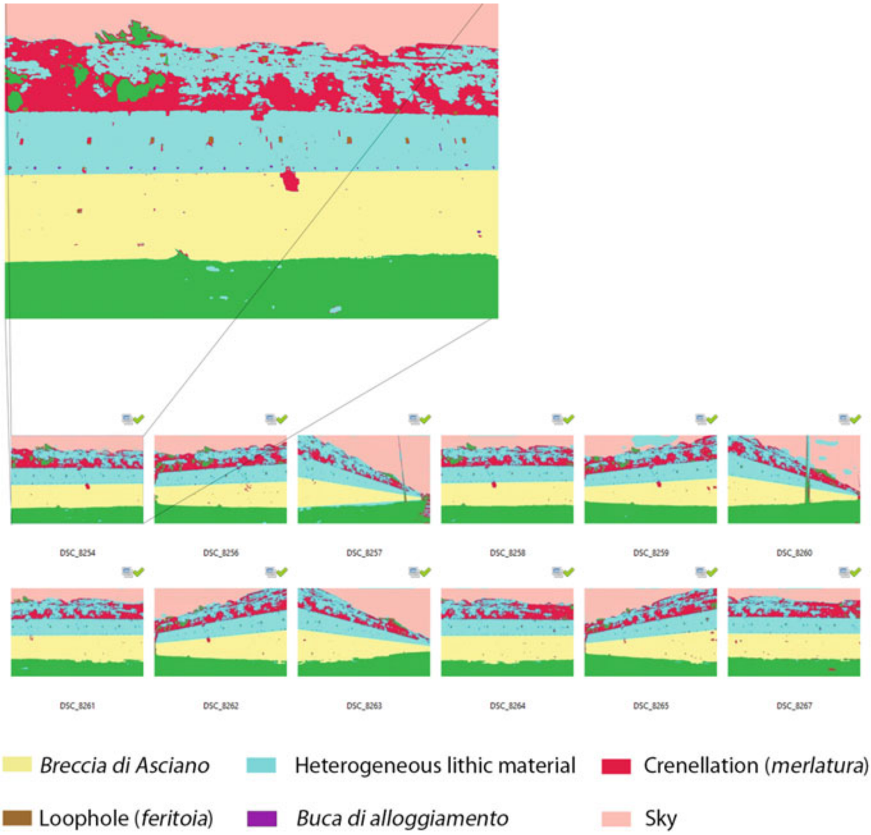

Fig. 5 Whole classified image set for the track in Tersanaia (*Editing* V. Croce, M. G. Bevilacqua, G. Caroti and A. Piemonte)

consider adjusting and equalizing the color values of the source images, relying on brightness, contrast and hue value adjustments. On the other hand, since the stratifications vary with the height of the wall sections, the classification of the images could be combined with other types of classification, e.g., with the classification of the 3D model based on geometric features, in order to rely on the height value (z-component) as a discriminative descriptor.

6 Conclusions

This paper combined ML-based image segmentation, leveraging the RF algorithm, and semantic annotation propagation for the stratigraphic analysis of the different lithotypes of Pisan urban walls. The work was aimed at testing the effectiveness and

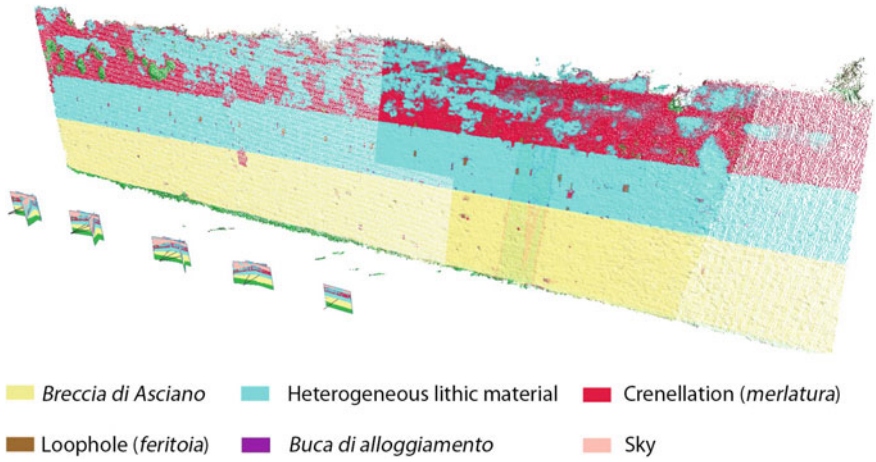

Fig. 6 Semantic segmentation annotations are transferred from the images to the 3D point cloud for the track in Tersanaia (*Editing* V. Croce, M. G. Bevilacqua, G. Caroti and A. Piemonte)

validity of supervised ML-based classification algorithms to support stratigraphic studies.

The results, presented on two pilot proof-of-concepts of the track in Tersanaia and the track between Torre Santa Maria and Porta murata di Santo Stefano, are promising in terms of multi-modal semantic enrichment of different 2D/3D digital representations and suggest a possible application of the proposed methodology to the remaining wall parts. However, in the case of lithotype classes presenting color homogeneity, misclassifications may occur if only texture-based approaches are applied: wherever the stratigraphic variations of masonry walls are more subtle and do not yield large color differences, it is believed that the combination with other classification methods -even conducted on 3D models as point clouds or meshes and taking into account geometry-based features-, might become essential.

A third relevant section of the city curtain wall, which concerns the portion between the Porta Calcesana and the Canto alle Piagge, is subject of current studies and is also being highlighted as a trait of historical importance: on this specific case, it is likely that it will be difficult to highlight the section corresponding to the breach opened by the Florentines during the siege of the city in the early 1500s, which has been recomposed with waste materials and rows of bricks (Fig. 10). More articulated sections of the wall, where the stratigraphic units are less legible, will be investigated in the future.

Furthermore, it should be noted that the results presented refer to image sets all acquired on a single day, with homogenous lighting and shadow conditions.

The application to image sets of the same object, acquired at different times, could be complicated due to the difficulty of combining all available images into a single photogrammetric model. The spatialization of images acquired in-the-wild, and the handling of the problem of radiance in 3D reconstruction from unconstrained photo

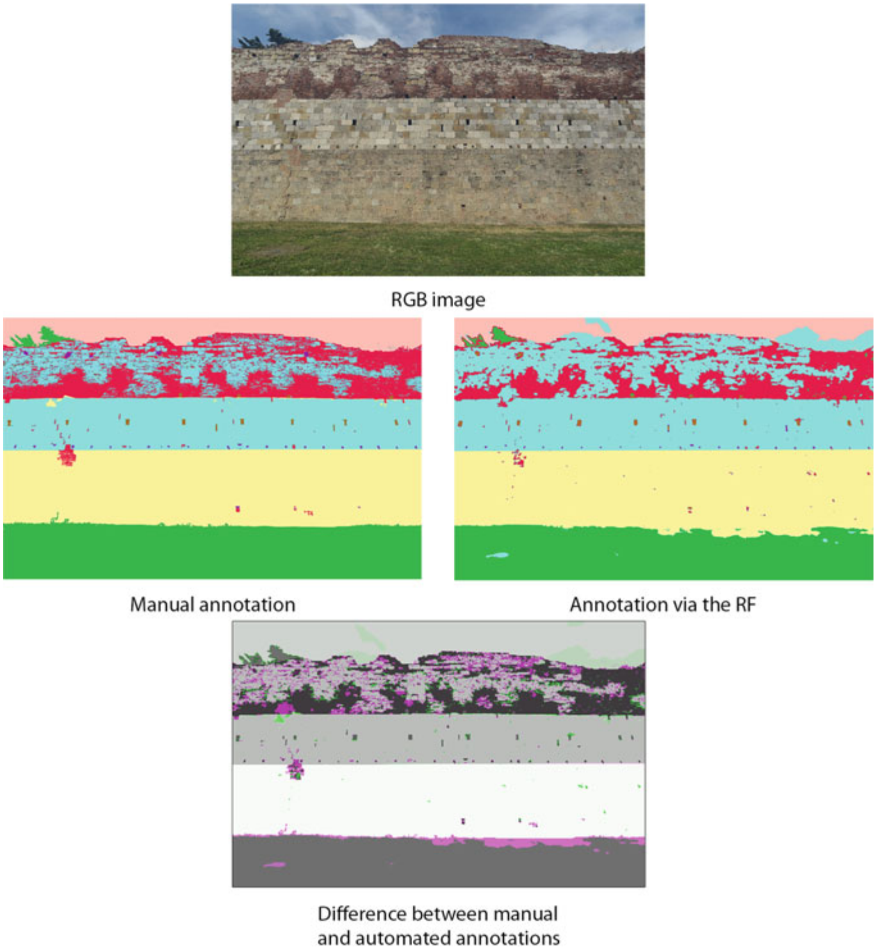

Fig. 7 Comparison of manual and automatic annotation of a sample RGB image. Magenta and green regions in the composite image (bottom) show areas of the images with different intensities (*Editing* V. Croce, M. G. Bevilacqua, G. Caroti and A. Piemonte)

collections, is a problem that still needs in-depth study, but which finds possible solution in the application of tools such as Neural Radiance Fields [24].

The extension to new case studies and the definition of more general tools for the semi-automatic recognition of lithotypes, taking into account the problem of scale of representation, are ongoing developments of this research, aimed at providing fundamental support for the stratigraphic analysis of masonry structures, also in the archaeological field.

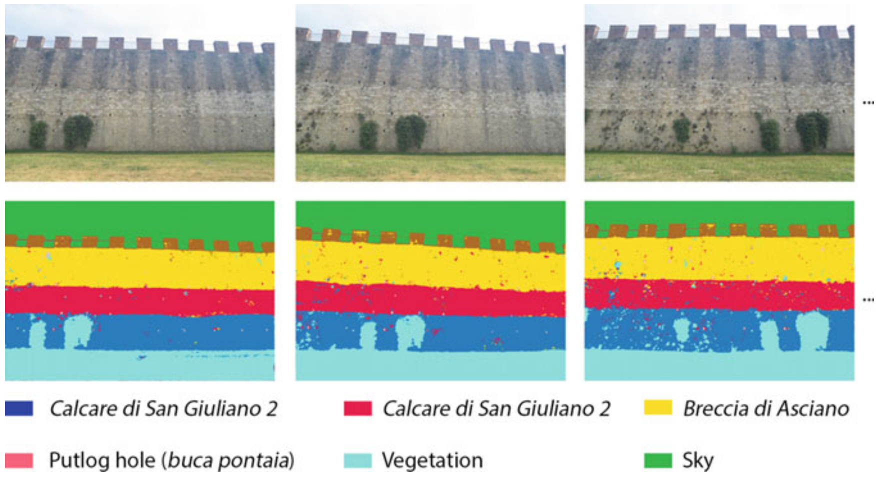

Fig. 8 Semantic segmentation annotations obtained on images for the track between Torre Santa Maria and Porta murata di Santo Stefano (*Editing* V. Croce, M. G. Bevilacqua, G. Caroti and A. Piemonte)

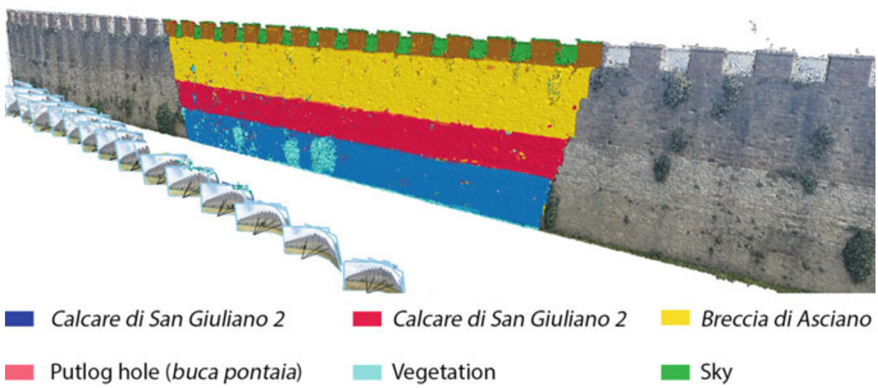

Fig. 9 Hybrid annotations between images and 3D point cloud for the track between Torre Santa Maria and Porta murata di Santo Stefano (*Editing* V. Croce)

Fig. 10 The breach opened by the Florentines during the siege of the city in the early 1500s in the wall track between the Porta Calcesana and the Canto alle Piagge (*Photo* V. Croce)

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Visual Programming for a Machine Semi-Automatic Process of HBIM Models Geometric Evaluation

Alessandra Tata, Pamela Maiezza, and Stefano Brusaporci

1 Introduction

The topic of the relationship between digital restitutive model and measurement can finds important development possibilities in machine procedures, of particular interest in the Historic Building Information Modeling (HBIM) field.

In fact, BIM uses parameterized and pre-defined objects in special 3D libraries articulated according to the architectural components, not corresponding to ideal configurations. Moreover, BIM platforms are limited in modeling deformations, damages, and degradations. All these aspects are fundamental for architectural heritage documentation and analysis, in particular for the restoration and management projects.

These difficulties in reconciling the standardization of architectural elements, typical of BIM, with the uniqueness of historical heritage, highlight the importance of evaluating the geometric accuracy of the restitutive models. Finally, the HBIM procedure differs from the BIM one, because it rises from the architectural surveying of the built artifact.

The present research investigates the relationship between the digital restitution model and the evaluation of geometric reliability. The paper aims to present the results of an ongoing experimentation relating to the use of the visual programming language

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for the development of a semi-automatic procedure for evaluating and declaring the geometric reliability of HBIM models, directly in the BIM environment.

2 Modelling Historic Buildings

The modeling of architectural heritage offers itself as a fundamental tool for the historical–critical analysis of its values. The three-dimensional model, in fact, makes it possible to highlight the characteristics of the architectural artefact in all its constituent aspects, leading to a deeper knowledge of the asset [1].

During the modelling process, the scholar analyses and interprets the data at his disposal, coming from different sources: archival documents, surveys, diagnostic investigations, etc. Thus, he arrives at the critical-interpretative model of the architectural asset which, in the necessary simplification of the three-dimensional representation, brings an increase in the level of knowledge.

In order for these models to have scientific foundations and therefore be testable by other scholars, it is essential that their elaboration process is methodologically founded and that this is made known, declaring the sources and the relative level of interpretation. In other words, it is necessary to declare the level of reliability of the three-dimensional model, both from a geometric-dimensional point of view and in terms of information content [2, 3].

In this context, BIM, as a graphical representation linked to a database, amplifies the importance of the reliability statement.

With regard to geometric modeling, in particular, HBIM poses the question of how to represent the complex and often irregular forms of historic architecture, characterized by the attribute of uniqueness, using parametric modeling based on typed objects, loaded by special libraries designed for new construction projects. It then becomes even more important to assess the deviation between the real object and its three-dimensional representation, in other words, it becomes essential to assess the deviation between the point cloud, a cast of the architectural element, and the 3D model [4, 5]. Measuring this deviation for each architectural element and, subsequently, evaluating whether it is acceptable or not, according to the purposes of the modeling and the characteristics of the architectural object, constitutes a fundamental phase in the process of representing architectural assets. In this the Visual Programming Language (VPL) can facilitate and speed up a process that can also be long and onerous. As well as for the modelling of building components themselves, VPL can be used to create algorithms through which a semi-automatic evaluation of the relative deviation can be carried out, significantly reducing the time needed.

3 The Reliability of the Representation

See Fig. 1.

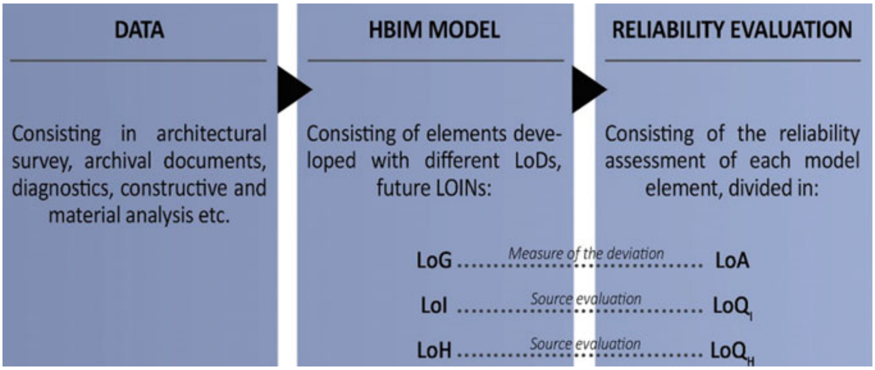

Fig. 1 Workflow of the BIM modelling of historical architecture: the data, once collected, are critically analyzed for the creation of the HBIM model, whose reliability must then be evaluated for all its information contents (geometric and otherwise) (*Editing* A. Tata, P. Maiezza and S. Brusaporci)

In the specific case of HBIM, in which the geometric representation is accompanied by the informative aspect which constitutes a fundamental characteristic of the model, the interpretative nature of the latter is amplified. Therefore, the importance of the scientific transparency, understood as the identification, evaluation and documentation of the sources used in the modelling phases, and of the reliability evaluation, to ensure the intellectual integrity of the methods and results of digital visualization, is evident.

Since the three-dimensional representation of the heritage is not to be understood as geometry alone but also as informative heterogenous content, the reliability of the HBIM model must concern both contents [6].

With the intention of guaranteeing the effectiveness of the HBIM process for the documentation and restoration project of historic buildings, a procedure based on the transparent declaration of the sources that substantiated the modelling and on the evaluation and communication of the reliability of the digital reconstruction through the introduction of a specific level, was defined [7].

In order to include all the heterogeneous aspects typical of historic buildings, often not fully taken into consideration in the BIM processes born for the new, three levels of reliability of the BIM models have therefore been introduced. Those levels are: the Level of Accuracy (LoA) for geometric attributes (LoG), which expresses the geometric accuracy of the three-dimensional representation with respect to the real object; the Quality Level (LoQ) for the non-graphical attributes, with a different subscript to indicate the reference to the informational attributes (LoI), or to the historical ones (LoH) (Fig. 1). The LoQ, in particular, expresses the reliability of the sources used for the modeling and can be divided into several sublevels, as many as the different types of information included in the model.

The Level of Accuracy (LoA) depends on the Level of Geometric Development (LoG) of the architectural element, and is evaluated differently depending on whether

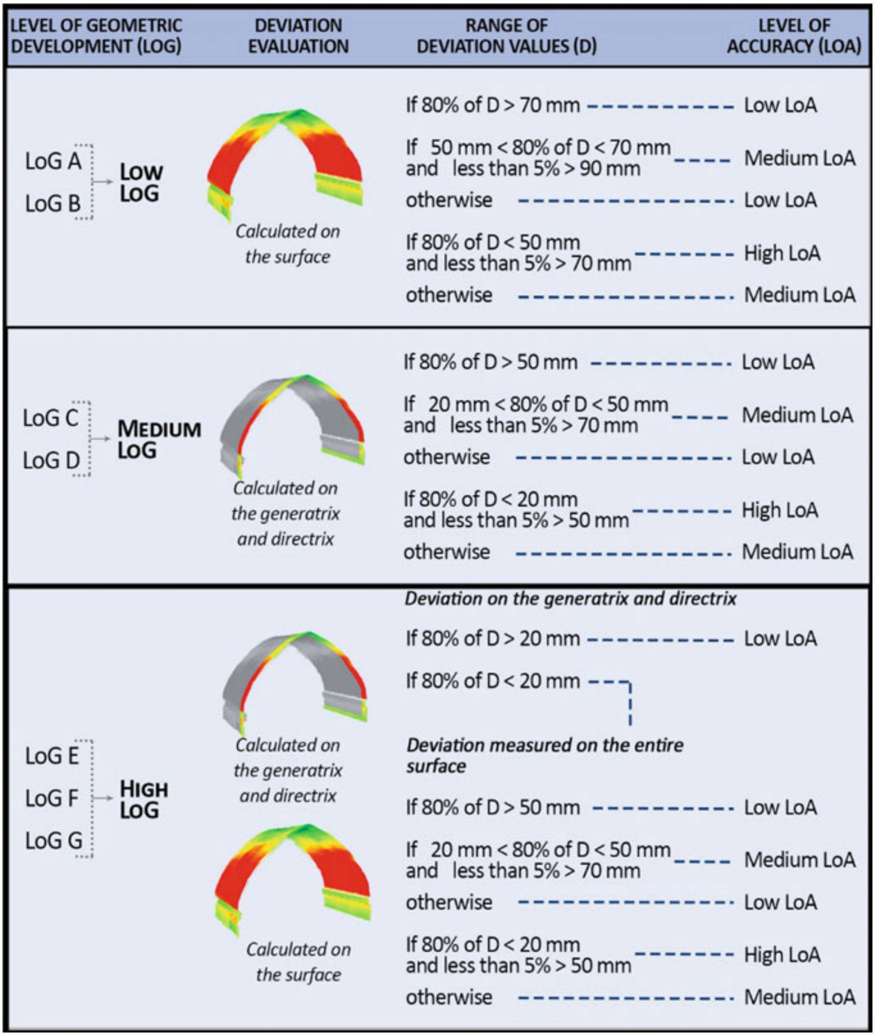

Fig. 2 Assessment of geometric reliability: based on the geometric development of the model element (LoG), reference ranges of the deviation between the point cloud and the model with corresponding Level of Accuracy (LoA) are proposed (*Editing* A. Tata, P. Maiezza and S. Brusaporci)

the LoG is low, medium or high. Specifically, the standard states that the geometric reliability is evaluated: with respect to the entire surface of the object, in the case of low LoG; with respect to the element's generatrix and directrix, in the case of medium Log; both with respect to the generatrix and directrix, and to the entire surface, in case of high LoG.

For each of these levels, acceptable deviation ranges have been established, which become more restrictive as the LoD increases.

Finally, to define the Level of Accuracy, the proposed standard, after the evaluation of the deviations, requires compliance with certain percentages (Fig. 2). Specifically, therefore, to have a specific LoA, based on the LoD, the eighty percent of the deviation must fall within the range of deviation concerned, and no more than 5% must be greater than a certain deviation value considered acceptable for that particular LoD. Otherwise, the LoA of the model element will be the immediately lower one.

Therefore, in operational terms, assuming the need to evaluate the reliability of a tridimensional element with a low LoG, the reliability will be high if the 80% of the deviations is less than 50 mm, and no more than the 5% of the deviations have a distance greater than 70 mm, otherwise the LoA of that model will be medium. Similarly, if 80% of the deviation is within a distance of 50 to 70 mm, and no more than 5% is greater than 90 mm, the LoA of that model will be medium, otherwise low.

This percentage constraint is also valid for the evaluation of the deviations on the directrixes and generatrixes.

So, taking the high LoG as an example, if more than the 80% of the deviations on the generatrixes and directrixes is greater than 20 mm, the LoA will be low, if more than 80% is less than this distance, however, the LoA will vary depending on the deviation measured on the entire surface. In this case, the model may have:

- A high LoA, if at least the 80% of the deviation is less than 20 mm and no more than the 5% have a distance greater than 50 mm.
- An average LoA if at least the 80% of the deviation is less than 20 mm, but more than the 5% is more than 50 mm apart, or if the 80% of the deviation is between 20 and 50 mm and no more than the 5% have a distance greater than 70 mm.
- A low LoA, if at least the 80% of the deviation is between 20 and 50 mm but more than the 5% is bigger than 70 mm, or if the 80% of the deviation is within a greater distance to 50 mm.

The Quality level (LoQ), on the other hand, concerns all those information contents that cannot be traced back to a directly measurable geometric shape and depends both on the LoI and on the sources on which the modeling is based (direct, indirect, exhaustive or not).

4 Visual Programming Language for the Semiautomatic Assessment of the Geometric Reliability

See Figs. 3, 4, 5, 6, 7, 8, 9.

Computational design consists in the application of computational strategies to the design process and has the aim of improving the latter, by identifying and codifying the aims, constraints, and goals of the project, through the use of computer language.

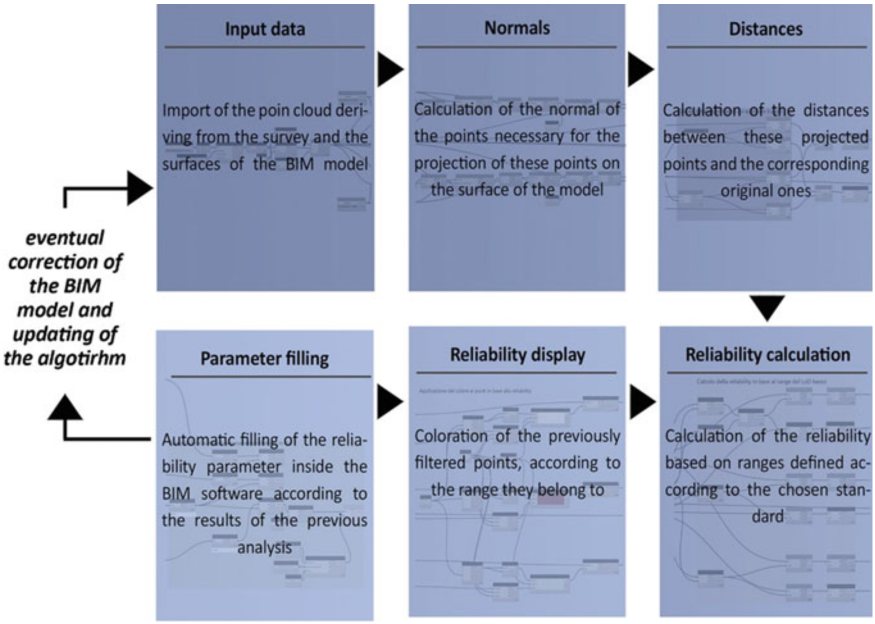

Fig. 3 Operational steps for assessing the geometric reliability of the model using Visual Programming Language (VPL): import of the point cloud and BIM model into the VPL environment; calculation of the normal of the points with respect to the surfaces of the element; calculation of distances between the projected points and the corresponding ones belonging to the original point cloud; evaluation of reliability according to the standard; visualization of geometric reliability; automatic compilation of the reliability parameter linked to the model element (*Editing* A. Tata, P. Maiezza and S. Brusaporci)

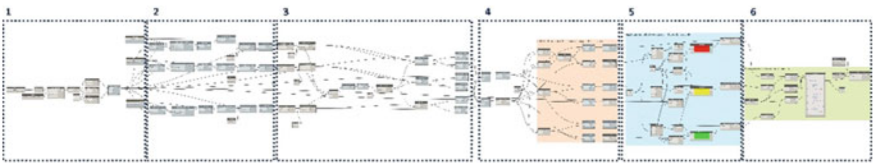

Fig. 4 Algorithm for the calculation and the evaluation of the deviation, and for the declaration of the reliability, according to the six identified operational steps (*Editing* A. Tata, P. Maiezza and S. Brusaporci)

Many computational design tools are nowadays relying on the use of Visual Programming Language applications, in which programming takes place through the manipulation of elementary graphic units called nodes, each with a specific task, which are connected in a dynamic system, and in logical sequence, by using wires that connect the outputs of one node with the inputs of the next. Programming flows from one node to another through the network of connections. The result is a graphical

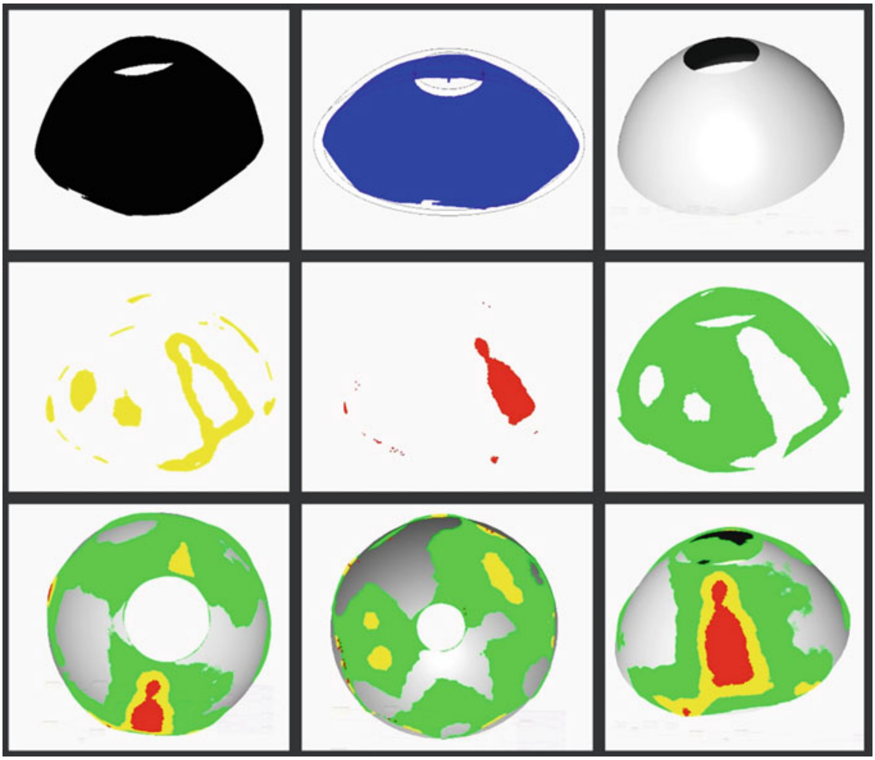

Fig. 5 Display of the different stages of the deviation assessment of a case study (the dome of the baptistery of Santa Maria Extra Moenia in Antrodoco, RI) with the progress of the execution of the algorithm. The first line shows the creation of the point cloud in the VPL environment to the left, the use of the point cloud as a guideline for the creation of the HBIM model, in the centre, and the import of the model surface into Dynamo on the right. The second line of images shows the outcome of the reliability assessment into Dynamo, and the third one shows its overlap with the model surface (*Editing* A. Tata, P. Maiezza and S. Brusaporci)

representation of all the steps necessary to achieve the result, in which the modification of an input of one of the nodes spreads to all the connected elements, making unlimited and semi-automatic modifications possible.

Visual programming tools offer a possible development in the application of BIM to historic buildings, being increasingly used today with the intention of overcoming some of the limitations of HBIM, particularly in the various areas of modelling and management of complex geometric shapes, characteristic of heritage buildings [8–10].

The use of VPL, in fact, can increase the possibilities given by BIM software, born for new buildings, making their use more flexible, reducing both the difficulties and times of modeling and managing the information content, making it possible to control every aspect and constraint, and partially automating the modification processes.

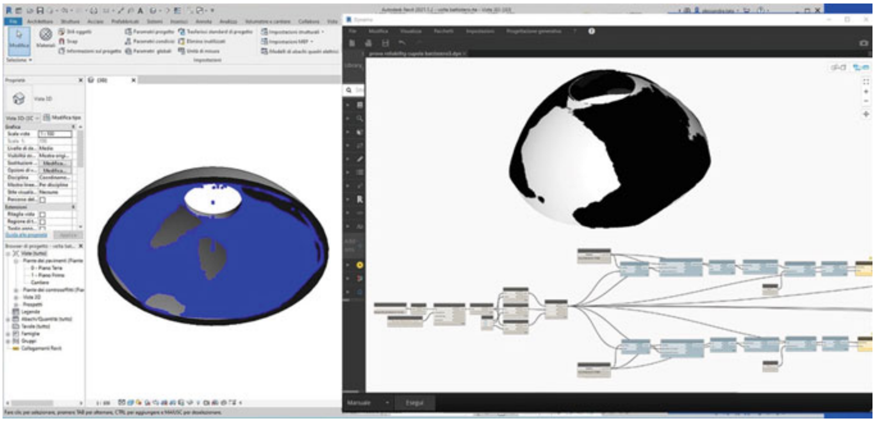

Fig. 6 First phases of the assessment of the reliability of the dome with medium LoG in the BIM environment and in the VPL environment (*Editing* A. Tata, P. Maiezza and S. Brusaporci)

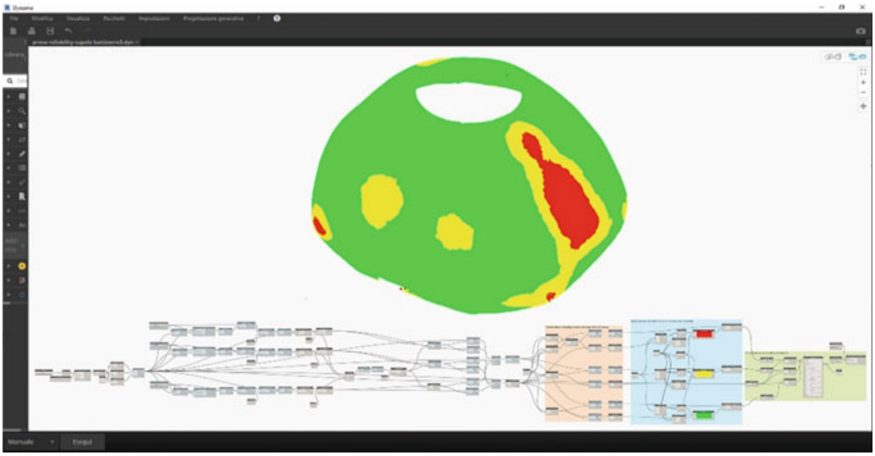

Fig. 7 Assessment of the reliability of the dome model with average LoG in the VPL environment (*Editing* A. Tata, P. Maiezza and S. Brusaporci)

The current experimentation was developed using the softwares Autodesk Revit and Dynamo, which allows the direct connection between the algorithms and the BIM environment.

Based on the standard defined and presented formerly, a programming for the calculation, the evaluation and declaration of the LoA, valid both for the calculation of the model accuracy on the entire surface, and on generatrixes and directrixes, was then developed.

The developed algorithm can be organized into six functionally different phases (Figs. 3, 4, 5).

Fig. 8 Evaluation of the deviation on the dome's generatrix and directrix (*Editing* A. Tata, P. Maiezza and S. Brusaporci)

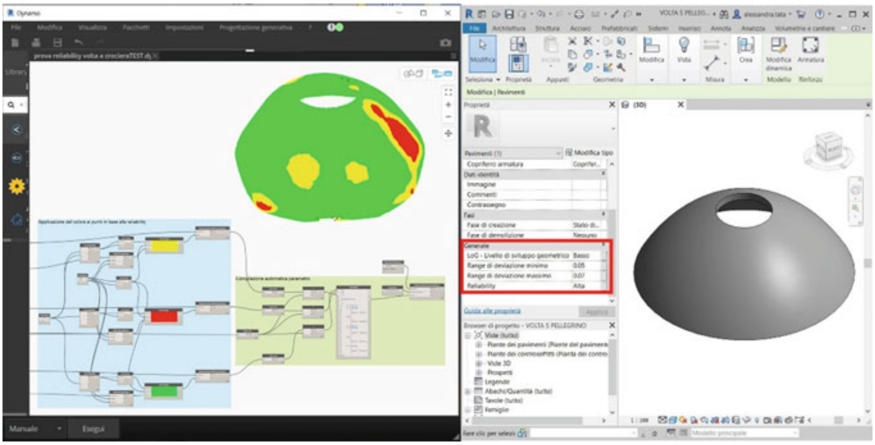

Fig. 9 Evaluation of the deviation on the dome surface and automatic compilation of the parameters in the BIM environment (*Editing* A. Tata, P. Maiezza and S. Brusaporci)

The first part of the algorithm consists in importing into the VPL environment the point cloud deriving from the survey and the surfaces of the BIM model element of which you want to measure the deviation and evaluate the geometric reliability. The points are imported in the form of coordinates within an Excel file, and are created directly within Dynamo, while the surfaces are selected directly from the model in the BIM environment, through the use of specific direct selection nodes (Fig. 6).

The second part of the programming is dedicated to the calculation of the normal of the points with respect to the surfaces of the element.

This part is necessary to ensure that the algorithm can apply the points to the corresponding surfaces, guaranteeing a correct reliability calculation, regardless of the complexity of the point cloud and the quantity of surfaces of the element whose reliability is being calculated. The calculated normal, in fact, are used as directions to project the points perpendicularly onto the surfaces of the model, and thereby select only the projected points that actually intersect them.

The projected points are then used in the third part of the algorithm to calculate the distances between them and the corresponding ones belonging to the original point cloud. Since some points can be projected perpendicularly and can intersect several surfaces, to be sure of applying them to the correct ones, the distances of the points compared to all surfaces were measured and, in the presence of several distances, for each point it was selected the smaller one.

Finally, a belonging check was carried out within the lists containing the distances of the points with respect to the various surfaces, and for each surface the points of the cloud were selected based on the resulting distances and the previously set constraints.

In the fourth part of the programming the deviation values based to the ranges defined in the chosen standard are then imported. The distances of the points resulting from the third part of the programming are filtered according to the acceptable ranges, defined according to the LoDs, and the geometric accuracy of the model with respect to the point cloud is evaluated.

The fifth part of the programming is dedicated to the visualization of geometric reliability. Through the use of specific nodes, the previously filtered points are colored (red, yellow and green), according to the range they belong to (respectively low, medium or high) (Figs. 7 and 8).

Finally, the sixth part of the programming consists of the automatic compilation of the reliability parameter linked to the model element. In this phase, the calculated distances percentage of belonging to the three ranges of reliability (low, medium or high) is then calculated and, according to the maximum percentages assessed as acceptable in the standard previously defined, the reliability parameter of the BIM element is then automatically and compiled, thus allowing to know, directly within the BIM environment, the accuracy of the three-dimensional object (Fig. 9).

5 Conclusion

The declaration of the reliability of the model, both geometric and informative, is a fundamental aspect for the representation of the architectural heritage. With regard to geometric reliability, in particular, HBIM amplifies this need as it requires reconciling the uniqueness of the historical architecture with a standardized and typified modeling, for which the evaluation of the deviation with respect to the real object becomes even more important. This operation, indispensable for each architectural element that makes up the model, involves a considerable consumption of time, which can be significantly reduced thanks to the aid of visual programming.

The advantage relating to the use of VPL is that, once the programming has been developed, it can be repeated several times, both on the same object and on different elements belonging to different assets. By updating the three inputs (Excel file containing the coordinates of the point clouds, surfaces of the BIM element and values for the reliability ranges depending on the LoD) it is therefore possible to semi-automatically calculate the geometric reliability of the three-dimensional elements and automatic filling of the relative parameter, directly in the BIM environment.

Furthermore, in case of unacceptable deviation values, it is possible to modify the model and re-verify it expeditiously, remaining in the BIM environment, thanks to a partial automation due to a modifications cascade propagation system, which speeds up the reliability evaluation process and the relating parameter compilation. The developed algorithm, therefore, makes it possible to semi-automatically evaluate the reliability of the three-dimensional object, on the basis of the rules, constraints and inputs pre-established in the standard, and according to the quantity and extension of the deviation.

In conclusion, the use of algorithmic programming within the HBIM processes, through the use of the VPL, allows to deal with the critical issues of BIM environments for the architectural heritage in a more flexible and rapid way.

In fact, the joint use of BIM and VPL, if structured effectively, could lead in the future towards the use of dynamic and flexible alternative workflows, which allow the creation of structured, reliable and easily queryable models, useful for the documentation, study or development of restoration projects, carried out with total respect for the qualities of the building.

Acknowledgements Although the paper was conceived unitedly, Tata is the author of The reliability of the representation, Visual Programming Language for the semiautomatic assessment of the geometric reliability and Conclusion, Maiezza is the author of Modelling historic buildings; and Brusaporci is the author of Introduction.

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New Representation Tools in VR and Holographic View

Cecilia Bolognesi and Daniele Sorrenti

1 Introduction

In the field of Cultural Heritage (CH) as well as design and new construction, people enjoying representations of individual architecture belong to different groups: from art historians to non-specialized audiences, simple users, engineers, architects, or ordinary people [1]. Representation in these multiple contexts assumes a key role and addresses important issues such as shared symbols and tools. Representation always interprets a process of translation within it of procedures, norms but also deep content that must be able to be understood by individuals or groups, specialized or not. This process of mediating between the object made/to be made and a wider public equally touches both the field of the built and the designed [2]. Comprehensive representation is an essential necessity in the field of architecture and pressing in an increasingly complex field, that of construction. It is quite evident that efficient informed representation leads to improvement in the construction process. The quality of the process of representation during the design stages goes hand in hand with an optimization of implementation, reducing misunderstandings among designers and improving user satisfaction. The same can be said for the representation of existing CH (Cultural Heritage) examples; accurate representations are the primary means of communication among scholars as well as among a wide audience of enthusiasts [3]. However, the current representation, which tries to broaden the audience of users, has often failed to meet the requirements of increasingly complex projects; this can be blamed on an increasing complexity of projects, a permanence of the fruition of 3D models still in the traditional mode on two-dimensional surfaces, and a less and less crescent

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figurative education. This situation opens many challenges for representation as a medium for communicating architecture [4] both for CH and project communication for the AEC industry since the demand for a better understanding of the artifact is increasingly growing, regardless of the actors involved (simple users, stakeholders, specialists). In CH the growing needs for building protection and digital acquisitions [5]: to maintain the memory of places likely close to destruction by environmental or other hazards grows expectations for digital models that are perfectly consistent with the existing [6]. In the field of Architecture Engineering Construction, a progressive separation of knowledge, has seen the dividing between the skills of the architect, engineer and builder, causing confusion and misunderstanding, and ultimately causes defects and waste of time, making a moment of representative synthesis of the whole artifact even more necessary [7].

Both expectations fuel the demand for new forms of vision with respect to the object, not only more engaging but certainly more understandable by all [8]: and such drive for process integration introduces new communication challenges for the industry. With the advent of Industry 4.0, there is an increasing need of the creation of a digital value chain that enables the communication various stakeholders, and the digitization and automation in manufacturing processes too [9]. One of the most effective technologies to communicate heritage and digitize the construction process is virtual reality (VR). VR is defined as an entirely computer-generated environment where users have experiences with the environment and surrounding objects, navigating these environments. The 3D computer-generated representation surrounds the subject who can move around in the virtual world and see it from different angles, interacting with it. The advantage of VR lies in its ability to produce visual synthesis when put in relation to traditional representation methods by sharing 3D models that reduce spatial interpretations that are often the result of two-dimensional decomposition and users' poor reading skills. Its characteristics become the easy way to get a synthetic view of the three dimensions of space [10].

VR can be divided into two specific fields that are in fact different in the type of device with which it is enjoyed: fully immersed VR and partially immersed VR. Immersion indicates the objective level of sensory fidelity of a VR system; fully immersed VR, immersive VR, has a higher level of immersion; the user can only see the virtual world because it is covered by devices such as goggles or headsets. 3D tracking systems and stereoscopic projection displays are the necessary tools to support VR systems [11]. On the other hand, the partially immersed VR system, is typically displayed using a computer screen, or mobile devices and users who are aware of the real environment when they are experiencing a virtual environment. In this paper, we insert a third viewing possibility, also in VR but not in a laptop but in holography, therefore related to the 3D representation embedded in physical space in three dimensions. This type of visualization loses some of the immersiveness of full VR but acquires a spatial dimension perceivable through goggles that track users' movement and allow stereoscopic viewing.

2 Immersive Environments

2.1 The VR Perspective

To better understand how VR can potentially improve the communication of representation in the CH and AEC sector, it must be understood what aspects of communication through VR have been studied for now. Trends of VR application in CH can be described as: the dissemination of immersive environments for the reconstruction of monuments that no longer exist [3, 12, 13] the creation of educational an learning games [14]; the study and historical analysis; the repurposing of settings for creative industries; and the repurposing of environments for evolved social [15].

In the AEC construction domain, VR has been used for industry-specific education [16], visualization of complex environments, sharing with stakeholders and different interest groups for construction safety training.

The VR can enhance the communication processes within the CH and AEC domain, and this is both in the educational domain of learning [17], as well as in the domain of the profession or fruition to a non-specific audience so for both industrial and educational applications.

The aim of this paper can be useful to both practitioners in the field and researchers in AEC and CH-related contexts and spur recognition of the potential of these applications to guide research and development of VR for many field of knowledge to implement the virtual value chain that supports communication of architecture. It should be noted that it is only a recent interest the use of VR as a tool for representation education in CH and construction learning; a blended approach of teaching is shown to be much more fruitful than traditional teaching with greater cognitive benefits [18, 19]. However, no application of VR is generally considered during its design for the specific domain that it wants to foster, while efforts should be directed in this direction precisely to evaluate different approaches in learning and knowledge.

For this reason, this paper will evaluate Immersive experience VR/AR for both educational and professional project by implementing apps for the representation, interpretation, and management of Cultural Heritage [20]to be enjoyed in immersive realities for more engaging experiences [15]. Just the same will be done for an app that will be developed for fruition on the professional side. With the lowering of the cost of tools for immersive enjoyment, it has gone from a technology that can be used by a small group of researchers to one for a wide audience making it in fact a complementary technology in education [8], useful to many laboratories in research centers as well as universities [21–23], opening new doors for distance and remote learning improvement.

2.2 *The First Steps*

VR as we understand it today is a totally immersive environment that allows users to interact with what they see by altering their perception to the point of convincing the brain that their perception of the environment is real. Its beginnings are commonly shared starting with Morton Heilig's invention of a multi-sensory simulation device called Sensorama patented the Telesphere mask: the first Head Mounted Display (HMD); the device allowed the user to view not-interactive films and was equipped with stereo sound although with no head tracking system. One year later, two Philco Corporation engineers (Comeau & Bryan) patented what can be considered as the first headset of history: Headsight. The greatest novelty brought was a fully working motion tracking system, implemented by a closed-circuit camera linked to the magnetic system; head movements would move a remote camera, making the user able to navigate inside the simulated environment. The same research for the most immersive user experience can be found in 1968 when Ivan E. Sutherland, developed with help of his students, a prototype of The Sword of Damocles (Fig. 1), consisting in an enormous HMD connected to a computer that would generate wireframe rooms over what could be seen from the user perspective.

The Sword of Damocles was the first HDM generating and visualizing images with a computer instead than visualizing from a camera.

Making the user able to interact with the simulated environment can largely enhance his perception over it, to make the interaction possible where hand movement detection is mandatory and, in 1977, a first prototype, the Sayre gloves, implements it through light-based sensors situated all over a glove. In the field of professional education and training, a growing interest was developed from last century to present days around stereoscopic view and immersive tools realizing amazing advances in the field of vision (Fig. 2); after that VR's pervaded higher education in different projects connected with scientific contents. At the beginning of the 90s Virtual Reality shifted

Fig. 1 Ivan Sutherland Sword of Damocles (1968) (*Source* ResearchGate)

Fig. 2 **a** Stereoscopic (1830) **b** HTC Vive (2016) **c** Oculus Quest 2 (2020) (*Editing* D. Sorrenti)

from its private research nature into a public oriented one, where VR device were explicitly created for entertainment purposes. Today VR devices comprise mostly headsets, or Head Mounted Displays, where the illusion of 3D is accomplished through two stereoscopic lenses that distort the screen into two slightly different 2D images. These images are then elaborated by the user perception into a fake 3D image. To create the 360° environment in which the user shall feel immersed into, display is moved accordingly to the user head movement, tracked with sensors mounted on the headset; head movement tracking is also utilized for audio computing, then played on two different speakers, one per user ear, exploiting new spatial audio technologies. In general, all VR headsets revolve around isolating the user's view from the outside world, using a pair of Fresnel lenses and screens to trick the eye into perceiving the depth of the reproduced objects. As the uses are different, the technology has diversified.

2.3 The Actual Hardware Environment

There are currently three different families of devices for immersive enjoyment that we list below [24].

Lightweight headphones: these are devices that have the ambition of being able to be used in any situation and therefore have a high degree of portability. Comfort and weight can affect the fidelity and complexity of the system they handle, so they are very simple in design and lack the computational units used to render scenes autonomously. In most cases they also require the use of a phone either as a screen or as a controller to manage the applications within them. Among these- Google Daydream View- Oculus Go- Vive Flow. For some of these, development has already stopped as they have not met with the hoped-for public favor. The leading model does not require connection to a PC to work, but still needs to be recharged periodically and can be plugged in via a USB cable; the device does not allow wireless but works with Bluetooth. It supports hand tracking and is an agile device that can render views on its own; its design is much more like a pair of glasses than a full headset.

Standalone headset: here the design focuses more on the ability to reproduce most uses of VR without the need for an attached external rendering unit, less computational power but directly installed into the headset. To be used without any external aid, inside-out tracking is always used to follow the user in 3D space, and the headset is equipped with controllers. Equipped with built-in processing units they allow rendering of more complex scenes but while covering most uses, they do not have the processing power to render more complex scenes and high-fidelity models by resorting for these situations to an external unit via pluggable cables.

Examples are Oculus Quest 1 e 2, Vive Cosmos e Focus.

Wired headset: when greater accuracy and processing power is required, wired headsets are usually the best choice since they rely on an external computer for rendering. Most often they use outside-in tracking, in which dedicated sensors take care of tracking the headset and controllers in 3D space. Processing on an external unit, as well as tracking, leaves much more room inside the headset design to better screens, and they are the best choice when it comes to having a dedicated VR environment where complex scenes with large amounts of data must be developed. Examples of such devices are: Oculus Rift, Vive Pro, PSVR.

With the increasing quality of standalone headsets that can be used in most VR cases, this kind of device is beginning to be considered somewhat obsolete even though the leader in this category is still used abundantly in development environments as we did in the case study developed. The great advantage of all these devices is the portability and immersiveness that allows a total disconnection from the real environment that simulates belonging to a different world. But the substantial flaw lies in single fruition, in not sharing the experience and content synchronously among multiple stakeholders, which can be a flaw and, in some cases, education classes and stakeholders' opinion, can be necessary. For this reason, immersive fruition show different possibilities with different devices such as immersive theaters or holographic tables. Among these possibilities our goal has been the implementation of some features for better representing Architecture in the Virtual domain through specific visualization tools both in Oculus and Holographic Table.

2.4 Holographic Immersion

Holographic visualization makes possible to overcome the limitations of a flat computer screen in the exploration of three-dimensional digital content. With holographic devices, 3D and mesh three-dimensional models can enter the real world in the form of holograms and seem to be the most challenging way to visualize and act on both large-scale and highly detailed digital data with applications ranging from industry to medicine. In recent years, holographic visualization has been entering both educational and professional practice by enabling the visualization and management of heritage architecture as well as design: it can become an integral part of preservation procedures and understanding of CH structures.

The holographic table considered is configured as the latest find in the field of multi-user visualization and is based on the principle of refraction of light rays that converge in the creation of a single model. The device typically consists of a flat screen and a built-in projection system. The latter allows 3D models to be displayed in the center of the table up to a height of 70 cm in a hemispherical volume. The holographic system is operated by workstations with powerful graphics cards.

One of the two receives images to be displayed on the glass surface in the center of the table through four projectors A specially designed wand and goggles enable immersive interaction with the holograms, which use an infrared tracking system to calculate position and orientation in space in space. The tracking equipment consists of four tracking domes arranged at the four corners of the table and the controllers, Radio Frequency Dongle and Sync Emitter, connected via USB to the PC.

Two spheres on the wand and goggles allow their correct position location to be determined. The Sync Emitter takes light from the glasses and wands and synchronizes all devices to work together. Two primary users (equipped with wands and glasses) can together view and interact with the hologram. A secondary user (equipped only with glasses) can be added for each primary user, who must be on the same side of the table as the primary user.

With the innovative multi-user hologram technology, two people or two groups can see projections of objects on the table from different sides.

In the case of larger groups of people, an external projector can be connected, allowing what is displayed on the glasses to be displayed on the wall, losing the immersive effect. Usage can vary from displaying point clouds, 3D models or meshes. Parallel to holographic tables there are other devices to simulate 3D projection in space such as transparent films or projections on films on glass, but these are precisely simulations on transparent surfaces.

It is also possible to carry out implementations and modifications of the language using Unity, and it is on these implementations that are useful in teaching as well as research.

3 The Developments

Enhancing the process of 3D modeling with new experiences for the students and stakeholders, testing new technologies and then experiment and exploit to provide the best, immersive, and responsive experience possible is the aim of this research: establishing a workflow between 3D models and devices such as the holographic table and Virtual Reality devices the natural action to reach the goals. New data exploration features have been designed and implemented to fully exploit the immersion provided by devices. Both Virtual Reality devices such as Headsets and Euclideon HoloTable are supported with a well suited Unity API; furthermore Unity provides a proprietary plugin, Unity Reflect, that helps in converting model, from geometric to informed models into a Unity format freely exploitable.

3.1 The Development Environment

Unity Reflect [25]is a software specialized in converting 3D objects between modeling software (Architecture side) and Unity editor (Technological side) [26] this feature opens a wide range of opportunities in developing custom applications that both include representation modeling capabilities of 3D modeling software, and application versatility with Unity. Unity is a game engine for application development, capable of interacting with external devices and software with a user-friendly plugin system; both Holographic table and Reflect need to have their plugin installed on the editor to work correctly with the application. The developed software utilizes Unity Reflect Develop feature (possible with Unity Reflect Develop license) to create a custom Unity program that can interact with Unity Reflect API, allowing the importation of models created in 3D modeling environments such as Revit, Rhino or Sketchup, to be visualized with new tools and technologies coded with the Unity editor.

Purpose for this application consisted in implementing a user-friendly pipeline between any modeling software and Augmented/Virtual reality technologies, specifically the Holographic table, and Virtual Reality devices such as Oculus Rift to improve the ability to understand objects. This can be reached by improving the three-dimensional perception of the object and offering more tools for spatial visualization; this pipeline has been developed with the specific intent of being usable with little to no technical knowledge of the underlying Unity and Unity Reflect technologies, promoting collaboration between informatic and architecture environments, informatic and architecture students, vastly different in coding and technological backgrounds. It's worth mentioning that this pipeline has been coded with scalability as a top priority, facilitating the introduction and implementation of new features and tools and minimizing the effort required for integration with the previously implemented tools.

3.2 First Tool: Annotation in VR

Unity Reflect provides a collaborative annotation feature. Users are capable, by utilizing this tool, of selecting an object and writing an annotation attached to it and these annotations will be visible to all users and can be replied to, deleted, or edited by allowed users. To utilize this feature and other Unity Reflect Review tools (such as light manipulation, BIM information visualizer, filter, measure tool) users needs a Unity Reflect Review license. It is worth mentioning that it's also possible to purchase Unity Reflect Collaborative licenses for view-only usage, these licenses can be dynamically utilized by non-registered users with a link sharing system. The workflow is clear in the following image (Figs. 3, 4).

The main model to be visualized at the end of the pipeline needs to be created with a Reflect supported software and the appropriate Reflect plugin installed (currently

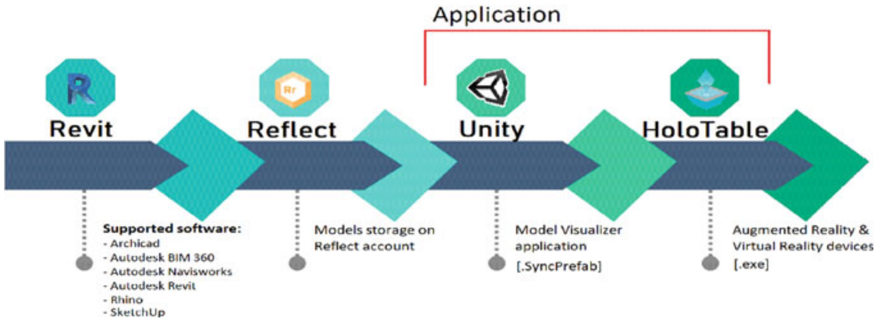

Fig. 3 General workflow from digital model to the application both for Oculus and Hologram Table (*Editing* C. Bolognesi)

Fig. 4 Annotation case on a Cultural Heritage monument, the Airuno Sanctuary floor; view from laptop or Oculus or Hologram Table (*Modelling* D: Bassorizzi; *Editing:* D. Sorrenti)

supported programs are ArchiCAD, Autodesk BIM 360, Autodesk Navisworks, Autodesk Revit, Rhino and SketchUp); the user also needs a Unity Reflect account for exporting and storing the models. Every object that can be opened with those programs with a 3D view can be exported and analyzed with the custom application further on; it's worth mentioning that Unity Reflect stores metadata linked to the objects composing the model, keeping information during the entire pipeline process. This data will then be exploited for the new tools design and implementation on the custom application such as the Heatmap tool.

The plugin allows to export a 3D view of the model and store it (both cloud or locally) on the Unity Reflect account, during the exporting process the 3D view is converted in a Reflect format importable on Unity through the specific plugin (Fig. 5).

Once stored on the Reflect account, the model can then be imported into the application using the plugin Reflect Importer feature as a .SyncPrefab, a format used by Unity to store and utilize linked objects with information such as position, references to other objects, data and textures. Every object of the prefab is enriched with a Reflect add-on in the form of a script, a Metadata script that contains methods and attributes used for retrieving object data elaborated from the modeling software model, such as the width of a wall, plumbing coefficients of pipes, structural components and so on. Each parameter is saved in a data structure called Dictionary, composed by a Key (specifically in this case key consists in the name of the parameter, such as Width) and a Value (in this case a custom object with every relevant information for the parameter) as the following Fig. 6 shows.

This application has been developed with the purpose of visualizing information related to multiple models at once with the possibility of dynamically turning off/on models to facilitate comparisons among different sections, as a common use case, user is able to view the structural, plumbing, and architectural models all at once or with any required combination to view common parameters or highlight respective positions of objects among different models. The application instantiate the .SyncPrefab objects related to the selected models in the menu and effectuate the required computation to all the models (Fig. 7); it's worth mentioning that with an adequate shared coordinates system, different views referring to the same model will overlap the same way seen on the modeling software.

During this step the entire Holographic table surface will be used by the User Interface. Whenever the View button is selected the models will be instantiated on

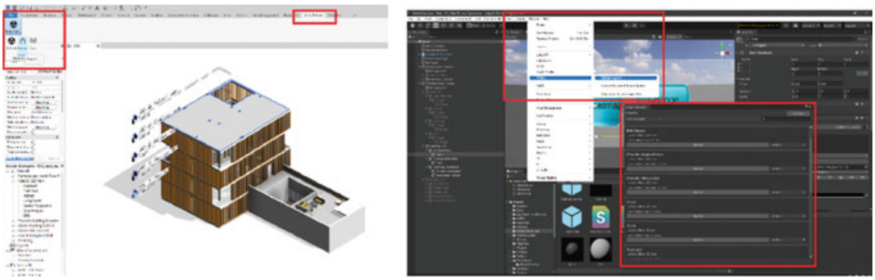

Fig. 5 On the left: Unity Reflect plugin Revit-side. On the right: Unity Reflect plugin Unity-side, window for importing models into the scene (*Modelling* C.V. Antisari; *Editing* D. Sorrenti)

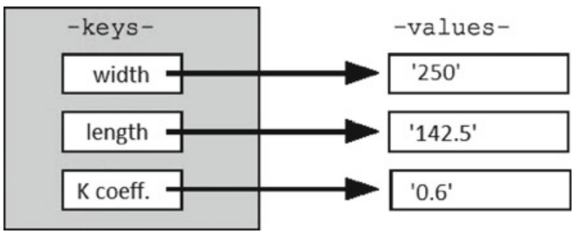

Fig. 6 Dictionary behavior, each key has a linked value and can be searched as width, will return '250' Second tool: representing models by functions (*Editing* D. Sorrenti)

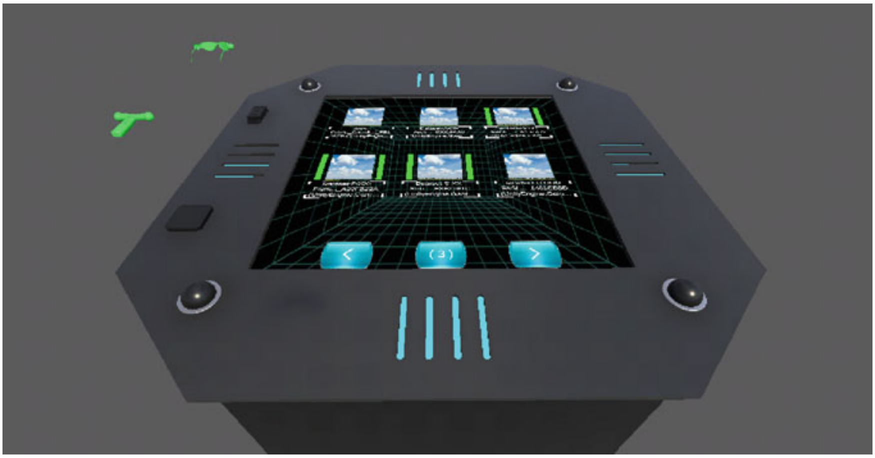

Fig. 7 Model selection menu, each model selected as green will be visualized in the application (*Modelling* C.V. Antisari; *Editing* D. Sorrenti)

the center of the table (Fig. 8), one side of the table surface will be visible to the user regardless of the model position as a control panel; the user interface on that side will be always visible by the user to make interaction with the program always possible.

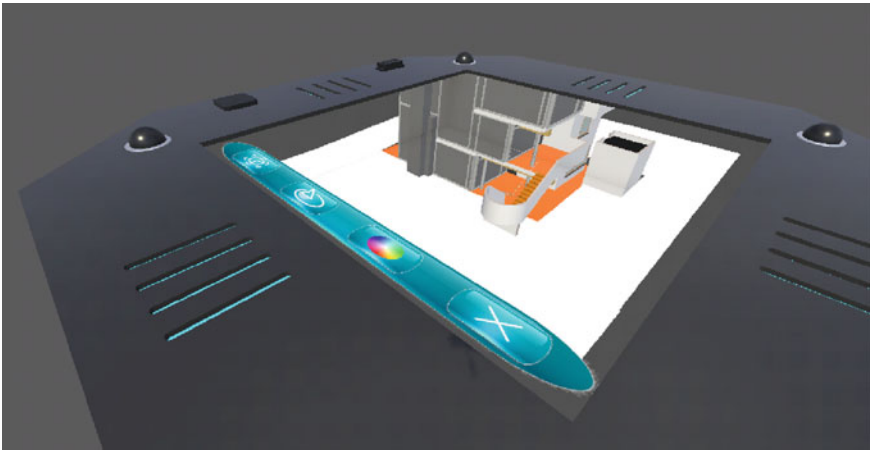

Fig. 8 Main application menu with a model visualized (*Editing* D. Sorrenti)

3.3 Second Tool: Introducing Section Plan

It's possible to get horizontal sections effect with the Holographic Table by physically leaning on the visualized model; the software will truncate the model according to the physical position of the user while a vertical section effect on the other hand is physically complicated to retrieve. For this specific reason a new tool has been designed and implemented to easily get a vertical section effect on the model.

Whenever the tool is activated a 3D plane is instantiated in the scene through the model, line boundaries have been added to the plane in order to have visual feedback on its position and orientation; the user can freely move the plane with user-friendly commands in the form of buttons on the control panel, situated on one side of the Holographic Table, making rotation and translation of the plane (Fig. 9) completely up to the user. The effect is that of a dynamic cut thus offering the possibility of shifting the plane for the discovery of details and parts that are difficult to visualize in context.

The section effect has been implemented with a custom shader generated from a Unity Shader Graph, a computation is required for each fragment of the objects mesh to ensure section can affect even portions of an object.

The shader program is provided with the position of the section plane center and its normal (a vector perpendicular to the plane, indicating its orientation) (Fig. 10); it computes for each fragment the vector linking the fragment position and the plane center.

These two different vectors are then compared, and the result is utilized to determine its position relatively to the plane (mathematical tool utilized is the scalar product between two vectors, sign of the result of this operation is related to the angle between the two vectors that can be utilized to discriminate between points

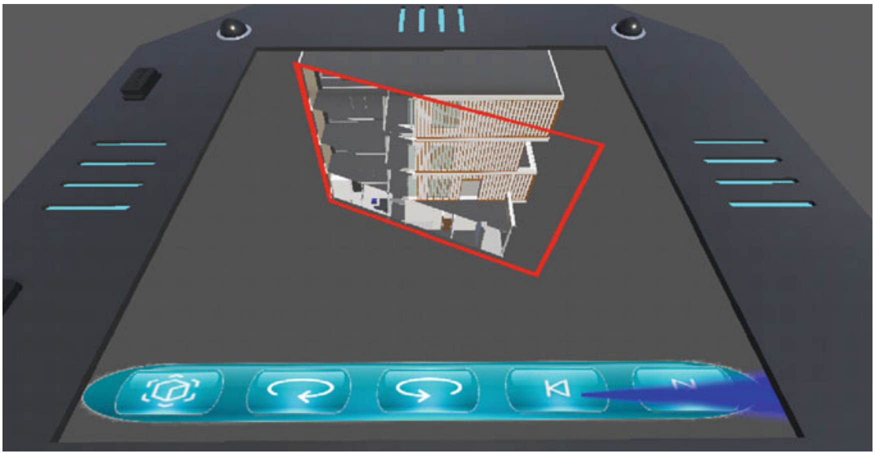

Fig. 9 Section plane moved to visualize from cross section to longitudinal (*Modelling* C.V. Antisari; Editing: D. Sorrenti)

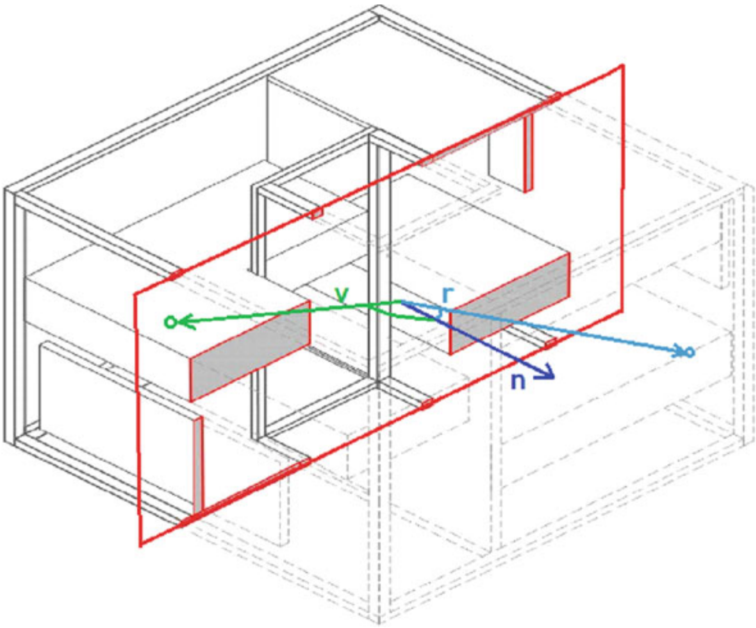

Fig. 10 Mathematical reasoning behind the section feature, the angle between the section planes normal vector and the vector Plane center to point is used to compute the point transparency (*Editing* D. Sorrenti)

on the same side of the plane as the normal and others). Depending on the result of the computation a different Albedo (color) is provided to the fragment, fragments on the sectioned side have the Alpha value set to zero, making the fragment fully transparent, others are provided with their original Albedo. The resulted effect consists in a fully shiftable 3D plane that provides a section effect on real time with intra-objects precision among every model visualized. The spillover effects in teaching effects are soon said: the ability to understand spatial relationships between plane and volume is increased, the ability to read different objects in different planes, the ability to control intersections between parts belonging to specific patterns that possibly may have been processed separately (as in an informed model).

3.4 Third Tool: Heatmap

Unity Reflect is a powerful plugin capable of saving a great quantitative of information related to the modeling process; data can be inferred by the program, such as volume or width of an object, or saved from the modeler inputs. This approach has been followed by Unity Reflect developers for the most realistic and information dense model representation that can be exported from modeling software to Unity

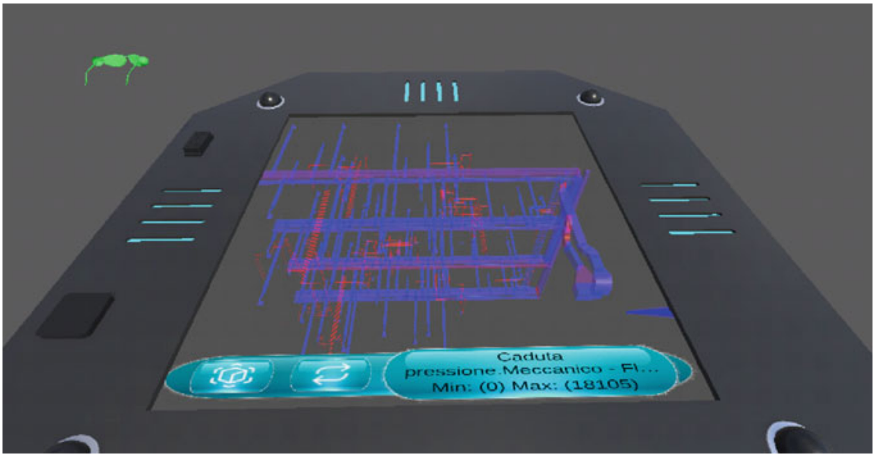

Fig. 11 Screenshot of Heatmap tool, each pipe and mechanical structure is tinted with a color related to the Pressure Drop value of the object (*Editing* D. Sorrenti)

pipeline. This enormous quantity of information provides a great opportunity for visual feedbacks of parameter distribution across the models, this new tool has been designed and implemented with this very specific purpose.

With the Heatmap tool (Fig. 11); it's possible to select one numerical parameter among the complete set available from the selected models, this set is computed in real time by the program during model initialization and cleaning process. Every object visualized is then assigned a custom material half transparent and with a variable color, this color is manipulated by the program accordingly to the selected parameter: every object that include the selected parameter in its list (this list is compiled and initialized by Unity Reflect during the exporting process from the modeling software) will have its material change the color to a tint between a low values color and a high values one, every other object that do not include this parameter are tinted with an almost fully transparent material to ease vision on significant objects.

In the figure Blue has been selected for the low values and Red for the high values, through the Heatmap tool is hence possible to provide the user a visual feedback of the selected parameter Pressure Drop highlighting the plumbing system of the building; each object is tinted with a color between Blue (corresponding to the minimum found value of 0) and Red (corresponding to the minimum found value of 18.105). This opens up endless possibilities for reading in dynamic models [27, 28] that can be used in architecture as well as in the urban context; from an educational point of view, coloring can individualize specific objects related to parameters present in the model and that do not require additional processes such as AI or machine learning processes with respect to the model itself by simply using parameters that already exist within it.

Acknowledgements These experiments were carried out through the instrumentation of LaborA, Laboratory of Physical and Virtual Modeling-Politecnico di Milano.

Appendix

A short video of the presented work is available at the following link: https://youtu.be/g1cTgj_67yo (*Editing* D. Bassorizzi; C. Bolognesi; D. Sorrenti).

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BIM and Data Integration: A Workflow for the Implementation of Digital Twins

Carlo Biagini and Andrea Bongini

1 Introduction

With the advent of the Industry 4.0 approach [1], the construction sector has also been involved in the development of systematic digitization processes [2] and its progressive transformation into a data-driven production sector now appears to be irreversibly underway. Moreover, the introduction of information management with Building Information Modeling (BIM) tools and methodologies in public supply, service and works contracts has highlighted the need to define structured and planned flows of data and information exchange between the various phases of the delivery process and operation of building estate assets.

The operation phase in particular engages about 80 percent of the total investment and management costs of a building's life cycle, and the management and monitoring activities of spaces, building components, and facilities play a decisive role in ensuring the well-being of users and health and safety in living and working places. In fact, for some time now, research in the area of Facility Management has seen its focus on the use and optimization of BIM tools and methodologies aimed at more efficient asset management of built heritage assets, and this also with a view to contributing significantly to the achievement of the goals set by the European Green Deal and Sustainable Development Agenda 2030 [3–5]. Knowledge and data about building elements within a monitored environment is a topic that has been on the fringes of research and discussions until now, but instead must be the key that can accelerate the digital transformation of the sector.

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There are currently several systems or tools for managing the operational phase of an asset, including Computerized Maintenance Management System (CMMS), Computer-Aided Facility Management (CAFM), Building Automation System (BAS), Integrated Workplace Management System (IWMS). There is, however, a lack on creating an integrated system to manage multiple pieces of information distributed across different databases. The advent of BIM can lead to the definition of a centralized repository that can contain all information related to the building and its context [6]. Improved information management and tools or technologies to understand and collect the characteristics of building products is a key requirement. The issues of circularity and sustainability have highlighted new areas of research where information circularity and traceability, as well as the ability to better structure and manage data, are critical to enabling sustainable and more efficient practices. The availability of reliable and up-to-date real-time databases on the operating conditions and efficiency of a physical asset is there-fore a central issue in order to plan effective control actions and manage planned maintenance and emergency situations. In this context, the implementation of Digital Twin of real estate assets represents one of the obligatory steps in the digital transition of the construction industry, as the real-time connection of the physical world with the digital environment opens new scenarios in the predictive management of the behavior and performance of the building system throughout its life cycle.

The big data collected through the DT allow to enhance information management developed through BIM models, which can lend support to the experimentation of Artificial Intelligence (AI) techniques for the optimization of various analysis, simulation, predictive evaluation, and decision-making processes affecting the quality of the built environment and the interaction of humans with their living spaces. To this end, the flow of data from digital IoT (Internet of Things) technologies deployed within buildings for real-time monitoring of the environ-mental quality of spaces and the performance levels of building and plant components, can be suitably integrated with the structured information implemented within asset BIM models, thus going on to pre-constitute coherent databases for the development of decision-making processes and predictive analysis referring to the specific building context.

In architecture, the integration of data between BIM and IoT therefore declines the creation of DTs, combining digital information related to the geometric characteristics of spaces and the technical-constructive properties of the components of the various building sub-systems with data coming continuously from sensors, and making monitoring activity available to operators in real time through appropriate forms of data visualizations.

This paper sets forth the results of research, which aimed to develop a methodological and operational work-flow for the creation of Digital Twin of buildings. Specifically, within the BIM model data from various types of sensors were converged, linking them to model objects to increase their information level and expand their semantic field (static, dynamic). Since the most common BIM authoring software is only capable of receiving static data, it was necessary to use an external platform for linking the two semantic fields. Thus, on the one hand, a federated BIM model was created, divided by disciplines, in an open and interoperable format such as IFC, and containing all the static information needed to describe the component elements. On the other hand, real-time and continuously updated data acquired from a system of installed sensors at different locations in the building are recorded and stored in a central server. The open-source Snap4City platform has thus made it possible to create links between these different types of data and create visualization and control dashboards.

2 From BIM to Digital Twin via AI

In recent years, the massive development of digital technologies for data capturing from variously dislocated sensors for a variety of uses and purposes, both within buildings and in the urban environment, made necessary an expansion of the traditional semantic domains of the construction industry with particular reference to BIM-based information management processes [7, 8]. Initially created as a method for exchanging data between different silos, BIM today is increasingly being approached with concepts such as big data, IoT, and AI, which are seen as potential solutions for automation and inclusion of broader environmental contexts. The evolution of interoperability solutions, from ISO STEP to IFC to IFCOWL are leading to the transformation of a static BIM to a new web-based paradigm [9]. In fact, the information model must be able to accommodate and store not only static data, produced in the survey and/or design phases, but also to manage dynamic data, coming in real-time from dispositive for monitoring the environmental quality of architectural and urban spaces.

In this sense, the smart-city already offers numerous examples of data acquisition and integration referable to different semantic domains in the field of infrastructure and service management (mobility, transportation, energy, tourism, culture, environment, etc.), which highlight, on the one hand, the complexity of data processing in terms of GDPR (general data protection regulation), and on the other hand, the multiplicity of exchange standards (format and communication), which can influence each other. Similar approach can be extended from the urban domain to Building Information Modelling, transferring big data analytics procedures for the development of decision-making processes and predictive analysis referring to the building context. In fact, the BIM model as a database can explicate the dual function of a repository for the collection and storage of building in-formation, and at the same time an information vector of continually acquired data as input for more complex analyses. In BIM, the integration of static and dynamic data opens up scenarios of great interest in the Digital Twin implementation perspective of real estate assets.

Monitoring physical processes concerning the life cycle of buildings is the essential prerequisite for the development of predictive decision-making processes that lead to prefigure artificial intelligence (AI) enabling applications that can autonomously operate managed assets with the goal of fulfilling specific tasks.

Pan and Zhang [10] argue that in the construction sector, the main application fields that can benefit from the introduction of AI are the following: automation, i.e., the ability to develop procedures for managing the construction process in a more automated and objective manner; risk mitigation, to monitor, recognize, assess and predict potential risk in terms of safety, quality, time and cost in the supply chain; high efficiency, for optimized management of processes with the aim of making them leaner and more efficient; computer vision, with the development of automated techniques for surveying, monitoring, and recognizing anomalies and defects in buildings and infrastructure; digitization, to facilitate information management of the delivery and operation phases of real estate assets. In the latter area, Building Information Modelling plays a fundamental role as a database for storing, exchanging, sharing and analyzing real-time data at various stages of the building life cycle. Indeed, data can be extracted from a BIM model and used for Machine Learning algorithms or data mining processes [11]. The first significant applications of AI to building management are already being tested around the world. The One Taikoo Place Building [12] in Hong Kong is equipped with an artificial intelligence system, called Arup Network [13], that can save energy through advanced data analytics capabilities, machine learning, and predictive maintenance algorithms.

The Edge [14] in Amsterdam, equipped with 28,000 sensors, is considered the smartest building in the world [15]: Deloitte, the main tenant, collects gigabytes of data on how the building and its users interact with each other. A series of centralized dashboards unifies data of different types, (from energy consumption to coffee machine refills) in order to optimize the proper operation of facilities and contain energy consumption. An Italian case is the Green Pea in Turin, Italy [16] powered by various renewable sources (geothermal, photovoltaic, wind) that leverages Honeywell's BEMS TREND solution to manage energy and water consumption and constantly monitor indoor air quality, ensuring full energy and environmental efficiency.

Anyhow there is not a single DT solution, as this may vary from time to time based on specific needs, just as its implementation is subject to evolve over times. According to Mêda et al. [17] there is a kind of common awareness about the evolutionary path that needs to be taken to achieve a true connected DT. The way data flows between the two counterparts helps us identify three evolutionary levels: digital model, where data flows in a manual manner, i.e., there is the presence of a BIM model but the data is updated manually by the operator; digital shadow, the flow of data occurs in a unidirectional manner, i.e., automatically only from the real world to the digital world as there is no possibility to interact with the real assets; and finally digital twin, where the exchange of information occurs in an automatic and bidirectional manner, a smart building collects data from IoT devices and is able to implement actions in the real world.

2.1 Information Requirements

Much of the information produced in the construction phase is lost, with only a small portion passed on to the successive management phase usually in the form of spreadsheets with 3D information added according to client specifications. A crucial point in having more control over the data included within a BIM model then becomes specifying both BIM Uses and Information Requirements from the outset. However, the way in which to encode this information is not well defined and is subject to many variables, thus making it difficult for users to choose the method best suited to their needs. There are multiple standards regarding the transmission of information requirements, and although the multiplicity of guides on information management there is no consensus on the method for validating and representing these requirements. In common practice, IRs are specified in customized documents or through proprietary solutions that do not follow any standards [18].

Information transfer from one stage of the process to another is accomplished through the adoption of the IFC data model. The IFC schema revolves around two basic concepts, which are: Information Delivery Manual (IDM), obtained through expert reports on the requirements of a particular information exchange, consists of process maps, exchange requirements and functional parts, and Model View Definition (MVD), translation of an IDM into portions of the IFC schema for implementing information exchange between different tools or platforms. buildingSMART has created official MVDs such as COBie for information exchange in the management phase focusing more on the construction domain, however, leaving out the typical information protocols. In fact, the latter is a generic MVD and can sometimes find difficulties when going into too much detail. These shortcomings often lead to the creation of custom MVDs that are able to integrate the information needed for different needs [19]. On the other hand, for IoT devices many communication protocols (BACnet, OPC, …) and semantic models are available to support information exchange between devices but there is only partial integration with the IFC schema for the building part. The use of extensions to the IFC schema is also still an immature process and provides only limited support for the integration of this information [20]. In addition, the IFC format is designed for transferring data from one tool to another and is therefore not meant to be dynamically modified or transformed. The definition of Linked Data (LD) and the Web Ontology Language (OWL) has recently attempted to address these issues.

The most recent literature agrees that there are still a number of obstacles to the implementation of DT of existing built heritage real estate assets including: the lack of awareness among the management of the various managing entities that they are part of a larger interconnected system; the lack of standards and protocols for da-ta exchange and interoperability; and emerging issues related to security, privacy and data ownership.

3 Workflow for Digital Twin Implementation

In the study presented below, the aim was to outline an operational workflow for the collection and management of data, starting from the implementation of DTs of existing real estate assets (Fig. 1). These models will be the basis for the integration between BIM and IoT, oriented towards subsequent developments of big data analytics through AI applications. The primary objective is to support the decisions of the various operators involved in the operational phases of the buildings with the aim of scheduling planned and/or corrective maintenance actions, generating content, recommendations, best practices and making forecasts on the managed assets. A special in-depth study was conducted for the optimization of integration processes between BIM and IoT in relation to interoperability issues and data-set exchange in the creation of DTs, and to enable real-time visualization of monitoring data from BIM models for FM.

As part of a collaboration with the Building Area of the University of Florence, a research program has been underway for several years for the implementation of BIM information models of the University's real estate assets, with the objective of information management [21] This is characterized by numerous assets, differing both in terms of function, construction, plant engineering, etc., and in terms of historical-architectural value, which require different intervention methodologies and maintenance systems from case to case. There are many difficulties in their information management mainly due to the heterogeneity of available data and information, as in many cases the documentation is still in paper format. It is therefore necessary to move to an information management that uses BIM tools and methodologies, so that data and information on the building are produced, managed, stored and exchanged

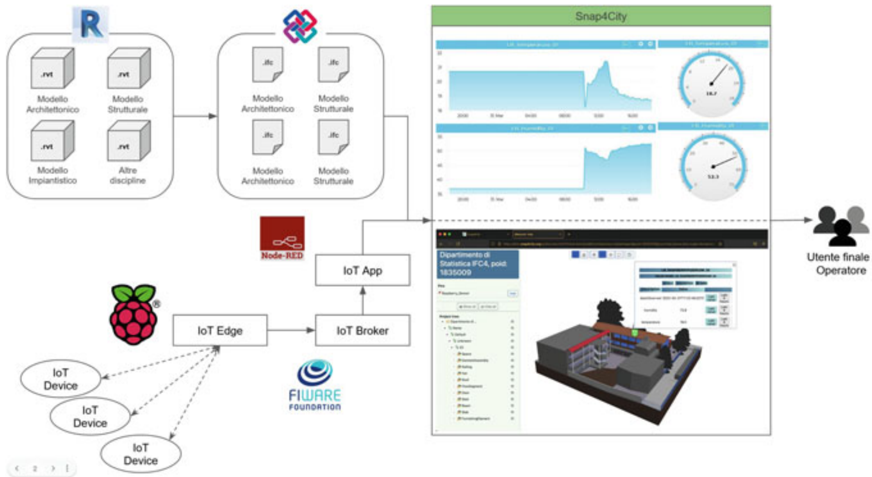

Fig. 1 Workflow for the digital twin implementation (*Editing* A. Bongini)

in a secure, reliable and consistent way within an CDE, which allows not only the uploading of files but also the writing of metadata related to them [22].

In the first modelling phase, the available data were selected and catalogued, starting from the information obtained from archive sources and survey graphics, defining the level of information need in relation to the different objectives and BIM Uses envisaged [23] by the research program. The next phase involved the integration of data between the BIM model and IoT devices in open and interoperable formats [24]. The aim was therefore to create a DT, which would combine not only the data coming continuously from the sensors, to be made available to operators through appropriate devices, but also all the digital information related to the characteristics of the spatial assets, buildings, plants, etc. resident in the BIM model. The 6 operational phases, in which the DT implementation process was articulated, are summarized below [25]:

(1) Creation, introduction of sensors to measure environmental and technical inputs from the physical world.
(2) Communication, two-way connection/integration procedure between the physical world and the digital environment.
(3) Aggregation, collection of data within a repository, to make them available in subsequent phases.
(4) Analysis, analysis and visualization of data in different ways depending on the purpose.
(5) Insight, creation of dashboards, in which the actual trend of the value of a certain parameter is reported, to be compared with the expected one, so as to have immediate feedback in the event of malfunctions.
(6) Action, identification of the problem reported in the previous step, which may generate a direct action on the asset via the actuator, or an alert to the operator/user.

This process must be supported by an appropriate infrastructure for collecting and processing data from the as-sets, using the following IT technologies:

(a) Internet of Things (IoT), adoption of smart and non-invasive sensors for real-time sensing of inputs from the real world.
(b) Edge Computing, on-site computing units capable of processing data from devices and transmitting them to a central server.
(c) Cloud Computing, cloud platforms as computational support for big data management.

4 Case Study

The workflow proposed was carried out, choosing the headquarters of the Department of Statistics of the University of Florence as a case study (Figs. 2, 3). It was built in different periods and it is composed by three building blocks and three building stories. It has a total surface area of 4250 square meters with a prevalent use for

Fig. 2 External and internal views of the Department of Statistics in Florence (*Photos* G. Manetti)

classrooms and offices for teachers and administrative staff. The central body presents an interesting architecture inspired by the Finnish design of the 1950s, with the wooden structures of the main staircase connecting the floors and the roof declined in organic forms.

Since a laser scanner survey was not available, the BIM model was based on the restitution of geo-spatial data extracted from heterogeneous documents provided by the Building Service of University of Florence, including the original 1958 project and regulatory adaptation of the 1990s, as well as from the direct and instrumental survey campaign to collect technical information on building components and installations (Figs. 4, 5).

The aim of this process was to create a federation of disciplinary models, subdividing the complex by category (architectural, structural, plant engineering and furniture). In particular, the plant modelling was performed based on a technical registry conducted only on the terminals detectable by visual inspection. As for the management side of the modelling, a set of shared parameters was created to reflect the information needs of the Building Service, subdividing them into groups according to disciplines.

The implementation phase of the DT instead involved the use of some environmental sensors (DTH22 type), placed inside the building, capable of recording temperature and humidity data. The solution adopted for data collection was Snap4City [26]. This is an open-source platform developed by the research group led by Prof. Paolo Nesi (DIEF) of the University of Florence. The platform was created for the management of Smart Cities and has recently been broadening its scope to

Fig. 3 External view of the Department of Statistics in Florence (*Photo* A. Bongini)

Fig. 4 BIM model of Department of Statistics of University of Florence: main fronts (*Modelling* G. Manetti)

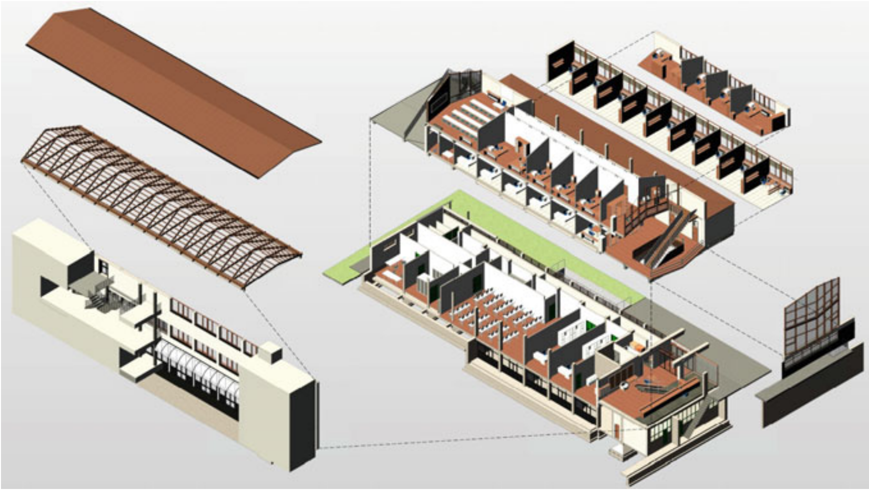

Fig. 5 3D model of the case study (*Modelling* G. Manetti)

include the management of buildings and integration with the BIM methodology. At present, the platform covers multiple domains dealing with topics such as mobility, energy, people flows, pollution, Industry 4.0, vehicle tracking, tourism, culture, … To these are added vertical links that need to be integrated with each other, such as smart parking, smart waste, smart bed, smart ambulance, smart light,…

Among the main features of this platform are the possibility to create customized dashboards, manage historical data through data aggregation and indexing systems, it is a data-driven solution, i.e. certain actions occur following the arrival of certain information, and it also allows Data Analytics and Machine Learning operations. No less important is its being an open-source project, conforming to the major international standards and managing heterogeneous data. It also has Fi-Ware certification, it is GDPR compliant and multi-tenant, i.e. it allows several organizations to work together on the same platform.

The first step of the procedure involved the transmission of data from the sensor within the Snap4City platform. The DTH22 sensor was connected to a microprocessor—in this case we have used a Raspberry Pi Zero 2 W (IoT Edge)—which allowed us to process the output data directly within it. This data was then processed by setting up a workflow within the Node-Red development environment [27]. This is a visual programming tool based on the flow of nodes, which can be chosen from two different libraries, one basic, for end users, and one advanced, for devel-

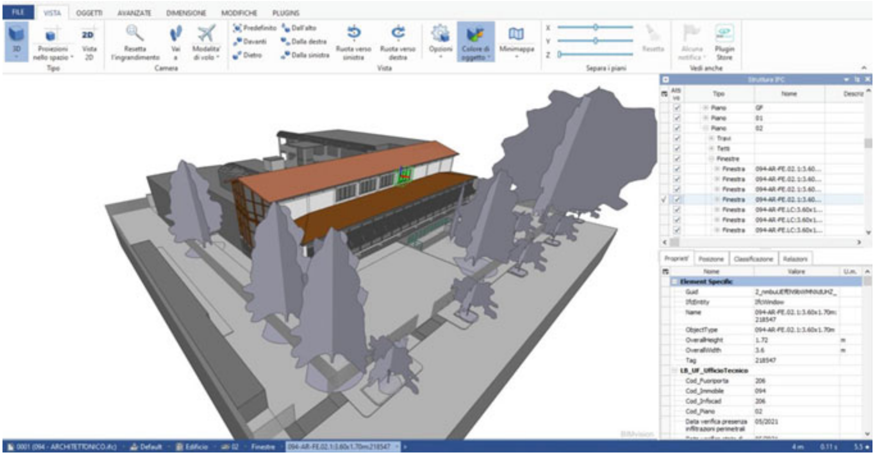

Fig. 6 IFC file inside BIM Vision software (*Editing* A. Bongini)

opers. In parallel, within the Snap4City platform, an instance was created, called an IoT Device, which is representative of the sensor used, setting its characteristics, geographical location and the type of data expected. Each IoT Device has been assigned a reference server, or IoT Broker, whose task is to collect and index the in-coming data. The collected data is then transmitted to the reference IoT Broker and associated to an IoT Device. As the data is recorded within the platform, it can be processed again via a new node flow, within an interface called the IoT App (Fig. 6). This is still based on the Node-Red programming tool, but instead of using the computational capabilities of the individual processors powering the sensors, it uses those of the server hosting the platform. Finally, the data was inserted into a customized dashboard with the intention of obtaining an overview of the environmental conditions of the building under examination.

With regard to the input of BIM models, the platform uses BIM Surfer [28, 29], a web-based IFC model viewer. Thanks to this interface, it is possible to associate the individual model elements with one or more of the IoT Devices created in the preceding steps, and consequently the information related to them. Once the BIM model, in IFC format, has been uploaded into the BIM Surfer module, it is inserted as External Content in the same dashboard, into which the previously collected data has been merged. This provides a complete overview, both geometrically and sensor-wise, of the current state of our building with real-time updates (Fig. 7).

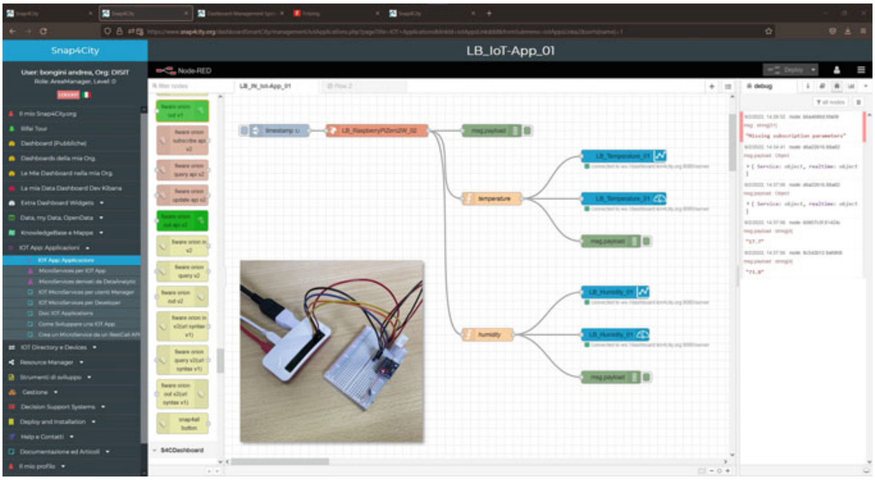

Fig. 7 Workflow of IoT App inside Snap4City platform (*Editing* A. Bongini)

5 Conclusion

The integration of BIM and IoT data for the creation of a DT of built heritage assets provides useful information for controlling and monitoring the performance of a building during its operational phases, enhancing the decision-making capabilities of facility managers and fostering user participation in optimizing building performance also from a broader perspective of resource rationalization.

The operational workflow presented exemplifies a possible approach to the implementation of DT through the integration of BIM information models and IoT systems, oriented to the collection, processing and visualization of environmental data, using an open-source platform already known in the smart city field, deriving from a city-scale approach an effective application at the building scale (Fig. 8).

The information model created with a BIM authoring platform requires export to IFC format. A key aspect of the proposed methodology is to maintain interoperability between the various disciplines and data aggregation and management platforms in each step of the procedure. To this end, the Snap4City platform offers significant support, being able to handle a large number of protocols and exchange formats. However, this approach still suffers from some limitations: the DT implementation procedures have to be developed in a VPL programming language, which, although quite intuitive, requires from the operator basic skills on script writing and notions about the different types of formats and protocols used; a further issue is related to the data integration of the BIM model, which to date can be used only at the geometric level, since the available interface cannot display all the semantic contents of the various building components, but only their hierarchical position within the IFC file.

The use of BIM information models for the creation of DTs for monitoring environmental and technical parameters of buildings constitutes the first phase of an

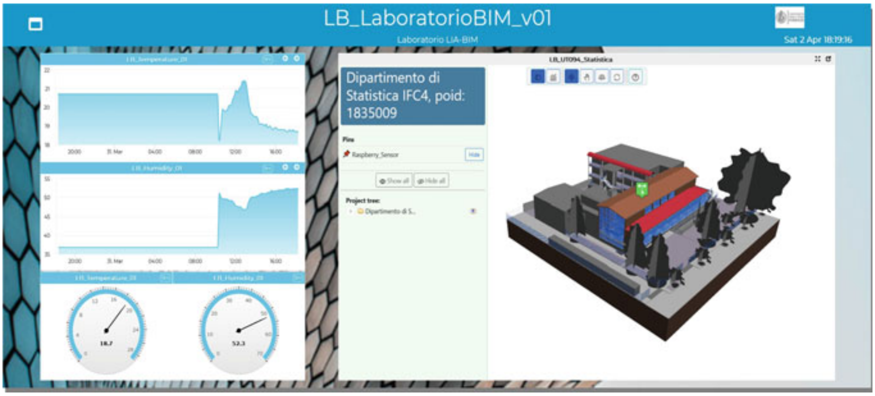

Fig. 8 Custom dashboard with temperature and humidity control (*Editing* A. Bongini)

experimentation of Big Data analytics and Artificial Intelligence techniques applied to the development of analysis, simulation, and predictive evaluation processes in Facility Management. In this perspective, further insights will be conducted to improve the efficiency of the operational workflow for DT implementation.

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