Representation Challenges. New Frontiers of AR and AI Research for Cultural Heritage and Innovative Design.

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AR/VR Contextualization of the Statue of Zeus from Solunto

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Abstract

The aim of the research is to test how VR and AR technologies can contribute to a virtuous reconnection between the museums, where archaeological works of art are exhibited, and the sites where these works come from. The connection between the museum and the site will be operated with panoramic images generated with SfM photogrammetric tools; these images will set up a twofold reconnection: i) between the work of art and the building where it was hosted; ii) between the building and the site, with the landscape around. The connection between the site and the museum will be operated with Augmented Reality, through the visualization on site of the works of Art exhibited in the archaeological museum.
The case study is the giant statue of Zeus, today exhibited at the archaeological museum A. Salinas of Palermo; the statue was found in the site of Solunto, a Roman town located 20 km east of Palermo.

Keywords
statue of Zeus, augmented reality, panoramic images, Museum Salinas, Solunto.

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Introduction

In the past two decades digital technologies have been successfully used for the documentation, visualization and dissemination of Cultural Heritage. Laser scanners and SfM photogrammetry are today widely used and the digital twins of works of art and architecture provide the reference for actual restorations and virtual reconstructions.
Archaeology is one of the privileged subjects of researches on digital technologies for Cultural Heritage; hundreds of ancient buildings have revived thanks to digital survey and representation; some of these have become the virtual set for well-known movies as *Gladiator* and *Troy*.
This study aims at testing the use of digital technologies for the contextualization, in their original location, of archaeological works of art today exhibited in museums.
The pioneering and reference work for all researches aiming at this purpose is no doubt the short film *Parthenon*, realized by a multidisciplinary team led by the Canadian computer engineer and researcher Paul Debevec; the film is centred on the contextualization of the marble statues of the Parthenon, today exhibited at the British Museum of London, in their original location in the Acropolis of Athens [Debevec et al. 2003].
Even if almost 20 years have passed and the technology has moved far away, the film of Debevec keeps its fascination and can be considered an utmost result of the use of digital technologies for the knowledge and dissemination of Cultural Heritage.
In the first decade of this millennium a campaign of researches focused the temple C of Selinunte and some of its metopes exhibited at the archaeological museum of Palermo. Amici and Marconi worked on the reconstruction of the temple and its decoration; the project LandLab, soon after promoted by the University of Lecce and the Canadian NRC, achieved a high resolution digitization of the metopes from Temple C and E exhibited in the Metope Hall in the museum of Palermo. The video titled *The metopes of Selinunte* was awarded in different scientific events, but the contextualization of these metopes was not the focus of the research [Beraldin et al. 2003].
In the years that followed the research moved to explore digital solutions for the on-site and real time visualization of virtual reconstructions, using both AR and VR solutions.
Before the latest technological developments have made AR an effective tool for the visualization of Cultural Heritage, the experiments on the contextualization of lost buildings were mainly developed with panoramic images.
A pioneering work in this area of research is the *Cluny* project developed in 2012; the textured reconstruction model of the Cathedral of Cluny was used for the realization of a panoramic image. A customized display, placed on the point of view of the panoramic image, allowed the navigation of the reconstruction model of the church and the contemporary match between the displayed image and the site where the Cathedral was once sited. The match between the few fragments on site and the image of the reconstructed model resulted effective and fascinating [Landrieu et al. 2012].
At a later stage panoramic images were used for the on-site visualization of the virtual reconstructions of some Greek temples and buildings of Siracusa in their original context [Gabellone 2015].
The main limitations in the use of panoramic image for the purpose of on-site visualization of digital contents, is the link to a fixed point of view and the mismatch between the environmental light depicted in the image and the light on site at the moment when the user displays the image.
The link to a fixed point of view could be a problem especially in open sites, where the identification of a point on the ground could be puzzling for visitors.
Augmented Reality has been, for a long time, a marker based technology; digital objects were linked to flat patterned surfaces and appeared only if the marker was framed by the camera of the device. It is easy to see that this limitation has been a great obstacle for the use of Augmented Reality for the visualization of buildings in their original context.
The research work of G. Reitmayr and T. Drummond of the University of Cambridge led in 2006 to an important contribution for the use of augmented reality in urban spaces, with

the development of the first markerless system based on the recognition of environmental features [Reitmayr et al. 2006].
From that time on, many research centres have hardly worked for the development and improvement of markerless-based AR; in 2016 the Anglo-Japanese Kudan Computer Vision has developed innovative solutions that use the SLAM (visual Simultaneous Localization And Mapping) technology to track the position of a mobile device inside a specific environment; at the same time Microsoft developed HoloLens, an advanced head-mounted display featuring semi-transparent visors that allow virtual elements to be superimposed to the real environment.
To date, the most widely adopted solutions are based on Google's ARCore technologies, an evolution of the 2016 Tango project, and on Apple's ARKit technology; both platforms allow the development of augmented reality applications compatible with a wide range of mobile devices.
In 2016 Google's *Tango* project has been tested by the Department of Culture del Progetto of the IUAV University of Venice for the contextualization, in their original location, of architectural fragments exhibited in the Cité de l'Architecture et du Patrimoine in Paris, one of the most important museums fully dedicated to architecture and monumental heritage.
The research presented in this paper aims at evaluating the use of digital surveying and representation tools for the contextualization of an archaeological work of art, today exhibited in a museum, in the building and site where it was originally located. The contextualization is developed both for visitors of archaeological sites and for visitors of museums.
This proposed workflow aims at creating a virtuous double link between museums and sites, that aims at inspiring people who visit the museum to go and visit the sites where the works of art were once located; symmetrically, the on-site contextualization of works of art can stimulate visitors to go and examine the real piece in the museum [1].

The Case Study

The case study is the giant statue of Zeus today exhibited in the archaeological museum A. Salinas of Palermo; the statue was found in the site of a sanctuary in Solunto, a Hellenistic Roman town located 20 km east of Palermo.
The sanctuary, located at the south eastern corner of the theatre, is made of two rectangular rooms divided by a wall; each room is terminated by a niche where the remains of stairs are visible. The chronicles of the late 19th century excavations [2] locate the fragments of a colossal statue of Zeus in an area close to these rooms, but later studies proposed the location of the statue in the southern room.
Lo Faso reports that the fragments of the statue were reassembled by the sculptor Valerio Villareale [Lo Faso 1831]. The original fragments included the head and the right feet, but visitors at the archaeological museum envision the statue as a whole, since the work of Villareale is perceived only by experts.
The statue, 2.7m high, is today located on a pedestal 0.9m high in a niche opening onto the northern wing of the portico that delimits the biggest courtyard of the Archaeological Museum of Palermo "Antonio Salinas", once convent of the religious order of Saint Philip Neri.

Proposed Methodology

Surveying was developed with laser scanning and SfM photogrammetric methods. SfM photogrammetry was used to build up the textured mesh models of the surveyed elements and scenes; laser scanning point clouds provided the reference for the orientation and scaling of photogrammetric models.
The first step of the surveying process addressed the statue of Zeus in the archaeological museum of Palermo: 256 photos were taken with the aid of a high tripod, in order to reach the top of the head; six scans from the ground provided the documentation

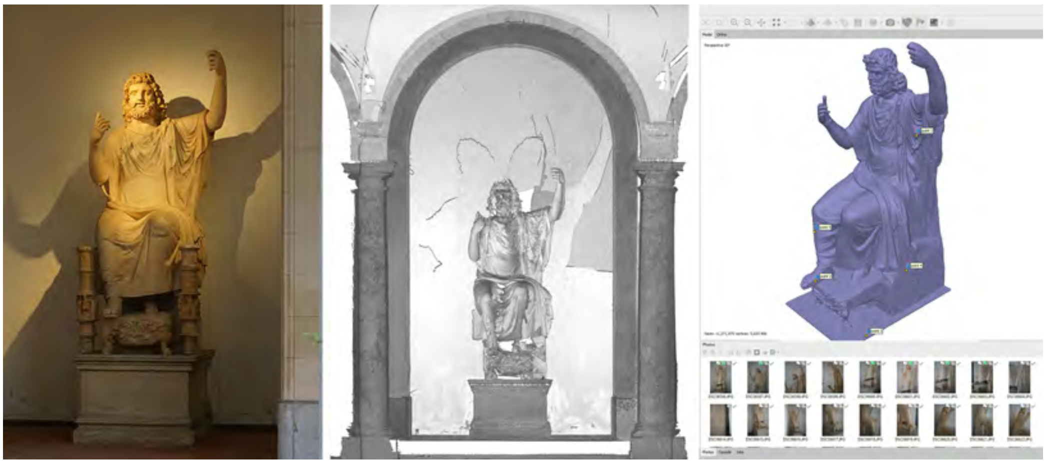

Fig. 1. The statue of Zeus surveyed.

Fig. 2. The sanctuary: Survey and panoramic image.

of a good percentage of the visible surfaces (Fig. 1). The location of the statue did not facilitate the acquisition of scans and photos and the back face could not be documented. The second step of the surveying process, developed on site, addressed the documentation of the ruins of the two halls of the sanctuary. 500 photos allowed the photogrammetric generation of a textured mesh model; the photogrammetric model was scaled and oriented with the coordinates of points taken from the laser scans.
A second set of photographic images was taken on site with the aid of a camera fixed onto a Nodal Ninja mechanical bracket, supported by a tripod. The use of the Nodal Ninja bracket, when properly executed, allows to fix the point of view of the images and thus support their stitching and the creation of a panoramic image. The images can be stitched with dedicated software tools, but in this research panoramic images have been processed with a SfM photogrammetric tool capable of managing the orientation of images taken from a single point of view [3], stitch the images and export the panoramic view.
The images were uploaded in the photogrammetric project and were stored in a dedicated folder classified as "Station" Folder; the software assumes that all images stored in a "station" folder share the same point of view.
The images from the "station" folder and the standard images were aligned at once and then scaled and oriented (Fig. 2). The advantage provided by photogrammetric stitching is the calculation of the coordinates of the point of view of the images taken with the Nodal Ninja bracket. These coordinates are obviously referred to the reference coordinate system of the laser scanning point clouds.
The photogrammetric tool allows to export the coordinates of the points of view of the cameras loaded into the project and the Euler angles that fix the direction of the shooting axe; the coordinates of the cameras loaded in the "station" folder, as expected, result invariant.
Having solved the problem of calculating the position of the centre of the panoramic im-

Fig. 3. Alignment of corresponding panoramic images.

Fig. 4. The site displayed in the museum.

age in a surveyed scene, the final question is the orientation of this image, i.e. the rotation around the z-axe that makes the matching between the image and the surveyed scene. The photogrammetric process provides the orientation of the panoramic image as well; the image can therefore be mapped onto a sphere and does not demand any further visual adjustment inside the representation tool.
A visual check of the orientation of the sphere can be easily performed in the representation tool; the sphere is scaled from its centre till it envelopes the entire mesh model of the site. Placing the perspective point of view on the centre of the sphere, the visualization of the textured mesh model of the site showed a good correspondence with the panoramic image.
In the following step the statue of Zeus was placed inside the model of the ruins of the sanctuary, according to the location proposed by archaeology scholars.
The coordinate of the point of view of the nodal images, that make the panoramic image of the site, and the contextualization of the statue in the sanctuary, allowed to measure, on the 3D model, the distance of the point of view from the basement of the statue, and the height of the point of view from the floor of the porch. These measures were used to place the camera inside the porch of the museum Salinas and take a new set of images with the Nodal Ninja mechanical bracket. The position of these images was calculated once again with photogrammetric methods. The statue provided the reference to compare the model of the museum and the model of the site. At the end of the process the mismatch between the coordinates of the centres of the images used for the two panoramas resulted 14 cm, a value more than acceptable for the purposes of the experiment (Fig. 3).
The panoramic image of the site and the corresponding image taken at the archaeological museum resulted therefore aligned (Fig. 4).

The symmetric experiment, as mentioned above, aims at the Augmented Reality visualization of the statue of Zeus in the Sanctuary in Solunto. The AR platform Google ARCore has been used because its technology Persistent Cloud Anchors is capable of generating multi-users and persistent visual AR experiences.
ARCore uses SLAM (Simultaneous Localization And Mapping) algorithms to estimate the pose of the device and track its position in the real world. The SLAM technology integrates the data captured by the device's camera, processed with SfM techniques, with the data on velocity and orientation recorded by the IMU (Inertial Measurement Unit).
One of the features of SLAM processes is the ability to refine the mapping of the real scene in real time during the acquisition phase, so that the position of the camera and the position of the virtual objects placed in the scene is updated frame by frame.
This feature could result puzzling for visitors, since the adjustment of the position of virtual objects can demand relevant movements and rotations.
Anchors have been developed to fix this problem and provide a stable alignment between virtual objects and the real scene; an anchor is an invisible object that is placed in the real scene; the visual features of the area around the anchor are recorded during the AR session and support the permanent update of the position and orientation of the virtual object. Thus, both anchors and virtual objects result linked to the real scene.
Anchors can be used during a specific AR session, but they can as well be stored on the cloud to provide shared AR experiences, to allow more users to visualize the virtual objects at the same time and enjoy an interaction.
Anchors can be temporarily stored in the cloud for the creation of Real-time collaborative experiences; Persistent Cloud Anchors allow the permanent storage of anchors and thus allows to retrieve the AR scene at a later stage.
In this research Cloud Anchors API have been used for the implementation of an AR App capable of allowing multiple users at different times to visualize the statue of Zeus in its original location with a standard mobile device.
The access point for the activation of the AR experience is the information panel located just in front of the sanctuary area. For this purpose, the laser scanning survey of the sanctuary included this panel and a temporary marker has been placed at its barycentre. It was therefore possible to place the anchor at the barycentre of the panel and then refer the position of the statue to the anchor.
The position of the anchor and the storage on the cloud have been managed with a dedicated app developed with Unity and with the multi-platform framework AR Foundation; the additional package ARCore extensions allowed to manage the Cloud Anchors technology inside Unity.
The application is capable of detecting and associate a plane to the information panel; once the barycentre of this plane has been detected, the position of the anchor is fixed by simply tapping the display (Fig. 5).

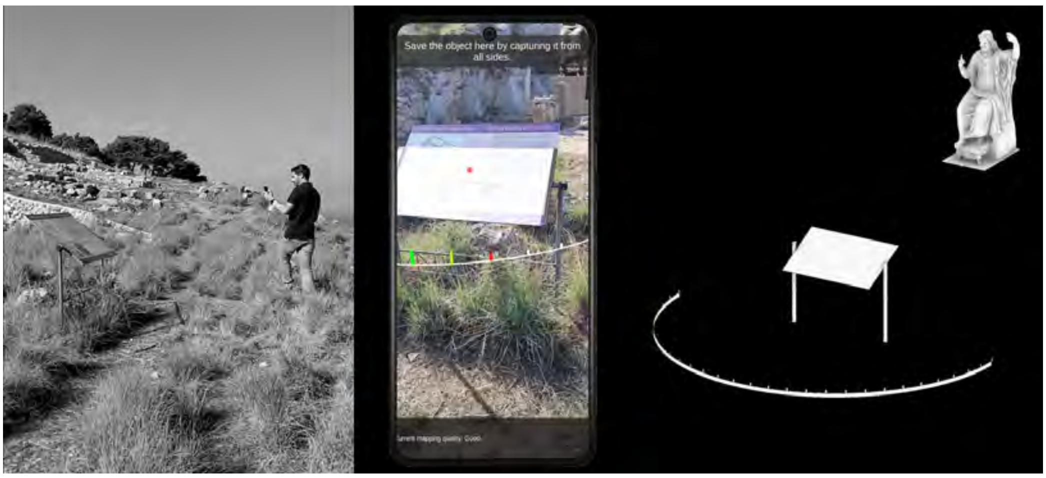

Fig. 5. Creation of the anchor at the sanctuary.

Fig. 6. AR visualization of the statue of Zeus.

In the following step the AR developer will perform the acquisition of the visual features of the area around the anchor by simply framing this area with the device's camera.
The movements of the camera has to be slow; a graphic on the display of the mobile device will show the quality of the captured data that will be used for the implementation of a 3D feature map of the area around the anchor.
This map is finally stored on the ARCore Cloud Anchor service and the Anchor is assigned an ID. This ID will allow to retrieve the Anchor, and the digital object linked to the anchor, from a different app dedicated to final users.
Once the ID of the Anchor associated to the panel has been retrieved, choosing the ID from a list or with the aid of a QR code, the user is requested to simply frame for one or two seconds the information panel.
The image framed by the user's device is automatically uploaded by the ARCore Cloud Anchor service (an Internet connection is needed) that almost in real time will provide the solution of the anchor, i.e. the detection of the link between the anchor and the information panel.
The whole process, computed in less then one second, allows to position the statue of Zeus in its original location. From now on the user, thanks to the motion tracking processes based on the SLAM technology, will be free to move in the sanctuary and observe the statue from any point of view (Fig. 6).

Conclusion

The research aimed at testing the use of panoramic images and AR tools for the creation of a virtuous link between archaeological sites and museums.
The experiment on the AR on-site visualization of the statue of Zeus has verified the efficacy of the Persistent Cloud Anchors technology of Google's ARCore platform in supporting the implementation of an AR app for the visualization of Cultural Heritage artefacts that needs to be accessible to more users at the same time and easily retrieved at each session.
The experimented solution, based on a system that allows the storage of data on the cloud, demands a not consuming internet connection, strictly limited to the download of the data needed for the solution of the anchors.
If AR successfully brought the exhibited statue into the site, panoramic images were used for the symmetric connection that brings the site inside the museum. Panoramic images are affected by many limitations when compared to AR solution, but they have the potential of documenting the astonishing landscape of archaeological sites.

The alignment between the panoramic image of the site and the similar image in the museum has been processed with SfM photogrammetric tools. The visitor at the museum, standing in front of the statue of Zeus, close to a point that could be marked by a simple tile, can overlay the vision of the statue with the vision of the sanctuary and, turning around itself, watch the landscape of Solunto, with the Mediterranean flora and the sea.

Notes

[1] The authors contributed to the research as follows: Marco Geraci developed the survey of the statue; Mirco Cannella and Fabrizio Agnello cared the survey on site; Fabrizio Agnello cared the experiment on panoramic images; Mirco Cannella cared the development of the app for the AR visualization on site of the statue.

[2] "…al cominciar dell'autunno del 1825 i villici circostanti, allettati da' piccoli guadagni ritratti da alcuni oggetti rivenuti fra queste rovine, invogliaronsi ad imprendere scava menti di maggior importanza (…) Allora appunto fecesi l'acquisto prezioso (Tav. III) di una statua semicolossale, che riunita ed opportunamente ristaurata dal nostro valentissimo professor di scultura il Villareale, forma uno degli oggetti di miglior pregio, che adornan presentemente il nostro nascente museo" (Lo Faso, 1831, p.8).)

[3] The photogrammetric processing of panoramic images has been realized with Agisoft Metashape.

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MAD Memory Augmented Device: a Virtual Museum of Madness

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Abstract

This contribution focuses on the topics of identity and memory and how Augmented Reality and Artificial Intelligence are a useful tool for the enhancement of some areas of study still not fully accepted from the cultural point of view. In particular, the objective of the study is the rediscovery of asylum complexes. These, before being conceived as places of therapy, were conceived as places of confinement and control of a social 'problem', for a long time managed within the walls in which the mentally ill were isolated. Through the application to a specific case in which Augmented Reality and Artificial Intelligence act in synergy, the contribution presents a research path aimed at restoring value to the identities of individual patients, hidden and denied first by necessity and then by the will of obliteration.

Keywords
identity, memory, psychiatric hospitals, asylum tourism, digital avatar.

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Introduction

After the closure of psychiatric hospitals, established in Italy by the so-called Basaglia Law (Law 180 of May 13, 1978), these complexes underwent a phase of progressive abandonment. This was followed by a reawakening of interest that led not only to the rediscovery of these places, but also to their re-functionalization, both in continuity with their original function (for example, reusing them as mental health centres or public health services) and in a freer way, but still aimed at enhancing their vocation and memory (for example, turning them into museums for the public). These interventions allowed "to address the psychiatric issue from a new point of view by emphasizing and integrating ex post facto the drive for openness and visibility of the psychiatric world already advocated by Franco Basaglia." [Guglielmi 2020, p. 178]. This has highlighted the architectural heritage of disused psychiatric hospitals, which have become an important element in the construction of collective identity, becoming part of the so-called 'asylum tourism', now widely spread not only in Italy. The many experiences of reuse, recovery, redevelopment and return to public use of these complexes are configured as actions of redemption compared to the inaccessibility that had marked them in the past and open to a renewed interpretation of asylum places as vehicles and living testimonies of memory and identity. It is precisely on the themes of identity and memory and the need for their enhancement that further reflection is necessary. Not only for the consolidation of a change in approach but also for the potential offered by the technologies of Augmented Reality and Artificial Intelligence that, for their ability to allow applications capable of proposing and communicating innovative content in an immediate and immersive way, can be usefully employed in the processes of enhancement of specific areas of study and not yet fully accepted by the cultural perspective.

From Asylum to Cultural Function

In the last twenty years there have been many studies and researches aimed at investigating the history of Italian asylum complexes in order to describe their role, to rediscover their activity and to define their value, both from a historical and architectural point of view and from a social and cultural one. The first exhaustive mapping of public asylums, including some significant private institutions in the hospital scene, was promoted in the nineties by the Benetton Foundation Research Centre and published with a title illustrative of its nature: *Per un atlante degli ospedali psichiatrici pubblici in Italia* [Fondazione Benetton studi e ricerche 1999]. This first cataloguing experience led to two important activities: the project *Carte da legare. Archivi della psichiatria in Italia*, a census of Italian psychiatric archives, whose results are collected in the portal of the same name that allows access, with the appropriate authorization levels, to the archival records of mental hospitals [www.cartedalegare.san.beniculturali.it]; the PRIN 2008 project *Spazi della follia*, articulated in five local units (University of Camerino, Seconda Università di Napoli, University of Palermo, Politecnico di Milano, Politecnico di Torino), dedicated to the knowledge and enhancement of the historical-architectural heritage of former asylum complexes. The results of this second project have been published online in the portal *Spazi della follia* [spazidellafollia.unicam.it] and then in the volume *I complessi manicomiali in Italia tra Otto e Novecento* [Ajroldi et al., 2013]. The use of the tools offered by new technologies has been an essential step for the enhancement of the results of such research, allowing to disclose the results to a wide audience, made up not only by scholars, but also by a community increasingly involved in learning content of considerable identity value [Guglielmi 2020, pp. 177-204]. In particular, in the recent period, some experiences aimed at deepening and spreading the knowledge of asylum structures through a variety of digital tools appear emblematic: in addition to the already mentioned freely consultable websites, there are also multimedia supports used in the setting up of physical places used as museums, often located in the same asylum structures. It seems important to underline how these experiences represent some of the fruits of the path strongly supported by the psychiatrist Franco Basaglia in the 1970s, aimed at opening up and making visible the asylum structures,

or rather, at promoting interaction between psychiatric patients and the inhabitants of the cities that housed the asylum structures themselves. [Foot 2014]. In this sense, his experience at the San Giovanni psychiatric hospital in Trieste is exemplary, where he implemented a revolutionary conception of life inside the asylum. Having become director of the hospital in 1971, Basaglia transformed the ward of the 'calm' into a laboratory, where the patients, both men and women, could work together with invited artists. Among them is his cousin Vittorio Basaglia, a sculptor and pupil of Marino Marini. Together with Vittorio, the patients created the *Marco Cavallo*, a large sculpture of wood and papier-mâché 4 meters high. On 25 March 1973, the sculpture leaves the hospital and enters the city of Trieste, followed by over 400 patients. Its belly was filled with tickets on which were written the dreams of the 1200 patients hosted in the structure. The event has a strong resonance so as to attract the attention of intellectuals of the time. Among these, Umberto Eco who describes the *Marco Cavallo* as "a giant, evoker of myths, memories, collective fantasies". [Tobagi 2018]. After five years, that "collective fantasy" begins to have concrete possibilities of realization.
In 1978, with the approval of the Basaglia Law, asylums were gradually abandoned. From places referring to an imaginary of imprisonment and drama, isolated from the life of the city, these places became part of the city circuits, welcoming new recreational, educational functions or the enhancement of the memory of those places and the people who lived there. For example, the green spaces of asylum facilities, previously enclosed within gates, are converted into public parks or gardens made available to the community: such as the park of the former psychiatric hospital of San Giovanni in Trieste, now a public place known as *Parco di San Giovanni* [parcodisangiovanni.it] and the park of the former provincial psychiatric hospital of Gorizia, now a laboratory of social entrepreneurship of welfare and creative activities known as *Parco Basaglia* [itineraribasagliani.org]. Or again, the interior spaces of asylum structures host educational functions, often linked to the world of literature and art: such as the former psychiatric hospital of Maggiano in Lucca, today seat of the *Fondazione Mario Tobino* [fondazionemariotobino.it] or the former *Ospedale Psichiatrico Paolo Pini* in Milan, today seat of the *Museo d'Arte Paolo Pini* [mapp-arca.it]. Finally, asylum facilities are transformed into museum spaces for the preservation and narration of the memory of those places, making accessible to the community both the intangible heritage (consisting of the testimony of doctors, relatives and patients) and the material heritage (consisting of objects owned by patients, medical records or protocols adopted for treatment). Just think of the case of the former *Manicomio di San Servolo* in Venice [servizimetropolitani.ve.it/museomanicomio] or the former *Manicomio di Volterra* [manicomiodivolterra.it], which are representative of similar experiences in Italy.

AI and AR for a Renewed Use of Asylum Complexes

The educational, cultural and social role characterizes museum spaces by definition. From this point of view, the use of advanced technologies, with particular reference to interactive and immersive tools through the use of AI and AR, favors the possibility of dissemination to a wide audience. All the more so when the memory to be transmitted concerns dramatic places or events whose deep understanding involves dynamics of empathy and identification. Thus, on an international level, the *Memory Lane* museum complex in Kubinka, Russia, is dedicated to the narration of the dramatic events linked to the Second World War through a series of installations that extend for over a kilometer, evoking scenes of war in which the visitor is directly involved through interactive experiences [1418museum.com]. Still, at the national level, the *Gallerie di Piedicastello* in Trento consist of two disused road tunnels converted into laboratory and exhibition spaces, respectively characterized by white and black interiors, intended to convey knowledge about the events of the war in Trentino: the white tunnel through educational activities and the black tunnel through performance installations aimed at directly involving the visitor in those events. [museostorico.it]. With specific reference to the theme of mental hospitals, there are two main types of action. On the one hand, museum experiences in which the transmission of knowledge about mental illness and

Fig. 1. *Museo della Follia*, 2011 (left) and *Museo Laboratorio della Mente*, 2000 (right), the multimedia exhibition.

asylums takes place mostly by offering visitors a collection of material goods or oral sources from former patients or medical staff (as in the case of the *Bethlem Museum of the Mind* in Beckenham [museumofthemind.org.uk], England, or the *Oregon State Hospital Museum of Mental Health* in Salem [oshmuseum.org], USA). On the other hand, there are also projects based on a real narrative structure through an oscillation between objects and life stories. All this with the intention of offering the visitor the tools for critical knowledge and to activate real 'educational processes'. Just think about two exemplary experiences belonging to the Italian context. On the one hand, the *Museo della Follia*, the evocative traveling exhibition developed by Vittorio Sgarbi since 2011, in which the visitor crosses dark spaces, intentionally disorienting and disturbing: through paintings, photographs, sculptures, objects and multimedia installations with the theme of "Madness" (varying in relation to the city that temporarily hosts the exhibition), the visitor is introduced into a path of knowledge that passes through the identification with the other [museodellafollia.it]. From the other, the *Museo Laboratorio della Mente*, realized in 2008 by the synergy between ASL Roma and Studio Azzurro: inside the pavilion VI of the former asylum of *Santa Maria della Pietà* in Rome there is an immersive and multimedia exhibition that stimulates the active participation of the public, in a continuous fluctuation between real and virtual elements [museodellamente.it] (Fig. 1). At the same time, there are initiatives aimed at connecting ongoing research and projects addressed to the memory of asylums (conducted both at regional and national level) also by proposing completely virtual visits. This is the case of *Mente in rete*, a network born in Italy but with the prospect of expansion at the international level, aimed at safeguarding, preserving and enhancing the memory of psychiatry and promoting mental health through virtual itineraries [menteinrete.it], as well as *Risme*, a project dedicated to the creation of a virtual museum of studies on the mind and mental health in Bologna and Emilia-Romagna in the nineteenth and twentieth centuries [risme.cittametropolitana.bo.it].

MAD Memory Augmented Device

The case study analyzed, which in the context of the present research takes on a pilot value, is the former neuropsychiatric hospital of *Santa Margherita* in Perugia. The following is a summary of its main events. [Agostini 1924; Rotondi, Nocentini 1993; Rotondi 1995; Corinaldesi 2010; Salvo 2010; Salvo, Di Lorenzo 2013; Rosi Cappellani 2014-2015]. The area in which the complex rises is located on the edge of the city, on the east side of the historical center, in the area of the park of *Santa Margherita*, and is characterized by an articulated orography and by a rich naturalistic landscape, revealing from the origin its aptitude to host architectures of isolation, distributed on multiple heights and characterized by wide open spaces. The asylum is placed there in 1825, absorbing functions of assistance of psychiatric patients already active in other locations of the city of Perugia since 1699, and there will remain until its suppression. At first inserted in a pre-existing convent building, the asylum expanded over the years with the construction of new buildings designed by excellent authors. Luigi Poletti, assisted by his pupil Francesco Cellini, and later Giulio Maria De Angelis, configured over time what would later be called the *cittadella dei pazzi* for its "village-like" articulation, in line with French theories for the treatment of psychiatric disorders not limited to segregation but oriented to care through a wide range of open spaces (Fig. 2). At the end of the nineteenth century, the complex, consisting of eight buildings spread throughout the area and dedicated to the hospitalization of different categories of patients, is organized into two distinct nuclei. The main one in the area of *Santa Margherita*, for a male section, and the second one close to the district of Monteluce, for a female section. The two nuclei were communicating by means of a flat avenue in the green and equipped with a track for transport. The subsequent developments of the *cittadella* are aimed at a functional reorganization: some buildings are demolished and replaced by new and more functional pavilions; further small extensions follow until the end of the thirties of the twentieth century and provide the complex with services for patients (theater, library, bar and store). After World War II, a national design competition for the construction of the new Provincial Neuropsychiatric Hospital of Perugia was held. The winner is the Venetian architect Daniele Calabi. This project and a next project of enlargement by the Perugian architects Francesco and Pietro Zannetti will never have followed. In 1965, the renewal of the Provincial Administration presided over by Ilvano Rasimelli started a process of deep change in the conception of psychiatric assistance, which involved a renewed vision of the patient and his care: the hospital gradually opened its doors, putting the rights and dignity of the person at the centre. Thus, in 1978, with the approval of the Law Basaglia, the asylum of Perugia is already prepared to the dismantling. This reaches to fulfillment in 1980, while to national level the closing will be completed only to half of the years Ninety.

Thus, research was conducted on the archival documentation of the asylum preserved at the *Archivio di Stato di Perugia* (ASP), with particular attention to the analysis of the original medical records (filed from 1824 to 1981), with the aim of enhancing the memory of the former provincial neuropsychiatric hospital of *Santa Margherita* in Perugia and to give voice to the silent identities of the former patients (Fig. 3). The investigation revealed the subdivision of the conspicuous documentation on the basis of the departments that constituted the hospital itself at the time: in addition to the documents concerning the psychiatric patients of the *Santa Margherita* hospital, there are also those relating to the inpatients at *Villa Massari*, the *Regia clinica delle malattie nervose e mentali dell'Università di Perugia* and the *Reparto libero*. The individual patient file is divided into three main parts: the administrative documentation, that is the correspondence between the Direction of the Neuropsychiatric Hospital, the Mayor of the City and the President of the Court of Perugia; the medical-health documentation, which in turn consists of the questionnaire for admission to the hospital (aimed at reconstructing the patient's clinical-family history by means of ritual questions), the actual medical record, and the certificate of identity (in which the patient's personal data and a photographic image were reported), the nosological register (in which, in addition to the description of symptoms, the final outcome of the hospitalization for discharge or death

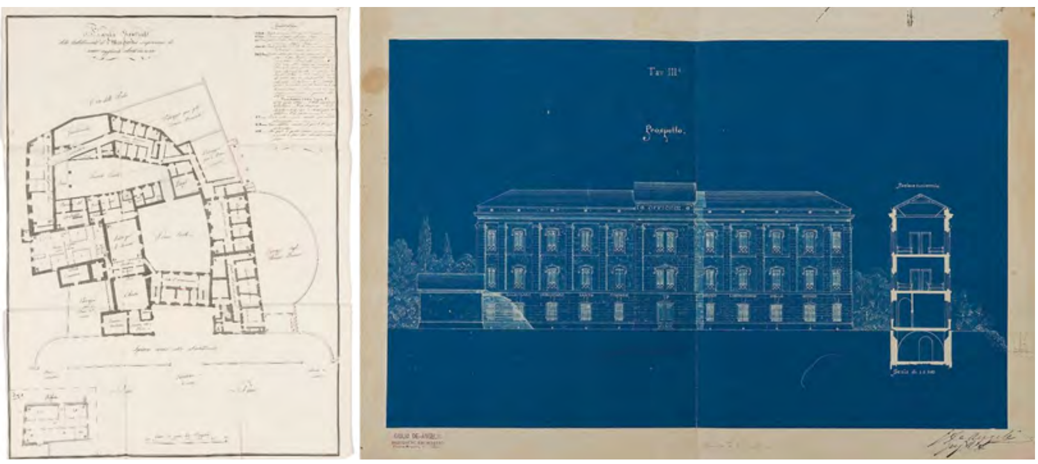

Fig. 2. Poletti L., *Adaptation of the Hospital of Santa Margherita in Perugia*, General plan of the Santa Margherita hospital, Civic Art Library of Modena, 1832 (left);
De Angelis G., *Project for the pavilion for sick workers* (later called the *Adriani pavilion*), 1884-86, frontal view, Archivio di Stato di Perugia (right).

of the patient was transcribed), the clinical diary (in which the developments of his mental condition were recorded), medical certificates and any diagnostic tests; Finally, the private documentation, consisting of the patient's correspondence with family members. In detail, the symbolic document of the "medicalization of madness" [Foucault 1998, p. 58], was definitely the medical record. The records found, filed in two subseries (men and women), were ordered chronologically with respect to the date of admission and represented dossiers in which all the information related to the hospital stay was reported by the neuropsychiatric hospital itself: the patient's personal details, the patient's serial number (a unique element of identification of the patient within each department and assigned at the time of admission), the medical history and the diagnosis of the treating doctor. The project is based on the results of the analysis of this documentation in order to create an integrated museum where AI and AR interact synergistically. A physical museum, whose installation is proposed inside a disused gallery located in the immediate vicinity of the area of *Santa Margherita* in Perugia, the original site of the asylum complex, contributing to enhance through an immersive installation an urban space otherwise forgotten because now unused. But also, a virtual museum, which finds space in social networks through an *Instagram* profile in which a multitude of digital avatars are the actors of the narration of individual personal stories. These virtual constructs 'impersonate' within the *MAD* museum the testimony of the alienated, reconstructed from the analysis of medical records. In particular, the virtual graphic transposition of the 'patient-type' was possible thanks to *Reallusion's Character Creator* software, which allows the interactive design of realistic three-dimensional characters by determining their posture and facial expression, as well as allowing them to be equipped with clothing and accessories. In the specific case study, the physiognomy of the patient Natale Barbafina (1922-1973) was virtually reproduced. His physiognomic features were derived from a photo attached to his medical record and reconstructed using the *Headshot* plug-in for *Character Creator*. Based on AI, the plug-in is able to generate in real time the somatic features for digital avatars starting from a single photograph of the person. Once the basic human structure is recreated, the program lets users modify and refine the virtual character's facial features and traits using the *Sculpt Morph* command. Specifically, by keeping the source image as a transparent background, it was possible to 'sculpt' the 3D model of the avatar in a more accurate way, so as to increase the correspondence with the real photo of the patient. Through sculpting operations on the control areas of interest, three types of parameters were then set; parameters that define the general configuration of the head such as height and width (*global morphs*), parameters that shape the contour of the face by acting on the front and side lines (*peripheral morphs*) and parameters that trace the details of the face from the eyes to the mouth (*feature morphs*). Subsequently, through the *Edit facial* function, the character was given a unique and distinctive facial expression, customized from the predefined ones and able to evoke the attitude of the subject. Finally, *Reallusion's iClone* program was used to animate the avatar's face. Specifically, through the *Acculips* feature, it was possible to perform lip synchronization and translate each phoneme into a viseme. So, the stories of the alienated, who remained within the walls of the asylum, are narrated by virtual patients, electing the MAD integrated museum as a choral tale of a forgotten past (Figs. 4-5).

Fig. 3. Original medical records (filed from 1824 to 1981), Archivio di Stato di Perugia (ASP).

Conclusions

As in the case of all Italian asylums, the history of the former Psychiatric Hospital of Perugia is also made up of denied identities. The asylum is a 'microcosm' which, although inspired by an ideal model of society, declares itself with an impassable perimeter of walls and protective nets. The apparent spontaneity of the images of daily life inside the *cittadella dei pazzi* is the filter imposed by an altered normality, in which every action is subject to precise rules of behavior on which the will of the individual patient cannot influence. The faces and stories of the many psychiatric patients (whose declared pathological condition often derives from a less than perfect adherence to the conventionally defined roles of social behaviour) are closed in the archives and wait to be rediscovered. Through this interpretation, reflecting today on the theme of identity takes on an even more significant value. Man lives in a society oriented towards a potential drift algocratic that seems to deny the value of individual identity. Just think of the portal *thispersondoesnotexist.com*, which exhibits the performance of AI by generating perfectly plausible faces of non-existent people, and consider its social implications as a result. Recovering the meaning of each individual's identity right through AI becomes a search for authenticity that gives depth of meaning to these tools. Even more so when identity is linked to memory and when the memory to be rediscovered and consolidated is composed of individual identities that have been forgotten because they have been denied. The *MAD* project ascribes to AI the role of memory fly-wheel: no longer a random generator of identities that do not find a real correspondent (in this sense poor in value) but an actor in the valorization of real identities obliterated by history. Through the project, the identities of places and people are remembered and collected in an experiential museum in which the uniqueness of personal experience contributes to the construction of a collective identity in which to recognize and through which to grow new shared meanings.

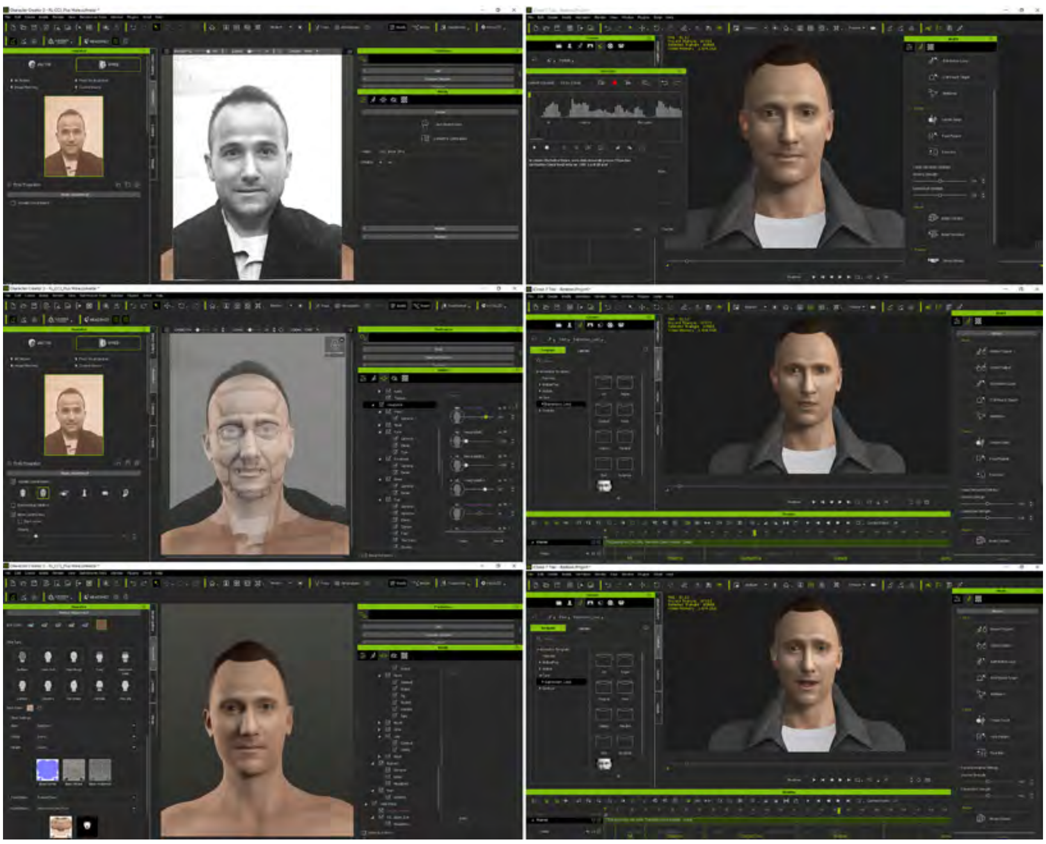

Fig. 4. Digital patient modeling (left) and animation (right) through Reallusions's Character Creator and iClone software.

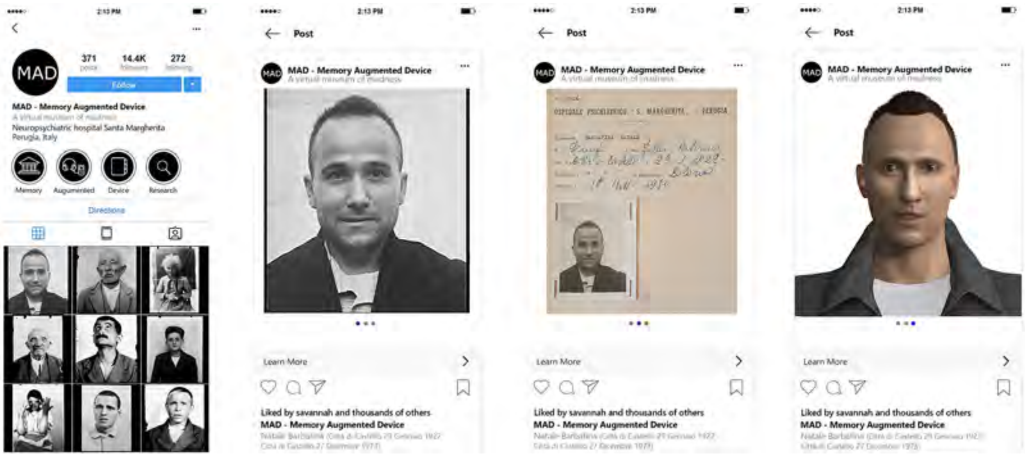

Fig. 5. Instagram profile of the *MAD* project with patient photos, medical records and digital avatar.

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Virtual Canova: a Digital Exhibition Across MANN and Hermitage Museums

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Abstract

The paper presents the results of a scientific collaboration between the Interdepartmental Research Center Urban/Eco of the University of Naples Federico II and the MANN (*Museo Archeologico Nazionale di Napoli*, National Archaeological Museum of Naples).
The research activity was aimed to the digitisation, design, and development of an AR/VR-powered narrative experience regarding Antonio Canova's statuary that is currently exhibited at the MANN, loaned by the Hermitage in St. Petersburg: Cupid, Hebe, Dancer, Cupid and Psyche, the Genius of Death and The Three Graces.
The project is motivated by the will to realize an active example of a digital museum, where cultural and formative experiences related to the fruition of architectural and artistic artifacts can be relived over time, even when manufacts are not physically and/or temporally located in the space where the experience takes place.

Keywords
digitisation, photogrammetry, digital museum, Unreal Engine, virtual/augmented reality.

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Canova and the Ancient: the exhibition

Antonio Canova's artistic production is strongly tied to the city of Naples.
The so-called "modern Phidias" arrived in Naples in 1780 to admire the beauties of the city and the antiquity of Ercolano and Paestum. He was always greatly fascinated with the classical ruins, and with the majestic art of museums and urban galleries. His travel notes recount his visits to Cappella Sansevero, to the Gallery of Capodimonte and to the museum of Portici. At that time, the latter hosted a collection of the antique manufacts from the ruins in the Vesuvian area. In his recollections, the sculptor associates Naples with Heaven. The "marvellous beauty" that he sees in the city leads him to develop entrenched relationships of study and work in the territory, and their results can still be admired nowadays. Some gypsum moulds, realized by Canova to study and draw the nude during his period at San Carlo delle Mortelle, are kept in the Plaster Cast Gallery at the Naples Academy of Fine Arts.
Following the artist's directions, a portrait statue commissioned to him by the king Ferdinand IV of Bourbon is exhibited in the niche of the Monumental Staircase of the National Archaeological Museum of Naples since 1821.
Plebiscito Square is dominated by the statue of Charles III, crafted by Canova and commissioned by the king's son, Ferdinand I of Bourbon, after he regained the throne of Naples as the King of the Two Sicilies. Actually, the king requested Canova the completion of the equestrian monument that was meant to be dedicated to Napoleon by Joseph Bonaparte, and later by Joachim Murat.
In addition to the mentioned works exhibited in the city, other "Neapolitan" productions by the artist are not located in Naples, for various reasons. One example is represented by the marble statuary 'Venus and Adonis', realized for a temple in the garden of marquis Francesco Maria Berio's palace in Via Toledo and now in Geneva; 'The Vestal', a work realized for the count Paolo Marulli d'Ascoli, left Naples for Switzerland, and then for the Getty Museum in Los Angeles; the sculpture 'Hercules and Lichas', conceived by Canova for the Neapolitan Onorato Gaetani, was then bought by the Roman Giovanni Torlonia and never reached Naples; we know only the chalks of Caroline and Joachim Murat's marble portraits, carved during the French decade, as the statues were lost.
The events here reported clearly highlight the relationship between the master Antonio Canova's art and Naples, or in general, classicism.
These considerations led to the realization of the exhibition '*Canova e l'Antico*' (Canova and the Ancient) at the MANN in Naples, within a vast action programme, characterized by a high scientific value, and at the same time by a keen eye to modernity [Giulierini 2021a; Giulierini 2021b]. The exhibition was curated by Giuseppe Pavanelli, and open from the 28th march to the 30th June 2019; it has been the first one to highlight the continuous, intense and fruitful relationship between Canova and the classical world, exalting his figure as "the last of the Ancients and the first of the Moderns". Hence, only this Museum could allow the development of such a complex and fascinating proposal, which related Canova's creations with the great works from the past.
The exhibition was divided along two floors of the Museum and presented the whole variegated artistic production by Canova, from drawings, sketches, to gypsum and marble, with first-class masterpieces.
The loans from the Plaster Cast Gallery of Possagno, the Museum of Bassano Del Grappa, the Bohdan and Varvara Khanenko National Museum of Arts in Kiev, and the Naples Academy of Fine Arts played a fundamental role.
The exhibition was enriched by the technological support, which allowed providing information on the initial section and on the unit with the tempera paintings from Possagno, restored with the support of the MANN. The final unit contained some shots by the photographer Mimmo Jodice.
The keystone of the exhibition was represented by the sculptures from the Hermitage in St. Petersburg: this museum and the MANN are related by a 4-year protocol, begun by Maurizio Cecconi and supported by Villaggio Globale International. These sculptures include the renowned statuary of the Three Graces, exhibited in the charming Meridiana Salon, together with all the other statues from the Russian museum. (P.G.)

Canova and the Future: the *Virtual Canova* project

Virtual reality (VR) is nowadays an indisputable technological solution to many challenges: making it possible to create environments that simulates the real world and create interactions, it guarantees experiences that would be impossible otherwise, just as in the case of virtual museums exposing operas that are not physically available because of many reasons.
Since the 90s, virtual spaces called "virtual museums", where present on the Internet aiming at disseminating art experiences online. The further step from online dissemination toward onsite experience extension was just a question of time and of VR devices cost decrease.
Many definitions of VR can be found in the literature but almost in any of them the following concepts are systematically present: simulation, interaction, and immersion. In a virtual environment users can interact with the operas and with the environment, VR generates a deeply realistic sense of immersion. Many virtual tours have been described in literature [for a review see Loaiza Carvajal et al. 2020] pictorial art is frequently considered as the type of art to be shown, as introduction of 3D digitation techniques as those depicted in this work, are still poorly spread in the related scientific community. The introduction of low-cost VR visors and the use of laser-scanner and photogrammetry opens to a new ecological environment where visitor can enjoy of an interactive virtual space with almost the same amount of degree of freedom of the "real" reality, and sculpture museums become an ideal training ground for new mediality.
The idea of the Canova experience come out by the will of some of the authors of this work to maintain and extend the presence of Canova in Naples. The artist already left important signs of his art in the city, while spreading his masterpieces all over the world, and when the exhibition at MANN was designed, which included loans of artworks that probably we will never see again in Italy, the occasion to scan the operas and maintaining their flavoral presence in our town was really too tempting. (F.C.)

The Digitisation Project: Container and Content

The digitisation was performed on six marble statues by Canova, coming from St. Petersburg and included in the exhibition '*Canova e l'Antico*' organized at the MANN in Naples: Cupid, Hebe, Dancer, Cupid and Psyche, the Genius of Death and The Three Graces.
The acquisition of geometric and chromatic data was carried out on the architectural context and on the statues – at a more detailed scale – in order to realize the 3D representation of both the digital collection and its room, in compliance with the dual relationship between the container and the content.
Hence, morphometric and radiometric data from the Meridiana Salon – the room where the Russian collection was exhibited – have been collected first, through a TLS survey campaign, The room was surveyed with 12 planned scans, performed with a phase-modulating laser scanner, Faro Focus3D X330, setting the maximum distance between the range maps acquired to 10 metres. The distribution of the station points was related to the spatial design of the exhibition. In fact, exhibited sculptures and materials were collocated according to a complex geometric design, in order to allow the visitors to move fluidly around the art works. As a consequence, the position of the TLS has been chosen so as to cover the whole space, considering the occlusions caused by the statues because of the incidence angle of the infrared illuminator on their target surface (Fig. 1). The spatial configuration of the environment and its architectural characteristics have led to choose an average scan resolution of 6 mm at a distance of 10 metres. These parameters resulted to be suitable for the digitisation of the Meridiana Salon with a sufficient degree of accuracy and detail, with respect to the goal of the research.
In order to simplify the following phase of range maps alignment, a number of spherical targets were located at several points in the area and framed during the shots. The position of these targets has been designed so as to guarantee their visibility from different locations, in particular from points that presented criticalities with respect to the alignment of scans.

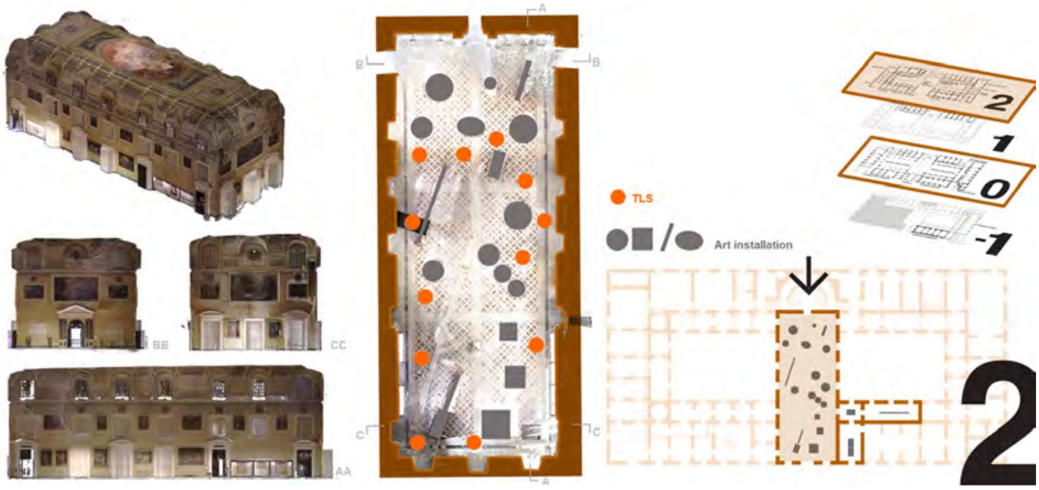

Fig. 1. Meridiana Salon, MANN. TLS Survey.

The 12 range maps have been aligned with the proprietary software FaroSCENE, through automatic geometric primitive fitting algorithms on the considered elements (spheres and planes). The automatic procedure required no additional manual integration of further homologous points for this survey, as no alignment errors occurred. The tension between the targets on each scan is within the range of 1 mm. The registration of the final point cloud, constituted by around 230 million points, was performed in FaroSCENE. It allowed processing several orthophoto mosaics related to the pavement of the Meridiana Salon: as detailed in the following, this was aimed to reconstruct a virtual setting for the fruition of the digitized collection, yet keeping the characteristics of the real venue of the exhibition.
The second data collection was carried out on the six statues by Canova.
The digitisation of the statues has been performed by photogrammetry: successive photographic shots were taken with a Reflex Canon EOS1300D camera, with an on-axis shooting system, by moving around each statue along a circular path. The photos have been taken at different heights: from the bottom, few centimetres above the floor, with an image tilted upwards; at eye level, with the image plane parallel to the dominant plane of each statue; with a telescopic rod, with the image plane tilted downwards. The telescopic rod was used both because of the significant height of the marble sculptures (some almost reached the height of 2 metres), and for the system adopted by the MANN for the exhibition. All the surveyed statues were located on a 30 cm tall platform, round or square-shaped depending on the case. Moreover, while some statues were exhibited alone, others were coupled with statues that did not belong to the Russian collection. So, the shots were made more difficult by the obstruction and the shadows produced by the coupled statues.
During the acquisition stage, a huge focus was given to the lighting conditions, and to their effects on colourimetric data and shades. In fact, big light sources had been placed above the platforms for the exhibition: this condition led to the presence of incoherent shadows on the statues, projected downwards by the light sources in the top. Moreover, the colour temperature – they were warm lights – also affected the realism of colourimetric data, which will be detailed in the next paragraph. The need to overcome this situation led to use a pair of spotlights on a tripod during the photographic shots; the colour temperature of the light was varied as appropriate, and the tripod was moved as the images were acquired, by rotating it around the statues (Fig. 2).
The photographic dataset collected for each statue was processed in compliance with the established practices of digital photogrammetry. The obtained data allowed drafting a synthetic comparative framework that outlines the dimensions of each statue, the specific characteristics of the exhibition design, and the dimensional relationships between the statues and the visitor (Fig. 3). (V.C.)

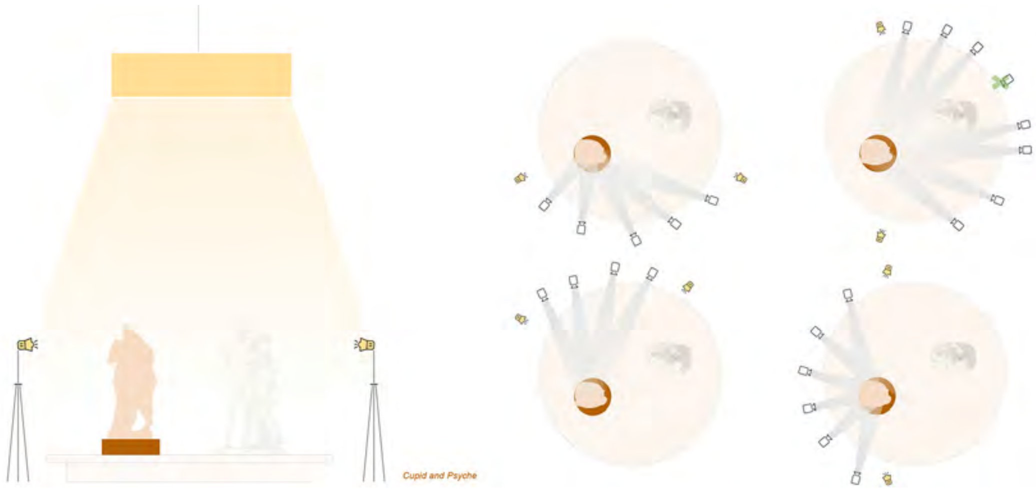

Fig. 2. Image acquisition system with spotlights.

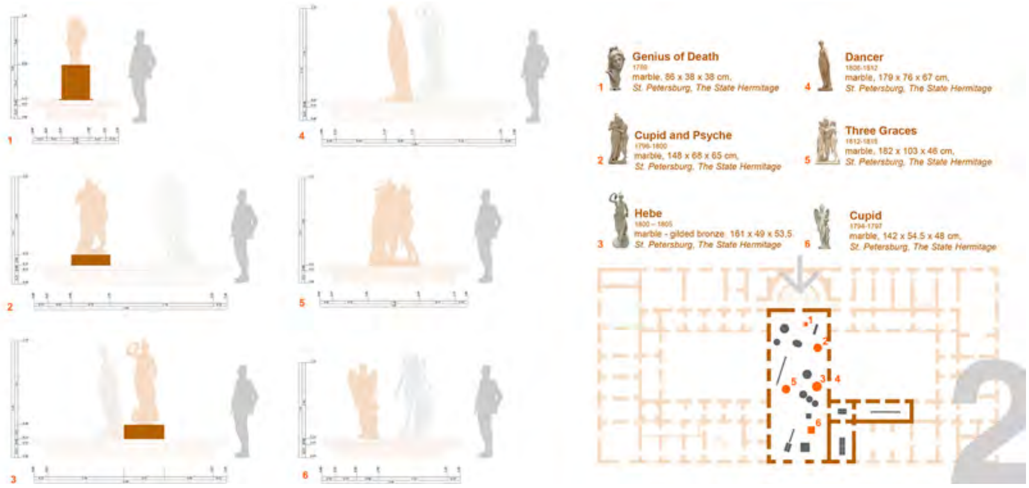

Fig. 3. Synoptic comparative table.

The Design of the VR Experience

The fruition experience was designed in Unreal Engine, with a strong focus both on the manipulation of the digital models and on the information content associated to them.
In first place, the manipulation processes of the digital models have been studied in order to identify the most opportune modalities of graphical simplification for the elements of the collection. The goal has been to achieve a high degree of fluidity in their use in VR/AR applications, yet keeping a high level of photorealism [Campi et al. 2019; Cera et al. 2018].
Starting from the point cloud, a high poly mesh was obtained using Delaunay triangulation (Fig. 4). Since this type of mesh has a very high density and is not suitable for real-time rendering, decimation strategies were applied. Quadric Edge Collapse [Cignoni et al. 2008] was applied first to reduce the number of polygons, with a minimal impact on visual quality (Fig. 5a). Then, retopologisation allowed reconstructing smaller parts of the statues that were incorrectly recorded during the survey phase [Perticarini et al. 2020]. For example, the latter was performed on the cup held by Hebe in her left hand. This element had not been correctly reconstructed because of the lighting conditions and of its specific material: these led to the presence of strong shadows, which hindered Structure from Motion algorithms. Hence, it was necessary to operate manually, with a nurbs modelling of the cup based on the partial data acquired through photogrammetry (Fig. 5b). Likewise, some details related to the anatomical features and shapes of the human body required an intervention of retopologisation, by placing vertexes and mesh polygons (an example is represented by the posterior calves of the Cupid).

To further reduce the computational power needed to render the statues in real time, a more aggressive decimation step was applied to obtain low poly meshes. This led to the loss of geometric details: normal maps and ambient occlusion maps were then computed to simulate them. These maps were obtained by using a Texture Baking procedure, considering the difference between the high poly mesh and the corresponding low-poly version. For some of the more complex statues, full-scale decimation did not provide good quality meshes, so it was necessary to decompose the initial mesh in sub-parts and apply the procedure to them separately.
To implement the virtual visiting experience, Unreal Engine 4 (UE4) was used. UE4 is an industry-grade photorealistic engine, employed to manage real time interactive 3D experiences. Over the last 30 years, it has been mainly adopted by the gaming industry to produce many AAA titles. More recently, the applications of UE4 have also been extended to other fields, such as Architectural Design, Virtual Production and Simulation.

Fig. 4. 3D Modeling. Results.

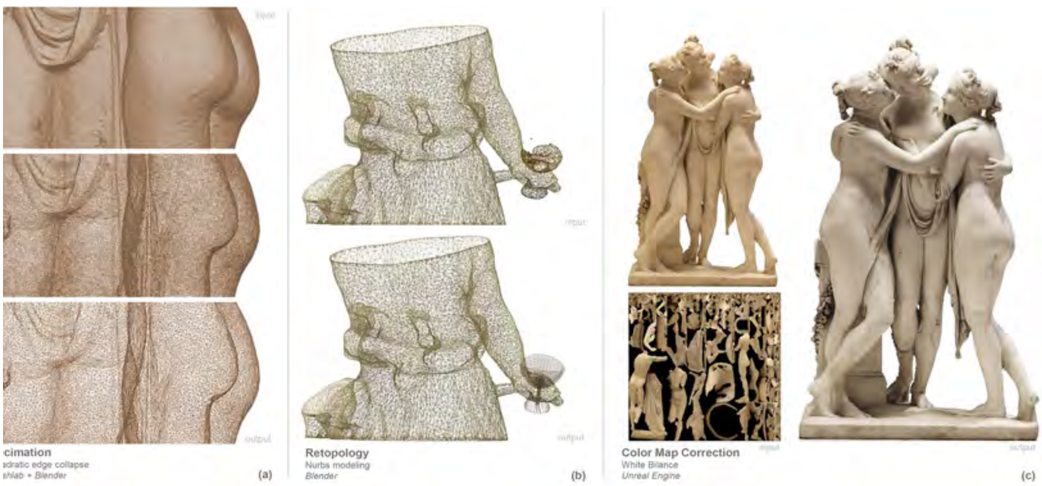

Fig. 5. Model manipulation for implementation.

The interactive experience was designed to simulate a visit to a virtual environment inspired by the original setting of the exhibition in the Meridiana Salon. In particular, the same floor was reproduced in the virtual setting, as it is a very recognisable feature of the real room. Also, the room colours were used to paint the virtual walls and the illumination system was designed to match the lighting of the room at the time of the survey. However, warm lights were used to light the statues, and so the colour textures had a strong yellow component. This effect was compensated by adjusting the white balance in UE4 (Fig. 5c).
Concerning the experience itself, the statues were positioned in the virtual room and each of them was associated with a virtual panel designed to show general textual information and

specific details about the statue. Descriptive texts were associated with the parts of interest and a virtual interface designed for the Oculus Rift controllers was implemented. Users could approach the statues and move around them as in a real setting. Moreover, hot points on the statues marked the presence of textual content that could be accessed by pointing and clicking. The room has also been provided with a virtual screen that showed different kinds of accessory material, together with the descriptions of the statues (Fig. 6). (V.C., A.O.)

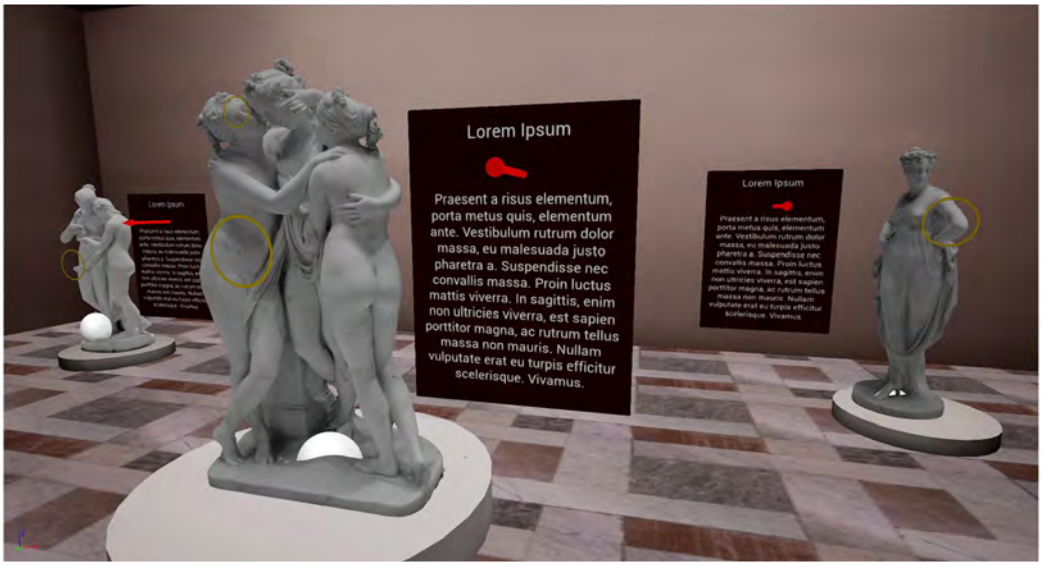

Fig. 6. Virtual scene.

Conclusions

The scientific collaboration between the Interdepartmental Research Centre Urban/Eco of the University of Naples and the MANN – National Archaeological Museum of Naples has provided the chance to realize an active example of digital museum. There, cultural and formative experiences related to the fruition of architectural and artistic artifacts can be relived over time, even if the manufacts are not physically and/or temporally located in the space where the experience takes place.

The implementation of the project has called for a strong degree of interdisciplinarity, as the required skills range from real digitization processes to the computer structuring of virtual environments. The paper also highlighted the need to carry out specific studies on the exhibition venue of the virtual experiences. In fact, the spatial composition of the digital environment where the statuary was located and its related visual perception were studied through specific activities: the study of colours in the hall, the analysis of materials of the pavement and walls, the study of light.

The strong goal of the concrete realization of an experience open to public has led to the Virtual Canova exhibition, which will be inaugurated in the summer of 2022 at the Educational Centre of the MANN. (V.C.)

Attributions

Although part of a shared work, in writing this contribution Francesco Cutugno (F.C.) has dealt with the paragraph: *Canova and the Future: the Virtual Canova project*; Valeria Cera (V.C.) has dealt with the paragraphs: *The digitisation project: container and content*; *The design of the VR experience*; *Conclusions*; Antonio Origlia (A.O.) has dealt with the paragraph: *The design of the VR experience*; Paolo Giulierini (P.G.) has dealt with the paragraph: *Canova and the Ancient: the exhibition*.

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Virtual Reality in Future Museums

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Abstract

The current global situation underlined the necessity of new accessibility standards in the field of cultural dissemination. Due to the limitations defined to contain the pandemic, the process of digitalization of art and knowledge increased its speed, exploiting practices and technologies which once were commonly used in specific sectors. In this climate of fervent developments, the use of Virtual Reality is growing as a medium to convey information, working on themes like immersivity, interactivity and simulation, and considering the previous experimentations in cinematography and videogames, to define experiences which connect sensory perception, engagement and learning. The faithful reconstruction of the Pavilion 2B of the ex Mattatoio di Testaccio in Rome aims to create a virtual environment to be used for digital exhibitions by students and visitors, working on innovative tools to convey art and culture.

Keywords
digital, museum, communication, VR, heritage.

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Latest Developments in the Digitalization of Cultural Heritage

During the last decades, a fast and articulate process of digitalization has been carried out in the fields of art and knowledge, aiming at finding new ways to preserve, analyze and communicate culture and places of interest. Many museums, archives and institutions, along with artists and companies specialized in visual and interaction design, digitalize their own collections to make them available online, creating vast catalogs and even virtual tours to provide an immersive and stimulating experience [Antinucci 2007, pp. 94-121]. The Louvre Museum and the Gallerie degli Uffizi both developed partial digital exhibitions, using respectively 360° panoramic pictures and laser scanning to create models where the visitor can dive in and navigate through hotspots, admiring works and the architecture around, and reading information using interactive elements (Fig. 1). The digital transformation is also one of the main pillars of the program *Horizon Europe 2021-2027*, strictly related to the *Athene Charter* and *London Charter* in configuring the main aspects behind for the proper ways to digitally represent of architecture and archeology.
Due to the safety restrictions made to stem and control the current pandemic situation, which has changed dramatically people's experience of interaction and movement inside and outside their own countries, this process of digitalization is facing a strong evolutionary impulse, increasingly bringing alternative techniques and modalities of dissemination and use of cultural heritage [Toffoletti 2021, pp. 15-45]. The ultimate purpose is possibly the research for a wider and more articulate accessibility, capable of allowing everyone to engage with culture and knowledge, everywhere and anytime, incentivizing inclusivity and overcoming the crisis caused by the pandemic to the ordinary communicative paradigms.
In a fervent climate of investigation, the choice of developing Virtual Reality as a medium for the dissemination of art and knowledge could address these necessities with innovative ways yet to be explored, providing a different model for transmitting information and unveiling new meanings in the relationship between people and cultural heritage.

Virtual Reality in Architectural Communication

The use of Extended Reality (XR), in its multiple forms, is expanding as a new and alternative tool to understand and interface with the historical and artistic heritage, both material and immaterial, allowing deep and diachronic investigations. In this evolution, cinematographic and videogame industries hold a substantial role, being among the first fields to invest on digital innovation and having worked for decades on themes like immersivity, simulation and the direction of human perception. Interdisciplinarity and contamination among fields are vital to build a concrete and valuable research project, working on the boundaries among disciplines.

Fig. 1. Screens taken from the virtual tours created by Louvre (left) and the Uffizi (right).

Among the many variations took by XR, Virtual Reality (VR) consist in creating a completely artificial environment using sensory stimuli generated by devices, where Augmented Reality (AR) can be seen as a real-time overlay of information and actions over physical world images captured by a device. Being profoundly related to the tridimensional representation of a space, VR has a solid connection to architecture, landscape and environment, making this medium suitable to investigate and communicate these themes [Greenard 2019, pp. 37-53]. Exploiting advanced technologies and VR, it is possible to create reconstructions of real places, with different levels of accuracy and resemblance to the original, which can be used to set up alternative experiences of exhibitions and visits, working on immersivity and interaction with the virtual environment as key-points to capture users' attention, blending information with entertainment, in order to convey a message through engagement. VR guarantees the opportunity to create and experience spaces free from the limitations imposed by physical reality, especially when it comes to cultural heritage and its conservation. It allows the users to explore distant places, sites inaccessible due to their conditions, faithful reconstruction of destroyed buildings, or even parallel realities in which unbuilt architectures can find their own location and show a different look of a landscape "that could have been" [Cianci 2019, pp. 1357-1366].
The representation of architecture and spaces has developed to become closer to reality, trying to simulate all its qualities. Starting from perspectives, continuing with digital renders, the perception of the reproduction has become even more faithful and detailed, but the architectural imagery remains detached from the observer, who usually doesn't have an active role and undergoes the bidimensional image. The main turning point produced by Virtual Reality is the break with the limited frame given by the physical medium: through devices like Head-mounted displays (HMD), it is possible to explore the scene all around with a wider degree of freedom, opening at new ways to understand, design and communicate architecture from the inside, experimenting spaces directly in first person.
This powerful achievement, which unfolds an unlimited range of possibilities of interaction, also causes an interesting issue when it comes to narrate a place: traditional methods for directing and manipulating the users' attention cannot contain their autonomy in choosing how to experience the virtual environment, as far as many compositive rules lose their strength and need to be revised. In a virtual environment, the dynamic, articulated and multidirectional space creates a challenge for storytelling, as it is difficult to transmit information neatly and coherently without a "backstage" to hide ploys and special effects [Butcher 2017, pp. 80-126]. Therefore, the narration of a digital space must be designed through the entire navigable area, as the audience is part of the stage, working on users' perception and behavior to channel or divert their interest, using alternative elements like spatialized sounds, optical alterations, lights and movements, or even trying to trigger sensory stimuli by using synesthetic stratagems. Furthermore, by introducing new devices and techniques to simulate senses, other than VR displays, it is even possible to reach a deeper connection with digital replicas, reproducing a richer quantity of data which can help communicating the subject in a more complete and unique way [Riccò 2008, pp. 28-32].

Related Case Studies

Among the many experimentations of virtual museums developed during the last decades, an original case study was carried out in Buenos Aires by the *Centro de Investigaciones Ópticas* and the *Falcultad de Ingeniería de la Universidad Nacional de La Plata* [Loaiza Carvajal 2020, pp. 234-239]. Not only the project works on creating a virtual museum for cultural heritage dissemination, combining Captured Reality and 3D manual modelling, it also aims to produce a synergy among different curatorial teams to convey two unique and rich virtual tours.
In *Virtual Collections* exhibition, Structure from Motion technique was used to capture detailed reconstructions of heritage manufacts (Fig. 2a), using drones for bigger objects; then, they were simplified to be usable in a fluid real-time application. The architectural space, the signage and the supporting furniture were designed and modeled by the team to emphasize

the objects, paying attention to users' eye fatigue in reading digital descriptions through an HMD. The exhibition didn't have a specific orientation, so the circular path can be followed freely by the visitor, starting from any point.
Krause. Vestigios disponibles exhibition primarily contains drawings, paintings, models and a collage of photographs, so Captured Reality was used for fewer manufacts, choosing to digitize the rest and use it as textures to apply on simple surfaces; this process lightened the model, made it easier to be used for the virtual tour. In this case, the museum was mostly reproduced with manual modelling to communicate the collection with lights and furniture close to the original.
Both the applications were developed in Unity game engine and thought to be used first on computer screens, and then implemented for HMDs. Users can navigate pointing at the place to reach and pressing a button, guaranteeing a free exploration of the museums (even if not continuous and fluid). Manufacts can be look closely but manipulations are not allowed, as it happens in almost every museum.
A particular case study is the virtual museum of Regolini-Galassi Tomb in Cerveteri, a research born within the European project *Etruscanning* [Pietroni 2014, pp. 1-29]. The team focused on the recreation of a deep and detailed simulation of the scene, capturing users' attention through their senses to convey themes ranging from landscape to archeology and ethno-anthropology. The site is one of the richest and most famous tombs of the Orientalizing period, dated 675-650 a.C. and discovered in 1836. It's inaccessible and almost empty nowadays.
The main point of the project was to investigate new ways of experiencing cultural and landscape heritage by introducing a fictional storytelling to evocate an imagery and narrate funeral rites in a suggestive journey. By mixing VR systems and Captured Reality, the team articulated a complex scenario using Unity game engine, generating a digital environment, true to the original site, and using it as the ideal stage to exhibit photo-modeled artifacts (Fig. 2b), hypnotizing their exact location in the tomb and giving them an interactive role.
Two voices, representing the people buried in the tomb, accompany visitors, narrating their own stories through relics and ordinary tools, which can be selected and analyzed to get descriptions. It's an escamotage to captivate users and obtain an improved willingness to learn. Similarly, sensory stimuli were used to direct users through their experience, while preserving their freedom: spatialized sounds from the forest outside the tomb-museum; dynamics lights from torches to progressively unveil the environment, hidden in the darkness of the night. The project also implemented a wider range of senses to the virtual experience, introducing the kinetic element as an immersive form of connection between users and virtual exploration, increasing the embodiment, the feeling of "being really there", to better and actively channel information through engagement. In a dark room, visitors take place in front of a screen and a sensor captures the gestures of their arms, moving the camera accordingly, so the body participate actively in navigating the museum.

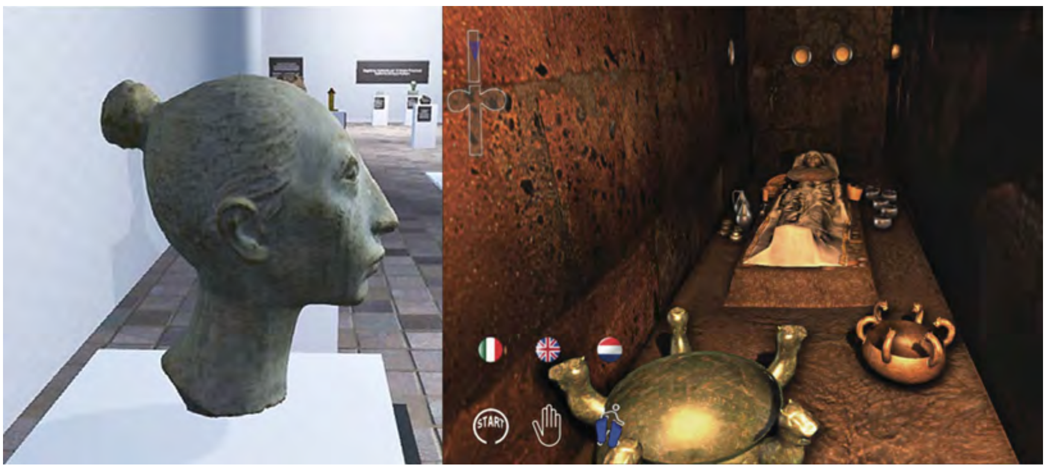

Fig. 2. Screens from two case studies analyzed: (a) a photogrammetric model of a cement head sculpture; (b) relics inside the Tomb Regolini-Galassi.

Creating the Pavilion 2B Exhibition

The project aimed to recreate a faithful reconstruction of one of the pavilions of the *ex Mattatoio di Testaccio* in Rome and use it as a virtual museum to host temporary exhibitions for students and visitors. Exploiting the infinite possibilities of a digital environments, capable of things not allowed in the physical world, the research focused on creating a support scenario for multiple experiencing, combining VR features, sensory suggestions and entertainment elements to communicate art and culture in multiple forms.

Built between 1888 and 1891, the new slaughterhouse was design by Gioacchino Ersoch in the Testaccio neighborhood to replace the previous one realized in Piazza del Popolo. Characterized by a rational distribution of functions to guarantee a better hygiene and surveillance, the area was divided in pavilions, which were built using masonry walls, marble, iron structures and wooden roofs. The pavilion 2B, the one chosen for the study, contained stables for tamed cattle, right next to the main entrance of the complex. The slaughterhouse was dismissed in 1975, assuming various functions through time, and becoming part of the *Città delle Arti* restoration project, housing the Architecture Department of Roma Tre University since 2000. The Pavilion 2B was completely restored in 2013 and intended for classrooms and laboratories, exploiting its structural subdivisions to implement movable walls, creating an open and flexible space for multiple uses.

During the first stage, a replica of the pavilion was developed as a direct tridimensional reference to help designing the museum later, optimizing the control over the process. To do so, a photogrammetric survey was planned inside and outside the building, paying attention to the link between the parts. Using a reflex camera and working on cylindrical panoramic shooting through selected points on the axis, the interiors were captured, leaving some blind spots due to the articulation of the upper part of the building, especially because of the iron rails and the skylight. The two external facades were easily captured using parallel axis shooting, while it was not possible to obtain a complete survey of the roof, which should have been made using a drone. This step was avoided for time and authorizations issues, giving more attention to the inside of the pavilion. Furthermore, the role of the photogrammetric reconstruction was primarily to have a faithful reference for the actual model, which was later build manually starting from original drawings and implemented with current element. This choice was made to better manage its heaviness and complexity, two essential parameters for a fluid and practical real-time experience. Choosing a Captured Reality version of the pavilion to design the museum would have required much higher technological resources, made it less usable for ordinary devices [Basso 2019, pp. 2414-2425]. Photos were then selected, edited and imported in Photoscan to create a point cloud of the pavilion (Fig. 3a), which was cleaned, meshed and textured, before being exported. The pavilion 2B was then manually modeled in Rhinoceros, using digital drawings obtained by scans of the original project and other resources provided by AUT catalogue [1] (Fig. 3b). It focused on giving a detailed representation of the interiors, paying attention to materials and the relationship between original and added components; outside, the environment was simplified to just guarantee an immersive but light context to the scene.

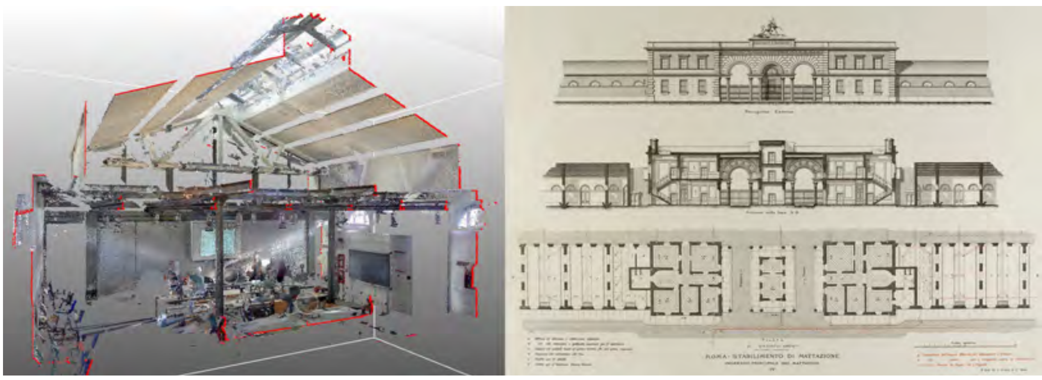

Fig. 3. References for the digital reconstruction of the pavilion: (a) sectioned photogrammetric model of the current state of the Pavilion 2B; (b) one of the original drawings for the Mattatoio's project.

To design a virtual museum for the first exhibition, a masterplan was developed, considering principally three themes: the collections involved, the relationship with the appearance of ex-industrial pavilion and the tight subdivision its interiors. The catalogues chosen for the first experimentation contained drawings and models elaborated by students, divided in various themes, going from the study of spatial complexity and Purini's works, to Manifestos, Terragni's unbuilt projects and Italo Calvino's *Città Invisibili*. Three groups elaborated ideas, which were later merged into a single cohesive plan (Fig. 4). It was decided to give each of the seven areas a subject, generating a double path from the entrance, following two narrative strands to be visited in a free but consequential way. The masterplan almost totally hid the pavilion from the visual plane of the users, made it visible just by the ceiling. A continuous red ribbon runs through the museum, changing its form and function according to the exhibition, while other surfaces were kept black or white. Small groups focused on designing each of the themed area, balancing the integrity of the masterplan concept with the narrative and the peculiarities of every collection. Ideas mostly used were pedestals, opaque and transparent stands, holographic elements, niches and audiovisual chambers (Fig. 5). Many of the objects were modeled as predispositions to be completed during the latest stage, as it was for lights and manufacts to be animated.
The virtual museum experience was developed in Unreal Engine 4.27, starting from a first-person template to optimize time and coding, as this one already had some preset features, like camera movements, reducing and simplifying programming even for non-experts. This choice was principally made to give the visitor an immersive experience of the museum, working on the sense of embodiment and deep engagement; a first-person point of view would have also allowed a further implementation of stereometric vision and HMD systems. A base model of the pavilion was imported in the project, choosing a specified origin, to create a template for every group. Materials were created to be as close as possible to the originals, using cast iron, plaster, clear glass and concrete for the interiors, marble and bricks for the facades of the Pavilion 2B; the rest of the context was left white, to focus the attention on the main subject. A system of complex collisions was then generated, starting from

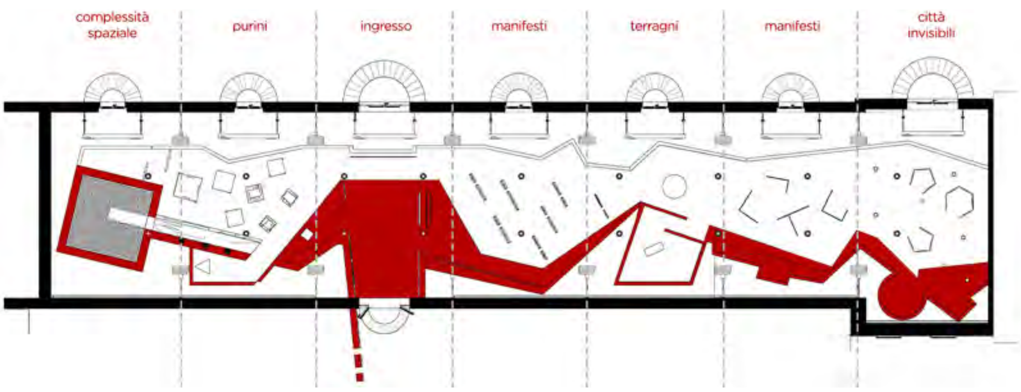

Fig. 4. Masterplan of the virtual museum, created by selecting and merging ideas from three different concepts.

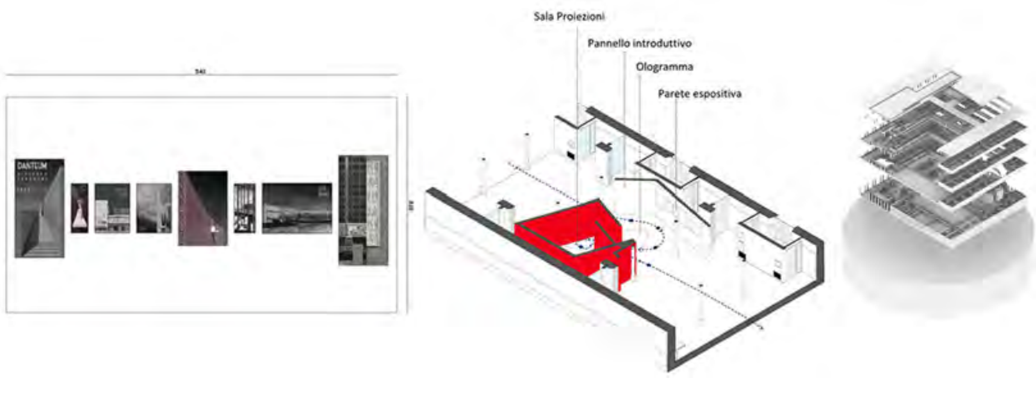

Fig. 5. Project concepts showing the process of designing the exhibition, from selecting and organizing works (left), to defining paths and functional areas (center), to creating models for animations (right).

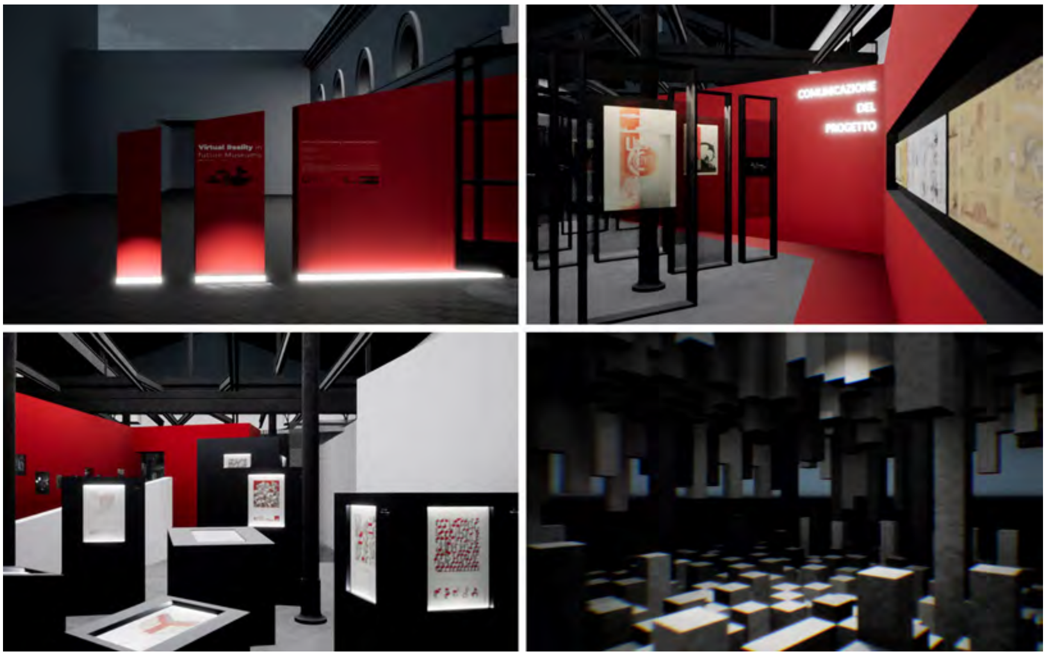

Fig. 6. Screens taken inside the virtual simulation. From top left: the totem at the entrance; Manifestos; Purini's works; inside the Cube Chamber (Spatial Complexity).

the model's meshes, to simulate the physical constrains in the virtual experience. Each group imported its own part of the museum on a copy of the base project, using the same origin, to keep the possibility of working separately and then merging all the results together. This optimized the development of the seven parts of exhibition but gave some issues later, in importing and reorganizing the scenes, as some minor unintentional changes created differences with the original model, which were easily fixable but delayed the process.
For each area, groups imagined interactive elements to engage the users and better convey information. Drawings were used as materials and applied to surfaces with the same proportions to simulate actual artboards. Objects were programmed using *Trigger Volumes* to activate animations or special effects when the visitor entered their area. Some videos, like an interview to Purini and some Terragni's works, were used to create cinematic rooms.
The experience was imagined to be an evening exhibition to enhance its lighting design, which was thought both to direct users' attention on artworks and narrating them through a fluid sequence of dark and bright areas, introverted chambers and surreal spaces.
Spatialized sounds and visual effects were also used as key elements for creating a multisensory exploration, not only to articulate different areas with a dedicated atmosphere, but also to create suggestive imageries, as it was for the cavern echoes and altered colors in the *Cube Chamber*, or telling stories, as for the lens flare effects and narrating voices in representing Calvino's *Città Invisibili*.

Conclusions and Further Applications

Starting the simulation outside the Pavilion 2B, visitors are invited in by the red stripe, which becomes a totem to describe the evening exhibition. Going inside, music and holographic descriptions of the building welcomes them, giving some direction to users and letting them choose how to explore the museum in total freedom, generating an immersive and interactive experience which brings them to get in touch with multiple themes thanks to an alternative reality made it possible by the virtual environment (Fig. 6).
Though there were some issues during the process, mainly deriving from time and technological resources, the project developed allowed to experience new tools and methods for communicating arts, exploiting techniques which could lead to innovative paradigms for the dissemination of culture, and giving a virtual stage ready for future exhibitions. Further appli-

cations considered are the extension of the exhibition to the external areas of the *Mattatoio*, adding new parts to the Pavilion 2B, and the investigation of new interactive features to help the engagement and the transmission of information, like commands and other complex animations. The implementation of HMD and binocular vision to deepen the experience is also one of the main themes to be pursued in a future development.

Notes

[1] AUT – Archivio Urbano Testaccio is a documentation center, born as part of research fields of the Department of Architecture of Roma Tre University, which focuses on the study of Testaccio neighborhood and the ex Mattatoio.

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Enhanced Interaction Experience for Holographic Visualization

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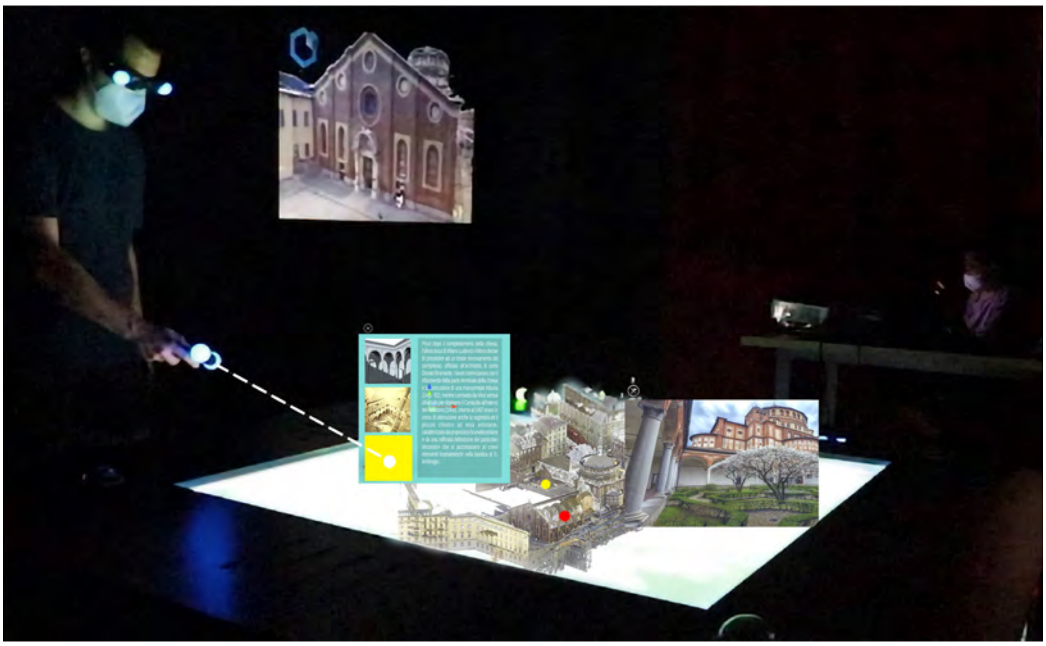
Abstract

Nowadays, holographic visualization pushes further the limits in exploring tri-dimensional digital content. 3D models typically displayed through a computer screen now enter the real world as holograms. The Hologram Table allows users to visualize and manipulate huge 3D models as if they were in the space in front of them. Its use has already proved helpful for the virtual fruition and presentation of complex cultural heritage buildings and their design interventions, but it surely can do more. The work aims at exploring the possibility of expanding the capabilities of the Hologram Table interaction by developing a custom-designed experience to interact with 3D point cloud data coming from survey activity. The test case was the interesting building of the Santa Maria delle Grazie (Milan, Italy) basilica. Initial results are encouraging and show that the point model can be enriched with associated information and additional content (images and texts) available for holographic visualization.

Keywords
cultural heritage, euclideon hologram technology, hologram table, point cloud, Unity.



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Introduction

Holographic visualization allows you to overcome the limitations of the flat screen of a computer in the exploration of tri-dimensional digital content. Thanks to holographic devices (e.g. Microsoft HoloLens [Weinmann et al. 2021], Magic Leap [Wunder et al. 2020]), 3D point and mesh models now can enter the real world in the form of holograms [Kyung-Jin et al. 2020]. These seem to be the most futuristic way to view and intervene, even on large-scale or large-detail digital data. These visualization tools proved useful in many different applications ranging from industrial to medical [Fraga-Lamas et al. 2018; Brun et al. 2019]. In this ever-changing context, the world of Cultural Heritage (CH) strife to keep up with applications mainly relegated to tourism, dissemination and museums [Voinea et al. 2019]. In recent years, holographic visualization is entering the professional practice allowing for visualization and management of monumental heritage architectures [Teruggi, Fassi 2021]. Holograms could become an integral part of conservation procedures and virtual understanding of CH structures [Reaver 2019]. The difficulty lies in the production of the 3D content to be displayed. Indeed, if the modelling process is straightforward for industrial and standardized objects, it is not so for CH objects. In this field, similar elements are instead different in their geometry when considerable metric accuracy has to be maintained; besides, the complicated and time-consuming modelling phase usually introduces a certain degree of simplification, which depends on the subjective interpretation of the operator or specific software limits.
However, thanks to the considerable advancement made in the survey techniques, nowadays, it is possible to have a complete and accurate description of even the most complex object in the form of point clouds. Architects, designers, historians, installers, and researchers could benefit from these accurate and precise representations. They could act as tools to collect and display digital models and their referenced information that can be accessed at any time and for any purpose. Having the possibility of tri-dimensionally enquiring and navigating through this data can undoubtedly enhance object understanding as well as communication exchange between all actors involved in the conservation/reuse/design process.
Previous works investigated the possibility of using the Euclideon Hologram Table to visualize and manage complex and huge CH point clouds [Bolognesi et al. 2021]. The tested Euclideon proprietary software package allows setting up and displaying a dynamic 3D presentation where the users can navigate 3D models at different scales. This first experiment outlined a great potential in the holographic device and visualizations. Despite the high number of points to be managed, the navigation is incredibly fluid and lets to zoom in to see a high amount of detail. However, the standard interaction paradigm with the point model stops here; it is only possible to pan, orbit, zoom, and some basic annotations (e.g., labels, measures), but all basic information added during the navigation is lost when the device is turned off. Adding information and modification to the point clouds or the mesh models must be performed outside the holographic environment.
Recently, Euclideon Holographics released the Unity Toolkits (V0.5.62082), which are library integrations that allow developers of the Unity 3D game engine to interface with the hardware of the Euclideon Hologram Table. This new aspect opens a world of possibility, allowing it to enhance and expand user capabilities to interact with holographic models. In this work, the authors explore the possibility of broadening table device interaction capabilities by developing a custom-designed experience to interact with 3D point cloud data coming from survey activity. The test case was the basilica of Santa Maria delle Grazie (Milan, Italy).

The Basilica of *Santa Maria delle Grazie* Digital Survey

The basilica of Santa Maria delle Grazie has been digitally surveyed during several measurement campaigns due to its significant dimension and complex structure [Bolognesi, Fiorillo 2019]. The south side of the complex is occupied by the Solarian church (with three naves on the longitudinal layout and side chapels) with its Bramante tribune. The Chiostro dei Morti (post-war reconstruction after 1943 bombings) borders are on the south side with the

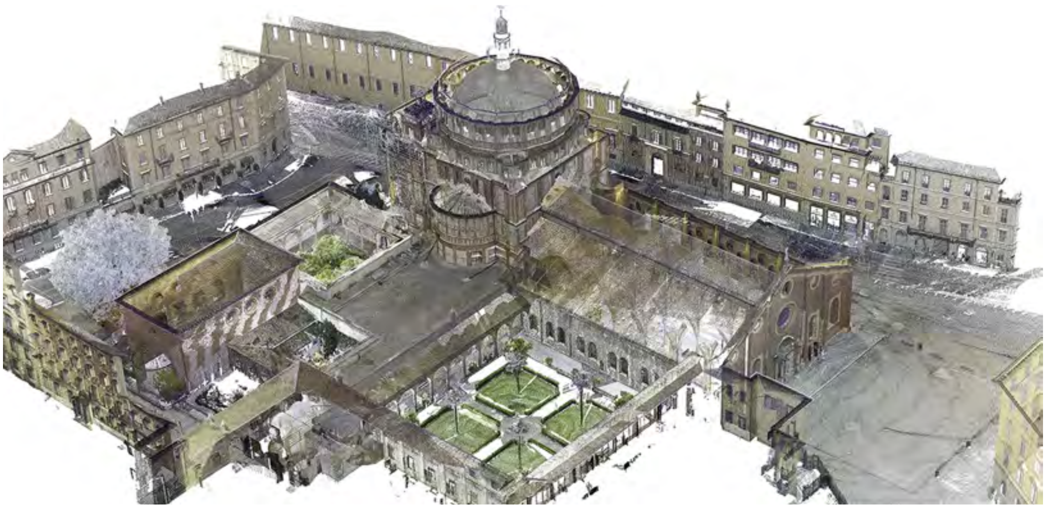

Fig. 1. The Basilica of Santa Maria delle Grazie, Milan, Italy (Point Cloud view).

church, on the east side the new sacristy of Ludovico il Moro and on the west side with the refectory (where the Last Supper fresco by Leonardo da Vinci is located). The old sacristy and the Chiostro delle Rane by Bramante and the small Chiostro del Rettore (also known as Chiostro del Priore) are located on the east side of the monastery complex. The church was included in the UNESCO World Heritage List in 1980 as an outstanding example of Renaissance art, together with the Cenacolo Vinciano.
The first survey activities conducted in 2019 interested the following areas: the Chiostro delle Rane (16 scans with Leica HDS7000), the Chiostro del Rettore the old and the new sacristy (36 scans with Leica P30). The final model output of these first surveys reaches more than 2 billion points. The most recent on-site campaigns (2020-21) were instead carried out with a Leica RTC360 for the 3D measurements of the tribune dome (internal and external surface) and the outer perimeter and indoors of the church. The latter 3D survey consists of 122 scans reaching about 4 billion points. Each TLS survey campaign is associated with a project where all the scans are referenced in a local coordinate system. All projects then were registered in a single absolute reference system working with cloud-to-cloud alignment algorithms (Leica Cyclone REGISTER 360). Once the registration step was completed, the scans were cleaned up by removing non-interesting objects in the scene (cars, people, etc.) and the noised points (far away, tangent to surfaces, edge effect points, etc.). The final cloud (Fig. 1) resulting from the merge of the 174 scans was sampled at a resolution of 5 mm, also removing the duplicated points due to the significant overlap among the scans (the latter is necessary above all for the target-less registration used).
The case study has undergone many structural transformations over time, offering interesting insights for our research. In the first place, the holographic visualization can help understand and represent this morphologically complex building and better design any interventions. Secondly, by customizing the hologram table interface, many historical, technical and technological data can be added that otherwise would be difficult to associate with the different areas involved quickly. In this way, the point cloud collects at the same time and in a single digital content the metric and geometric information of the current state and keeps track of the interventions and changes made to the building.

Hardware Setup for the Holographic Visualization

The Euclideon Hologram Business Table belongs to the equipment of the LaborA physical and virtual modelling laboratory (Politecnico di Milano) and is arranged in a dedicated darkroom. The device (2.1 m × 2.1m × 0.6 m) is formed by a flat-screen (1.2 m × 1.2 m) and an embedded projection system (Fig. 2). The latter enables to appear 3D models in the table screen centre up to a height of about 70 cm in a hemispherical volume. The holographic

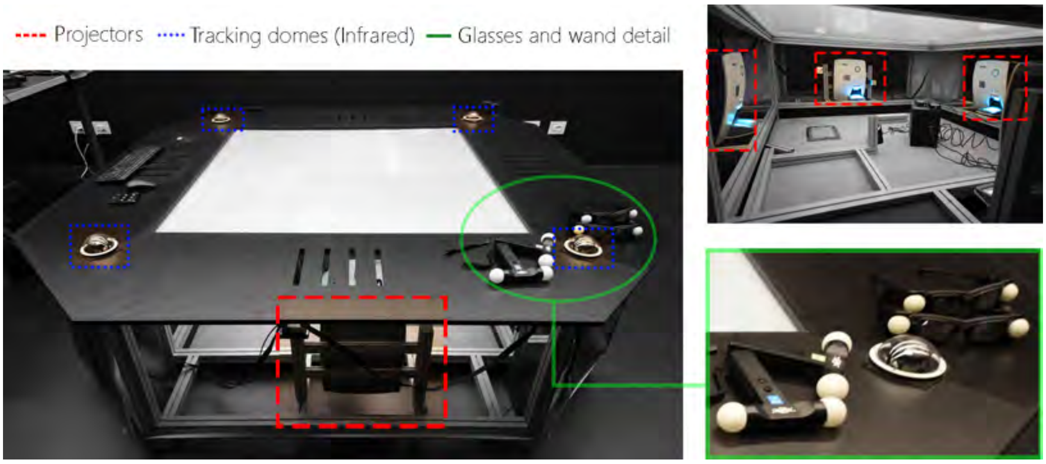

Fig. 2. Euclideon Hologram Table hardware.

device is managed through a workstation (5820 Dell Precision Tower) equipped with two graphics cards (AMD Radeon Pro WX5100). One is dedicated to rendering an external secondary screen (a traditional projector) that allows the model visualization even without glasses. At the same time, the other receives the images to be displayed on the glass surface in the centre of the table through four projectors (Vivitek D757WT with a maximum resolution of 1920 x 1200 at 60 Hz).
A specially designed wand and glasses allow immersive interaction with the holograms, both of which use an infrared tracking system to calculate their position and orientation in space. The tracking equipment consists of four tracking domes arranged in the four corners of the table and controllers, Radio Frequency Dongle and Sync Emitter, connected via USB to the PC. The spheres on the wand and the glasses allow their correct position determination. Indeed, the sync emitter takes light from glasses and wands and sync all devices to work together. Two primary users (equipped with a wand and glasses) can together view and interact with the hologram. A secondary user (fitted with the glasses only) can be added for each primary user, who must be on the same side of the table as the primary user. Thanks to the innovative Multi-User Hologram Technology, two people or two groups can see object projections on the table from different sides. In addition, a supplementary group of users without immersive devices can still participate by looking at the screen or external secondary monitor.

Software and 3D Model Setup

The proposed holographic experience has been developed inside Unity 3D software, a game engine that allows developers to create content for a wide range of devices. Ranging from desktops to virtual and augmented reality applications, software capabilities are limited only by the availability of libraries to interface with the targeted device. The latest Unity Toolkit libraries (V0.5.62082) released by Euclideon have to be imported to interface with the hardware of the holographic table. They contain all necessary functions and methods to access and use sensor streams coming from the device (e.g., wand position, button trigger, wand ray).
The up-to-date HoloTray software has to be installed on the Holographic Table workstation, which is in charge of all background processes necessary to have a correct holographic visualization.
By default, Unity 3D software is able to work and import tri-dimension models in FBX (FilmBoX) format. However, this file format is not compatible with point cloud models coming from survey activities. Therefore, it is necessary to use the PCX [PCX 2021] libraries to import and render point cloud data in PLY – Polygonal File Format inside the Unity game engine. Their most basic function is reading all points that make up the model allowing the

software to treat them as a unique 3D mesh model composed only of vertexes (with no sides). Each vertex brings the (R, G, B) data associated with the corresponding point.
Nevertheless, the most common file for point cloud exchange among different digital survey software is E57 [Huber 2011], a compact, vendor-neutral format for storing together with the point coordinates the images and metadata produced by 3D imaging systems. Therefore, file conversion and more processing actions (e.g. point cloud decimation, orientation and so on) are needed to import the model inside the developing environment. In this work, all point cloud elaboration have been performed using CloudCompare software, an open-source GNU General Public Licence (GPL) software that can manage/edit both 3D point and mesh models.
The whole point model of the Santa Maria delle Grazie complex is comprised of around 6 bln points at an average resolution of 5 mm. Due to the enormous number of points, the point cloud was subsampled at 5 cm resolution with a final PLY of 14,985,027 points and a dimension of 214 Mb. This point reduction allows i) to ease computational requirements on the hardware during both processing and navigation phases and ii) to retain a good visualization quality when the point cloud is holographically displayed on the Hologram Table. For the correct visualization of the point cloud in Unity3D, it is necessary to flip the Y axe with the Z when saving to the PLY file because the software, like most game engines, works with a left-handed reference system. Only (R, G, B) data are read inside the game engine. Depending on the instruments, survey data could include other attributes (e.g., normal vectors and reflectance). To visualize this additional information in Unity, they must be converted into a corresponding to the (R, G, B) data type associated with each point. This process overwrites the default radiometric information. It is thus necessary to create a different version of the same model to visualize different types of data acquired. For this work purposes, only the authentic (R, G, B) colours of the basilica of Santa Maria delle Grazie have been taken into account.
In summary, the work pipeline that allows employing the survey data in the Unity environment includes the following steps (Fig. 3): 1) scan alignments and point cloud editing (the output file format is generally the E57); 2) point cloud setup for holographic display (model decimation and orientation; 3) model export in a PLY file format compatible with PCX libraries to finally arrived at using Unity Toolkits for the Hologram Table.

Enhanced Interaction Experience

The research aims to transform the point cloud of the complex of Santa Maria delle Grazie into an informative model with associated other relevant information: e.g., pictures, historical photos, textual information, survey data, and technical drawings. Every part of the holographic experience must be programmed using the Unity Toolkits available functions to reach this goal (Fig. 4). From an operative point of view, inside the Unity scene, it is necessary to add the point cloud model and the asset of the Hologram Table present inside the toolkits. This allows to i) have a 3D virtual model of the device and all its sensors inside the unity scene and ii) have all necessary background scripts that will stream the holograms through the table four projectors. All virtual models that have to be displayed on the Hologram Table surface must be positioned referred to the model of the Unity Toolkits asset that can be moved or

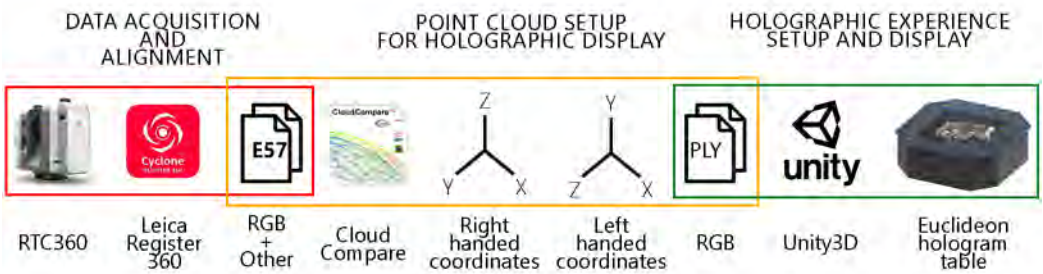

Fig. 3. 3D model setup pipeline.

Fig. 4. Unity3D scene setup pipeline.

scaled as necessary. Each object that does not fall into the flat display of the device will fail to show up when running the application. The point model positioning can be aided by simulating the user 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 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.

Specific scripts of the toolkits must be attached to the unity game objects that must react to interactions. These allow each 3D model to be responsive to different actions performed by the user. For example, the toolkits give access to the wand controller ray cast. This is a ray that projects forward from the virtual model of the wand controller and indicates the direction to which this is pointed. Every object looks for an intersection with this ray before allowing interactions. Furthermore, it is possible to access wand signals through specific functions when a particular button is triggered. This allows the development of a conditional system for which a specific task is performed when the 3D object is pointed with the wand and a determined button is pressed. For the basilica holographic project, pointing it with the wand and holding down the secondary button of the wand allows translation 3D content according to the wand position.

The basic setup of the experience presented foresees four different elements that constitute the scene:

1. The Santa Maria delle Grazie point model.
2. 3D red sphere corresponding to each informative hotspot.
3. Planes and text objects that represent the informative table (and its relative information).
4. A contextual menu with info and control buttons.

The hologram model is placed at the centre of the device flat display as the main object of visualization. When the experience is started, only this model with the associated hotspots is visible and responsive to interactions (Fig. 5). Red spheres are manually placed at the position of the correct hotspot and cannot be moved independently from the model. Both objects are responsive to wand interaction; the basilica model can be moved and zoomed, and clicking on the hotspots will turn on the relative table, which is invisible by default. The hotspot table is composed of three-square planes on its left side and a text field on the right part. A single solid colour plane acts as a background for better text readability. While the text field is associated with historic relevant information, a specific picture is associated with each square plane as its texture. Clicking on these last objects will turn on another plane associated with a full-resolution version of the corresponding image. It is important that the tables (and all relevant user interface elements) are placed almost parallel to the device display area. This alignment allows for better readability of the content that can be contained inside the 70 cm height dome rendering areas above the table. Specific, close buttons associated with plane objects allow the full resolution image or the whole table to turn off. The contextual menu is used to access information regarding the survey activity performed. Clicking on the central button allows displaying a table with all relevant point cloud details. Instead, the side buttons allow rotating the model of the basilica displayed. During the development stage, it is necessary to fill in all data contained inside the table and all hotspots associated with the point cloud. Once the setup is finished, it is possible to build the final solution that can run and be displayed on the Hologram Table.

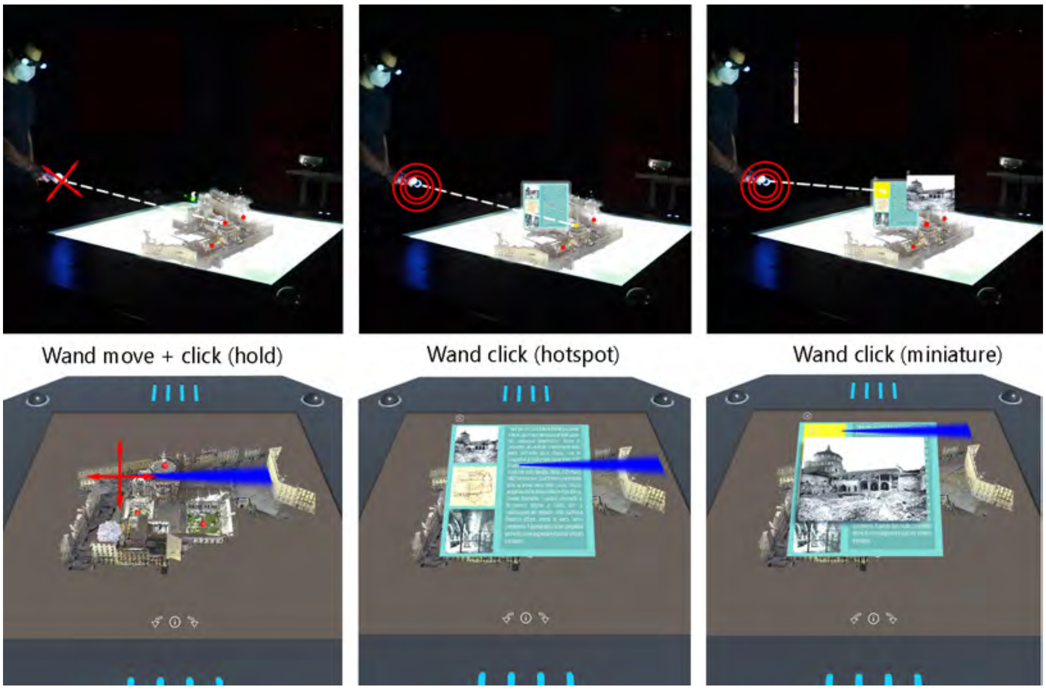

Fig. 5. Holographic experience sequence with first and third-person views.

Conclusions and Future Works

Euclideon Hologram Table, used in its native standard modality, proved to be a powerful point cloud visualization tool and digital model presentation. The advantages of using the standard proprietary software package (Presenter) are different: the management of high numbers of points thanks to the Euclideon Unlimited Detail technology [Euclideon 2013]; no restriction about the point cloud file format; no developer skills need (beginner level of user). However, interaction with the 3D content is basic: pan, zoom, orbit and essential measuring functions.
However, Unity 3D software, expanded with the recently released Euclideon Unity Toolkits libraries, let us transform raw survey data into a powerful, informative holographic model to explore and enquire about different types of knowledge associated with complex heritage geometries. The test experience allowed building a final application where the user can interact with hotspots and virtual information regarding different parts of the CH building. Therefore, the most significant benefit is that both the user interface and digital content are 100% fully customizable. On the other hand, this aspect implies the need for advanced programming and developer skills. One should consider unfavourable aspects to take into account: the restriction about the point cloud file format and the related need to use PCX plugins; and the current impossibility to exploit the Euclideon UD tech to render points using the Unity Toolkits for the Hologram Table. Therefore, it poses a strong limit on the number of points that can be displayed. It is necessary to subsample the point models to an acceptable resolution to retain a good visualization quality while lowering the strain on the device.
The last open question that can be developed and improved is whether all associated information to the point cloud is decided a priori. The data embedded in the application during the development process are stored locally on the device. Hotspot position, table fields, and images cannot change during the hologram runtime. The final user can only access types of information and hotspots decided during development. A new version of the application has to be exported each time digital content is added or changed, including user interfaces (UI).
For example, hologram visibility is strongly tied to the height of the user. If the application is set for good readability with a certain user height, it may be possible that a lower height user will not see all UI elements due to a high incidence angle of its field of view with the table. Therefore, this change has to be during the UI development in Unity.

In conclusion, this first experiment opens a wide path for future directions. Providing the user with the possibility i) to load/modify/add content (e.g. live section) and hotspots during runtime of the hologram display or ii) to download it through an online connection with a reference database would enhance the information exchange process. Furthermore, adding the possibility to save preferences in different sessions and enabling UI elements to adapt to different users heights would certainly boost both the usability of the product and the overall quality of the holographic visualization experience.

A short video of the presented work is available at the following link: https://youtu.be/hLP9U3XRVXM

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The Rooms of Art. The Virtual Museum as an Anticipation of Reality

Isabella Friso
Gabriella Liva

Abstract

In this essay we propose a methodological approach for the realization of a virtual expositive space in which converge on one hand the results of a scientific research based on the study of author's paintings whose contribution has embellished the Venetian territory, and on the other hand a strategy based on a credible interactive proposal for the users, for a creative fruition able to involve emotionally the observer and facilitating at the same time the learning.

Keywords
virtual museum, digital fruition, virtual tour, interactive graphic, digital vision.

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Discovering the Rooms of Art

During the last decades, with the beginning of the so-called "Digital Era", museums have seen a significant expansion of the spaces and media for the knowledge dissemination about their collections and projects. In contemporary society, the increasing presence of ICT has inevitably pushed cultural institutions to update themselves and begin a complex process of digitization carried out at several levels. Museums have shown a growing interest in the web[1], no longer considered only as a promotional space, but as a valid and innovative tool for interaction and user involvement [Mandarano 2019, pp. 65-112]. The museum can be effectively supported by its online one and by Immersive Reality experiences in the performance of its functions, participating in the dissemination of heritage knowledge both because it uses digital reproductions of the preserved works and because it goes beyond the physicality of real spaces. The online version intercepts a public that moves more and more on the web, guarantees global visibility and, above all, brings an extremely diversified audience closer to the world of museums.

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

The exploration of dynamic interfaces, interactive graphic systems, the interrogation of databases accessible by thematic and sensitive maps, 2D/3D tours and a whole series of activities are designed to arouse and stimulate curiosity and creativity.

Certainly, the current communication technologies have stimulated the search for multiple forms of learning and a different way of interacting with the knowledge contents, encouraging a much more widespread promotion and dissemination, but also generating a growing impatience with the digital paradigm [Arcagni 2016, pp. 3-35]. If, on the one hand, technological devices and social platforms have redesigned the grammar of seeing, focusing on narration forms that are increasingly interrelated to digital logic, on the other hand, museum institutions are moving towards the experimentation of hybrid exhibition models in which the virtual component, combined with traditional analogue supports, creates places of multidisciplinary knowledge, favoring the possibilities of expression and inclusion. "It is not, in fact, a matter of preferring digital to analog, but rather of developing an integrated system of communication" [Mandarano 2019, p. 9] [2].

The museum defined as the privileged place "of visual testimonies, which concern culture and the human environment", is the place "that shares the task of collecting, preserving, documenting and studying cultural heritage, but is distinguished because its relationship with the public passes through the exhibition, that is, the presentation and interpretation of objects" [Marini Clarelli 2021, p. 13].

Unfortunately, following the recent pandemic, the containment strategies triggered by the health emergency led to a rapid change in the forms of communication and fruition adopted or being adopted up to now, and to abandon the direct experience of anthropic spaces for an educational re-enactment totally replaced by digital devices. In an attempt to guarantee the right to knowledge, the absence of direct contact with the works has led to an increasing development of dissemination projects that can be implemented on websites, to the exclusive access to resources of the archives on the web, to the sharing of information in social networks and to a continuous proposal of virtual visits [Balboni Brizza 2006, pp. 37-44].

In line with the cultural strategies of many national museums, the authors' interest in digital experiential paths, closely then connected to the virtual museum, stems from the attempt to concretely experiment an alternative solution to the temporal slippage or even the suppression of possible permanent or temporary exhibitions that have occurred in some regional contexts. The exhibition proposal able to clone and digitally transform real environments with multiple information devices and artifacts on display is not intended to replace a physical exhibition, but to collaborate with it, to manage possible emergency situations or to ensure a knowledge dissemination to people who do not have the possibility to reach the existing places.

During the period of physical isolation imposed by Covid-19, in the first year of the Master of Science in Architecture at the Iuav University of Venice, students were given the

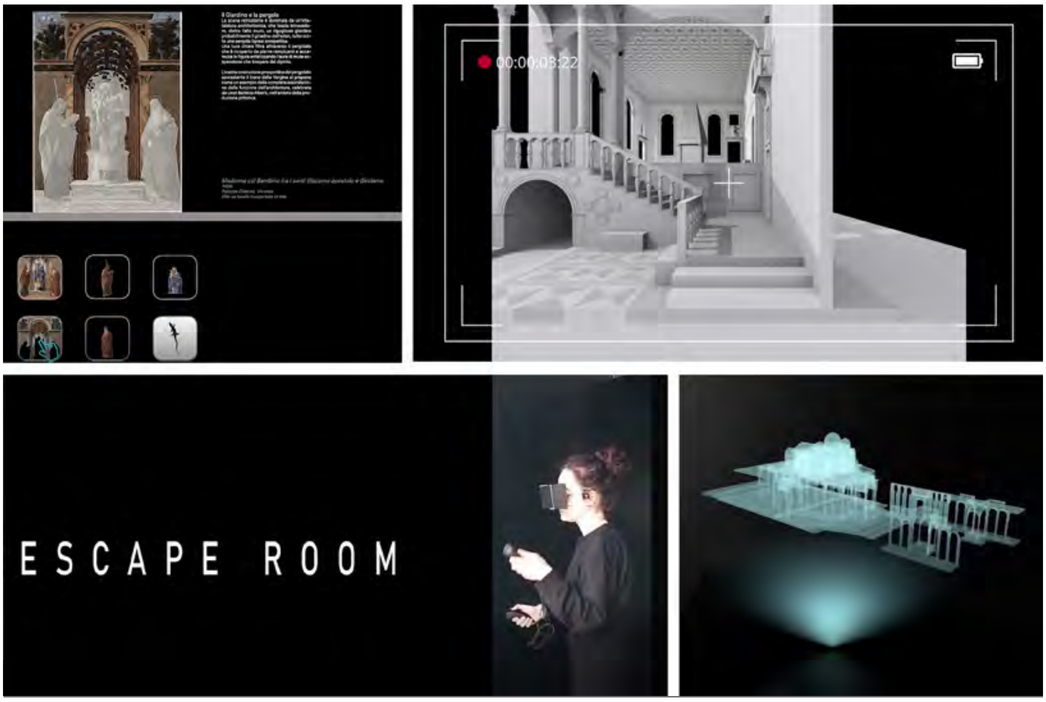

Fig. 1. Simulation of multimedia and interactive technologies, related to gamification strategies.
Università Iuav di Venezia, a.a. 2020-21.

task of creating a virtual exhibition within an existing physical space, the Gino Valle classroom of the former Venetian cotton mill, a space periodically reserved for exhibitions or cultural events [3].
The final goal of this didactic experience concerned the genesis of a multimedia file, about ten minutes, able to illustrate an exhibition path that reasoned about an idea of contemporary space contaminated by the most advanced multimedia and interactive technologies (Fig. 1). From the various examples that ranged from the famous cycle *Le Storie di Sant'Orsola* by Vittore Carpaccio (1465-1520) at the Gallerie dell'Accademia, to individual works by Gentile Bellini (1429-1507), Giovanni Mansueti (1465-1527), Cima da Conegliano (1459-1517) in the Veneto Region, significant reflections emerged not only on how to effectively communicate information (historical data, geometric constructions, architectural artifacts, augmented and virtual reality, entertainment formulas), but above all on the limits of virtual settings and on how to modify the cultural offer in digital format to increase the degrees of freedom of the user.
It is evident that the experiments conducted at the university have highlighted a certain rigidity in conveying the exhibition contents. If on one hand the user is able to understand the possibilities of interaction in the exhibition, on the other hand he involuntarily undergoes the fruition of the exhibition without being able to choose the times of observation and interaction in the single areas of the room. He remains a passive observer who can only observe how to visit the exhibition, the path proposed by the curator and the division of space into thematic areas. The flow of time is constrained by the times imposed by who made the video, deus ex machina who controls the shots, the reconstructions and the learning times.
In light of the considerations, the digital simulation of an exhibition space, certainly useful in communicating events and replacing a physical visit, becomes even more effective when considered as a visual synthesis of a larger work.
The layout proposal and the concluding video can become themselves the storyboard of a virtual tour in which the user is able to acquire his autonomy in choosing the contents and the time dedicated to them. The digital format allows to associate to the space continuous deepening, also from the scientific point of view, activated by the user/navigator that makes himself more participant in the path of knowledge.
Well-known examples, even if characterized by a basic level of content transmission, certainly intended and designed for a heterogeneous public, are the virtual visits [Orlandi, Zambruno,

Vazzana 2014] managed by renowned museums such as the Louvre Museum [https://www.louvre.fr/en/online-tours#virtual-tours], The National Gallery [https://www.nationalgallery.org.uk/visiting/virtual-tours/google-virtual-tour], or the Vatican Museums [https://m.museivaticani.va/content/museivaticani-mobile/it/collezioni/musei/stanze-di-raffaello/tour-virtuale.html] in which it is possible to access individual rooms, to understand and cross the space, to approach the texts or captions, to observe the artifacts on display (Fig. 2).
Ranging from museum rooms to archaeological sites, Virtual Tours offer a digital vision that has invaded cultural offerings, hybridizing them in new ways and demonstrating that in our society "the machine learns from the human eye and the digital eye offers a new support to the human eye" [Arcagni 2016, p. 21].

Exploring the Rooms of Art

Cinema and photography represented the main form and cultural interface of the twentieth century, the tools through which it was possible to achieve a "recording and storage of visible data on material support" [Manovich 2009, p. 1] to write and describe movement. In the era of digital representation, it is virtual reality – necessarily produced through the use of computers – that steals the scene from common forms of data archiving. Consequently, the screen of a PC is in fact the limit of virtual vision, the tool with which the operator/observer is forced to interface by means of windows on an 'illusory' space. This is a physical threshold that offers the possibility of looking at a mosaic of information perceived from multiple points of view with respect to as many different reading planes. The main novelty of the man-computer-culture interface lies in the way machines present cultural data and allow us to interact with them. The contemporary communication technologies have stimulated the research of new forms of learning and a different way of interaction with the contents of knowledge, in order to promote and disseminate them more widely.
Taking advantage of New Technologies, it is possible to experiment with the most up-to-date exhibition and virtual fruition models.
In the Course of Drawing at the first year of the Master's Degree in Architecture at the Iuav University of Venice, the students were given the arduous task of creating a virtual exhibition within a real physical space: the Gino Valle's classroom of the ex Venetian cotton mill. The room designated to its function of container, able to virtually accommodate the didactic contents, has been chosen in function surely from the extremely familiar connotation of the environment that has induced the students to lead back the virtuality of the experience with the real architectural dimension that the classroom imposes (Fig. 3).
The strategy adopted, based on a credible interactive proposal for the user, has provided several stages for a creative fruition that pays homage to famous painters belonging to the humanistic-renaissance Veneto. The work has been divided into precise phases that concerned the historical-critical analysis of the case study, the perspective restitution necessary to obtain the internal orientation and through the homology technique the spatial data for the orthogonal projections, the digital model of the painted architectures (Fig. 4).
Subsequently followed the 3D modeling of the exhibition hall and the exhibit (Fig. 5) to then focus on the storyboard definition that allowed to control the linear sequence of events, favoring a narrative anchored to gamification strategies [Petruzzi 2010].
The final multimedia file illustrates an experiential path that has allowed us to think about an idea of contemporary space contaminated by the most advanced multimedia and interactive technologies.

Fig. 2. On the left: Paris, Museo del Louvre, *Founding Myths: from Hercules to Darth Vader*, login screen, 2022. In the middle:London, The National Gallery, Google virtual tour, 2022; On the right: Rome, Musei Vaticani, tour virtuale *Le stanze di Raffaello*, 2022.

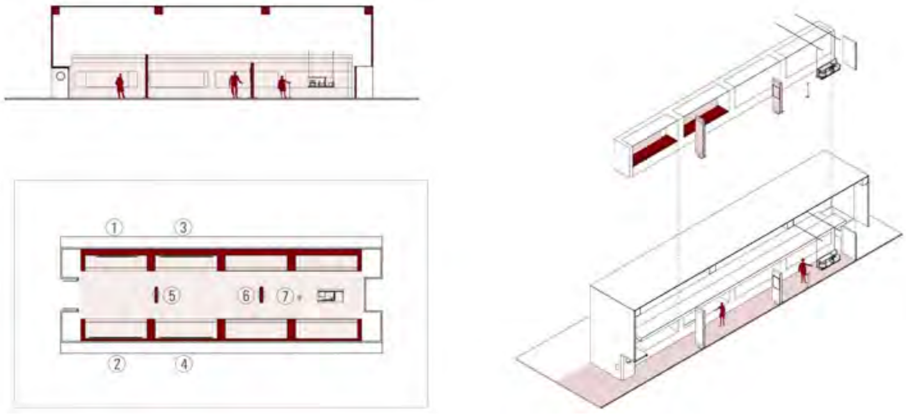

Fig. 3. Gino Valle's room. Plan, section and axonometric cross-section.

The final product is presented as a digital simulation of an exhibition space, but above all it becomes the storyboard of a possible virtual tour: the starting point for the construction of a virtual tour inside the Gino Valle classroom set up as designed by the students and subsequently realized by the authors.

The virtual fruition of the room and the possibility to visualize its interior at 360° happens through the realization of spherical images. Panoramas mapped on the internal surface of an ideal sphere, in order to simulate a 360° panorama (Fig. 6).

The virtual tour has been realized with an open source program. The software is Marzipano that provides for a step by step assembly of the tour.

At first, the 4 spherical images related to the 4 different areas of the exhibition have been imported. The presence of hotspot links makes it possible to create a connection between one room and another, facilitating navigation with the mouse.

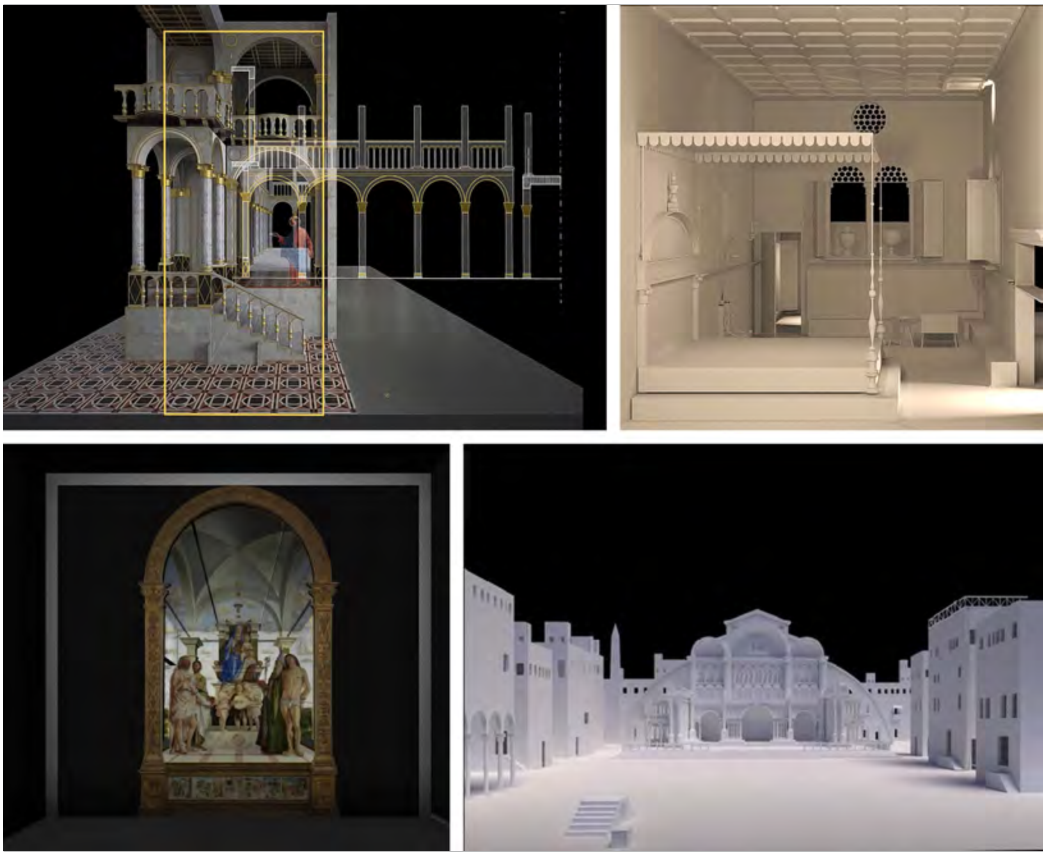

Fig. 4. 3D models of painted architecture. Università Iuav di Venezia, a.a. 2020-21.

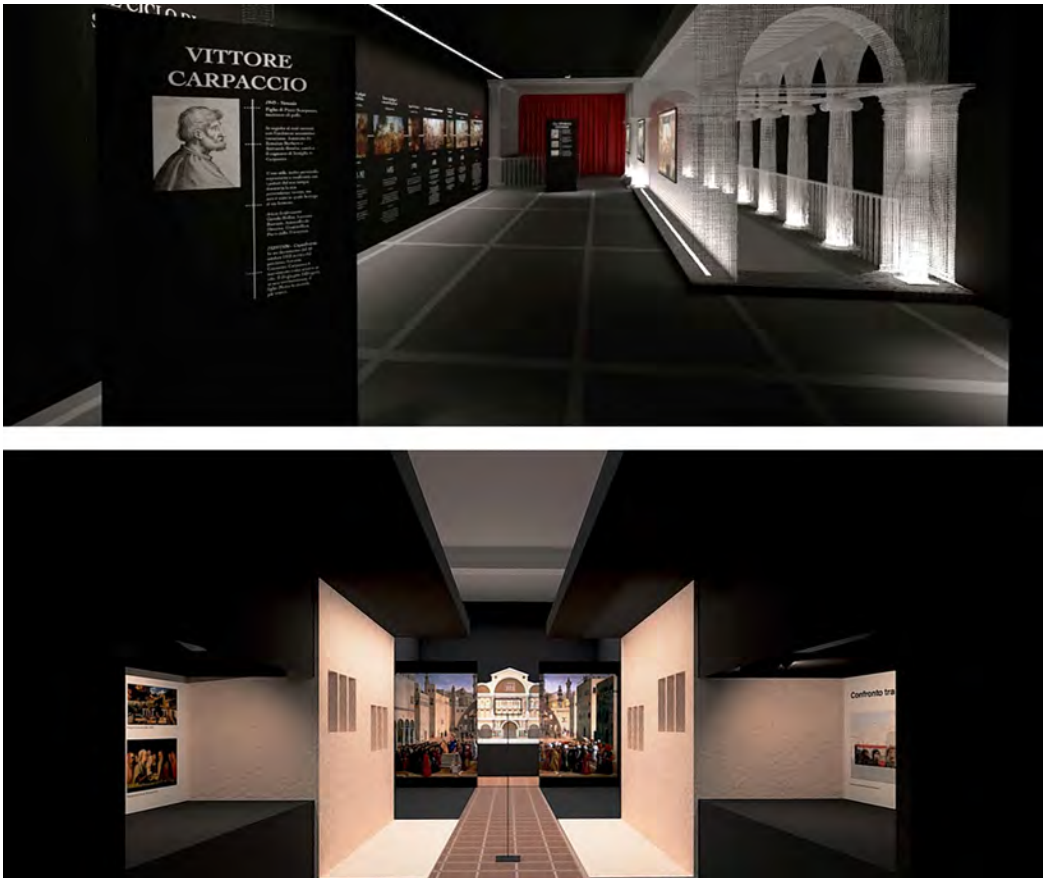

Fig. 5. Examples of virtual exhibit inside the Gino Valle's room. Università Iuav di Venezia, a.a. 2020-21.

On the other hand, the possibility of accessing info hotspots or informative and questionable links allows you to implement knowledge thanks to the inclusion not only of text files but also static images or multimedia files that aid reading and facilitate learning. Thus allowing the user to freely access and query the documents or multimedia files for in-depth study of some of the topics analyzed (Fig. 7). In fact through the virtual navigation it is possible to move among the rooms through a guided path indicated by arrows. The goal of the virtual exhibition is to accompany the visitor on a journey towards an in-depth knowledge of both the artist and his works.
The aim of a virtual tour is to widen considerably the spaces and means for the diffusion of knowledge without aiming at substituting a real fruition, but flanking the museum institutions in the relaunching of cultural objectives and contributing to the success of the educational

Fig. 6. One of the Spherical image of Gino Valle's room.

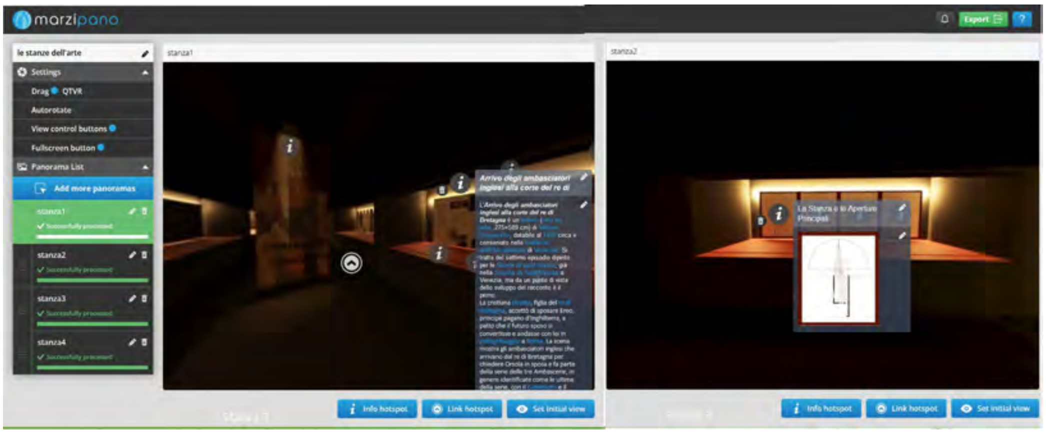

Fig. 7. Screenshot from Marzipano software.

action. In fact, what is missing in these new educational tools is the emotional factor that is present only when the visitor is in direct contact with the work of art and not when the vision of the same is mediated by technology.
In this panorama, the new systems for sharing and consulting catalogs in digital format present themselves as an innovative means of accessing information.
The virtual museum achieves its purpose if it fulfills the functions of research, didactics and alternative information, without aspiring to replace the real museum, but working alongside it in the revitalization of cultural objectives and contributing to the success of educational action. And so, in the last few decades, the progressive introduction of digital devices in museums has found space in many sectors, ranging from the management and preservation of databases, to the cataloguing of materials and the increasingly frequent use of technologies applied to restoration and virtual reconstructions [4].

Notes

[1] All the quotations are translated by the authors.

[2] Museums have expanded online, either by opening official profiles on social networks, or by creating new or redesigned websites.

[3] For more information about the teaching experience at Iuav: Loosening distances: an educational experience of virtual exhibition fruition. In: Aa. Vv. Connecting. Drawing for weaving relationships. 42° Convegno internazionale dei Docenti delle Discipline della Rappresentazione. XVII Congresso dell'Unione Italiana per il Disegno. Roma: Gangemi.

[4] *Discovering the rooms of art* was written by Gabriella Liva and *Exploring the rooms of art* was written by isabella Friso.

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IoT and BIM Interoperability: Digital Twins in Museum Collections

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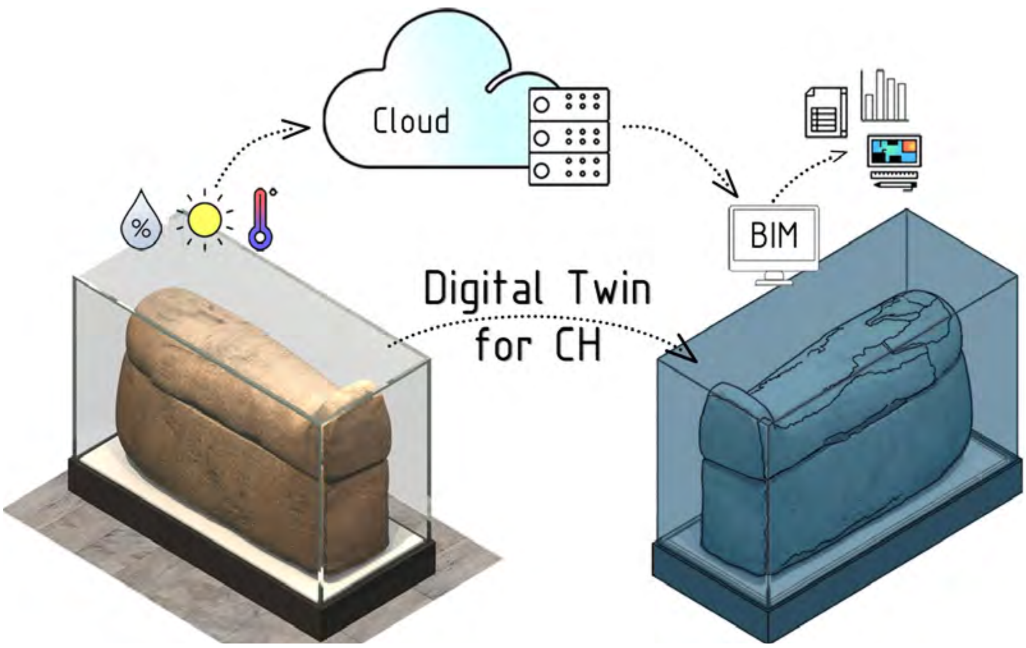
Tomalini Andrea
Pristeri Edoardo

Abstract

According to the 2017 International Council of Museums (ICOM) guidelines, data on museum collections must be stored in a secure environment, supported by backup systems that allow access by all legitimate users, complete and unique identification, and description (associations, provenance, condition, treatment and current location) of each object are required.
Concerning these indications, it is therefore, a priority to establish precise protocols for the preventive conservation and analysis of data concerning not only the identity of the asset or the information collected during its study, but also how it is preserved.
This paper proposes a digital framework for the management of museum structures and collections, integrating Building Information Modelling (BIM) methodologies for the preservation and visualization of data with Internet of Things (IoT) methodologies for its collection and analysis.

Keywords
IoT, BIM, museum collections, interoperability, digital twin.



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Introduction

Museums are very complex bodies that perform various tasks, as summarized in the definition of the International Council of Museums (ICOM): "A museum is a permanent non-profit institution serving society and its development, open to the public, which acquires, preserves, researches, communicates and exhibits the tangible and intangible heritage of humanity and its environment for education, study and enjoyment" [Suay, Peter 2017].

As denoted by the definition, its functions – though varied – are directly related to both the material and the intangible heritage of humanity. Reasoning about material heritage it is easy to understand that over time museum collections will deteriorate. There are different reasons for this deterioration: environmental conditions, vandalism and the natural degeneration of materials. To stop – or at least slow down – the rate of deterioration of artifacts, collections are kept in constantly controlled microclimate where the conditions (of temperature, humidity and light) are appropriate to the material of which the work is composed [Jalpa, Biswajit 2016]. It follows that to prolong the life of museum collections, the monitoring, collection and processing of data regarding the environmental conditions of the museum and individual display cases is among the most important tasks.

In this essay, we propose the definition of a computer architecture structured on different levels that collects, analyzes, classifies and stores environmental information. The system, based on an interdisciplinary relationship, is divided into three different layers, each with its complexities: the first layer is a hardware interface (client) that collects the museum's environmental data and transmits it to the server (cloud or edge); a second server management layer acts as an interface for analyzing the collected data; the last layer, stores locally the processing carried out on the data; this last layer is necessary to provide decision-making tools based on human-readable data to plan more conscious interventions.

A unique feature of the proposed work is the integration of IoT systems and BIM tools through the writing of flexible algorithms in the VPL (Visual Programming Language) environment. The possibility of saving the outputs in a BIM environment facilitates the possibility of linking the information of the building (container) with that of the collections (content) for active management of the museum's issues, improving its enjoyment. The data of the collections are included as BIM objects, the collected information is also included in nested BIM families and both are included in the HBIM model of the museum.

The built prototype can also work in real-time and combines the adaptability of IoT tools with the versatility of BIM tools. The possibility of storing and comparing, through thematic maps, information about exhibition spaces, collections and the museum could optimize the decision-making processes of museum activities, improving security and collection management.

Digital Tools and Environments

IoT – The Internet of Things (IoT) is the discipline that researches how to make objects from our daily lives communicate and coordinate intelligently to provide services, using the network, be it local or Internet. Using sensors and actuators as interfaces to the real world, IoT enables the remote monitoring and management of objects and their environment, providing them with digital interfaces, making them 'smart' and part of our lives. As through the digitisation of every step of the production processes now Industry 4.0 can predict errors in the production processes or possible malfunctions, today we see examples where similar monitoring and prevention processes also take place in the AEC sector. This constant monitoring can be exploited to manage the museum environment and thus improve the conservation and security of cultural heritage or its usability. The use of sensors connected to IoT gateways in monitoring the museum environment has many advantages over traditional monitoring: low cost, low visual impact, low energy consumption, high accessibility, no invasive hardware infrastructure, easy deployment of sensor nodes and the ability to continuously monitor and control the environment.

Machine Learning – One of the main objectives of Machine Learning (ML) is to train a machine to detect patterns in structured data and, consequently, to assess its quality and whether it should be trusted. The data to be analyzed, in this use case, comes from the readings produced by the different edge nodes' sensors. To date, numerous algorithms are available, together with their implementations, to perform these tasks. These algorithms have recently become easily accessible and performing enough to allow developers to integrate these solutions in the most diverse fields, and architecture is no exception. Given the reduced complexity of the problem, for this prototype, we opted to use the open-source Python library scikit-learn, which provides Python language implementations of the most popular ML algorithms. This choice allowed for fast prototyping with little performance impact.

VPL – Visual Programming Language (VPL) applications allow algorithms to be constructed by linking graphic elements that synthesize specific commands. These applications are increasingly being explored in the architectural field because they simplify modeling processes for the production of complex geometries. In this research field, they are used to create a connection between the output of ML processing and the BIM environment. The structuring of this connection in the VPL environment allows an *in itinere* verification of the process and quick customization of the interoperability parameters between the different platforms. The application chosen for the development of this connection is Grasshopper as there are already several plugins that allow communication with BIM platforms. The IoT infrastructure and the ML algorithms are developed in a traditional programming environment to ensure a shorter and more flexible workflow, supported by the availability of consolidated libraries for this type of operation.

BIM environment – Building Information Modeling (BIM) methodologies, widely used in the AEC (Architecture Engineering Construction) sector [Dore et al., 2017] worldwide, catalyze important collaborative processes and interdisciplinary ways of relating through data structures. These structures cover the whole life of the architectural artifact that is intended to be represented utilizing a digital model (National Institute of Building Science, vi. Glossary). The bibliography of the sector is full of examples where BIM is applied not only to new constructions but also to already constructed buildings. In this case, the focus is on maintenance, upkeep, restoration, and the archiving and management of information related to the asset, thus defining the research strand of HBIM [Murphy et al. 2013]. To specific derivations of the methodologies introduced above, new acronyms were born [1]. One of these specific areas, involving the integration of HBIM and Museum Facility Management models, is called MBIM [Tucci et al. 2019]. In the case of modeling [2] of a museum, given the nature of BIM processes, it may be interesting to experiment with the "reuse" of data from multiple information datasets for the elaboration of models with different themes and purposes.

Related Work

We are witnessing several innovations in the AEC sector: the well-established innovations of Industry 4.0 are being translated into the field of architecture and the need to build a Digital Twin of the building is becoming increasingly strong. Smart Buildings, introduced by Clements-Croome's research in 2004, have evolved into Cognitive Buildings and are now able to learn and predict user behavior [Ploennigs et al. 2017] The ability to integrate IoT data with a BIM model of the building could offer new decision-making tools for the Facility Manager to identify potential problems intuitively [Wong et al. 2005].
Given this strong need, it is also possible to identify several examples in the bibliography where IoT sensors are used to reduce the risk of possible damages produced by the interaction between heritage assets and their storage environments. Manfriani et al. describe a virtuous case study where such sensors are used to monitor part of a small museum collection of the City of Genoa dedicated to Paganini, concerning two historical violins. The proposed intervention, consisting of a remote control system based on web-cloud-IoT technology, re-

sulted in a cost-effective improvement of the conservation conditions of the objects for the museum institution; the study is still in progress [Manfriani et al. 2021].
A further application in this direction of considerable importance is the recent example of the Natural History Museum in London. The museum property is 100,000 square meters and there are 15,000 sensors inside measuring every aspect of the museum. This data helps the Natural History Museum team to protect both the building and its collection. This data is stored within a Digital Twin which aims to better inform how it maintains the collection and the environment for visitors [Richardson 2020].
In this area of application of IoT systems for the heritage sphere, it is noteworthy that the spread of increasingly accessible low-tech hardware and visual programming languages, with more user-friendly interfaces and a faster learning curve than traditional programming systems, have allowed architects, engineers and curators to experiment with new strategies for designing or monitoring built architecture.
In terms of design, KM Kensek confirmed the effectiveness of the Dynamo scripting language as a parametric design tool, successfully using data from Arduino environmental sensors (humidity, sunlight and CO2) as input to modify parameters of the BIM model related to the case study project [Kensek 2014]. M. Rahmani Asl et al. suggested that data from simulations can be employed as design criteria using BIM-based optimization frameworks; the framework is developed on Dynamo and collects sensor data from buildings to optimize building energy performance and spatial daylighting based on simulated environmental data [Asl et al. 2015].
Regarding the monitoring of the built environment, Delgado et al. reported sensor families in the BIM environment, positioned at the physical sensors, which can accommodate the temperature and stress values of the monitored structure read by the edge nodes. Also in this case, the connection between IoT and BIM environment was made through the Dynamo application. This approach provides for the dynamic visualization of key structural performance parameters and enables real-time updating, long-term data management and model transformation via the IFC format [Delgado et al. 2018].
There are also some interesting examples for monitoring the museum environment by hybridizing BIM models and IoT sensing. La Russa et al. modeled in Grasshopper's VPL environment Artificial Intelligence algorithms to manage the entrances inside some rooms of villa Zingali, previously modeled in BIM environment, to preserve certain hygrometric conditions inside some rooms [La Russa et al. 2020]. Instead, Pepe et al., within the SensMat project, modeled sensor families in a BIM environment and communicated them with real sensors through Dynamo. The developed framework was designed to be applied to museums with very different themes and architectures [Pepe et al. 2021].

Methodology

The various IoT-connected nodes along with their sensors are placed inside the museum at predefined locations. The nodes can communicate using different wireless technologies, e.g. through Wi-Fi, Zigbee, or 4G. Once the connection to the network is established, they can then proceed to send the sensors' readings data to cloud storage services.
The transmission of data from IoT sensors to the database is done using the MQTT protocol. This protocol is often used in industry due to its flexibility and efficiency. The Sparkplug B v 1.0 namespace [Links 2017] was used to structurally organize the MQTT topics on which the data is transmitted. An example of an MQTT topic adhering to the Sparkplug B standard is the following: "namespace/group_id/message_type/edge_node_id". In our use case the namespace variable is "spBv1.0" given the standard used. The group ID is used to identify the different rooms in the museum environment. The use of this parameter makes it possible to keep track of the position of the sensor and to carry out spatial queries within the database. The message type field assumes the value DDATA, indicating that the payload contains readings from the sensors. Finally, the edge_node_id field contains the unique ID of the connected IoT node. The data is then collected in a database based on the information con-

tained in the MQTT topic and the payload. The data once in the database is then processed by an ML pipeline whose purpose is to remove outliers. There are different approaches in the literature to solve this kind of problem, but considering the nature of the data, a simple Isolation Forest algorithm is robust enough [Zemicheal et al. 2019]. Once the outliers have been removed the data is ready to be stored and queried by the HBIM client. . The connection between the database and the VPL environment is made via HTTP APIs. The data, which can be selected according to spatial and temporal interval criteria, are downloaded locally to be managed by the VPL platform. The interoperability of the data collected and those modeled in the BIM environment is guaranteed by the Rhino.Inside Revit plugin. The relationship between the physical edge node and the digital family is guaranteed through the assignment of unique IDs during installation.
The main objective of this framework is to spatialize the data collected from the real world in a digital environment to obtain specific thematic representations.

Development

For the development of this prototype the selected case study is not real, the BIM model used is the model of Alvar Aalto's Villa Mairea reconstructed from bibliographic sources in Revit. It can be seen from the images of the model how, in addition to the structural elements of the building (perimeter walls and internal partitions, columns, floor and pitched roof), it was also completed with a series of complementary fixed furnishings that could simulate a museum environment (Fig. 1). Finally, within the BIM model, some families of 3D objects representing some of the real monitored edge nodes that could be located in the museum were inserted. Concerning the latter, each node was reproduced in the model considering their real geometric dimension.
It was assumed to place one node in the environments Room A and Room B and two nodes inside the environment named Living due to its dimensions. During their installation it is possible to label each node concerning its topology. Fig. 2 provides the details that each node communicates with the cloud service (ID, location and monitored parameters).
To create a solution that would be repeatable in real projects, and to better structure the information related to the installed sensors, each family was enriched with specific parameters related to the individual components such as model, manufacturer, size, power supply needed, precision, measurement accuracy.

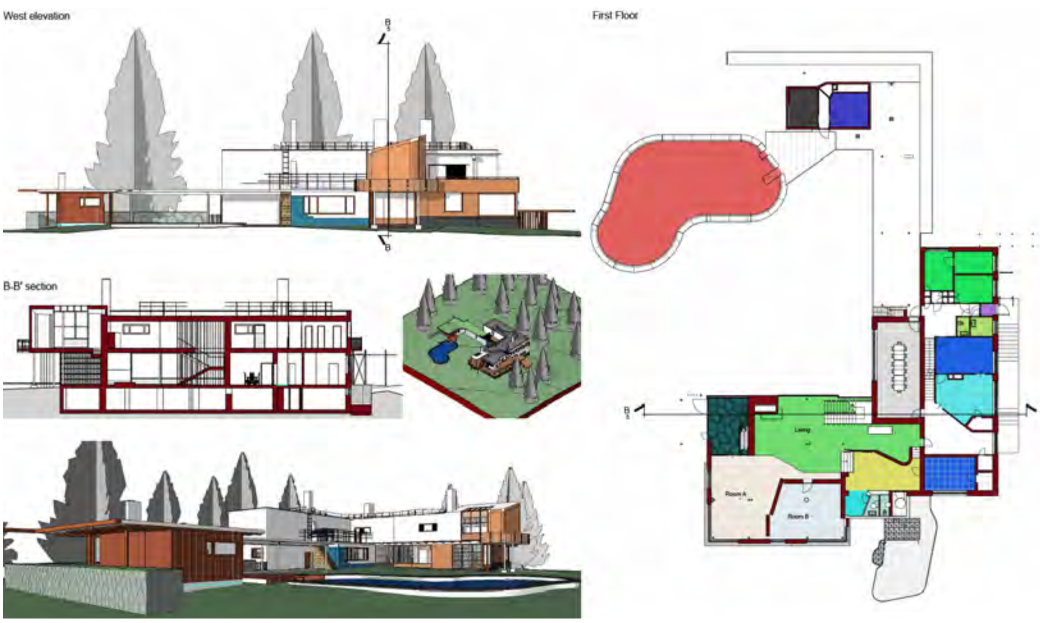

Fig. 1. BIM model of Alvar Aalto's Villa Mairea.

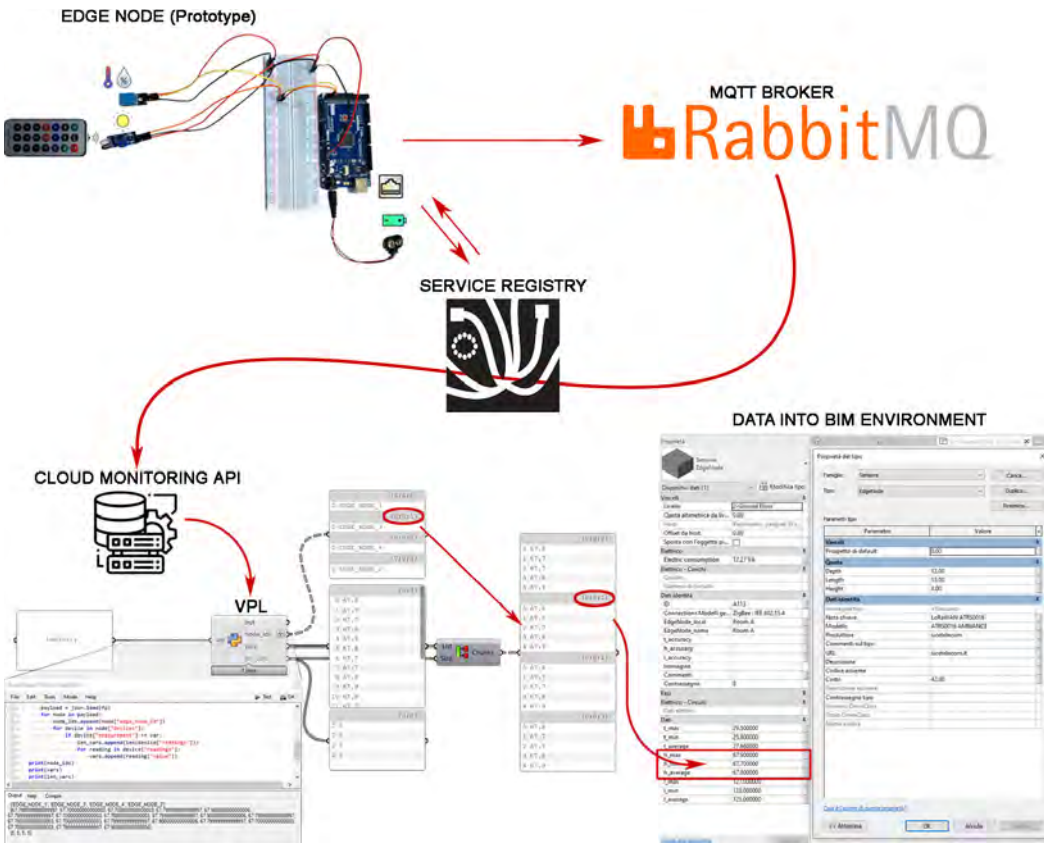

Fig. 2. Interoperability scheme between the different environments.

The code in the VPL environment is divided into three sections (Fig. 3). In the first section, once processed, the data is downloaded locally through a special cluster written in Iron-Python within the Grasshopper application. Each data query downloaded is preceded by the ID of the device. Once the ID has been recognized, the algorithm, using the data tree structure of the application, divides the data into a list of lists and consequently each branch of the data tree is associated with the correct sensor family previously inserted in Revit. The second portion of the algorithm is used to carry out further processing on the data and to make a local copy updated at the time of download in table format. In the third section of the algorithm it is possible to produce graphical displays that the user can view by selecting the corresponding sensor feature from the tree menu, or, as shown in Fig. 4 it is possible to simultaneously view the entire heatmap of a specific floor plan and the readings of individual cabinets or rooms (depending on the group of sensors selected). This feature is very important as it allows the user to view the temperature of the entire floor globally to facilitate the identification of any criticalities.

Conclusion

This paper presents the results of the first research born from the collaboration of a research group of the Department of Architecture and Design of the Politecnico di Torino and the LINKS Foundation Centre. The objective of this first research is to critically evaluate the potentialities derived from the hybridization of BIM systems and IoT technologies to improve museum management. The main characteristics of the workspace and the outputs that can be obtained were presented. The main difference between similar frameworks developed for ordinary building management and the proposed framework developed for museum management is the ability to represent the relationship between building and artwork, between container and content, a specificity that offers many insights for research.

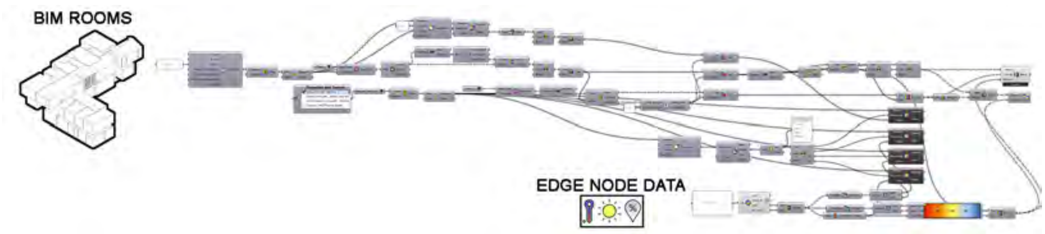

Fig. 3. Part of the code in VPL environment for connection with BIM environment.

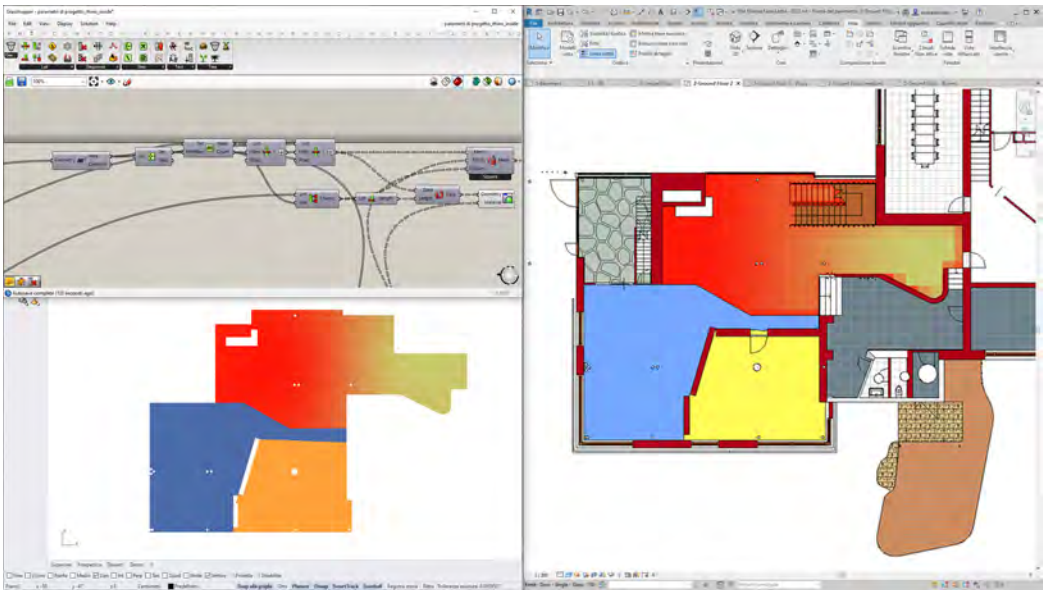

Fig. 4. Creation of heatmaps and visualization of data on a BIM model.

The potential of an integrated system that associates IoT information in traditional design environments, although in the prototype phase, is nevertheless considerable. During this first experimentation, some criticalities have been noticed that still need to be addressed: the installation of edge nodes in the halls must foresee protocols that eliminate human error (one could insert the group of sensors in the wrong place or assign an incorrect ID); the development of algorithms in a VPL environment, although suitable for a prototype phase, is not suitable for an operational tool open to museum staff; the creation of heatmaps should be carried out through a user interface that is simpler and closer to the skills of a curator. Once these critical issues have been resolved, the research group will go on to identify a real case study on which to apply this methodology.

Notes

[1] HBIM: Heritage/Historical Building Information Modeling; BHIMM: Built Heritage Information Modelling/Management [Della Torre 2016]; EBIM: Existing Building Information Modelling [Edwards 2017]; B(H)IM: Building(Heritage) Information Modelling [Simeone et al. 2014].

[2] The term modeling refers to the cognitive process that leads to the construction of a model. A model is a mental or theoretical representation containing the essential structure of objects or events in the real world.

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AR and Knowledge Dissemination: the Case of the Museo Egizio

Davide Mezzino

Abstract

In the context of the growing pivotal role of digitalization for cultural institutions, the digital transition of the Museo Egizio di Torino is centered on the integration of heterogeneous information and data to implement the management, dissemination, and promotion of the Museum's collection. This digital transition is intended not only as a mere acquisition of technological tools but rather as the construction of an integrated system that facilitates dialogue and connections between all museum activities, from daily management to research, from the design of installations to the generation of multiple possible narratives. Within this framework, the essay illustrates, through two empirical case studies, the opportunities of AR technologies to implement the knowledge and dissemination of tangible and intangible aspects of the millennial historical objects preserved in the Museum.

Keywords
museum, digital transition, immersive environment, augmented reality (AR), data visualization.

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Introduction: Digital Transition and Cultural Institutions

Digital Culture is progressively spreading to all fields of knowledge and activities. In the field of archaeology, and specifically in the case of museums, it is deeply transforming cognitive approaches and working methods.
The digital transition is influencing large parts of society, including the cultural heritage field. Digital communication, the sharing of data and information, as well as research, are high on cultural institutions' agendas. Within this framework, the wide range of possible methods and tools may have three main potentials:
a) to increase and improve the efficiency of the daily activities;
b) to open new directions of research;
c) to implement new ways to disseminate knowledge and information.
Digital elements are currently present in nearly all aspects of the organization and management of any cultural institution, including museums. Considering how the number and importance of digitalized information and data will keep increasing in the coming years a defined strategy is strongly needed. If all strategies are somehow at least in part interrelated, the Digital Strategy is a truly transversal field of action, that encompasses questions, answers, and decisions that are shared among different museum departments.Analyzing the current state of the art of digital services aiming to innovate the way institutions interact with visitors, it is easy to find discrepancies.
In Europe, there are some interesting experiments such as the Futurium Museum (Berlin), which, facilitated by the extremely innovation-driven nature of its content, has managed to achieve a perfectly integrated experience between online and offline through systems of in-depth analysis after the physical visit.
In Italy, the situation is quite different. Although 70% of museums have at least one technological tool to support the onsite visit (32% have a touch screen, 33% use QR code and e-beacon and 32% adopt audioguide) [Osservatorio Innovazione Digitale nei Beni e Attività Culturali 2021] only 24% of them have drawn up a strategic digital innovation plan, rethinking their digital strategies to meet a true innovation [Lampoonmagazine.com 2021].
Additionally, the interactions between institutions and their audiences remained almost unchanged compared to previous years. Only 5% of Italian institutions offer interactive activities and games to engage with potential visitors [Lampoonmagazine.com 2021].
Within this framework, in response to the digital challenges, museums and galleries have to grapple with organizations and their staff need to adjust to the new ways of thinking and working in a digital-physical world.
A Digital Strategy only in part depends on technical aspects. Technology is a tool, that must be mastered to convey precise messages, and these, in turn, must be established in advance based on a shared vision among the stakeholders and the overall cultural and legal policy of the country. Finally, the implementation of a digital strategy requests a specific financial commitment, that must be substantial but, most of all, constant over time, as the rapid technological evolution requests constant updates. Within a museum's Digital Strategy visual communication play a key role. Museums aim at preserving cultural identity and collective memory as well as interpreting and communicating their meanings to wide and heterogeneous audiences. By their nature, they are open and dynamic places that encourage, promote, and host the interaction between objects, researchers, and audiences. In this framework, digital advances in AR technology enable the creation of immersive interaction environments. This opens up great opportunities for data visualization supporting the understanding and interpretation processes of cultural objects.
The opportunities of Augmented Reality (AR) technologies can offer a wide range of solutions applicable to several contexts, objects, narratives, and audience targets, and with different access modes (i.e. individual or collective visualization, various immersive levels, etc.,). Within this framework, the following paragraphs present the concept, the design, and the outcomes of two AR applications tested by the Museo Egizio di Torino.

Innovative Ways of Visualizing and Communicating Concepts, Data and Information

The Museo Egizio di Torino, an archaeological museum and research center focused on socio-cultural topics [1], tested through two empirical applications the recent developments of AR and its potential for recognition, communication, and interaction with physical space. The two projects are heterogenous for narrative strategies, topic, communication goals and representation modalities testing different uses of AR techniques. Both projects have been selected to show the opportunities of AR to disseminate and communicate the research outputs of the analysis and studies carried out by the Museum.
The first one named *Stone. Pietre Egizie* has been developed by a team made up of geologists, architects, Egyptologists, archaeologists and computer scientists, which developed a new tool

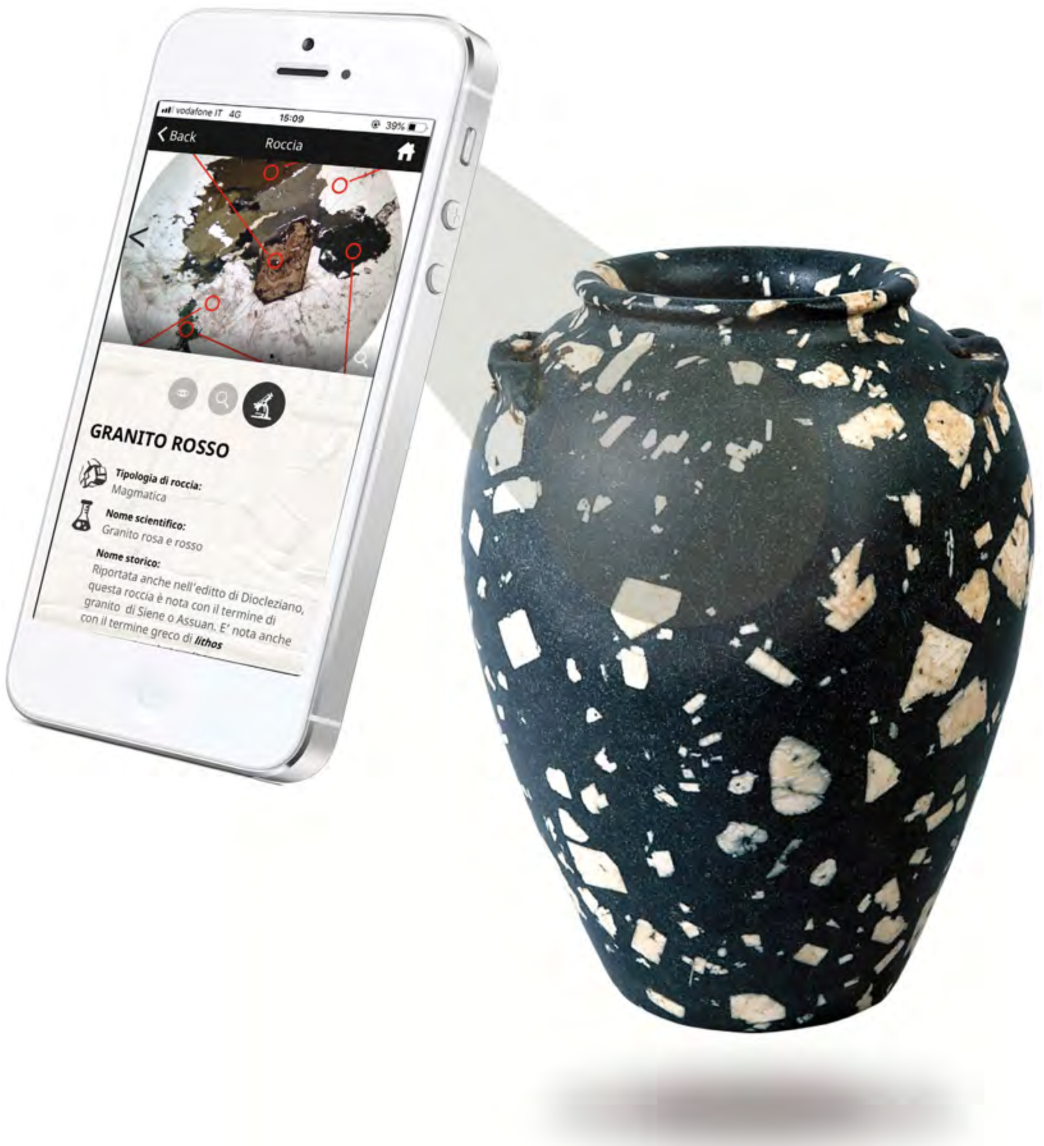

Fig. 1. Operation mode of the app "Stone. Pietre Egizie". Image elaboration: Author.

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 [2]. The app allows visitors to observe granite, porphyry, limestone and sandstone, discovering their nature, composition, origin and the reasons why they were chosen by the Ancient Egyptians (Fig. 1). The app is organized based on the historical and artistic importance of the collection objects, but also and above all on the type of rock used [3].
More specifically, fifty objects were chosen. The selected objects located in eleven different rooms within the Museum were identified according to historical relevance and type of stone material.
Further, the *Papyrus of the mines* was also included in the objects' list. The papyrus is the oldest geological map ever made, which boasts over 3000 years of history, dating back to the reign of Ramesses IV.
The app is structured into nine sections (Fig. 2). These include: 1) "Start" to begin the exploration and discovery of the objects made of stone; 2) "Introduction" defining methodology and goals of the app; 3) "Stones" reporting a list of the different types of stone that can be found in the Museum objects. This section provides a short info-graphic description of each stone including information on: stone type, scientific name, historical name, macroscopic description, main uses and quarries location in the Ancient Egypt; 4) "Artifacts" presenting the images of the selected objects and the stone they are made of. For each artifact there is a biography reporting information on epoch, acquisition period, place of discovery, dimensions and short description; 5) "Quarries of Egypt" locating and describing the quarries in ancient Egypt and in the Ptolemaic-Roman period; 6) "Geology" describing and explaining how

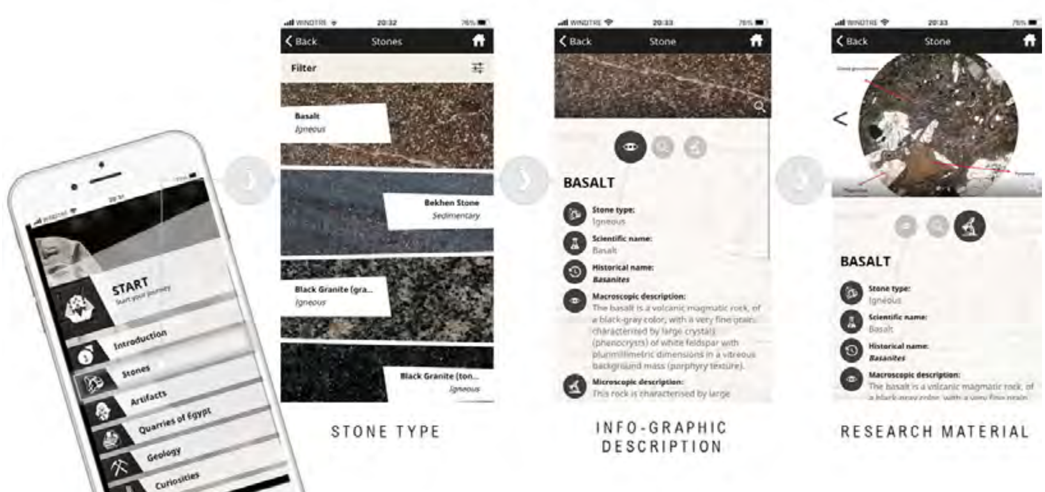

Fig. 2. Example of the section «Stone» focusing on the Basalt stone. This section provides a short info–graphic description of the basalt stone including information on the stone type, scientific name, historical name, macroscopic description, main uses and quarries location in Ancient Egypt. Image elaboration: Author.

the richly composite geology of the country made possible the wide variety of ornamental stones in Egypt; 7) "Curiosities" offering contents and providing the tools to investigate the rocks, as well as the possibility of observing the digitized objects, such as the statue of the goddess Sekhmet, at 360 degrees; 8) "Glossary" describing all the technical terms used; 9) "Credits" reporting the people involved in the project development.
According to the app structure, it is possible to choose several exploration paths, focusing on the masterpieces, following the chronological order, observing the types of rock at a macro and microscopic level, learning about the quarries from which the materials were extracted (supported by a glossary).
The section of the app dedicated to 'curiosities' offers contents and provides the tools to investigate the rocks, as well as the possibility of observing the digitized objects, such as the statue of the goddess Sekhmet, at 360 degrees.

Through the app, the designed AR content can be accessed by mapping existing elements including vases, statues, amulets, jars, sarcophagus, steles, etc.
The second case study consisted of the projection mapping of the Butehamon coffin [4]. Within the framework of the temporary exhibition *Archeologia Invisibile* [5], a section of the temporary exhibit was dedicated to showing the set of techniques used to study materials, production methods and the conservation history of finds – making it possible to question objects.
In the achievement of this goal, the workflow for the projection mapping on the copy of the Butehamon coffin included several steps.
The 3D digital documentation of the original Butehamon coffin has been the fundamental basis to generate a physical replica from a high-resolution 3D model of the external, anthropoid coffin of the scribe Butehamon. The survey included range-based and image-based techniques. The survey with a triangulation scanner, was useful to record all the small decorations of the surface, while photogrammetry allowed to obtain a complete 3D model and a high-quality and sub-millimetric texture of the recorded coffin [Mandelli et al. 2019].
From the 3D model of the coffin, it has been possible to generate a 3D printed copy, with millimetric accuracy, on a 1:1 scale. The generated replica acted as a support for a projection mapping installation meant to re-project a pattern of images onto the coffin's surface, including the results of different radiometric and colorimetric analyses [6] performed in the recent past by Museo Egizio and Musei Vaticani (Fig. 3). The 3D printed copy was meant to

Fig. 3. Example of the metric, radiometric and colorimetric analyses carried out on the Butehamon coffin. Image elaboration: Author.

have a projection-mapped on the lid part to show the audience details of the construction and the pictorial decoration process. Additionally, two side videos were used to represent the history, the craftsmanship, and the scientific analyses conducted on *Butehamon's coffin*. At the base of the projection mapping setup, there are the same data generated by the Laser scan process: an 8 million polygon 3D model for the lid of the coffin, obtained from the dense point cloud.
To make the animation process lighter and lower render times, a mixed retopology technique was used either by hand in the 3D software Maya and using Sketch Retopo. This allowed the final model to be more detailed in the face and crack zones. Retopology also allowed the geometry to follow the natural curves of the surface, thus making the UV Unwrapping of the texture easier and more consistent. The final model used for the animated content is made out of approximately 500.0000 polygons. All the details of the high-resolution 3D model were not discarded, but converted into a normal map texture through the normals baking process and then re-applied to the low-resolution model. Normal map textures keep the information on the reflection direction of the light (thus the geometry orientation) in specific zones where the texture is applied following the same UVW coordinates as the RGB color information, resulting in a sharper, more detailed model with a lower number of polygons. The same normal map was also used to obtain the X-ray version of the coffin. The X-ray photo of the lid was deformed using the visible light information stored in the RGB UVW texture and warped using the texture mapping internal tool in the Maya software. The same process was applied to the case of the coffin. For the video ani-

mation, the software Adobe After Effects and the plugin Element 3D were used. In After Effects the 3D OBJ, a low-resolution model was imported and scaled using a meter to pixels conversion. After a site inspection on-location, the position of the virtual top camera was estimated by measuring the projector-to-3D print distance and by converting the 1,19:1 projector throw ratio to an equivalent focal length.
The 3D model of the coffin and the projector were oriented horizontally to maximize the pixel used for actual color information. As the final installation consists of an animation mapped on the 3D printed replica of the coffin and two projections on the sides illustrating the stratigraphy and pictorial techniques, it was decided that all the three contents needed to be in-sync. Two additional cameras, a master and a slave camera, were created. They were meant to have a free movement, to be rotating around and getting closer to the coffin, to show the whole surface and close-ups of fine details of the coffin. The slave camera is parented to the master one and mirrors its movement along the Z (depth) axis. Following the main soundtrack of the installation the whole camera movements were animated and the captions for all the moments of the videos aligned in the timeline for the Master and the slave cameras (Fig. 4). Completed the whole animation, the two camera views (master and slave) were rendered and three 1920x1080 pixels, h.264, .mp4, 15.0000 kbps CBR files were generated to be used in three in-sync BrightSign players inside the installation. Once the 3D-printed coffin was in position, the projection mapping process began. The projector placed on top of the coffin was connected via HDMI to a MacBook Pro Laptop. The animation video of the top view was loaded in the

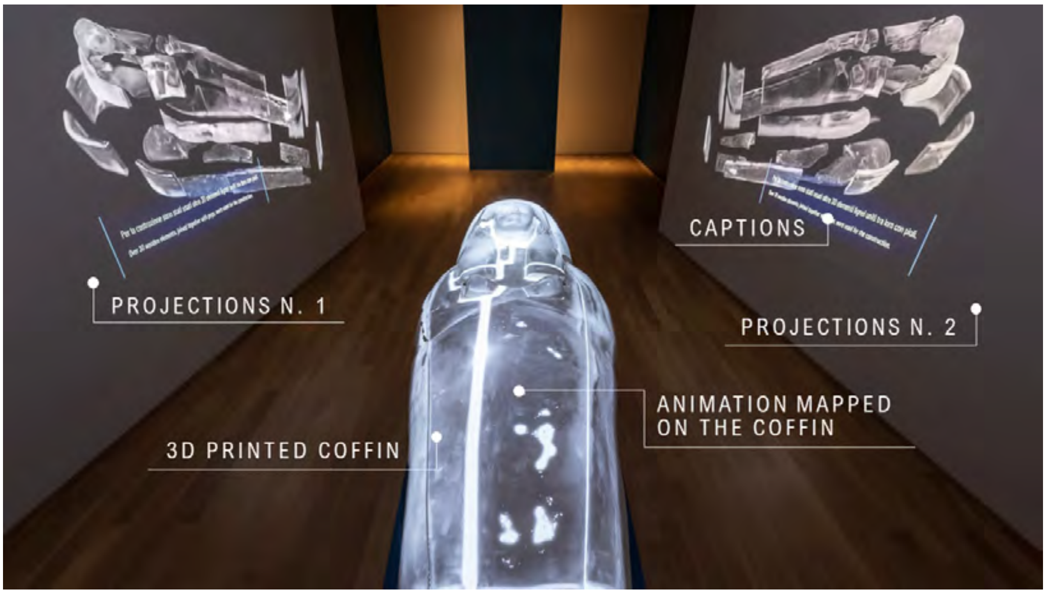

Fig. 4. Main elements of the projection mapping process on the 3D printed replica of the Butehamon coffin. Image elaboration: Author.

mapping software Millumin. This software allows users to apply a warping grid to a 2D video to align it with a 3D surface and to play it in real-time. The deformed video was then rendered, converted in the same format as the other two, and synced in the BrightSign player of the top projector. This installation required the collaboration of different experts in digital documentation, visual communication, visual design, 3D modeling, 3D animation.
This case study illustrates principles, tools, and results of the meticulous work of recomposing information, data and notions made possible today by digital documentation and representation technologies and tools. The final result encouraged a thorough discussion on the interaction of digital representation in the study and dissemination of archaeological objects.
The two projects are representative of the opportunities of AR techniques and tools in terms of communication and visualization of concepts, information and data. Both applications present two different access modes. The app "Stone. Pietre Egizie" has been designed for individual access to discover and know the materiality of the Museum's collection. In the case of the Butehamon coffin, the projection mapping has been employed for a collective and synchronous visualization representing the analysis carried out on this layered object with a millennial history.

Future Perspectives: the Opportunities of AR Applications

Future perspectives foresee the development of Augmented Urban Art (AUA) initiatives with the final aim of bringing the Museum out of the Museum's building. The idea consists in employing AR techniques to visualize from outdoor public spaces (i.e. the streets and the square that delimit the Museum) part of the indoor spaces of the Museo Egizio. This kind of application would have a double goal.

On one side, it acts as a teasing reveal strategy [7] to promote Museum exploration.

On the other side, Augmented Urban Art initiatives open up the Museum to the city, enabling visitors to grasp the urban history of Torino, and become aware of its cultural offer. The extension of this kind of initiative to other cultural institutions, at the city level, would be desirable to increase the potential audience and amplify the expected results. More specifically, the combination of digital representation with real built environments could: 1) increase the awareness and /or curiosity toward the Museum building and its collection; 2) promote the exploration of the museum; 3) test the potential of visual communication to disclose the content of historic building; 4) strength the relationship between the Museum and its urban context.

Another potential application of AR is related to the daily facility management and the museum's temporary exhibitions. Several studies have shown how digital models and associated information, schedules and databases can be shared through digital twins, favoring information sharing and minimizing data loss. Thanks to the development of AR platforms, it is possible to achieve an immersive form of human-model interaction [Banfi 2021].

Conclusions

The proposed examples underline the potential of digital representation for the dissemination of humanistic and technical knowledge in synchronous mode. The two presented projects required a transdisciplinary approach in which the representation played a crucial role. Digital representations combined with AR techniques allowed to communicate the complexity of transformations and historical layering that feature cultural heritage objects. The digital twins generated have been integrated with the real environment through interfaces and algorithms based upon data collected and processed through optical-perspective devices. Both empirical experiences share a common approach which is aimed at:

- Considering the real objects not just as the target for the activation of AR animations but as a base to georeference and localize the representation of invisible aspects and technical information that could not be displayed together by analogical means.
- Exploring the potential of AR visualization opportunities, paying constant attention to the relationship between real space and digital information.
- Testing different ways to share and disseminate information associated with the invisible features of the Museum's collection disclosing new meanings and stories embedded into cultural heritage objects.

The proposed examples evidence how representation solutions based on AR technology can provide the chance to re-design the relationship between material and immaterial culture, providing a more flexible interplay of the onsite/online public engagement by harmonizing the digital and material experience of cultural heritage as complementary phases of the same dissemination process.

Notes

[1] According to the ICOM definition of Museum, the museum has also to be intended as a research institution. Indeed, ICOM Statutes, adopted by the 22nd General Assembly in Vienna, Austria, on 24 August 2007, define a museum as follows: "A museum is a non–profit, permanent institution in the service of society and its development, open to the public, which acquires, conserves, researches, communicates and exhibits the tangible and intangible heritage of humanity and its environment for the purposes of education, study and enjoyment".

[2] The project stems from the collaboration between the Department of Earth Sciences of the University of Turin and the Museo Egizio Museum of Turin. The project goals aim at broadening and deepening the knowledge of the museum collection by proposing different interpretations tools. The app development included an interdisciplinary team coordinated by Professor Alessandro Borghi of the Department of Earth Sciences of the University of Turin. From the economic side, the project was developed thanks to the financial contribution of the CRT Foundation, in the context of *Research and Education* projects.

[3] In Egypt, ornamental rocks represent a huge tangible element of material, historical and cultural richness. This ancient civilization has been able to make the most of what nature has offered them. The Egyptians chose among the various types of rocks in their territory those with the best characteristics both from an aesthetic and mechanical point of view.

[4] The Butehamon coffin dates back to 1076–944 BCE. It is made of wood and it is fully painted. The dimensions of the lid are 211 x 75 x 42 cm, while the box measures 210 x 74 x 43 cm. The coffin is part of a set of coffins, probably found in the tomb of Nakhtmin (Theban Tomb 291) in Deir el–Medina, owning the Third Intermediate Period. Currently, the coffins of Butehamon are on display in the Galleria dei Sarcofagi at Museo Egizio, Turin (AA. VV., 2015), [Ciccopiedi 2019].

[5] *Archeologia Invisibile* is the title of the temporary exhibition that opened on March 13th, 2019. The purpose of the exhibition is to illustrate the principles, tools, examples 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 the findings.

[6] Museo Egizio and Musei Vaticani carried out a non–invasive diagnostic campaign disclosing several aspects of the object's history and on the carpentry techniques which were used. More specifically, the x–rays analysis revealed the general structure of the lid and the box. Moreover, the x–rays showed several interventions to re–shape the reused elements, both in the area of the hands and of the face. [Mandelli et al. 2019].

[7] The term 'teasing reveal strategy' refers to a campaign that is set up in two stages, first to encourage questioning and then to provide an answer in the form of revelation. The teasing phase exposes a subject, evokes questioning and creates interest to maximize the sharing of a promotion campaign. The second phase constitutes a revelation and brings an answer to the questioning phase, in this case, an actual visit to the Museum.

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AR to Enhance and Raise Awareness of Inaccessible Archaeological Areas

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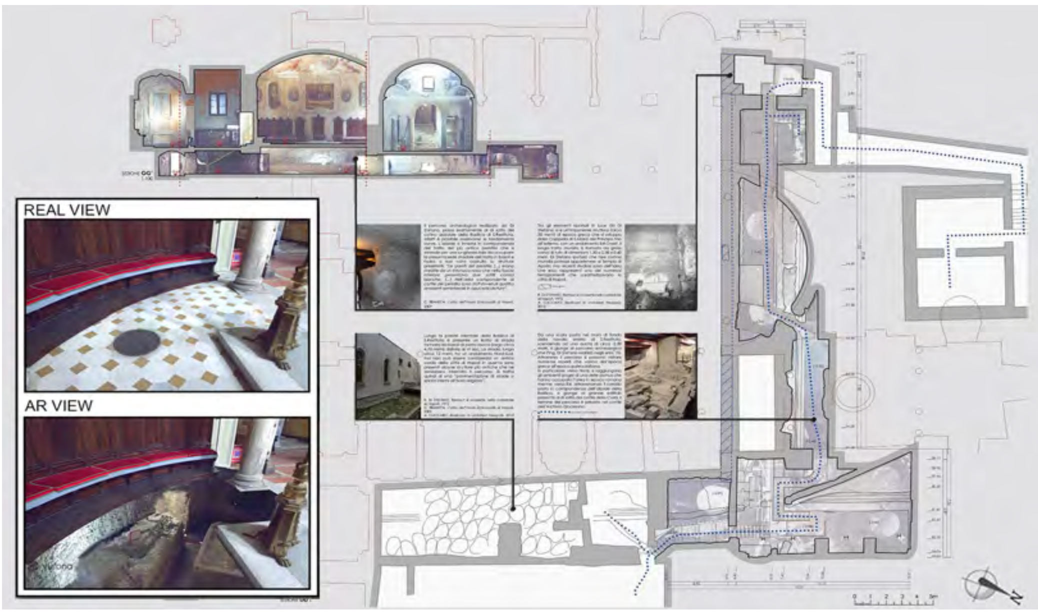
Abstract

This paper shows a research experience interested in exploring the potential of XR systems for the use and dissemination of knowledge about the architectural Heritage and, in particular, about those areas that are currently inaccessible. Specifically, the methodological approach adopted employs AR as a user friendly tool that, through the involvement of the user in experiences implemented by multi-media content, allows to highlight unexplored aspects of the Heritage.
The experimentation carried out involved part of the *Insula Episcopalis* of Naples, investigating the relationship between the Basilica of Santa Restituta and the archaeological area below. To this end, the instrumental surveys carried out to understand the relationships that exist between the different parts of the *Insula*, were of support for the construction of the communication project, constituting in fact the reference model on which the tracking of the scene and the anchoring of the different information was based.

Keywords
AR, reality-based model, archaeological area, architectural survey, information XR model.



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The AR Project Idea for the Accessibility of the Area

The whole process of knowledge and presentation of the architectural Heritage is nowadays permeated by the use of digital technologies which, if in part are already consolidated, in other part are assuming an increasingly relevant role in valorisation and dissemination activities [di Luggo et al. 2019]. This is especially true for those sites whose actual physical accessibility is strongly conditioned by one or more aspects, be they related to the specific conformation of the sites, to unsafe conditions or to specific safeguarding protocols [Quattrini et al. 2016; Spallone 2020]. However, the possibility of accessing the cultural contents conveyed by the historical-artistic heritage remains a fundamental requirement, and for architecture, which by its very nature is intrinsically characterised by multiple potential modes of fruition, technology becomes an extremely useful means to ensure adequate enjoyment.

In addition to this, the unexpected limitations induced by the recent pandemic situation have further increased the inconveniences related to the possibility of physically enjoying even generally available spaces. The need to renew processes alongside traditional ones in order to achieve extended forms of communication is therefore increasingly evident. This would bring us closer to and broaden our knowledge and appreciation of the assets in our territory. Designing digital access modes does not necessarily mean replacing real experience. Rather, it would guarantee an opening towards new readings capable of highlighting different aspects, sometimes hidden or not immediately perceptible.

The application of ICT, together with the various forms of eXtended-Reality communication, does not distort but renews the traditional relationship with the artefact, generating new relationships between the real and virtual environment, conforming fruitions that make the user an active spectator in the interaction with the added information content.

The various augmented reality (AR) and virtual reality (VR) projects are pushing towards alternative ways of accessing knowledge, through systems that hybridise the two worlds or propose a total digital simulation of them [Jung 2019]. Recent suggestions on the possibility of generating a Metaverse capable of merging the perception of everyday physical reality with digital worlds that can be totally superimposed on it, underline once again the international interest in the search for increasingly immersive and connective technologies.

The research presented in this contribution focuses precisely on the possibility of using an AR project to enjoy an otherwise inaccessible space, while maintaining a certain degree of relationship with physical reality. By creating an App for mobile devices, the experimentation conducted proposes a possible application approach that transmits and anchors digital content on reality-based three-dimensional acquisitions (Fig. 1). The study is part of a broader research work [Scandurra 2016] inherent in the identification of appropriate methods of dissemination of different aspects (historical, morphological, metric, artistic, etc..) characterizing the *Insula* of the Cathedral of Naples – and in particular the Basilica of Santa Restituta –, for an audience of visitors that includes from tourists to experts.

The *Insula*, in its current conformation, is the result of a mixture of architectural styles and artistic events that have taken place over the centuries and have written its rich history [Ebanista 2019]. Among the many events that have made it a protagonist, the work carried out by R. Di Stefano between 1969 and 1983 brought to light the remote memory of the

Fig. 1. Workflow from real data to augmented reality project.

Fig. 2. Underground archaeological area at the *Insula Episcopalis* in Naples.

place through the discovery of a vast archaeological area from the Greco-Roman period (Fig. 2). The area, concealed beneath the floor of the Basilica of Santa Restituta and part of the inner courtyard of the *Insula Episcopalis*, is currently inaccessible to the public and therefore little known.
The research aims to bring the archaeological site back to light – albeit indirectly – through the targeted use of tools made available by digital technologies, making the site observable in its morphological characteristics and communicating its undoubted historical value. Alongside this, a multilevel reading was proposed that, by breaking down the physical (real) reality, directly connected the above and below, reinforcing the perception of their reciprocal relations. Digital content superimposed on physical reality is thus a disruptor of physical reality itself, as it allows the vision of what it conceals.
Specifically, the AR project hinges on these objectives, and the results achieved are the result of reflections on both the correct overlap between real and digital, and the graphic coding in the representation of the various contents implemented, as well as the methods of accessing them. The choice of the technical solutions and software applications to be used was therefore made so that the AR App would meet the prefixed aims and not be influenced by the constraints imposed by the site. This last aspect was important in the design and execution of the AR itself because it affected, in particular, the dynamic mapping of the real environment and the correct display of the digital contents superimposed on it, which, as is well known, are linked to the decoding of the position and orientation of the user – or of the mobile device used.
From a methodological point of view, digital 3D models representing the state of the sites were first built. For this phase, it was decided to use reality-based surveys and data fusion processes of the relative point clouds. The sites were acquired using laser scanners with phase modulation technology and digital terrestrial photogrammetry procedures so that, through the well-known processes of data processing and manipulation, it was possible to obtain mimetic models of reality, recording in a digital environment the spatial configuration of the various environments that make up the Basilica and the archaeological area below (Fig. 3).
As with any architectural and archaeological survey, the choices made in resolving the models took into account a number of aspects. In this specific case, attention was paid to the level of accuracy necessary for the data to be usable virtually and to photorealistic rendering.

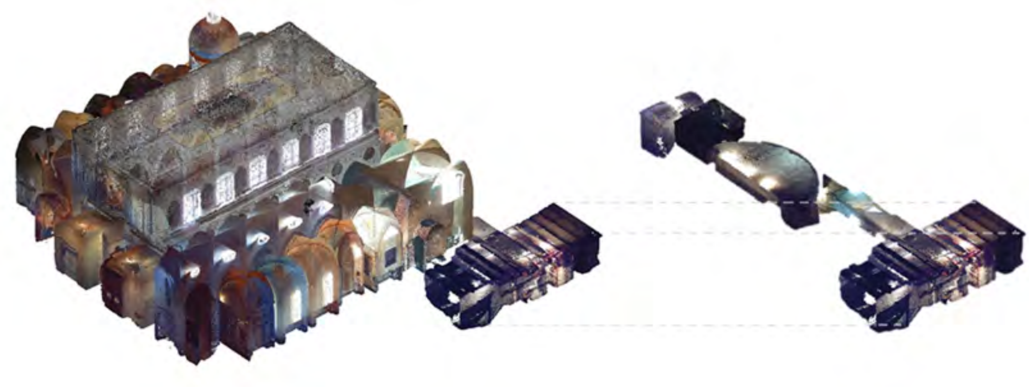

Fig. 3. Point cloud of the Basilica of Santa Restituta and the archaeological area.

These data, in fact, in addition to providing the necessary information for a metrically accurate and up-to-date documentation of the site, were of support for the construction of the augmented user experience: the point cloud returned by reality-based acquisitions was considered the foundation of the AR App. A part of it was used to build the digital content; another part, instead, was used to calibrate the well-known tracking phase of the scene for the alignment of the data used through the mobile device in situ. This operational choice was dictated by the desire to make the environment of the Basilica free from the presence of any fiduciary markers and the impossibility of using location-based systems due to the lack of GPS signal. The solution undertaken, therefore, bases the orientation of the device and the visualisation of the increased content on the optical recognition of the geometric and colorimetric characteristics of the real elements, framed by the camera integrated in the device used.
The operations described were managed through the *Unity 3D* game engine software and the *Vuforia Engine* and *Model Target Generator* tools. The association of the different applications, if on the one hand it has allowed a high degree of personalisation in the construction of the user experience and the achievement of the pre-established objectives, on the other hand, as we will see later, it has imposed specific solutions in the structuring of the digital data, especially in the manipulation of the point model.

Built Reality as a Reference for AR App

The archaeological area that underlies the Basilica of Santa Restituta passes mainly under the apsidal area.
This portion of the church and the archaeological finds were considered to be the most interesting areas for the construction of the spatial relations necessary to relate the digital content with the physical reality in the context of the AR project. The area of the apse was extrapolated from the overall cloud of the Basilica and was considered the digital homologue of the natural target, i.e. the reference on which to set the construction of the App. The archaeological area, on the other hand, was elaborated so that it could generate the main digital content usable by the users of the App. The experimentation, therefore, began by structuring the survey data in a specific way in order to make it suitable for the purposes (Fig. 4).
The portion of the point cloud relative to the apse was transformed into a continuous model made up of surfaces. The numerical consistency of the polygons that could be obtained from the meshing process for an accurate restitution of the plasticity in the architectural forms, clashed with the limitations of the maximum number of triangular surfaces that could be imported by the *Model Target Generator.* This required further editing phases of the survey

Fig. 4. Management of the point cloud for texturisation.

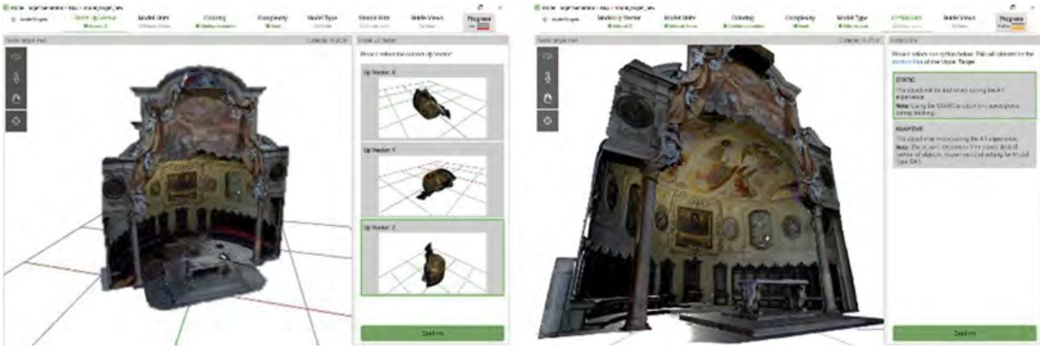

Fig. 5. The link between reality and digital content is made through the correspondence between the model and the constructed reality.

data in order to simplify it without excessively altering its morphological and topological characteristics. The complexity of the mesh was then decimated, through the execution of edge collapse algorithms and the definition of the maximum limit of polygons to be returned. Subsequently, the mesh was textured, in order to obtain complete information: the geometric data was integrated with the colorimetric data and the resulting 3D model, although simplified, presents a level of detail that allows a correct reading of the specific properties and the identification of those characteristics necessary for the univocal recognition of the reference elements to be used for tracking.
The textured mesh of the apse, thus constructed, after the appropriate refinements and export in *.fbx* format, was converted into a *Vuforia Engine* database by means of the *Model Target Generator* application (Fig. 5). Here, having read the morphological and dimensional characteristics, the orientation and the colour information of the 3D model, the application identified the elements (planes, lines, edges and other discontinuities) to be used as a reference during the tracking of the scene. In practice, by means of the device's camera, the AR App was able to detect the correspondences between the constructed reality and the digital model loaded in its database. Through this correspondence, the App updates in real time what the user sees on the screen of his smartphone or tablet, recognising his position and relative orientation.
Through the various operational sequences of the application, the information associated with the reality-based model has been used to extract the data useful to configure the digital content with reference to a specific point of view – and therefore to the relative shots – necessary to start the process of fruition. From the 3D model, the application elaborates a

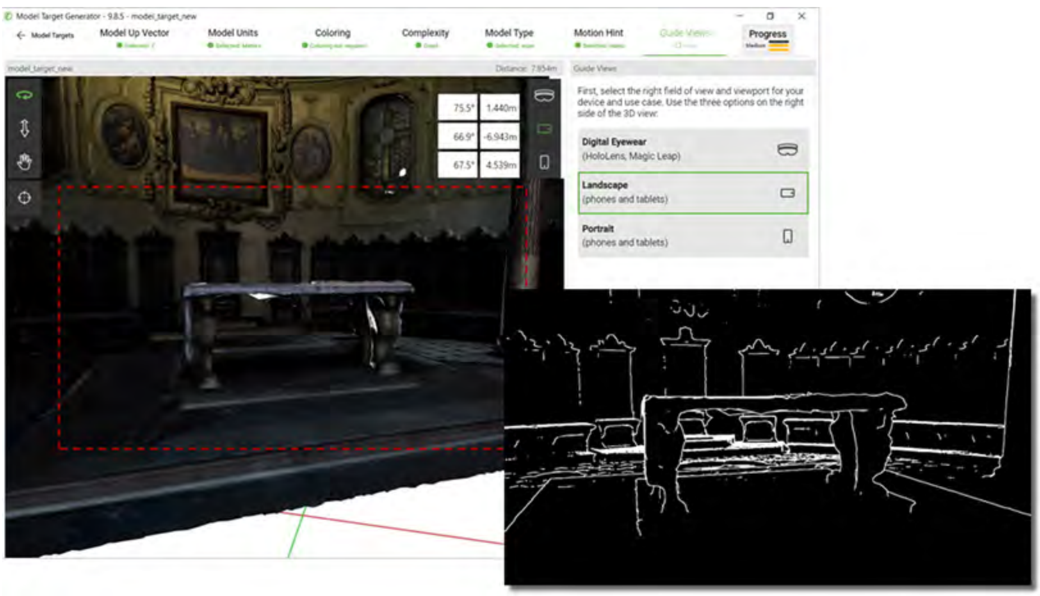

Fig. 6. Identification of the altar in the *Model Target Generator* for the use of digital content.

simplified 2D representation, where lines, edges and planes are highlighted in the creation of a real guiding image (Fig. 6).
In the specific case of the Basilica of Santa Restituta, in the AR App it was decided to identify the altar mensa as the start point; the user, therefore, only has to frame this part of the architecture with his mobile device in order to start the execution of the fruition project and, therefore, the visualization of the contents added to it.
What comes out of the *Model Target Generator,* in fact, is a 3D model cleaned of superfluous information, but accompanied by the 2D guide view and converted into a *Unity Engine* package which, together with the *Vuforia Engine* tool, implements the development environment of the gaming engine software with functionalities closely linked to AR. Among the technical solutions used in the programming of the App, it was chosen to make visible, on the screen of the mobile device, the references of the start point, supporting, in this way, the user in the correct alignment between the latter and the real object.

The Use of Digital Informations

Once the *Unity 3D* environment was prepared with the added component *Vuforia Engine* and the *.unitypackage* database exported from the *Model Target Generator*, the applicative experimentation of the research continued with the actual structuring of the AR App, inserting the different contents to be communicated to the user and programming the executable actions.
First of all, the model target of the apse and the *AR camera* for the rendering of the scene were placed in the three-dimensional space of the *scene view.* The first one is clearly essential in the construction and execution of the AR; nevertheless, the fruition is not influenced by its presence since, in fact, it is displayed only in the App development phase and, consequently, it does not interfere neither with the digital contents nor with the real space. The *AR camera*, on the other hand, replaces the traditional *main camera* – present by default in *Unity 3D* projects – with specific scripts and components. These relate the target model to the real environment on the basis of previously identified references and, at the same time, allow the overlay visualisation of the digital contents. In fact, the *AR camera* emulates the behaviour of the mobile device's camera and orients the information in real time in relation to the user's movements.
The scene view was then implemented with the different information the user can access, made *GameObjects*, to respond to the logic of the gaming engine software.
For the specific project of the *Insuala Episcopalis* – as anticipated –, it was decided to make the archaeological area below the apse of the Basilica of Santa Restituta usable, transforming, therefore, into *GameObjects* the polygonal model of the path that characterises it, with the set of wall and floor finds that make it of considerable cultural interest. The meshing and texturing process followed elaborations similar to those previously carried out for the apse, but differed in the degree of simplification implemented. Here, in fact, reflections on

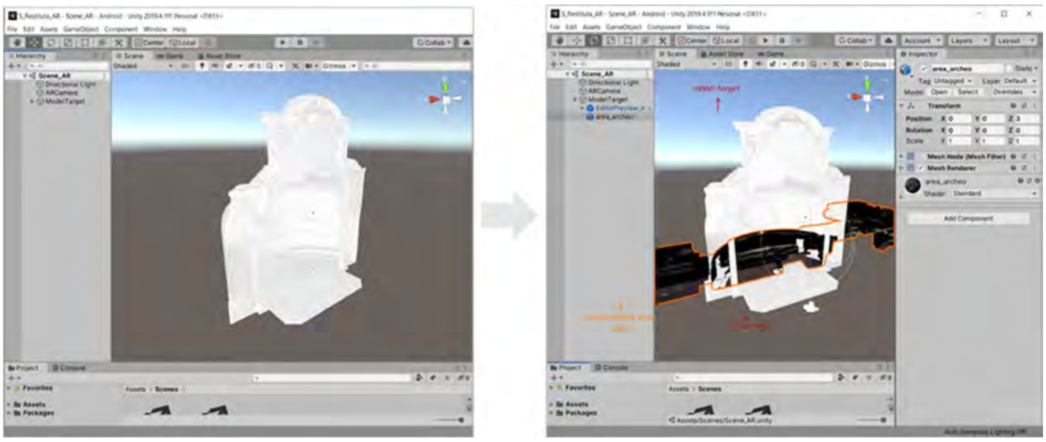

Fig. 7. Setting the overlap between target and *GameObject* in *Unity 3D*.

the typology of the 3D object and its rendering in real time, have led to the choice of a greater geometric discretization, this time not linked to a predetermined numerical value. This expedient – not applicable for the apsidal zone so as not to affect the determination of the reference elements, the generation of the model target and, consequently, tracking – was useful for obtaining a highly optimised model, but one that still has a high degree of correspondence with reality in its photographic rendering. This has made it possible to reduce the conversion time of the 3D data into a 2D image and to limit lag or inconsistencies with what is displayed in AR, facilitating, as is well known, the rendering process and restoring fluidity to the execution of the fruition.
The user who frames the apsidal area, therefore, opens a sort of digital window that breaks through the physical limit of the pavement he is walking on and allows him to observe the archaeology it conceals. To this end, the positioning of the mesh in the digital space of the *Unity 3D scene view* clearly took place in relation to the model target, simulating the visualization prefigured in real space. And, therefore, it was necessary to translate – along the vertical direction – the relative *GameObjects* in order to induce the sensation of being inside the archaeological area and, at the same time, to perceive the existing relationship with the Basilica of Santa Restituta just through the overlapping visualization between the real and the digital environment (Fig. 7).
In addition to the 3D model of the archaeological site, other elements have been included in the *scene view* to further implement the information conveyed to the user through structured data in different formats: short texts describe what is being observed, photographs allow the user to dwell on specific portions of the underlying path, two-dimensional graphics highlight the dimensional relationships and textures of the constructive apparatus found in the archaeological excavation. Access to the various contents takes place through the *UI Button* and *UI Toggle* of the *canvas*, i.e. activation buttons represented by graphic symbols that anticipate the type of data to which they are related. The user can then interact with the App and choose in full autonomy what and how much to look at, according to his personal interest (Fig. 8).
Finally, each *GameObjects* positioned in the digital space has been connected to the target model by means of *parent-child* relationships, i.e. they have been incorporated and made integral with it in their behaviour. This, in addition to conforming a single hierarchical data system, is necessary for AR visualization and to allow the AR camera to return them correctly during the execution of the App.

Conclusion

In conclusion, the aim of the presented research project was to make usable, at least digitally, an area that is hidden and not known to the majority of visitors who access the Cathedral of Naples and the Basilica of Santa Restituta due to inaccessibility for security reasons. The use of consolidated technologies for the creation of an app for mobile devices allows for easy

Fig. 8. Insertion and use of added information content: text, images and 3D model.

dissemination among users and a virtual visit that does not neglect the need to be physically on site and therefore reinforces the visit of the permitted areas. The project clearly hopes for the dissemination of knowledge about the archaeological area, but also for the possibility that in the near future the user will be encouraged to return to observe and experience the area for himself.

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VR, AR and Tactile Replicas for Accessible Museums. The Museum of Oriental Art in Turin

Francesca Ronco
Rocco Rolli

Abstract

This work is part of the agreement stipulated between the Department of Architecture and Design of the Politecnico di Torino and the Fondazione Torino Musei for the enhancement of the cultural heritage of the Museum of Oriental Art (MAO). The agreement aims at the realization of accessible exhibition paths including multi-sensorial experiences *in situ* (tactile paths and AR experiences) and online (VR proposals) in the MAO.
Specifically, six stages of this path have been identified, including the museum's entrance hall and five artworks (one for each geographical area of the collection) which are the subject of the survey and restitution process. This involves thesis students of the Design and Visual Communication course of Politecnico di Torino for the development of prototype apps on the selected works and one of the authors for digital fabricated models and replica.

Keywords
VR, AR, tactile models, museums, inclusion.

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Introduction

In the last few years, the development of three-dimensional digital acquisition technologies has led to interesting results in the field of cultural heritage protection and valorization. In the museum field, on the one hand, there has been the creation of digital archives and, therefore, the delocalization of collections, and on the other hand, a greater attention to accessibility in presence. AR, among other technologies, has become a tool for discovery-based learning that enhances the information accessed by visitors within galleries, interacting with objects in the real world [Ding 2017, pp. 1-15].
The goal is to increase visitor involvement, making the museum experience more educationally incisive and more inclusive, in a "Design for All" perspective [Ronco 2021, pp. 49-61], moving from a standardized end-user vision to a holistic one (real end-user) [Rossi & Barcarolo 2018, pp. 257-269].

Multilevel Experiences in the Museum Field

The models obtained with different digital acquisition techniques allow new ways of content fruition. Both virtual and physical outputs aim to increase the inclusiveness of collections, meeting the different needs of users related to age, physical, sensory, cognitive, cultural and experiential factors.
These technologies, digital modelling and fabrication permit the automation of processes and the reproduction of the object in different formats. The diffusion of VR and AR devices has allowed to define new ways of visiting with an increasing level of involvement of visitors.
VR technologies enable visitors to live an experience very similar to the real one, but above all to receive additional content, such as the spatio-temporal contextualization [Walczak 2006, pp. 93-95]. AR technologies, on the other hand, can change the way the on-site visit is understood [Barry 2012], by adding (side-by-side or overlapping) digital content to the real object.
AR, as the direct tactile experience, offers new opportunities for interaction, including people with sensory and cognitive disabilities. While typically linked to visual experiences, it can include auditory, haptic, and olfactory experiences, expanding the channels of knowledge transmission [Sheehy et al. 2019, pp. 67-85].
These technologies are being used by the most cutting-edge museum institutions internationally as a means of adding new methods of "reading" to more traditional visit paths [Petrelli et al. 2013, pp. 58-63]. Increasingly, multilevel and multisensory experiences are proposed, which contribute to the knowledge of the surrounding reality and to the autonomy of the user, rising respect and social inclusion.
This paper aims to demonstrate some concrete examples of the use of the above technologies and methodologies. In the Italian scholar panorama, Alberto Sdegno has been conducting research on the acquisition, reproduction, and visualization technologies (AR, VR, and digital fabrication for tactile models and replicas) for cultural heritage enhancement for several years. Recently, his research group worked on the physical reproduction of two busts by Franz Xaver Masserschmidt, located at Palazzo Coronini Cronberg [Sdegno et al. 2017, pp. 969-976]. They used the most sophisticated declinations of research tools from three-dimensional scanning, and advanced modeling to 3D printing, taking care to inclusive access mainly to people having reduced visual abilities. The workflow included the 3D survey with a structured light scanner, the reverse modeling, and the 3D printing. They used an FDM (Fused Deposition Modelling) printer, with a PLA (Polylactic acid) white filament, to be painted afterward. This activity represents a benchmark from a procedural point of view for the work subsequently presented.

Accessibility and Inclusiveness of Turin's Museums

Is there a "Turin" model for museum accessibility and inclusiveness?
In the last few decades, museum accessibility has made great strides and Turin is leading the way. The first experiments began in the 1980s.

Research and experimentation are continuous and have been made possible by the alliance between cultural institutions, associations that protect the rights and represent the disabled people, public administrations, private and banking foundations in the area [Rolli 2020, pp. 23-41].
As far as permanent installations are concerned, at the Museo Nazionale del Cinema, the first intervention for accessibility was started in 2006, as part of the project "*Oltre la visione: il museo da toccare, il cinema da ascoltare*".
In June 2007, the first tactile area of Mole Antonelliana was inaugurated proposing a tactile exploration of the architectural spaces that house the museum. A panel with a relief map and Braille writing indicates the position of the exhibition area and the services available on the reception level. At the ground floor is placed the wooden model of the Mole in section (scale 1:100) that allows knowing also through touch the structural characteristics of the building and its historical stratifications [Levi, Rolli 2012, pp. 40-43].
The second stage was the inauguration, in June 2009, of the exhibition room "*L'ottica*". Also in this case, different tools and information supports were provided: interactive exhibits, three-dimensional tactile models, panels with texts and drawings in black and transparent relief.
The other work presented is the one carried out in 2012 at Palazzo Madama on the panoramic tower. In correspondence of each of the eight windows of the tower, a visual-tactile panel was placed with the photographic reproduction of the portion of landscape visible from that position and the selection, through graphics, of buildings and orographic reliefs of interest. On each panel was placed a QR-code and an NFC (Near Field Communication) that allow the use of a video with translation in LIS (Italian Sign Language) and subtitling, which made the texts usable to the deaf.
In 2015 another project – "*Abili per l'arte*" – was carried out in Palazzo Madama, as the response to the challenge of learning not only about relief or three-dimensional objects but also about painting, whose fruition is traditionally limited to the verbal narration. Five paintings made between the Gothic and Renaissance periods were selected and a board was made for each one (Fig. 1). The works can be enjoyed by unsighted people thanks to the relief reproduction of the images and the possibility of activating the audio description.
Another example is the Galleria d'Arte Moderna (GAM) where, in 2021, thanks to the *Fondazione CRT's Esponente* project, it was possible to create some visual-tactile panels of paintings that activate audio-video descriptions in Italian, English and LIS (Italian Sign Language). The panels available to the public are in special containers placed at a usable height along the exhibition path. Through multimedia and multisensory devices, these can communicate in a simple and inclusive way the pictorial work to the widest possible audience, with particular attention to people with sensory difficulties (blind, visually impaired, deaf, hearing impaired).

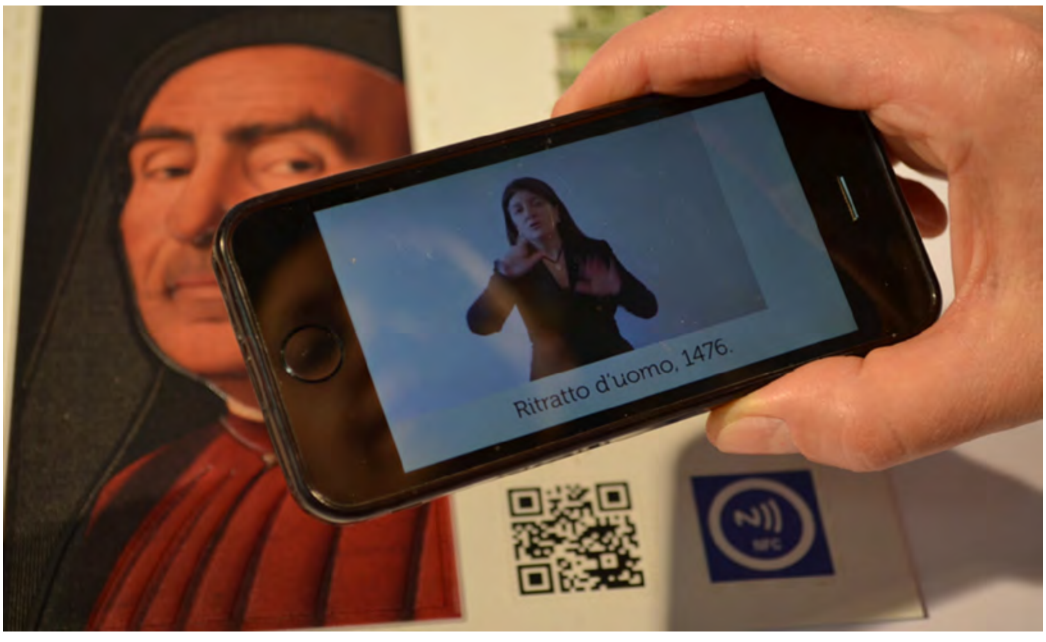

Fig. 1. Antonello da Messina, Ritratto, d'uomo, tactile panel and the LIS linked video (photo by R. Rolli).

The Museum of Oriental Art: the Case Study

The proposed research aims to build an accessible exhibition that includes tactile models of the architectural spaces and a small part of its collection within the MAO, which together with Palazzo Madama and the GAM, is part of the Fondazione Torino Musei, thus completing its offer.
Currently, the museum does not offer any structured arrangements within the exhibition space to ensure 360° accessibility and at the same time, the services offered are not yet conceived in an inclusive "for all" perspective, despite the will to do so. The educational services of the MAO, which are particularly active, propose activities with visit routes and workshops that are targeted and adaptable to different types of disabilities. Specifically, they propose a tactile path for blind and visually impaired people that develops within the collection of South Asia and Southeast Asia where it is possible to carry out the tactile exploration of selected works, mainly in stone [anonimous 2015].
The work of the research group, coordinated by Roberta Spallone and Marco Vitali of Politecnico di Torino, began in 2019 by the international collaboration for the project "New technologies for the analysis and conservation of architectural heritage", funded by the Ministry of Science, Innovation and the University of Spain. On this occasion, the participation as visiting professor of Concepción López of Universidad Politecnica de Valencia, implemented the research work carried out in recent years [Spallone, Vitali 2017]. The latter, based on brick-vaulted systems in baroque buildings in Piedmont, was thus enriched by data derived from a metric survey campaign with a terrestrial laser scanner (TLS). The atrium, the staircase and the hall of honor of Palazzo Mazzonis, headquarters of the MAO, are among the spaces surveyed.
An ongoing framework agreement between Politecnico di Torino and MAO has also allowed a certain continuity in the collaboration that has led to the development of several degree theses in Design and Visual Communication and the PhD thesis of one of the authors of this paper (F. Ronco).
Multidisciplinarity results as a fundamental element to allow the system to be replicable and scalable [Hervy et al. 2014, pp. 1-4]. The multidisciplinary team sees the involvement of museum conservators, professors, thesis students [1] for the development of prototype apps on the selected works and the arch. Rocco Rolli of Tactile Vision Onlus as a reference for the issues of accessibility and inclusion of the exhibition proposals.
The group, therefore, includes the knowledge of representation, information processing systems, art history, archaeology and museography.

From the Survey to the Museum Experience: the Workflow

The project involves the construction of new narratives inside the MAO through tactile, auditory and visual experiences in AR and VR. Specifically, the work is focused on the survey and restitution of some architectural spaces (entrance hall, monumental staircase and hall of honor) and five works (one for each geographical area of the collection), selected according to the parameters of: maneuverability and inspectionability; illuminability; roughness; perceptibility of details; opacity; chromatic richness.
The project involves the identification of a workflow management model from the digital survey of the object to its 3D virtual restitution used for different purposes: the digital fabrication of tactile replicas/models and the creation of VR and AR experiences, based on the original or on the replica.
The surveys were done with two different techniques: Structure from Motion (SfM) photogrammetry for the works and terrestrial laser scanner (TLS) for the spaces.
The acquired data have been processed with Agisoft Metashape® (in the case of the sculptures) obtaining the mesh model that finally has been exported in .obj for the implementation in Blender® environment.
The virtual model of the entrance hall of Palazzo Mazzonis, on the other hand, was made starting from the scans obtained with the Faro Focus3D. Autodesk 3D ReCap™ Pro software was used to clean and align them. The so-obtained point cloud was finally imported in Autodesk Autocad® and cut with vertical and horizontal planes to obtain the characteristic

sections that allowed the realization of the ideal three-dimensional virtual geometric model in Rhinoceros 6®.
Starting from these inputs, the outputs are multiple: modeling of the missing parts, digital fabrication of them and in general of the tactile models, AR and VR experiences.
The realization of these last took shape thanks to the use of Unity with some additional tools such as Vuforia, Model Target Generator, Google VR and Bolt.
All prototypes are developed for mobile devices, so the user can easily install the application on its smartphone.

AR, VR and Digital Fabrication Between Museum Spaces and Artworks

The sculpture of *Dama di Corte* (Fig. 2) has been chosen to test the technique of virtual restoration, linked only to the chromatic aspect. In fact, its excellent state of preservation allows one to appreciate the original colors but not in their integrity. Therefore, post-production work has been done on the texture of the digital model retrieved from the survey, to obtain colors that are close to the presumed original ones. The AR experience, developed with Unity® software, is activated by framing the work with a smartphone. After the introduction of the functioning of the experience, all the peculiarities of the statue (hairstyle, face and shoes) are highlighted in the various steps. Finally, the user can see the chromatic reconstruction of the same, through its digital copy.
On this artwork the process of digital fabrication through the 3D printer has also been started. At the moment a copy in scale 1:5 is realized, for a purely experimental purpose, to test the perceptibility of the details with the reduction of scale. The object turns out to be about ten centimeters high and could be evaluated as a marketing object. As for the tactile replica, now only a portion (the head) has been fabricated for dimensional reasons of the working plate of the 3D printer In the coming months, the other portions will be realized.
Two other selected works are wooden statues of Japanese origin called *Ni-tennō* (Fig. 3), magnificent examples of the artistic production of the Fujiwara period (898-1185). This is a pair of guardians typically derived from the group of *Shi-tennō*, also known as the protectors of the cardinal points. In this case, the most important work was to contextualize the two statues in the *Kōnjikidō*, or 'Golden Hall', located in the complex of *Chūsonji*, in Iwate prefecture, north of the capital. This small building,reproduces exactly the original appearance of the temples of the period.
The AR experience starts from the recognition of the artworks and is developed in six steps that tell the origin and appearance of the two guardians.
On *Ni-tennō* has also been developed a VR app intended for installation on smartphones, which involves the use of the Google Cardboard visor. The experience offers the possibility of observing the statue inside the temple, evaluated philologically compatible by the then director of the MAO, Marco Guglielminotti Trivel [Tamantini 2020, pp. 52-125].
The last artwork proposed here is the standing Buddha (Fig. 4) from the Gupta period, which was one of the major empires of ancient India, ruled by the dynasty of the same

Fig. 2. Dama di Corte: a) virtual model with original texture (by S. Tamantini); b) virtual model with restored colors (by S. Tamantini); c) 3D printed replica scale 1:5 (by F. Ronco); d) AR experience screenshot (by S. Tamantini).

name between the fourth and sixth centuries AD. The sculpture, in the typical spotted red sandstone of the Gupta school of *Mathurā,* shows the hands and lower limbs broken and an elegant body, enhanced by the large round nimbus that frames the head. The Buddha probably showed the gesture of *abhayamudrā* with his right hand and just held up a hem of his robe with his left hand, according to the canonical iconography of the period. The oval and full face and the high *ushnīsha* on the head are inserted in the center of the large halo – of which only the right portion is preserved – decorated with plant motifs arranged according to concentric frames that follow the central corolla of lotus flowers.
Here the 3D reconstruction of the missing parts was realized, in a perspective of digital archaeology. The reconstructed parts were made to complete the sculpture, but without the application of the texture, so that there is a clear distinction between the original work and the reconstruction. Similar works of the same period from other museums have been taken into consideration as a reference.
During the AR experience, the user can select the reconstructed parts by clicking on the touchscreen. A detailed description of the specific element appears: the selected element turns red, and an audio track begins as it is transcribed on a text panel [Castagna 2021, pp. 23-72].
The last experimentations proposed in this paper are the models of the atrium's vaulted system of Palazzo Mazzonis, the seat of the museum (Fig. 5).
After the survey with TLS technique, the point cloud was used to obtain an ideal virtual model of the vaulted system covering this space through sectioning with vertical longitudinal and transverse planes. This model was then used to devise two real models with different purposes.
In the first model, the sections have been transformed into real tangible interlocked planar slices, made of cardboard with the 2D cutting device Trotec Speedy 400® of ModLab Arch of Politecnico di Torino. This model, with a purely didactic function, emphasizes the perception

Fig. 3. Ni-tennō and Kōnjikidō: a) virtual model b) virtual reconstruction; c) AR experience; d) VR experience (by S. Tamantini).

Fig. 4. Buddha Gupta: a) virtual acquired model; b) virtual reconstruction of missing part; c) AR experience (by L.Castagna).

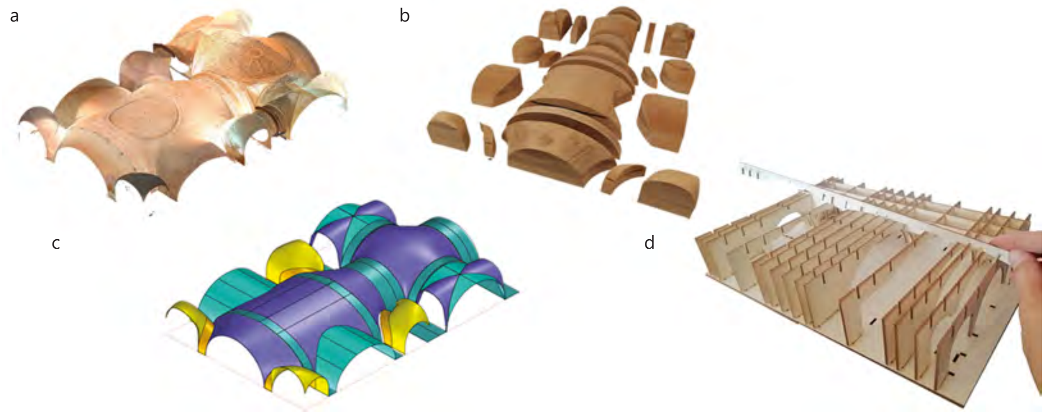

Fig.5. Palazzo Mazzonis atrium vaulted system: a) point cloud; b) virtual model; c) CNC milled model; d) laser cut model (by F. Ronco).

of the vaulted system of the atrium from bottom to top. Observing the waste material of the cutting process, a new model with the voids and solids reversed has been conceived. This handy object, fabricated with a CNC milling machine, allows perceiving the intrados surface of the vaults from above, in the perspective of tactile fruition [Ronco 2021, pp. 49-61].

Conclusion

The examples reported here want to be an example of the multiple possible uses of virtual models obtained with digital surveys in a perspective of interactive and inclusive use.
The collaboration with the museum is in continuous evolution and offers continuous opportunities to experiment with the languages of representation applied to the accessibility of the museum heritage. Only the integration of the applications presented can allow the involvement of the widest possible audience.
The research group formed between the Polytechnic of Turin and the MAO serves as an exchange, a catalyst for innovative ideas, and a means for knowledge circulating at the intersection of arts, management and technology. It represents a resource that leads to the innovative, effective and efficient integration of technology in the museum. Using VR, AR, tactile models and other cross-media techniques serves to deepen the relationship between a museum and its patrons.
The multidisciplinarity of the project represents on one side a great richness, on the other side requires a special effort on the part of those involved, which could be solved by systematizing collaborations and formalizing a research group across the academic and museum worlds. This would allow for cost containment, continuous updating on technologies and the involvement of specialized staff.
Finally, collaboration with local companies in the field of information technology and digital fabrication would allow for a broader range of experimentation possibilities.
The proposed experiences, therefore, will need to be validated with different categories of users, and in particular tactile models with visually impaired people. Thanks to the help of Dr. Franco Lepore, Disability Manager of the Municipality of Turin, and Arch. Rocco Rolli, founder of Tactile Vision Onlus, test groups will be constituted to verify the effectiveness of all the tactile models produced.
Another interesting development would be the hybridization of AR, VR and digital fabrication technologies to generate exciting new outputs.

Attributions

This paper, whose authors shared the methodological framework, was written by Francesca Ronco (par. Multilevel experiences; Museum of Oriental Art; workflow; AR...museum spaces and artwork) and by Rocco Rolli (par. accessibility).

Notes

[1] The students Serena Tamantini, Lorenzo Castagna and Luca Lombardi are coordinated by professors Roberta Spallone (Politecnico di Torino – DAD) and Fabrizio Lamberti (Politecnico di Torino – DAUIN), Luca Maria Olivieri (Università Ca' Foscari di Venezia), by the research fellow arch. Francesca Ronco (Politecnico di Torino – DAD, MODLab Design) and the MAO conservators Dr. Marco Guglielminotti Trivel and Dr. Claudia Ramasso.

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Virtual and Interactive Reality in Zaha Hadid's Vitra Fire Station

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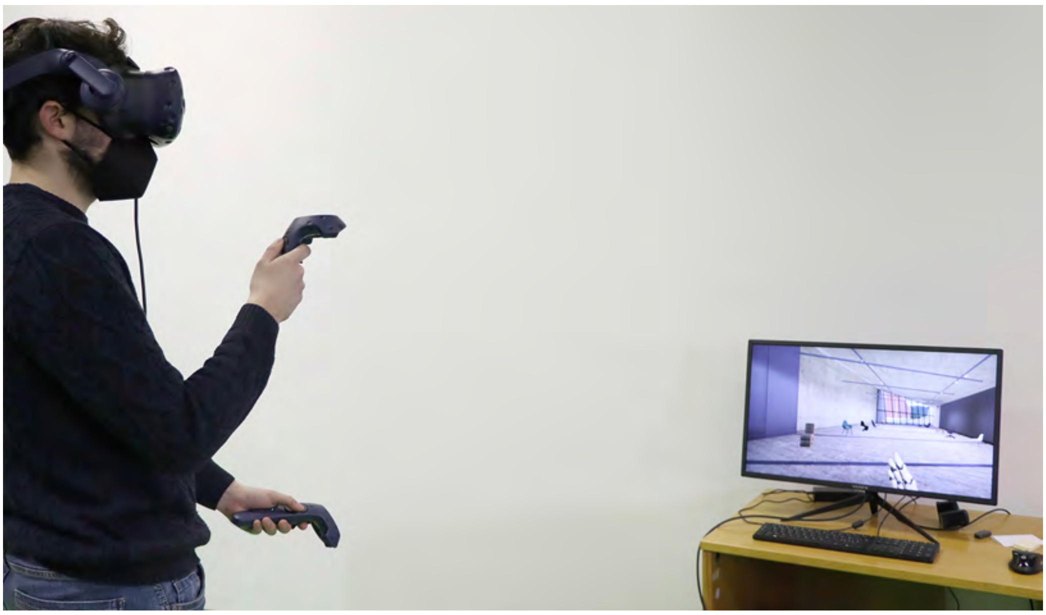
Paola Cochelli
Mattia Comelli

Abstract

The aim of the research was to analyze the project by Zaha Hadid's Vitra Fire Station in Weil am Rhein using advanced and interactive representation. Built between 1990 and 1993, today the building is a space for temporary exhibitions. We choose it to understand its morphological complexity and to experiment some different interaction systems. To increase the credibility of the virtual environment, we applied seamless textures from photographs samples during the surveys to the 3D model. The Virtual Reality (VR) exploration includes the external context and the building interiors, where we have inserted textual and manual interactions of some works preserved in the exhibition area. We generated two levels of interaction of the scene: with keyboard and VR headset. These two ways allow users to navigate both using hands and walking around.

Keywords
Zaha Hadid, vitra fire station, virtual reality, solid modeling, interactive representation.



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Introduction

Virtual Reality is increasingly proving to be a useful tool for the representation, communication and fruition of cultural heritage. Gaming software are the ideal environments for generating it, as they lend themselves well to simulation with real time rendering techniques. These immersive systems allow increasing the value of an architecture – realized, ideal or no longer existing one – going beyond the phases of three-dimensional modeling and production of static output images.
In a virtual exhibition space, it is possible to move and interact with its contents as in the real world: in fact, an observer can visit it, move freely, and take the time necessary to satisfy his personal curiosity about an artwork, an overall vision, or a constructive detail.
To obtain this result, it is necessary to observe an application protocol. A procedure that goes from the acquisition of graphic, photographic and documentary information of the architecture to be reconstructed, to low poly modeling (geometric for architectural or design elements and organic for natural ones), to the generation of specific textures (e.g. albedo, bump, displacement, normal, reflection and procedural maps) and lighting studies (with static or mobile lighting fixtures).

Vitra Fire Station by Zaha Hadid

We identified the VR case study in the Fire Station designed by Zaha Hadid (1950-2016) for the Vitra headquarters in Weil am Rhein.
Vitra is a Swiss company, originally German, founded in the mid-twentieth century whose design production line focuses on furniture for the home, office, and public spaces.
The company is famous for the production and distribution of works by great designers of modernity such as Antonio Citterio, Philippe Starck, Mario Bellini, Alberto Meda, Jean Prouvé and some others.
Willi Fehlbaum founded Vitra's headquarters in 1950 in Weil am Rhein, a German border town located on the eastern bank of the Rhine River near Switzerland and France, not far from Basel (Fig. 1). Here he also built its campus, conceived as a corporate museum and a unique collection of contemporary architecture desired by one of the most prestigious and recognized furniture manufacturers in the world [Kries 2020].

Fig. 1. The Vitra Campus in Weil am Rhein.

Fig. 2. Vitra Fire Station by Zaha Hadid (1990-1993).

Following the great fire in 1981, Vitra decided to have a fire department and commissioned Zaha Hadid to project the fire station (Fig. 2). Today, the building no longer has its original function, and it holds inside events and temporary exhibitions. Nevertheless, despite changing its intended use, today it is still known as a fire station. The building is the first architectural complex designed by Zaha Hadid, and some critics have defined it as a de-constructivist architecture. It is next to production facilities and suggests the effect of an explosion, or a wedge-volume with dynamic shapes that emerges from the ground: an assimilation of lines and planes with a narrow and elongated shape that recalls the neighboring agricultural fields, as if it were an artificial extension of them [De Sessa 1996].
The concrete fragments and ceilings slide over each other creating a straight horizontal profile; this creates a sense of instability that increases when the sloped ceilings slide over each other. Large and glazed cuts lighten the structure of the building, to the point of making one doubt its static nature. The interior of the building is also complex, developed through several partitions that break and tilt, creating a configuration that gradually changes. It consists of storage spaces for fire department tankers, showers and changing rooms, as well as a conference hall and kitchenette. The use of concrete, the lack of decoration and the sharp edges give the visitor a special experience.

Modeling Architecture for VR

Considering the great number of elements and the complexity of some of them, we prepared a working plan for the Vitra Fire Station executable project.
VR modeling must follow some graphical criteria, to ensure processing and visualization in terms of quality and fluidity. Obviously, this is also possible thanks to the high performance of the PC processor and video card.
In this phase, it is necessary to clarify the repercussions that geometric complexities can create for a 3D model. Three-dimensional polygonal modeling works on surfaces organized in mesh composed of polygons based on vertices, edges and faces. This technique allows full control of the creation process, but also offers to modify the 3D object with flexibility and approximate it compared to the real one. The advanced modeling software we used to

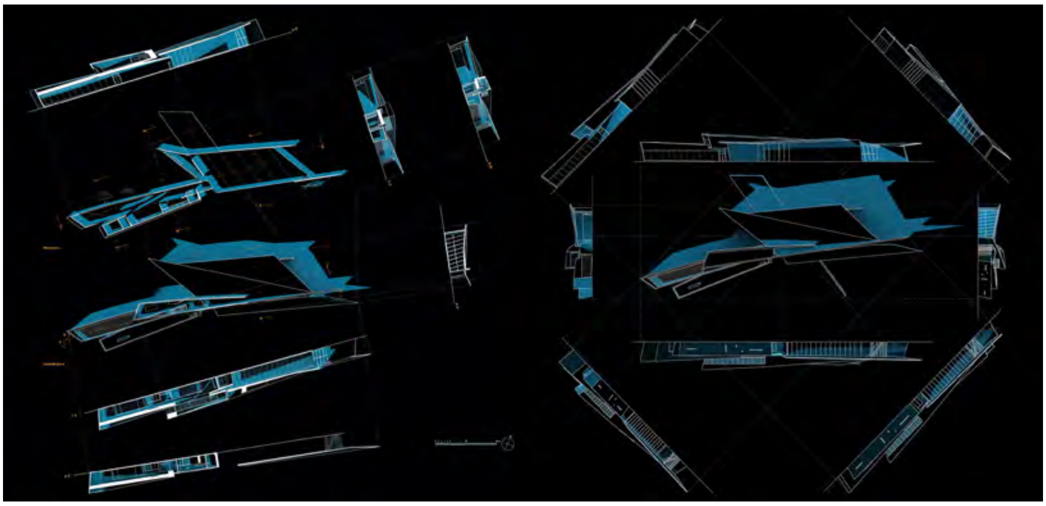

Fig. 3. Zaha Hadid's Vitra Fire Station: a) plans and sections; b) plan and elevations (digital drawings by Mattia Comelli).

create the fire station are the only ones that meet these requirements. We avoided CAD programs because they often produce the "overlaps" faults (surface flickering).
For this case study, we resorted to both geometric modeling, organic modeling, and their hybridization, simplifying the meshes remaining faithful to the real elements' complexity.
In fact, a small number of polygons (low poly modeling) is suitable because it improves performance of the computer, the calculation of shadows is much faster and the visiting experience is fluid, although the quality is lower. However it is little detailed and realistic, unlike high poly modeling. The latter one consists of a large number of polygons also obtained by tessellation but requires high computing capabilities. Surely, low poly modeling is the best one for the development of video games and in the use of VR devices.
However, often the best solution is in the middle (medium poly modeling). It is necessary to find the right compromise between realism and fluidity, even emulating the three-dimensionality with texture layers.
We created the virtual twin of Vitra Fire Station by elaborating and analyzing the drawings by Zaha Hadid (Fig. 3) [Hadid 2004]. However, the only original documents are not enough when you want to emulate a real environment. The visit to Weil am Rhein was fundamental to collect all the photographic material necessary to determine the correct geometry of the architecture and to highlight some differences between project and realization, but also for the reproduction of the real textures. In addition, to enhance the realism in the virtual environment, we also modeled a great part of the Vitra Campus, such as the Vitra Schaudepot by Herzog & de Meuron or the Factory Building by Alvaro Siza.
The survey was also essential to create furniture and design objects exposed inside, such as the *Mesa Table* (Fig. 4a). Thanks to the photographs and dimensional information stored on the website, we reconstructed the objects and applied chamfer modifiers (medium poly) to them to emulate plasticity.

Texturing and Lighting Architecture for VR

In addition to the 3D model, maps and UV textures also make up a VR scene.
The material yield in the graphics engine is an important component. We apply it to the mesh to control the visual appearance and calculate the interaction of light in a scene.
We applied an unwrap modifier to each 3D element. It is fundamental because it allows us to assign more channels to the same object. In the gaming environment, this guarantees a good shader, which must be composed of different image textures, mathematical expressions, and intrinsic material benchmarks. In fact, in addition to the chromatic data, a material has surface parameters such as roughness, opacity or reflection. If we aim for high realism through texturing, we need to structure definable visual scripting nodes in the material editor.

Thanks to pictures appropriately taken during the survey and the image processing software, we prepared the seamless textures of the fire station: floor and wall coverings (external concrete panels, bricks, tiles) but also the fabrics and materials of chairs and tables. We proportioned the real-scale reproducible maps and associated each material with different surface characteristics.
The lighting of the scene also plays a relevant role. We have also assigned an unwrap modifier to properly illuminate and structure each 3D entity (fig. 4b). This process allows us to convert the surface of a solid object into two-dimensional elements. The mesh faces are broken and placed on a Cartesian plane without overlapping. A large area occupied by this subdivision ensures a better quality of shadows.
The UV map serves the rendering engine. Depending on the lighting, it calculates the shadow and saves it on a secondary channel, in addition to the map itself. This operation avoids the further real-time processing of object shadows because they are preloaded previously.
The lighting takes place with an algorithm of light mass applied to the objects of the scene.
In the game engine, we find three kinds of lights: static, fixed and dynamic. This distinction is necessary because it greatly affects the way light works and its impact on calculation. Depending on the type chosen and adopted, there are different compromises between quality, performance and changeability of the scene. Static lights use only light maps, and we calculate their shadows during processing, before starting the gameplay.

Rendering

For VR, gaming software uses the Graphics-Processing Unit (GPU) to render faster but with lower quality than the Central Processing Unit (CPU).
The classic real-time 3D engine technique is Forward Rendering, instead gaming software uses Deferred Rendering. They differ in the processing of geometries and in the calculation of light. Once the scene is set, during the calculation phase the software creates a list of lights illuminating the object.
In Forward Rendering, the process is linear but disadvantageous, because depending on the scene framed, the calculation of rendering will have to consider every light in the scene for each geometric object.
On the contrary, Deferred Rendering allows treating lighting only in the space visualized in the screen. It calculates only what you see, going to temporarily leave out information that is not directly present in the field of view. This method considers fewer polygons and is therefore faster in terms of calculation.
Forward Rendering calculates the light for all the geometries, in Deferred one the calculation regards only the directly visible elements.

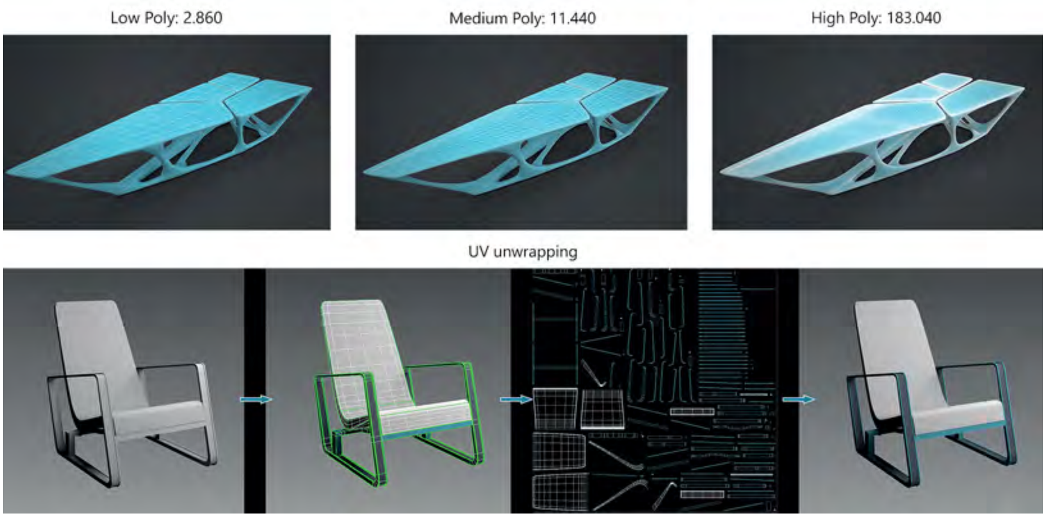

Fig. 4. a) Comparison between low, medium and high poly models applied to the *Mesa Table* designed by Zaha Hadid; b) UV unwrapping process (elaborations by Mattia Comelli).

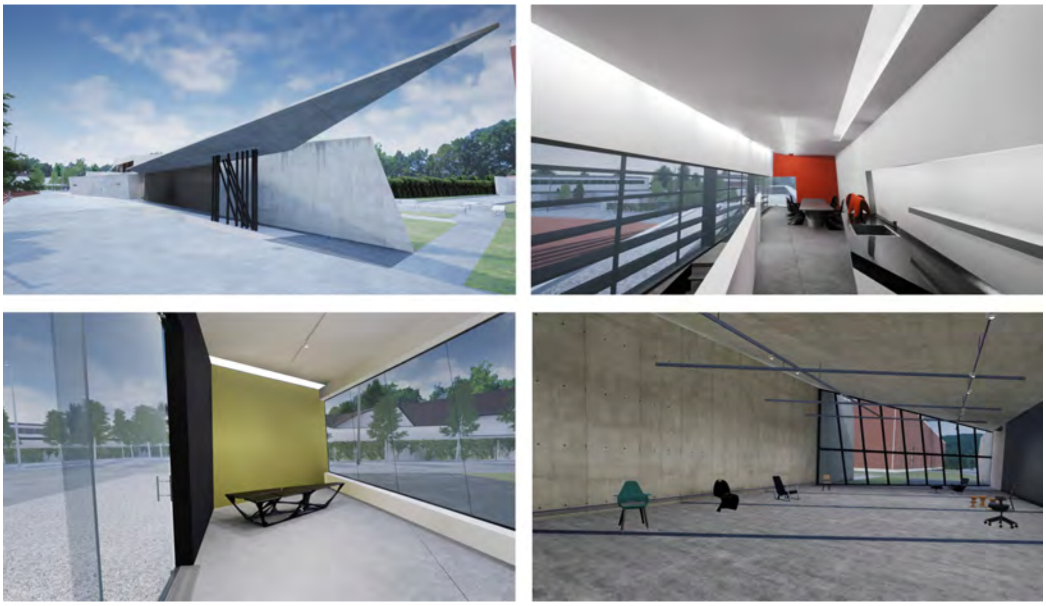

Fig. 5. Frames taken from the virtual twin of Zaha Hadid's Vitra Fire Station: a) exterior and context; b) first floor meeting room; c) ground floor and *Mesa Table*; d) Interactive-exhibition hall with design chairs (graphic elaborations by Mattia Comelli).

However, the Deferred Rendering presents some criticalities. The first issue is the calculation of geometries, because processing only what is displayed by the camera some geometries may get lost or distort the final effect. It also presents problems in the representation of transparent and reflective objects and in the accuracy of the calculation in post-production. Finally, in the display you notice the aliasing effect, a phenomenon in which oblique or curved lines have a scaled appearance.

Interactions and Virtual Visit

For an effective immersive experience, it is important to allow maximum freedom of movement and implement the system with the programming of interactions.
The virtual visit starts outside the building (Fig. 5a), in front of the entrance with the glass door. The navigation area has been set within two base stations at 3x3 m: in this space the user moves with direct movement, otherwise he can set a new approach through the trackpad, activating a trajectory for the teleportation system.
The virtual area of the Vitra campus containing the fire station covers about 850 sq. m. Inside, all the rooms on the ground and on the first floor can be fully explored in the virtual tour by the user (Fig. 5b-c-d).
Like materials and lighting, collisions and interactions are set and managed in gaming software. Collisions are important constraints for visiting VR environments. In fact, you must set up blocks so as not to go beyond the walls and allow you to travel through spaces. Collisions are the basis of interactions, and we can solve them through C++ or blueprint programming. Specifically, for this study we used the blueprint interface based on node structuring.
In addition to the physical constraints of walls, ceilings, staircase and terrace, we have added several levels of automatic and manual interaction. Automatic interactions relate to the movement of cars on nearby streets or the simulation of the breeze on vegetation. We find instead between direct interaction: the opening of the doors, textual and manual information activated approaching them or with trackpads.
In the exhibition room, approaching with the joysticks to the design chairs will appear short descriptive texts of the artworks, which report title, designer and year of implementation. On the first floor, in the meeting room, the visitor is even more involved in the VR scene because he can grab a toy in the form of an elephant, hold it in his hands simulated by trackpads and place it wherever he wants (Fig. 6).

Conclusions

Current Virtual Reality developments show that the systems now available are integrating and perfecting the three types of application – passive, exploratory and interactive – that until recently were distinct from each other or partially implemented [Aukstakalnis, Blatner 1992; Muscott, Gifford 1994].
These new multimedia technologies of fruition, in fact, allow to activate in a dynamic and interactive way the exchange between current events and virtuality, making the visitor an active participant of the digital-virtual scene proposed.
There are many strengths that these systems can offer in the fields of education, museums, and tourism [Özdemir 2021], as the creation of specific scenarios – related to the world of architecture, urbanism archeology, painting, history, design, etc. – can overcome the passivity of content transmission, increase knowledge by offering opportunities for multi-sensory and emotional involvement in the logic of "learning by doing" thanks to gamification strategies.
Through this VR project presented in this research, we can better understand and visit a complex architecture such as Zaha Hadid's one, a famous international building not always easily accessible to everyone.
The project for Vitra Fire Station is very useful to understand limits, potential, future developments and implementations for the creation of other executables.
By taking advantage of this complex building, we were able to understand and perfect the interaction system.
The results of this elaboration, therefore, allow us to proceed in optimal way in the successive investigations that regard the simulation in real time of an architecture of a certain morphological complexity inserted in an urban context, such as the Vitra Campus.
Currently our research is proceeding with new architectural projects and testing new hardware and software devices to exploit these systems in the dissemination and knowledge of cultural heritage.

Fig. 6. Textual and manual direct interactions in the VR model of Zaha Hadid's Vitra Fire Station.

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Storytelling for Cultural Heritage: the Lucrezio Menandro's Mithraeum

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Abstract

The essay is part of the valorization for the knowledge of Cultural Heritage and is articulated according to three different readings: a first semantic reading, concerning the meaning of narration of a specific "story"; an operational reading in which the proposed methodology is applied to a concrete case study; a reading on the possible scenarios of communication for knowledge, using AR. The first results of the ongoing digitization process of the collection inside the buildings of the Ostia Antica Archaeological Park in Rome are presented here, where innovative digitization and data optimization technologies are compared with the immense heritage of the Park, animating the exhibition-interactive itinerary, creating digitally usable content through AR, reflecting on the opportunity of these technologies to create new forms of digital storytelling for use and knowledge.

Keywords
storytelling, integrated survey, photogrammetry, augmented reality, Ostia Antica.

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Digital Storytelling, the Evolution of the Concept of "Storytelling" Over Time

Augmented Reality (AR) represents one of the innovations with the greatest potential in the field of fruition and dissemination of Cultural Heritage. As an interactive tool that guarantees a proactive approach to cultural life on the part of the user, this technology puts into practice one of the concepts of cultural democracy [Evrard 1997; Matarasso, Laudry 1999] and is able to modify the level of interaction of the public with culture and in particular the relationship between the user and the collection of a museum space, by expanding it with personalized and emotionally involving paths and contents. Man has always felt the need to narrate his surroundings. Since ancient times, works of art (such as manuscripts, papyri, cave paintings, architectural decorations) have been the means of communicating a specific message to the multitude, or to an elite public. Over the centuries the mediums have changed, but both the level of involvement offered by the story and the capacity of these tools to become bearers of knowledge have remained unchanged. Nowadays the narration of a particular Cultural Heritage, thanks to the advent of technological devices applied in the museum-exhibition field, can be democratically extended to all, sharing the message to be communicated to the whole community. In fact, the use of a personal device for interaction with the web is a must-have in all the activities of human beings: from asking for information about the route to be followed to integrating one's knowledge in front of a Cultural Heritage. Within this context, it is evident how Cultural Heritage can leave the real enclosure where it is currently located, such as the museum space that contains it, precisely through forms of interaction with digital devices using dedicated tools.

In particular, the use of these technologies is of greater interest to those who approach Cultural Heritage with greater difficulty, also by virtue of the ability to explain, in a visual and easy-to-understand manner, the history of the Cultural Heritage and the events that the space or objects on display have undergone over time. A history that is often complex and articulated and that, to be understood in its evolution, requires a knowledge base that is precluded to all those who are not experts. In this case, "representation" is an effective way of trying to solve this age-old problem precisely because of its ability to express phenomena and events in a simplified manner. All this is done through interactive images that show the narration, or storytelling, hidden in the archaeological remains *in situ*.

Talking about storytelling means turning our attention to an important cognitive tool capable of negotiating common concepts and conveying them in a functional way, responding to the individual's need to reconstruct reality by giving it a specific temporal or cultural meaning. Already exploited for years by marketing and communication to promote the success of a product, the use of narration has demonstrated and continues to demonstrate its usefulness also in the field of Cultural Heritage enhancement. When this is done using digital tools of interaction, it is possible to talk about Digital Storytelling [Bonacini 2020], i.e. implementing a series of practices that make use of digital mediums with the specific aim of attracting and capturing the user through the creation of interactive stories that make the narration of Cultural Heritage engaging, bringing the user closer emotionally [Maulini 2019] and amplifying the experience [Bosco 2016]. AR represents one of the most effective means with which to put this specific strategy into practice, as it is a "transformative" technology, i.e. capable of transferring emotions in such a realistic way as to induce a permanent personal change in the individual: thanks to the "sense of presence", blurring the perception between physical and digital reality, and thus becoming a vehicle for emotions [Cappannari 2020]. Emotions are generated by the meaning we give to reality: through new technologies it is possible to transfer the feelings we experience into the digital world, creating in the user a sense of wonder that transcends his or her classic mental schemes, resulting in greater emotional involvement, which thus allows an almost "natural" interaction between human beings and digital content. It is precisely this experiential and emotional approach that guarantees an improvement in the enjoyment of the heritage under study, redefining the museographic space, and focusing on the visitor's experience.

In this way we are witnessing a specific change of trend: if in the past the knowledge path took place only inside a museum in a monothematic, unidirectional and univocal way, now

the user can choose what to know inside a multiple exhibition space, can interact with the works present in it and get to experience the information even if not tangible, consciously enriching his cultural background and participating in the construction of the exhibition.
The research carried out on the *Mithraeum of Lucrezio Menandro* the subject of this contribution, moves within this framework. To be better understood, the Mithraeum needs to be recounted in terms of its various evolutions over time, which are difficult to perceive at first glance. In this context, it is evident that only a digital medium capable of overcoming the physical limits imposed by the material constitutes the privileged tool for the construction of the story. Through the possibilities offered by AR, it is possible to recount what is no longer visible, that is, what is only comprehensible through a reading of the fragments present within the space, and which AR makes it possible to bring back to life through a participatory and interactive process, telling the story of the evolution of the space.

Case Study: the Mithraeum of Lucrezio Menandro

The paper presents the first results in prototype form of a large research project aimed at digitizing the heritage of the Archaeological Park of Ostia Antica in Rome, where innovative technologies will be put at the service of conservation and dissemination by proposing AR solutions aimed at improving the exhibition itinerary. In particular, the research focuses not only on the digitization and optimization techniques of the data obtained by massive survey but will also verify the opportunities of using these technologies for the creation of new forms of digital Storytelling through interactive processes, aimed at improving the usability and knowledge of both the Archaeological Park and the Museum area.
Within this theoretical/conceptual framework, the present contribution focuses on the *Mithraeum of Lucrezio Menandro* located within the Archaeological Park. The decision to analyses this specific case study is to be found in its stratigraphic complexity which, to be understood in all its facets, requires a complex and articulated narration of the phases that over time have modified both its architectural components and its function. This has been made possible thanks to a continuous dialogue with expert archaeologists and restorers working in the Park [1], who have contributed to the research work by assessing the accuracy of the results and making available the results of their studies and the historical/critical documentation in their Archives. While an archaeological site does indeed involve us emotionally by virtue of its very nature, it also needs to be described in terms of its evolution (historical and formal) and the reasons why it has been transformed into its current definition. Precisely for this reason, the contribution proposes a solution to the narrative theme that makes use of AR by proposing a digital storytelling operation capable of involving the user through the explanation of the articulated evolution of the *Bene* from the traces that can be read on the surfaces that make up the space.
The *Mithraeum of Lucrezio Menandro* (Region I, III, 5) is in the homonymous block, between Via dei Balconi and Via dei Molini, in the central sector of the state-owned area of the Archaeological Excavations of Ostia Antica and a short distance from the Museum.
The building that houses the Mithraeum was built in mixed construction in the Hadrianic period (as can be seen from the brick stamps dating to around 127 AD) and faces Via dei Balconi with a row of *tabernae*. In this period, the rooms subsequently occupied by the Mithraeum and the adjacent rooms were probably used for commercial functions related to a bakery.
In the second phase, probably dating from the Antonine period, the rooms later occupied by the Mithraeum were renewed in their layout and decoration and used for purely residential functions. The room, previously used as a courtyard, was covered by a barrel vault (of which only the impost remained at the time of the excavation), divided into two rooms, and used as a reception room. The painted and mosaic decoration of the room dates to this phase, perhaps to the age of Marco Aurelio, and the floor was lowered in this phase by about 0.40 m from the floor level.
Later, the south-eastern sector of the building was transformed into a Mithraeum. The *spelaeum* was created in the room accessible from the north by a staircase. The central partition, which separated the two rooms while maintaining the original wall decoration, was demolished

in this phase, and two podia were added along the walls (0.45 m high and 1.25 m wide), with niches on the vertical sides in correspondence with the marble threshold, and the altar on the southern side. The altar (0.75 x 0.55 m), made of bricks, was decorated on the front with a marble slab engraved with a deep lunar crescent behind which a lantern must have been inserted, below which was the inscription *DEO INVICTO MITHRAE / DIOCLES OB HONOREM / C. LVCRETI MENANDRI / PATRIS / D(ono) D(edit) D(edicavit)*. The paleographic characters suggest a dating of the inscription to the first years of the 3rd century A.D., a period to which the transformation of the room into a Mithraeum can be attributed.
The *Caseggiato* of Lucrezio Menandro was probably brought to light in the years 1932-1933, as seems to be possible to reconstruct from the archive photos, which also document the first restoration works on the walls and frescoes.
The complex underwent further restoration in the early 1960s, during which most of the frescoes were detached and subsequently reassembled on concrete supports (including those now placed on the front of one of the podia), as can be seen both from the plaques on the walls (1965) and from the documentation kept at the Museum of the Early Middle Ages concerning work carried out on buildings of Region I. A further restoration, for which no documentation is preserved, was probably carried out in 1992-1993 (as can be seen from archive photos). In 2000, a further safety intervention was carried out, which included considerable work on the frescoes, which were detached and subsequently reassembled on concrete supports behind the perimeter wall and one of the *podia*. Finally, in 2021, the Mithraeum underwent major restoration work that returned it to its current state of conservation.

Methodology of Analysis

The building has undergone three different phases over the centuries, which have profoundly altered its use and architectural morphology, and three successive phases of restoration that have given it back its current configuration. Each of these has left traces which, in order to be understood in their evolution, require a narrative process accompanied by visual support. Given the complexity of the narrative, the use of a tool such as AR, capable of interacting with the space through a digital device, makes it possible to tell a visual story that can explain the spatial transformation over time, the interpretations of the restoration, and the reasons for the current state. After a documentary phase, carried out with the support of the Park's archaeologists and restorers, which made it possible to identify the space's evolutionary characteristics and to understand its stratigraphic complexity, a complex integrated survey operation was carried out, aimed at obtaining the data necessary for the various processes. Topography, laser scanners and cameras were combined in order to control the reliability of the multiscale measurement operations, which allowed a considerable amount of information to be obtained at the architectural scale and at the scale of extreme detail [2] (Fig. 1).
The survey operation was followed by a processing phase aimed at completing the documentation, through the creation of 2D and 3D models of survey and critical interpretation. In order to highlight the various themes addressed, in addition to the traditional architectural drawings on a scale of 1:50, photo plans on a scale of 1:10 of all the frescoed walls, the mosaic floor and the marble slab with engraving were also produced. For the marble slab, the retrieval of an archive photo made it possible to complete, through a process of reverse engineering, the missing part, working on the geometry of the form. All these elements constituted the indispensable data base for the subsequent critical reconstruction of the various phases necessary to complete the story and which were subsequently incorporated into the AR application.

Digital Storytelling: the Story in the Building

The current state of the building is the last trace of an articulated and complex history which, to be understood, needs to be critically recounted in its substantial phases. The aim of the narrative is to allow users to see the different phases of transformation of

Fig. 1. *Mithraeum of Lucrezio Menandro*, integrated massive survey, top point cloud generated by 3D laser scanner, bottom SFM of the Mithraeum details.

the building and to recognize the traces still present in situ. Currently, the space of the Mithraeum shows the coexistence, within the same environment, of a series of traces deriving not only from the different construction phases, but also from some choices made during the numerous restorations. This makes the spatial narrative unclear and the overall image that is proposed to the public gives a configuration that is difficult to read and ambiguous to interpret [3]. For this reason, the modelling has concentrated on the critical reconstruction of the various phases that can be digitally brought back to life within the display devices, restoring to the space the capacity to narrate its evolution in a dynamic and interactive manner. For an immediate comprehension of the spatial evolution, three-dimensional models have been created, which allow to clearly narrate the evolution of the analyzed space, highlighting each time the demolitions and reconstructions and telling, starting from the still tangible traces, the different functions it has known in time (Fig. 2):

Phase 1. The first phase shows that the area analyzed had an open space connected to the harbor, close to the neighboring blocks of flats.

Phase 2. This phase is characterized by the partial transformation of the open space into two covered rooms pertaining to a new residential building, which involved the construction of new walls, the lowering of the ground level and the construction of a vaulted roof, which were subsequently decorated with mosaics on the floor and frescoes on the walls.

Phase 3. Phase 3 is characterized by the transformation of the rooms into a single space used to contain the Mithraeum, which is accessed via a system of stairs located at the entrance. The Mithraeum, consisting of a single vaulted room, is denoted by the two podia placed at the sides of the walls and by a marble slab that identified the altar.

In addition to the architectural theme, the study focused on the chromatic reconstruction of the rooms by simulating, through a critical process, what the decorations in the various rooms must have looked like, completing the numerous gaps and reconstructing the various missing portions following a geometric study of the proportions that were still legible (Fig. 3).

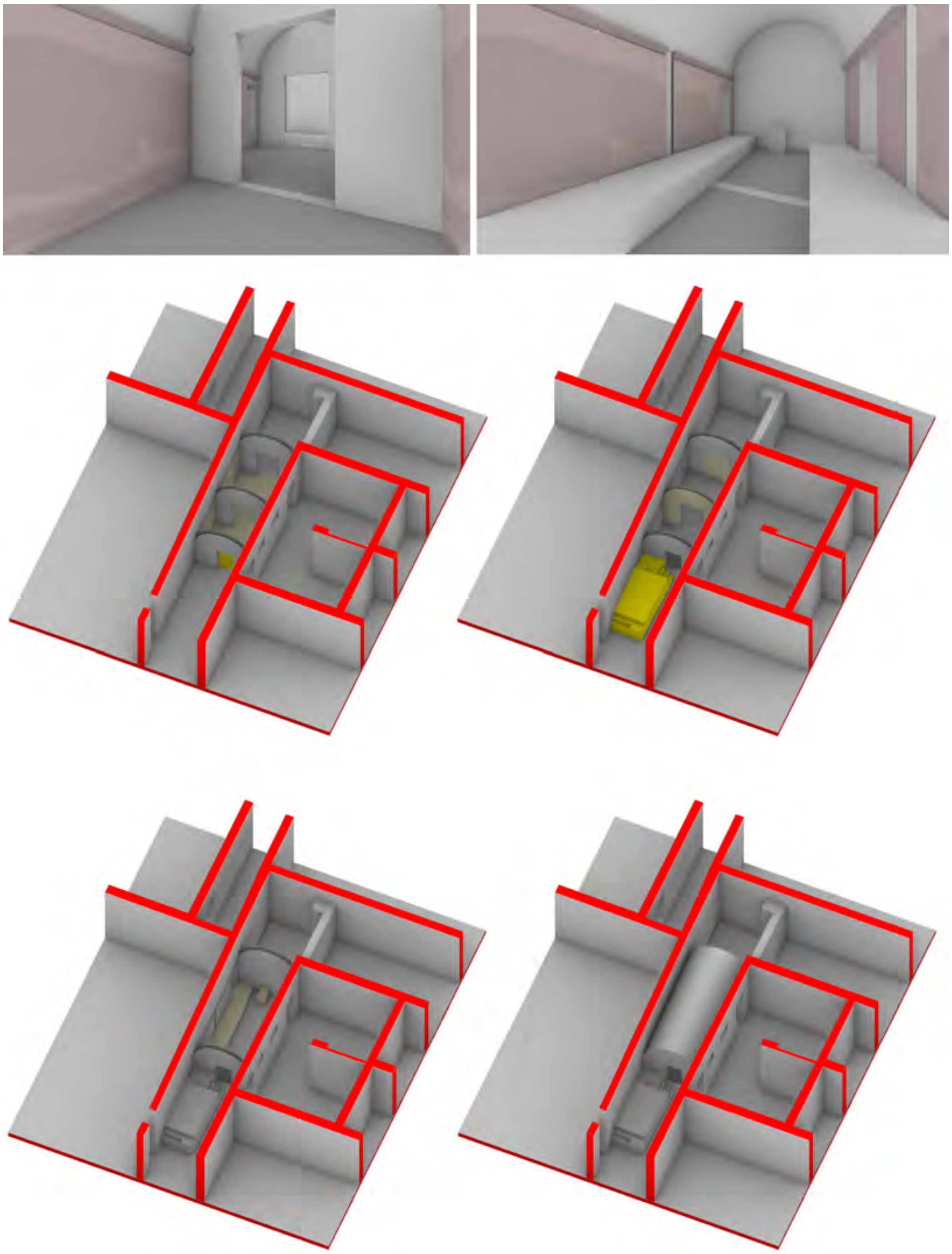

Fig. 2. Simplified 3D models of the case study showing the different phases of transformation of the Mithraeum space.

AR Application

Once the user enters the application, by framing a QR code located near the entrance, he or she can view the different phases that have characterized the Mithraeum on his or her own device, in total autonomy, comparing each time with the real space. Through an interaction with their device, the user can modify the quality of the model, passing from a simplified visualization characterized only by veiling, to the critical and reconstructive version with greater detail, able to guarantee a better understanding of the perceptive aspects [4]. At the same time, by clicking on the different tags present in the overall model, each user can access the scientific documentation that is the basis of the reconstruction, comparing reality in the

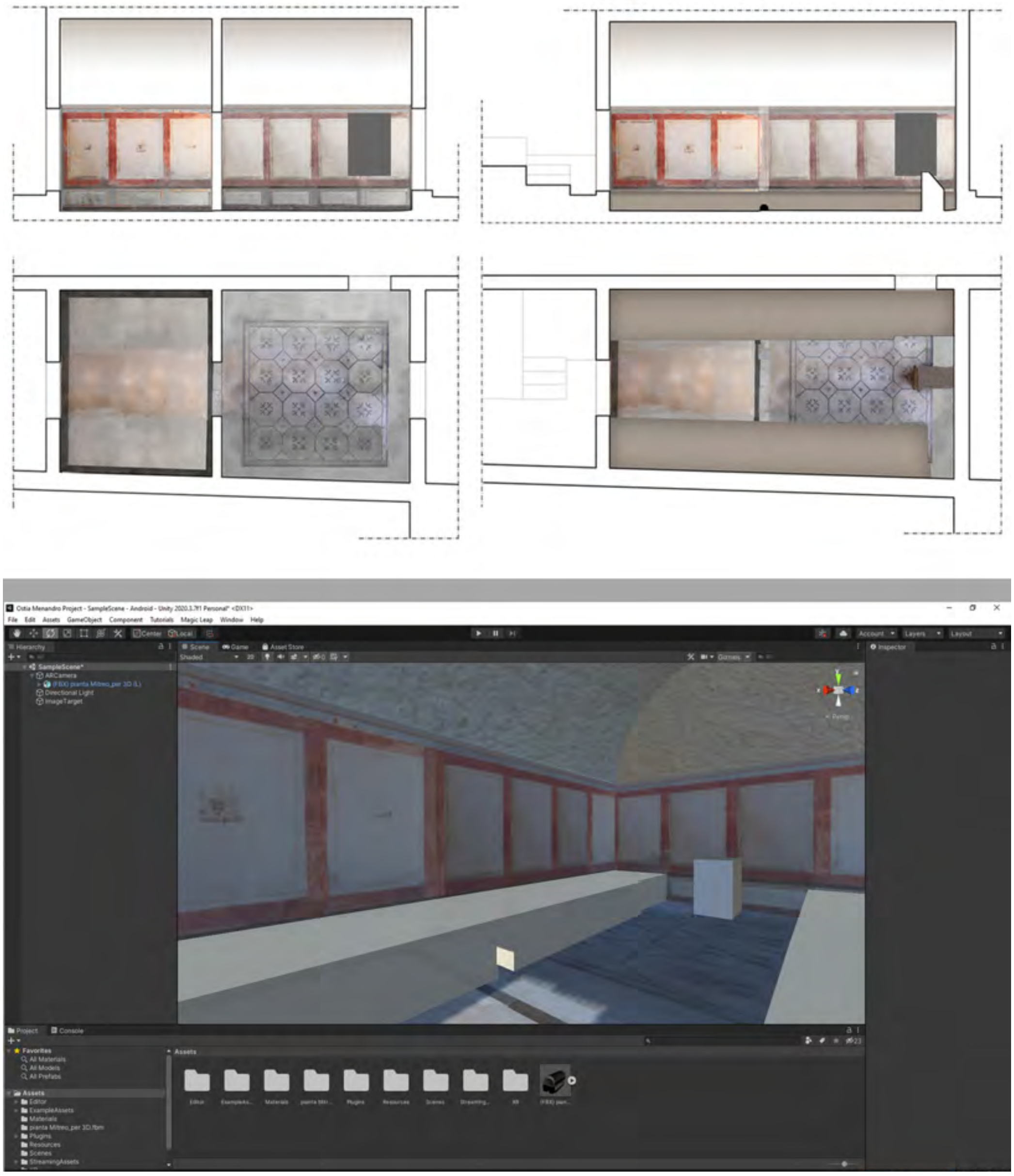

Fig. 3. At the top the reconstruction in plan and section of the two main phases of the transformation of the Mithraeum, complete with frescoes and mosaic decoration. At the bottom the insertion of the 3D model in the Unity software.

representation at different scales and for different purposes, integrating the visit in real time with supplementary information, archive images, with the "stories" hidden by the space and the decorative apparatus.

Conclusions

In the field of cultural and museum communication, storytelling has the specific aim of attracting the user with stories that make the cultural heritage, museum, archaeological monument or work of art attractive: telling a space through small stories, anecdotes, curiosities related to the works, are all strategic topics in cultural communication, allowing an emotional approach able to arouse interest in the public. For this very reason, it is equally important to understand which stories can be extrapolated to create emotional and empathic connections, drawing "unexpected meanings" from the details.
With this logic in mind, Digital Storytelling has been built to tell the story behind the archaeological remains, overcoming the physical limits of reality to offer the public a new way of

engaging with the case study. Although not yet tested in the field, the documentation work and the prototype phase of the application appear to have been completed and the AR application will soon be implemented within the visit route for Park users. This will enable a series of surveys to be carried out with the public, an essential action aimed at assessing the real effectiveness in terms of both involvement and understanding. It will therefore be the same user for whom the models were created that will provide a new key to interpreting the entire study, activating a process of circularity of knowledge: by defining the areas of improvement, the contribution of the users will make it possible to make the necessary adjustments to improve the quality and type of representation as well as the narrative aspects in a democratic and participatory process, so that we can really think about building an experience capable of giving new life to this important vestige of our past.

Notes

[1] The study was carried out with the support and valuable contribution of the Park's archaeologists and restorers. In particular, we would like to thank the Director of the Park, Dr. Alessandro D'Alessio, Dr. Claudia Tempesta, Dr. Alberto Tulli and the Restorer Antonella Docci, for the precious indications that have allowed the construction of the story told through the different elaborations.

[2] The documentation phase was carried out by means of an integrated multiscale survey using different technologies: Leica Tp 805 Total Station; Faro Focus 3D Laser Scanner; Full Frame Canon 6D MII digital camera. Once the topography of the study area had been defined, 27 laser scans were made for the architectural definition of the space, guaranteeing an accuracy of less than 1 cm. 1300 photographs were taken and used for Sfm applications dedicated to the study of details. In particular, the images allowed the construction of 3D models and high-resolution photoplans of frescoes and mosaic floors with an uncertainty of less than 1 cm, while for the engraving, a greater concentration of photographic shots allowed the construction of 3D models with an uncertainty of less than 0.5 mm. We would like to thank Prof. Leonardo Paris and the CRITEVAT Laboratory for providing the Laser Scanner used in the research.

[3] We refer in particular to the presence of frescos placed close to the podia and which were originally in continuity with those decorating the perimeter walls of the space, as well as to the lack of a roof capable of restoring the typical quality of space that characterised the places of worship dedicated to the God Mithras.

[4] Unity software was used for the augmented reality and subsequent reconstruction of the Mithraeum.

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Promotion of the Museum of Oriental Art in Turin by AR and Digital Fabrication: Lady Yang

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Abstract

A fundamental aspect of visiting museums is the involvement of visitors to facilitate the understanding of the collections on display [Black 2005, p. 7]: museums must therefore adopt techniques derived from the fields of relational and experiential marketing to improve the services offered.
This contribution focuses on an ongoing experience, conducted at the Museum of Oriental Art in Turin (MAO), which involves the use of augmented reality (AR) combined with digital fabrication, applied in the field of cultural accessibility and marketing.
In June 2021 the museum chose *Lady Yang* as artwork/mascot that would symbolically accompany the users in the visit path. It was decided to make this accompaniment tangible through digitally fabricated objects (a bookmark and a tactile replica) and an AR experience.
The contribution wants to show the research workflow, from the digital acquisition of the artwork up to AR experience and digital fabrication, in a continuous transition between real and virtual, to demonstrate how they are mutually enriching in the visiting experience and process of knowledge.

Keywords
AR, digital fabrication, replica, museums, promotion.

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Introduction

Advances in the technological field have become increasingly rapid in recent decades but it is undeniable that the current pandemic situation has produced significant changes in the field of content use: they have allowed, in many areas, to address the contingency by building new digital paths to access knowledge, culture, to promote and share.
In this panorama, museum institutions have undergone a radical transformation, subtended to take the museum itself outside its physical boundaries, making the collections usable through highly diversified digital modalities, guided by values of inclusivity. The trends already in place, oriented to the transformation of the museum experience through the overlapping of a digital experience to the physical experience, are now affected by a very significant phase of implementation, which will lead soon to an increasingly varied range of fruition modes.

Contemporary Museum Communication and Promotion

Before the Franceschini reform of 2014, museums in Italy had primarily been places where artworks were protected and preserved. The reform, stating that museums have to "talk with their public" offering real experiences of knowledge [Agostino et al. 2020, pp. 362-372], highlighted the importance of the educational and entertainment role of museum collections.
Marketing specialists theorize that in order to maximize visitor experiences and attract new audiences, a museum's communication strategies and engagement activities should focus on new technologies, creative events, and edutainment [Nechita 2014, pp. 269-278]. The increasing availability of digital technologies is making the promotion of museum collections more interactive, which greatly benefit from both acquisition techniques and promotion applications. Augmented reality (AR) is rightfully among these: it is recognized as one of the innovations that most engage users during their visit [Chung et al. 2015, pp. 588-599; Stogner 2014, pp. 11-21]. Thus, users are directed towards the complementarity between the real and the emerging digital (or virtual) universe.
The experience presented here starts from the consideration that "If there is one frustrating roadblock shared across the gamut of art lovers, it's the frustration over not being able to personally handle and explore a piece of art in a museum". In this sense, an interesting similar operation was carried out (2010) by the Getty museum with the Augsburg Display Cabinet. The museum proposed an AR web experience to overcome the constraints of a traditional gallery, where viewers can't touch the real cabinet. The virtual model of the 17th-century collector's cabinet is accessible in the gallery and on the Getty's website through an AR tag to generate excitement for what museums are all about: discovery and wonder [Hughes 2017, pp. 17-21].

The Museum of Oriental Art of Turin: State of the Art and Perspectives

The MAO is one of the most important and dynamic realities on the Italian scene as regards the valorization and diffusion of Asian art and culture.
The attention to digital communication of its heritage has always been present since its opening to the public at the end of 2008. It manages a dedicated website and has a YouTube channel and several social profiles: Facebook, Instagram, Flickr. Since October 2020, it has been participating in the new digital channel In Onda of Fondazione Torino Musei, designed to provide remote educational content and promote workshops for schools – not only remotely [Spallone et al. 2021, pp. 697-704].
The museum is totally visitable virtually via Street View by Google Arts and Culture. In June 2021, the Fondazione Torino Musei also launched a new app, created by La Consulta per la Valorizzazione dei Beni Artistici e Culturali, which can be downloaded for free and used to facilitate the usability of museums for different types of visitors, as well as increase the cultural and tourist attractiveness of the area. This new tool will provide various multimedia contents related to the three museums that are part of the Foundation (Palazzo Madama – Museo Civico d'Arte Antica, GAM – Galleria Civica

d'Arte Moderna e Contemporanea and MAO), to create new visiting itineraries, some of which can also be explored at home with a smartphone. The itineraries dedicated to Palazzo Madama are currently available; in the future, the project will also be developed for MAO and GAM [Fondazione Torino Musei 2021]. This tool will thus redress the current lack of multimedia in the visit to the permanent collections of the MAO: at the moment, only the classic audio guides in Italian and English with numerical selection are available.
The experience presented here is developed within the agreement between the Politecnico di Torino – Department of architecture and design and the MAO – Museum of Oriental Art.
The project has seen the involvement of different figures, bringing together the knowledge of representation and information processing systems with the historical, artistic, archaeological and museographic skills and cultural marketing to test new ways of communication and fruition of heritage. It represents at the same time an increase of the proposals usable in situ and remotely and the first step towards a more digital and more accessible/inclusive MAO.
This contribution focuses on an ongoing experience that combines the use of AR and digital fabrication, applied in the field of cultural marketing. Specifically, in July 2021, the *Abbonamento Musei* (Museums Subscriptions) association launched the initiative *L'arte con chi ne parte* (art with those who are part of it), for which MAO chose a work from its collection to be the mascot accompanying visits to the museum. The choice fell on the *Dancing Lady* from the Chinese collection, nicknamed *Lady Yang* for this occasion.
For this reason, it was decided to create a tactile replica of it in scale 1:1 to be exhibited at the entrance to the museum with an information panel in Italian, English, and Braille, with relief images. An interactive bookmark, depicting *Lady Yang*, completes the project. The visitors can obtain it by donating an up-to-you amount to finance the larger project *MAO for all* which aims to create accessible exhibition paths. In this way, in addition to the memory of the visit, they will have the opportunity to appreciate the digital replica of *Lady Yang* at any other time and place.

The Work Methodology

The work presented here complements the broader work that is the subject of Francesca Ronco's doctoral thesis (*Arquitectura, Edificación, Urbanística y Paisaje program of the Universidad Politècnica de València*), which involves the development of a management model aimed at the creation of inclusive, multisensory and modular itineraries, including multi-sensory experiences *in situ* (tactile paths and AR experiences) and online (VR proposals) [Ronco 2021, pp. 49-61].

Fig. 1. Lady Yang sculpture: the photogrammetric survey (photo by S. Tamantini).

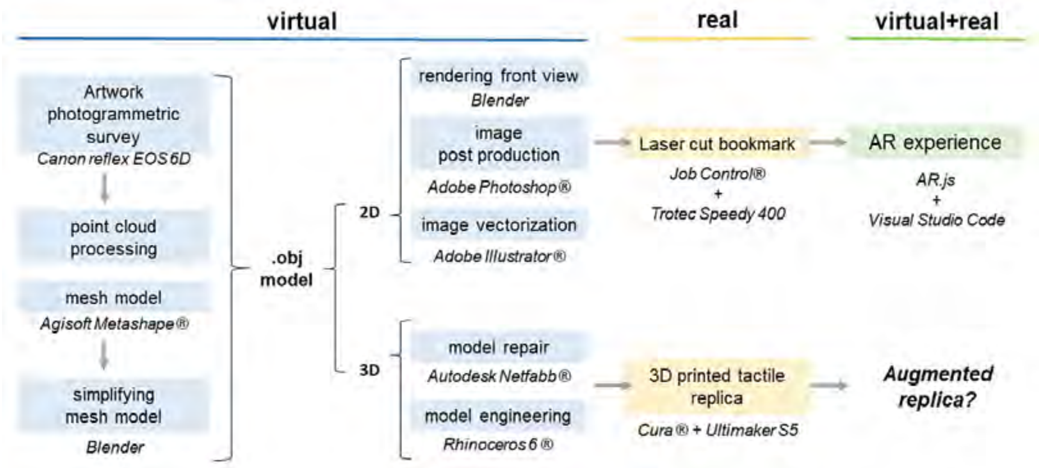

Fig. 2. The workflow.

Lady Yang is one of five MAO artworks (one from each geographic area) selected to test this model (Fig. 1).
The acquisition of the work takes place through a photogrammetric survey that provided the metric reference data, followed by the restitution of the virtual model of the same, from which it is possible to obtain different two-dimensional and three-dimensional outputs, real and virtual.
In the case analyzed here, the survey was performed with a Canon EOS 6D SLR from which an .obj model was obtained through Agisoft Metashape®, simplified with Blender.
The real outputs are represented by the bookmark (printed by laser cut on cardboard) and the tactile 3D replica of the work (3D printed with the Fused Deposition Modelling technique), while the digital output is an AR experience based on the AR.js system, that is a library in javascript language that needs only a web page to work. AR.js allows to develop AR functions with different anchoring and tracking systems, including image targets, two-dimensional matrix codes, and location-based systems (Fig. 2).

The Use of Digital Fabrication

The project involves the use of two different digital manufacturing techniques: laser cutting for the bookmark and 3D printing for the tactile replica. Since this is a launch proposal, we tried to contain production costs, so the realization of these two products will be managed exclusively within the MODLab Arch. of the Department of Architecture and Design of the Politecnico di Torino.
The bookmark represents at the same time a promotional object, but also a souvenir for the visitor. This double function is carried out by the object itself and by the AR experience that is activated by framing a code on it. In this way, the user can take the work outside the museum and enjoy it anywhere.
It, therefore, contains a frontal view of the artwork, a QR code, an AR tag, the logos of the partners (MAO and Politecnico di Torino) and an instructional text for the activation of the virtual contents.
The used laser-cut printer (Trotec 400, located in the MODLab Arch.) performs for this project all three possible processes: cutting (cyan), half-cutting (red) and raster engraving (black) (Fig. 3a).
The frontal view was obtained from the model acquired by photogrammetry, through an operation of rendering and subsequent vectorization of the black and white version.
A first debated topic has been the choice of the material. Plexiglass and cardboard were initially evaluated, but for reasons of perceptibility of the image, thickness and physical characteristics, Plexiglass was discarded. It was therefore decided to use 700gr colored cardboard in three colors (coffee, blue and raspberry) by the Fedrigoni company that kindly donated the material (Fig. 3b). The choice of colors was not random; particularly intense one were chosen that, on the one hand, were in line with the museum's graphics and with the aesthetics of *Lady Yang* and, on the other hand, were appropriate for the printing process. Specifically, attention was paid to the fact that with the raster engraving process of the laser printer, the lightest areas

would emerge, corresponding to the color of the cardboard pulp. In this way it was possible to ensure a high contrast that allows one to better perceive the various contents listed above, but especially the image of the work and the AR tag. In this regard, it was necessary to invert the whites and blacks, since from the point of view of production (raster engraving) the black areas represent those in which the machine removes the material, and which will therefore be the clearest when the work is finished.
Several hypotheses of AR tags were also examined that were consistent from a graphic point of view and that guaranteed sufficient stability to the visualization of the virtual model: finally, the one with *Lady Yang*'s initials was chosen, realized with the font used in the launch campaign of the initiative.
The other digitally manufactured product will be the 1:1 scale replica of *Lady Yang*, whose purpose, in addition to the promotional one, is to allow a tactile enjoyment of the work, making the launch of the broader project *MAO for all*.
The artwork is 49 cm height and the first theme addressed within the team was that of the scale. Initially, for visibility issues, the idea of making the replica in 2:1 scale was considered. This idea was then discarded in favor of the 1:1 scale, taking into consideration, among others, the manual of relief drawing [Levi, Rolli 1994, pp. 31-52] from which it is possible to extrapolate indications that, although referring to two-dimensional representations, can be applied to three-dimensional objects. One of the principles contained in this book is that of allowing the reader/user an easy 'vision' of the whole figure based on the simultaneous use of two hands. It should also be considered that the smaller the figure, the more easily it can be perceived.

Fig. 3. The bookmark: a) design; b) realization with laser printer (raspberry and coffee colours) (by F. Ronco).

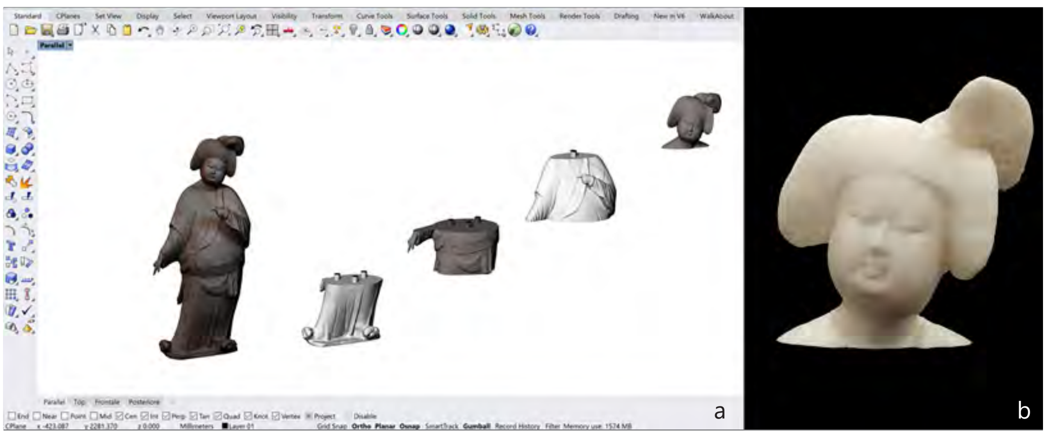

Fig. 4. a) Virtual model subdivision in Rhinoceros®; b) 3D printed head (by F. Ronco).

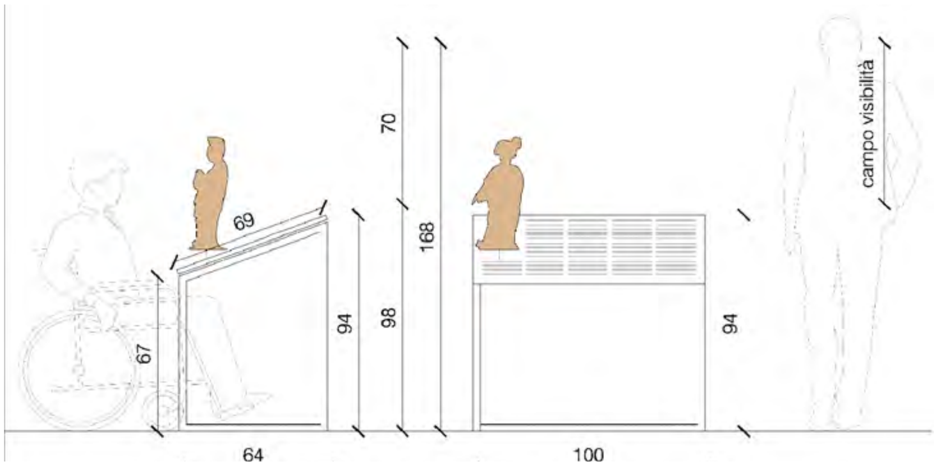

Fig. 5. Exposition hypothesis: 3D printed replica and tactile panel (design by F.Ronco).

The replica will be realized for parts, because of the dimensional constraints of the printer used (Ultimaker S5), each of which will be equipped with male-female joints to facilitate the correct assembly. The virtual model has been subdivided into four portions with the software Meshmixer and imported into Rhinoceros® for the modelling of the joints (Fig. 4a). The next step is to pass from Cura software® for slicing operations and the 3D printing (Fig. 4b).
The material used is PLA, the coloring is still being defined. At the moment the portion of the face was printed with the following parameters: 0.4 mm nozzle, fine detail level 0.15mm and 15% of filling. The realization time was 1 day, 4 hours and 12 minutes, using 213 gr of white pearl filament. The work will be accompanied by an explanatory panel containing texts in Italian, English and Braille, as well as some relief drawings (Fig. 5). They will presumably be placed at the main entrance of the MAO, in the seventeenth-century atrium of Palazzo Mazzonis.

The AR Experience: the Pilot Project

Along with virtual reality and the other nuances of immersive technology (the so-called reality-virtuality continuum [Milgram, Kishino 1994, pp. 1321-1329]), AR has been extensively studied over the past 20 years as an enabling technology for CH [Bekele et al. 2018, pp. 7:1-7:36]. AR can make the consultation of spatial information more intuitive than the typical on-screen display of three-dimensional models by superimposing digital layers on images of the real world [Amin, Govilkar 2015, pp. 11-26]. By tracking the user's position with respect to the surrounding environment (or a portion of it, such as a suitable small target), an AR system can generate images of virtual objects in physical space. In the field of CH, these tools have shown benefits for professionals in accessing, comparing and understanding space-related information about artifacts, and advantages in the development of compelling forms of storytelling aimed at visitors [Bekele et al. 2018, pp. 7:1-7:36; Luigini 2019, pp. 3-12].
The developed application is a study case to propose these emerging technologies to the museum visitors. The user-friendly and immediate solution allows recalling the museum experience and connected knowledge, even remotely. The AR application was developed through the AR.js library for the Javascript programming language [Shepiliev et al. 2020, pp. 84-93; AR.js Org Community 2022]. AR.js is a web-based system allowing AR development through different anchoring and tracking systems. These include image targets, two-dimensional matrix codes, and location-based systems. The project is free and open-source (FOSS) and supports fast prototyping and deployment of simple AR applications.
Producing a physical marker rather than markerless systems is a deliberated design choice. On the one hand, this solution is compatible with the lightweight web app system employed. On the other hand, we intended to design a tangible memento of the museum visit as a means to access digital information. We chose a class of matrix targets that features custom image integration ("pattern marker"). The image is interpreted as a small-sized matrix of grayscale values; there-

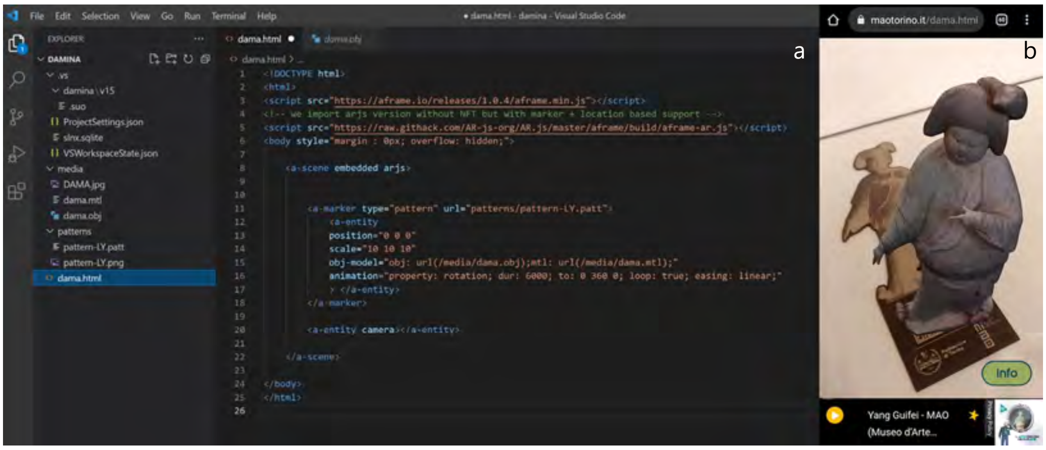

Fig. 6. a) AR.js scripting (by V. Palma);
b) screenshot of AR experience on bookmark.

fore, the selection of a high-contrast image is significant for its recognition. This type of marker is more customizable than barcode-like markers, but provides very stable tracking, supports the production of small targets, and is less CPU consuming than image targets.
The main advantage is that the web app can be reached simply by a link, without the need for registration, download, and installation processes. The app is lightweight, cross-browser, cross-platform, and is thus compatible with a wide range of mobile devices. In addition, new development and production versions can quickly be tested (even with just a local server) and updated. The distribution depends on the availability of a public server, although several free hosting services are available. The project is supported by good documentation and an active community. Being based on well-known technologies such as Javascript, HTML, and CSS, the development of basic AR.js programs does not require long learning times and allows you to easily integrate functions (buttons, links, and media embedding). In our case, the .html script (Fig. 6a) has been uploaded on the MAO's server website. Through a QR code we provided a link to an informative page about the project and the museum. It includes an audio player with the description of the artwork.
The main AR function can be activated by framing the target printed on the bookmark (sized 15x15mm). When the pattern is recognized, the app presents the model of *Lady Yang*. The model, in OBJ format, was reduced to a disk size of about 40MB (polygons and texture) to speed up page loading and foster smooth rendering. A detailed material texture (4096x4096 pixels), obtained through texture baking, balances the reduction in the geometric detail. The model is perpendicular to the target and is rendered at a 1:4 scale, making the displayed statue approximately 12 cm tall (Fig. 6b). The reduction in scale and the relative position of the target and the model allows the user to effortlessly frame the statue on the screen of a small mobile device, just placing the bookmark on a horizontal surface.
The main limitations of a web app concern the variety and complexity of functions. The anchoring modes are limited, e.g., they do not include plane recognition or markerless anchoring functions. Extended tracking, that is, the possibility of maintaining the relationship between model and real space by tracking the user's position is not available. Therefore, the two-dimensional targets must remain framed for the entire duration of the experience (except for the location-based option).

Conclusion

The research experience presented here constitutes a piece of a much broader panorama of activities, which involves the Politecnico di Torino – Department of architecture and design and MAO in the supervision of degree theses, educational workshop activities (currently being planned), and diversified research activities oriented towards the promotion of the museum and the construction of an inclusive offer .The final phases of the project presented here are currently being revised and upgraded, also concerning some changes regarding the distribution of spaces and functions in the museum's entrance hall.

The initial idea of displaying the tactile replica of *Lady Yang* at the entrance of the museum could be replaced by a stand for the promotion and dissemination of the research activity through which it is possible to share the whole experience with the museum public: the 3D printing of the replica could be live carried out, using a 3D printer that allows the use of natural materials (e.g. *terracotta*) to communicate the tactile characteristics (roughness, temperature, reflection, etc.), and not, of the materials and relate the work of art with the phases of processing that characterize its creation.

Credits

This paper, whose authors shared the methodological framework, was written by Marco Vitali (par. Intro, Contemporary Museums) Francesca Ronco (par. Museum of Oriental Art, Methodology, Digital Fabrication), Valerio Palma (par. AR Experience).

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AR&AI
Building Information Modeling and Monitoring

Reliability in HBIM-XR for Built Heritage Preservation and Communication Purposes

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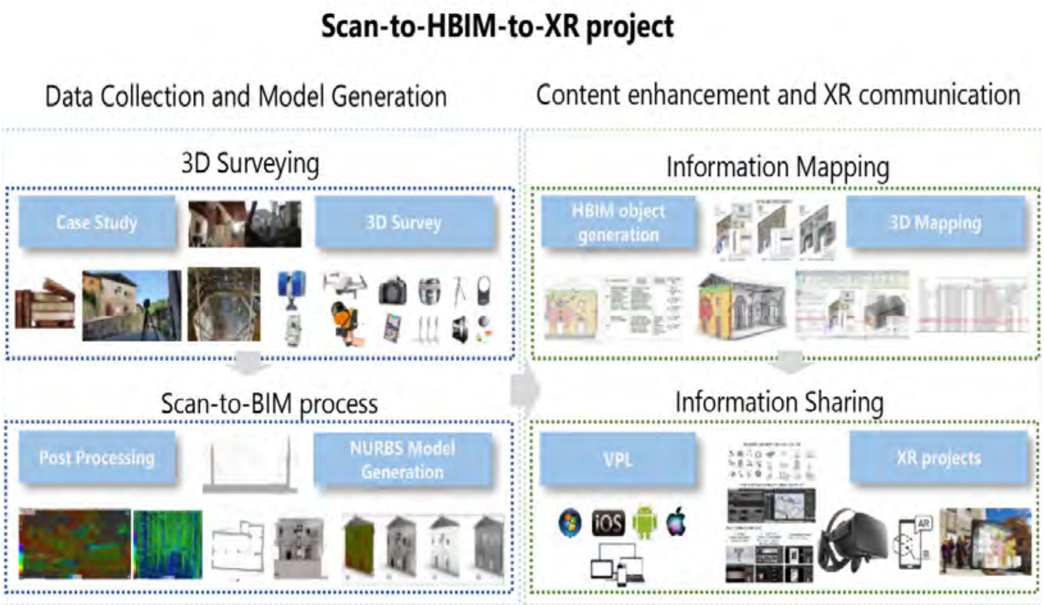
Chiara Stanga

Abstract

In recent years, applied research and building information modelling (BIM) have been directed to the scan-to-BIM process by implementing increasingly high-performance methods capable of managing a large amount of data such as laser scans and high-resolution orthophotos and textured mesh models from digital photogrammetry (terrestrial and aerial). On the other hand, the digitisation process of built heritage and the paradigms of the "reliability" and "transparency" of HBIM models have not yet been wholly considered by the main international BIM standards. For that reason, this study proposes a method and the development of HBIM parameters capable of communicating heterogeneous values to support the life cycle of the building, from the survey campaign to the restoration and maintenance of the asset. In this context, 3D modelling, HBIM, building archaeology, visual programming language (VPL) and extended reality (XR) have been directed to a scan-to-HBIM-to-XR method able to improve the information sharing of earthquake-damaged buildings such as the San Francesco church in Arquata del Tronto, moving from for different types of users, digital devices and virtual experiences.

Keywords
HBIM, XR, reliability, built heritage, VPL.



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Introduction

In recent years, the "digital revolution", technological developments and applied research in the Architecture, Engineering and Construction (AEC) industry are increasingly directing professionals update themself in their daily practices, exponentially changing the design and management of the building, from the first design phase to construction and management over time. We have seen how design and architectural representation have evolved in the last decades: from the advent of CAD vector drawings to the more complex forms of 3D digital modelling and BIM projects. In addition, we are already seeing how BIM, BIMcloud and InfraBIM are evolving into increasingly interactive and immersive forms such as digital twins. Thanks to the integration between models and sensors, it is possible to manage and monitor building behaviour. Furthermore, thanks to eXtended Reality (XR), we can give life to objects with visual programming language (VPL) and artificial intelligence (AI) and investigate new forms of "digital proxemics" and digital communication [Gironacci 2020, pp. 105-118; Ioannides et al. 2017]. Moreover, software manufacturers are progressively changing and improving the software interface to define the market in support of existing buildings and not only the new ones. In this context, various projects have demonstrated how the integration between 3D survey and digital modelling can support the scan-to-BIM process and more advanced forms of informative models oriented to preserving built heritage. On the other hand, the creation process of historic building information modelling (HBIM) models requires in-depth knowledge in many disciplines and different digital tools to go beyond the simple creation of geometric representation. Professionals need high digital skills such as computer graphics, computer programming, digital representation, restoration and archaeology. In this context, the paradigms of "reliability" and "transparency" of HBIM models are values to be shared appropriately to all professionals (and non-professionals) involved in the building preservation process and the subsequent forms of communication associated with it. Consequently, this research has tried to improve what is now called the scan-to-BIM-to-XR process aimed at heritage buildings that require a completely different approach to modern buildings, trying to improve the metric, geometric and informative reliability of digital models for preservation and communication purposes. Several tests related to the quality of the modelling process (i), the interoperability of the 3D exchange formats (ii), real-time synchronisation among the various software applications (iii) and human-computer interaction (iv) were conducted to give life to HBIM objects and interactive virtual objects (IVOs) of San Francesco church in Arquata del Tronto (Italy) damaged by the earthquake in 2016 (Figs. 1-2). The case study has allowed the authors to investigate and define a research method capable of increasing the communicative value of the digital model for different types of users, from experts in the construction sector to virtual tourists and students.

Fig. 1. San Francesco Church before and after the 2016 earthquake.

Fig. 2. 3D surveying campaigns and construction scaffolding as a temporary structure for support safety in the construction site.

The Case Study: San Francesco Church's Historical and Cultural Background

Arquata del Tronto was struck by the earthquake that hit Central Italy in 2016. The seismic sequence began in August 2016 with epicentres located between the upper Tronto valley, the Sibillini Mountains, the Laga Mountains and the Alto Aterno Mountains. Norcia and Arquata del Tronto suffered considerable damages, while Amatrice and Accumuli were almost razed. The loss of human life was relevant, togheter with the destruction of cultural heritage, such as the church of San Francesco in Arquata [Gailè, Vecchioni 2006].
Arquata del Tronto has always been on edge between territories with different cultural, administrative and economic backgrounds, on the western side of Regione Marche, which borders Lazio and Umbria. Arquata is enclosed within two protected natural areas: on the north, the Sibillini National Park, and on the south the Gran Sasso and Monti della Laga National Park. It was founded on a few mountain passes that provided an easy route from the Adriatic Sea to Rome through the ancient via Salaria. The strategic and military importance of Arquata arose around the 13th, with the fight for hegemony between Ascoli and Norcia, traces of which remain in the construction of the Stronghold on the top of the hill, overlooking the town. In this framework, the convent and church of San Francesco were founded. One Franciscan settlement is attested in 1251, although a church of the Minors is mentioned only 40 years later. The scarcity of information, mainly due to the dispersion of the archive, does not help reconstruct the history of the convent of San Francesco [Ciociola, Castelli 2010].
However, thanks to a careful study of the church – whose external walls are not plastered – building archaeology analysis, together with the study of documents, it is possible to make some assumptions about its construction phases. First, a small church was built and transformed with a single hall, without side chapels, a square choir around the 14th century. Then, a second nave was added between the 16th and the first half of the 17th century. The 20th-century restorations introduced concrete beams on the top of the wall and replaced the roof. The church stands on one of the fourth aisles of the convent, on the south, which is arranged around a courtyard.
The August 2016 earthquake caused slight damage to the church, which was still accessible. The most significant damages occurred during the second shock in October 2016 and the heavy snowfall in January 2017, which caused the roof collapse, the wooden carved ceiling, and, partly, the walls [Giallini et al. 2020].The safety measures involved reinforcing the walls with hydraulic lime mortar and strips of galvanised steel or basalt fibre mesh (main façade). Inside, a metal profile structure was built to support the arches and scaffoldings, which made the laser scanning survey challenging (Fig. 2). In 2019 the Municipality of Arquata del Tronto tasked the research group of the Politecnico di Milano

to draw the preliminary design project of San Francesco Church. It included the creation of an HBIM oriented to geometrical, material and historical analysis and a VR project. The same project encloses the study of the Stronghold of Arquata. The preservation plan of the Church and the Stronghold is part of a broader vision that includes the rebirth of the communities devastated by the earthquake that has severely affected Central Italy in 2016. Although the community of Arquata was deeply unsettled by the seismic event, which caused the abandonment of the houses in the historic centre and the construction of temporary houses, just outside the town, the church of San Francesco represents a landmark for the citizens, where intangible values are kept.

The Paradigm of Complexity in Digital Architectural Representation for Heritage Buildings: the Reliability and Transparency of HBIM Objects for Preservation and Communication Purposes

The paradigm shift from 2D CAD drawings to BIM has already overtaken the experimental phase with guidelines to standardise the 3D model generation. The AEC sector had to adapt to the new technological developments and methods. Guidelines are set both on a national level (i.e. the well-known NBS) or an intermediate level, i.e. the one set in 2012 by Bloomberg, Burney and Resnick of the Department of Design and Construction in New York City.

At the same time, BIM uses were affected by the companies' needs and ranged from the design to the construction site phase. In the last decades, the interoperability among different software became of primary importance due to the necessity to integrate point clouds (coming from terrestrial and aerial surveys), photogrammetry and historical documentation within the 3D modelling process, overcoming the logic of preset libraries of objects which do not adapt to the existing buildings. When dealing with historic buildings, the Level of Development and the Level of Detail (LOD) go into crisis, and the complexity of shapes and information turns out.

The uniqueness of the 3D architectural objects often requires modelling each element avoiding "copy and paste" operations. This involves a not easily interoperability among as-found, as-designed and as-built models and requires the knowledge of different types of 3D exchange formats. The difficulty also lies in the information associated with the objects, which sometimes are only based on assumptions, and may change, i.e. wall stratigraphy or the properties of the materials can be unknown, or historical hypotheses or interpretations

The paradigm of complexity in the HBIM domain refers to the shape, geometry, and physical features of objects and the information and values associated with them.

The last few years have been characterised by many HBIM projects and methods capable of managing the paradigm of the complexity of historical buildings and archaeological sites in an appropriate way, extending the concept of BIM to that of heritage (HBIM). HBIM projects have been improved by integrating different technologies such as 3D surveying, laser scanning, digital photogrammetry (terrestrial and aerial), and advanced modelling techniques [Russo, Manferdini 2015]. Furthermore, it was found that the understanding and interpretation of each artefact detected from a typological point of view is fundamental in the first model generation phase.

The need to increase the LOD and LOI (Level of Information) of HBIM models was consequently directly proportional to its decomposition into sub-elements capable of representing semantic structures, not necessarily dictated exclusively by the geometry or constructive logic of the building. The determination of intelligent parametric objects and the bidirectional relationships that they establish are fundamental for the subsequent phases of mapping information and sharing complex scenarios such as archaeological sites, earthquake buildings, and historical infrastructures. Accordingly, in a more general and holistic context, it is essential to update one's knowledge constantly and skills not only at a digital level, trying to reach a level of autonomous management of these technologies, digital tools, and methods.

The Digitisation Process: from 3D Surveying to HBIM Objects

In Italy, the reliability of a 3D model is mainly associated with the UNI 11337-4: 2017. The UNI describes the terminological distinction between LOD, LOG, and LOI. LOD (Level of Development of digital objects) comprised LOG (Level of development of objects – Geometric attributes) and LOD (Level of Development of objects – information attributes). Thus, we can find two main levels of reliability: on one hand, the geometrical and physical characteristics of each architectural object, on the other, the information associated with them. Transparency may be referred to the communication of the precision and accuracy of the model and related information. However, the LOD works mainly for new buildings, while it does not always easily apply to existing or heritage buildings. Many studies have shown that heritage objects do not fit with the BIM objects libraries due to their uniqueness. This is even more true in the case of archaeological sites, ruins, building damaged by natural disasters, such as the San Francesco church. Moreover, when dealing with complex shapes (i.e. damaged or out-of-plumb walls) the geometrical reliability of the 3D object often depends on the modeller. Sometimes, the LOD is defined without feasible rules – not acceptable for the historical objects – or adopted with no reference to the required representation scale. Thus, the "reliability" of the model should not only be based on the LOD concept and the main international guidelines of LODs should be oriented towards historic buildings, defining new scan-to-BIM parameters which accurately describe the quality of the model and its reliability in both metric-geometric and semantic terms. The 3D survey of the church was carried out in two survey campaigns. In the first one, 65 scans were acquired with Faro Focus 3D laser scanner, based on a geodetic network to allow a strong reference for the alignment. Multiple connections between inside and outside stations were established to guarantee a good redundancy of the network. The network was measured with Leica TPS1200 total station and a final least-squares adjustment provided an average precision of ±2.0 mm. The scans' final registration (Faro SCENE 6.2.30) provided an average precision of the target of ±4.5 mm (Fig. 3). During the second survey campaign, the data were integrated with the dataset acquired with a handheld Mobile Mapping System (MMS) to complete the external pathways of the convent. Then, UAV was used to get the dataset of the whole area.The 2D as-built CAD drawings refer to the main plans, overlapping plans, two sections, and internal and external facades. These first drawings were the basis for the first draft of the preservation plan, which included the material and construction technique analysis and damage assessment [Doglioni 1997]. Then, a Building Archaeology of the façade was carried out to understand the historical traces and transformation of the building. The HBIM was realised following the specific scan-to-BIM requirement based on Non Uniform Rational Basis-Splines (NURBS) algorithms to capture each architectural object's geometrical and semantic complexity [Banfi 2020]. The building archaeology analysis was transferred into the HBIM, trying to cope with the complexity of a historical building damaged by the earthquake. An auto-

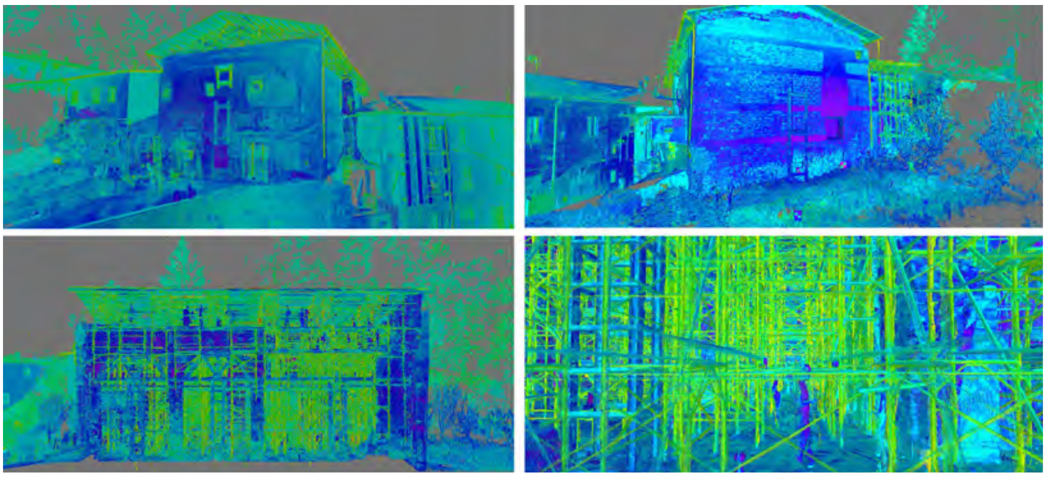

Fig. 3. 3D scans of the Church.

matic verification system (AVS) based on the standard deviation value between the 3D scan and digital model was used to verify the geometric and metric reliability of each architectural and structural element of the church. This approach made it possible to communicate the quality of HBIM objects created in geometrical-metric terms to the client (Municipality of Arquata) and the professionals involved in the building restoration process. Consequently, the HBIM parameters for each single modelled element have been developed to share the grade of accuracy (GOA), the source data used to model the elements, and data type (laser scanning, terrestrial/aerial photogrammetry, historical records). At the same time, the communication of specific information relating to each single modelled element ensured the "transparency" of intrinsic parameters of each data source used. The analysis that results from building archaeology is derived from integrating direct sources with indirect ones. In architectural research, common direct sources are geometrical surveys, on-site inspections, and material/decay analysis. All of these give first-hand information about a building. Indirect sources are reconstructions from primary and/or other indirect sources, such as reports and interpretations. Building archaeology resulted in a stratigraphic units (SU) subdivision of the walls differentiated according to the different construction techniques and stratigraphic relationships [Boato, Pittaluga 2000]. The HBIM of the church was then realised with the different SU so that each wall layer has its consistency and properties. HBIM properties were added regarding materials, observation and documentation for each SU, trying to transmit even the hypothesis (about construction phases or materials) and the source's reliability (if the information derived from observation or archival documents,…). For those reasons, building archaeology is used to represent the geometric and semantic complexity of the San Francesco church. The communication of these values will allow the professionals involved in the church restoration process to view the data used and the level of knowledge reached for each HBIM object (Fig. 4).

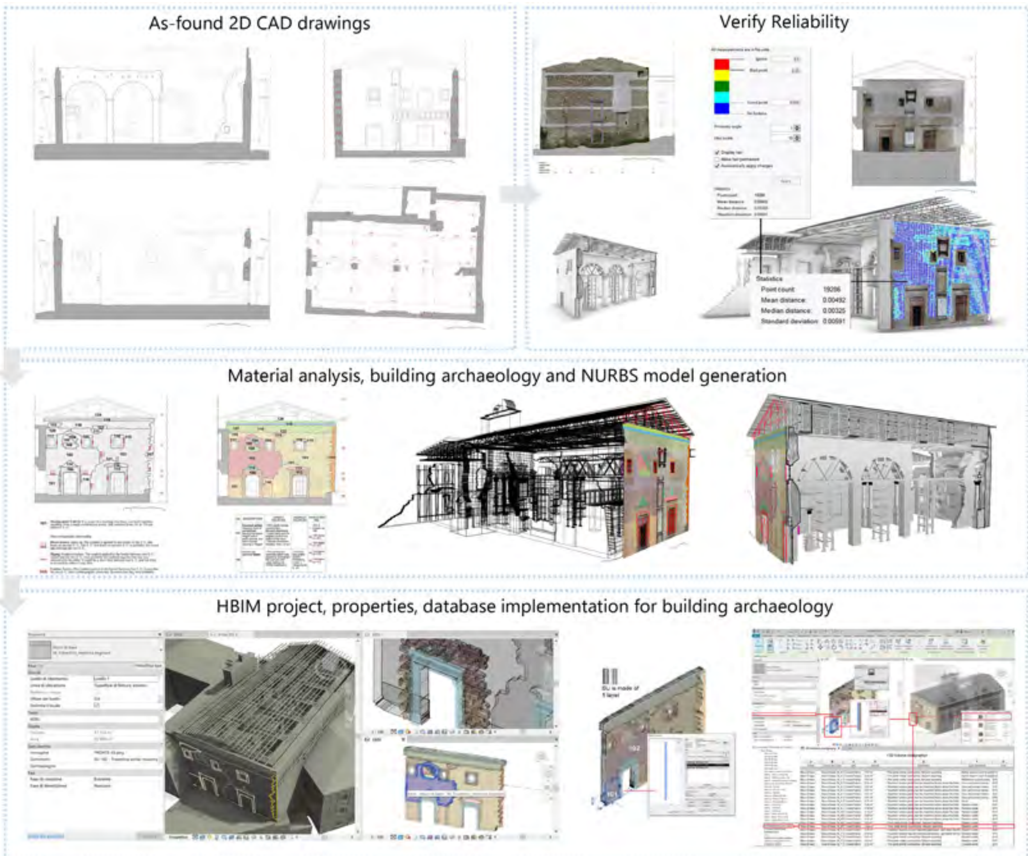

Fig. 4. From 2D CAD drawings and building archaeology to NURBS model, HBIM objects and properties.

Improving Communication Using XR Development Platforms: from Visual Programming Language (VPL) to Real-Time Immersive Architectural Experiences

Once the model was created and verified in reliability terms, the authors improved the flow of information associated with the HBIM objects created using XR development platforms. The ultimate goal was to reach a broader range, moving from professionals involved to virtual users who did not have specific digital skills. The VPL and XR development platforms have proved useful in increasing the communication of the church's historical and cultural background, the survey process, and preliminary information to virtual users. Given the objectives set, the authors opted to define a process capable of synchronising the building's HBIM model in real-time with the latest generation immersive environments without having to resume the orientation and adaptation phase of the model. Thanks to recent developments in the field of gaming development, it has been possible to use specific add-ins (developed by Epic games) able to synchronise in a single software flow such as Mc Neel Rhinoceros (oriented to geometric modelling), Autodesk Revit (used to create HBIM models) with Twinmotion and Unreal Engine 4 platforms, the latter able to associate the VPL with 3D objects. The transition between modelling environments and XR development platforms also made it possible to avoid a second phase of 3D mapping, using orthophotos and HD images from digital photogrammetry. The final step was to associate key blueprints (visual scripting by unreal Engine) to the various objects created in Rhino and then in Revit, passing from static entities to interactive virtual objects (IVOs). Once the development phase (VPL and HBIM objects) was completed, it was possible to use the platform's packaging functions to create specific apps oriented to VR and AR devices (Fig. 5).The VR project of the church envisaged the definition of virtual visual storytelling (VVS) capable of providing a virtual experience to the end-user. As is well known, a VR project requires three elements: content, geometry and dynamics. Objects and information associated with the environment define the content. Instead, the geometry indicates the physical extension that the user wants to attribute to the digital environment. Finally, the dynamics refer to interaction rules between the contents and the environment. By interpolating these three elements, a virtual environment is created, meeting the definition of a "real illusion" in which one or more users can interact with it through the use of specific devices (PC workstation, laptop, VR headset, tablet or mobile phone). In this context, the most exploited sense of the human body is sight, which is stimulated by factors that lead to an optimal configuration of virtual environments with high

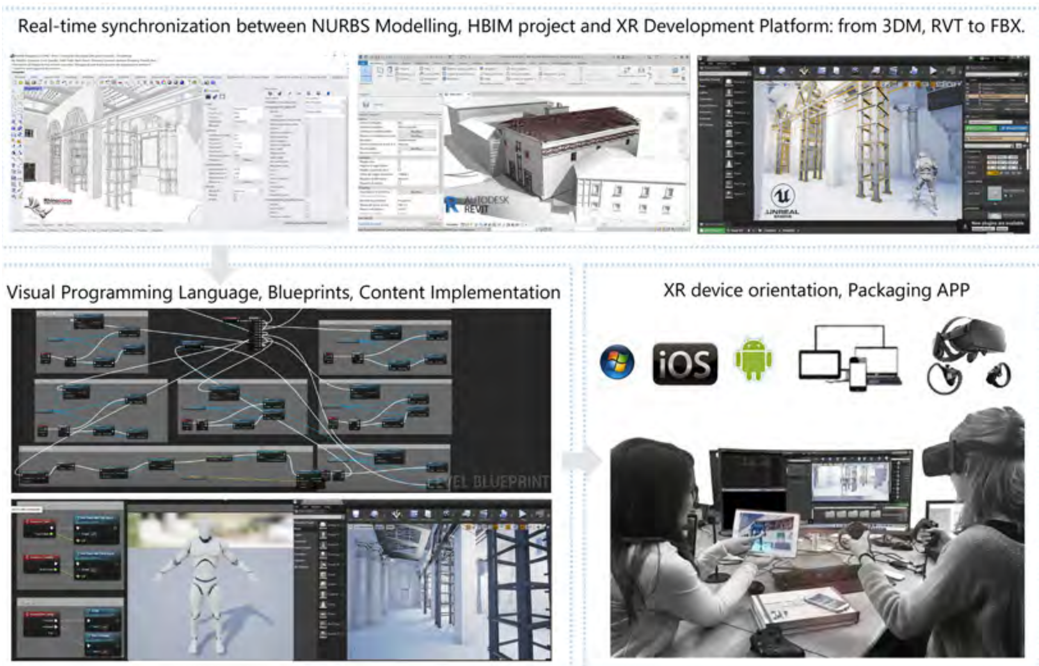

Fig. 5. From real-time synchronisation models to Visual Programming Language and XR devices.

visual quality. The research objective was to create an exclusively digital environment built to induce the user to experience sensations, emotions, and discoveries, consciously decided by the programmer who decides to make specific experiences three-dimensional and dynamic.

Conclusion

This research aimed at optimising a scan-to-HBIM-to-XR process that defines digital parameters to declare the quality of the informative models created in metric and semantic terms. The paradigms of reliability and transparency of the models are discussed and developed through the case study of San Francesco Church in Arquata del Tronto, where the building archaeology allows the authors to go beyond a pre-established semantic decomposition for architectural and structural elements. Different modelling approaches have been reported that show how the generations of stratigraphic units, identification of materials, construction techniques, historical phases can become real BIM parameters and shared to all users involved in the preservation process. Furthermore, thanks to new programming languages such as blueprints it has been possible to go beyond the static representation of digitised elements. The process, as demonstrated, allowed authors to pass from textured meshes and NURBS and HBIM models and manage interactive virtual objects (IVOs), thus allowing the possibility to increase the level of interactivity and immersion of accurate scan-to-HBIM projects.

Notes

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Data Structure for Cultural Heritage. Paintings from BIM to Social Media AR

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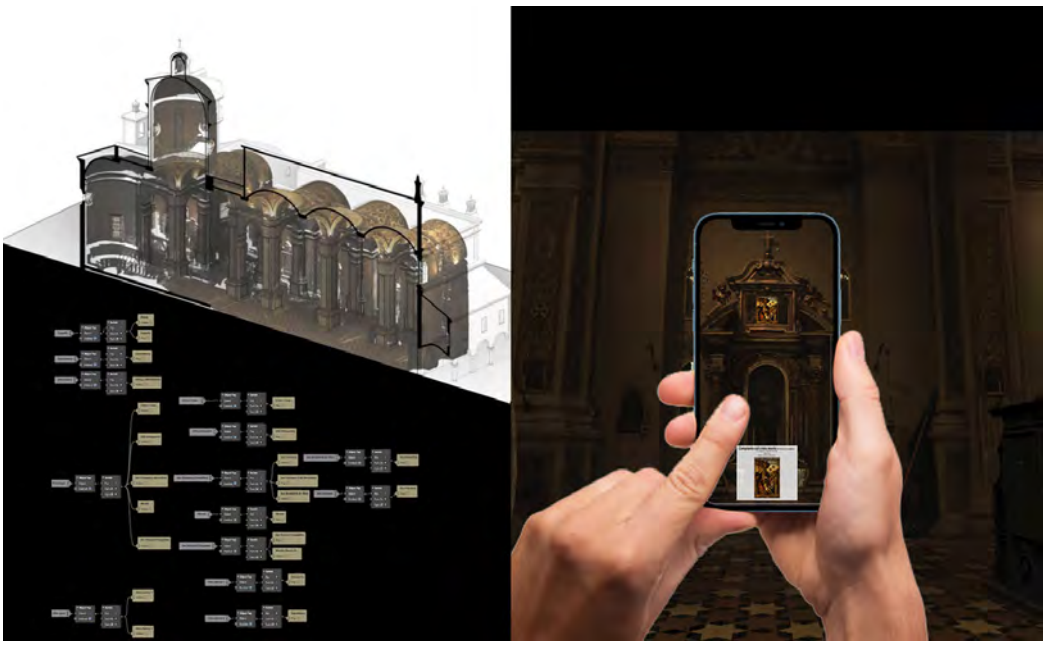
Annalisa Tiengo

Abstract

This paper focuses on a process to communicate and enhance cultural heritage value. In this context, one of the main challenges is to combine its value with digital strategies and methods without losing information and increasing communication and public-private involvement. The paper proposes a methodology that uses BIM (Building Information Modeling) and CDE (Common Data Environment) concepts to build and organize information of paintings through connected databases, typically produced by multiple actors. A case study in San Nicolò in Carpi verifies its application. An Instagram profile has been created transferring data from BIM models to Spark AR Studio to demonstrate a method that creates an Augmented Reality application for cultural heritage, without the need of coding.

Keywords
AR - augmented reality, lowcost, cultural heritage, social network, value.



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Cultural Heritage and Augmented Reality

This paper focuses on a process to communicate and enhance cultural heritage value. For the valorisation and a sustainable development in the context of cultural heritage, there is the need for a collaborative system of economy, space, culture, and social structures. For its promotion knowledge and strategic actions are fundamental concepts. In this regard, one of the main challenges is to combine cultural heritage's value with digital strategies and methods without losing information and increasing communication and public-private involvement. First, these processes use art and architectural historical knowledge, often paired with digital 3D modelling. It Is then crucial to propose a method that is socially and economically sustainable. The presented method involved BIM modeling, digital cultural heritage and Augmented Reality in order to obtain maximum diffusion and participation: with this aim social network opportunities have been explored.
One of the distinctive aspects of cultural contents is the relationship between the container, the architectural structure, and the content, such as paintings and sculptures. Moreover, the events that have transformed these relationships changed the original set and defined new configurations are opportunities for enhancing the value of cultural heritage. A common example is the painting moved to a different place, as in the church of San Nicolò in Carpi. The implementation of Augmented Reality enables new opportunities to describe scenarios that no longer exist and improve the users' experiences through their own devices.
In the first section of the paper, the authors explore significant experiences of AR application popularizing their cultural heritage artefacts through social networks.

State of the Art

The role of Augmented and Virtual Reality for cultural heritage and tourism has already been explored by scholars [Chung 2015; Yung 2019; Salerno 2019; Paliokas 2020]. The use of this technology is also popular in the industrial sector [Bottani 2019].
Significant applications of Augmented Reality in art museums highlight how the use of this technology is important to show contents related to cultural heritage (Fig. 1).
For instance, the temporary AR installation Reblink, promoted by the Art Gallery of Ontario in Toronto in collaboration with the artist Alex Mayhew, represents an interesting reference. It allows visitors to see some of the artist's works, as he has re-envisioned them. By using

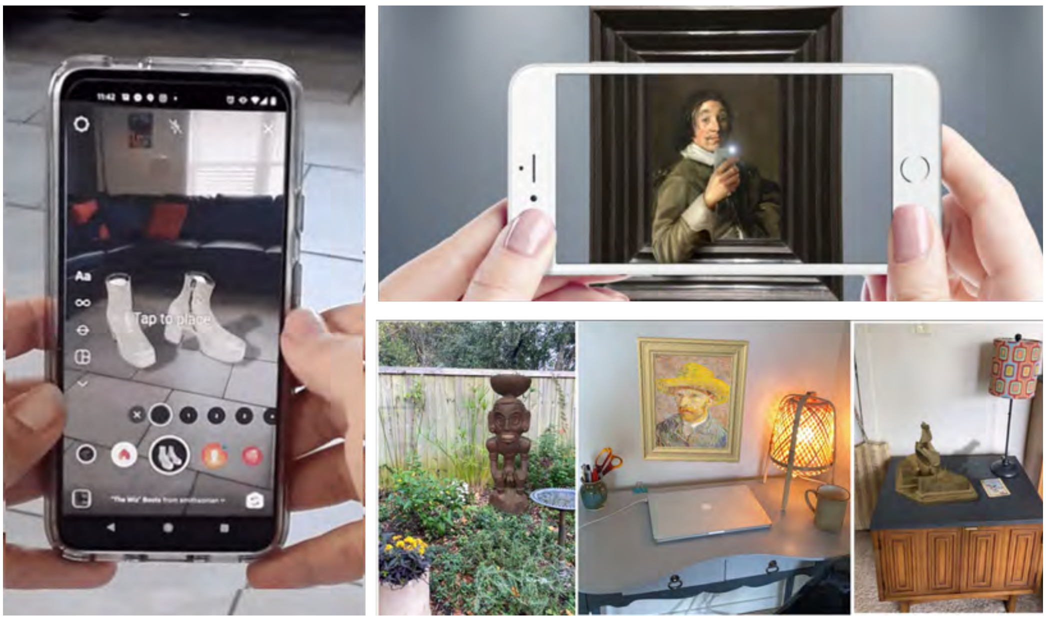

Fig. 1. example of AR and social network implementation for cultural heritge.

mobile devices, spectators can see the characters in contemporary and different environments. The artist is aware of this effect and wants to show spectators that mobile devices are flooding the user with an information overload. Mayhew's aim is to enhance his art through technology as an essential tool, rather than a distraction. Everything takes place inside the painting gallery, where visitors frame the artworks that act as image targets and enjoy watching the subjects in canvases while taking selfies, eating contemporary food or consulting their personal computer.
Other similar exhibitions confirm that Augmented Reality allows to reset space-time distances. In this regard, one of the most meaningful examples is the project *Do it for the 'gram: Exploring Smithsonian Augmented Reality on Instagram Stories* that shows the strength of the interaction between Augmented Reality and social networks. Thanks to the collaboration between five museums, the Digitalization Program Office and Facebook, Smithsonian created Augmented Reality effects for a selection some of its most iconic objects. Users can completely decontextualize all the objects available by placing them anywhere. Compared to a regular visit to the museum, this experience enables visitors to observe items closely and from different perspectives. The effects let people see the objects with the related information and acquire and share photos or videos through Instagram's tools. These objects, realized using Spark AR, are freely available and users can also share images and videos via Twitter and Facebook.
In November 2020, the Metropolitan Museum of Art launched a similar AR experience that brings famous objects and works of art in people's houses through the social network Instagram. The MET has designed three effects for the most used social media that allow everyone to approach the collection's famous objects. This unusual way to visit artworks overpasses certain limits: you can rotate the object to 360 degrees, observe it and zoom in. Besides observing the objects of interest, users can place them where they prefer, even inside their home, and then share them in their social profile.
Finally, in a context where the world of technology and digitalization discloses cultural content, the work of Olafur Eliasson is emblematic. The Covid-19 pandemic and the consequent restrictions have induced a stalemate that has affected all cultural activities. The artist replied by creating an app that recreates natural phenomena such as rainbows, suns, clouds, and rain in close spaces.

Information Exchanges, Actors and Roles in BIM to AR

The design of an Augmented Reality experience is a process that requires expertise and effort due to the use of specific software and the engagement of technical skills. Even though the organization of a large amount of heritage and effective investments in the so-called beauty economy is crucial in Italian economic and financial growth, in most cases fundings are not readily available to support this cost in Italy. In order to devise a low-cost process, it is helpful to think about alternatives that take into account open-source software and existing platforms. These platforms must be free, widely disseminated and predisposed to accommodate this type of technology. For this reason, social networks were considered the most effective mean to effectively disseminate such content. Above all, Instagram seems to be the most suitable platform, as it is based more on images and videos dissemination. Photo filtering, capturing and sharing contents with other contacts are basic actions on the Instagram environment. These features allow the public to appreciate information about the present heritage and visualize works preserved elsewhere or during their restoration (Fig. 2).
The creation of Instagram filters needs external platforms as Spark AR. The software offers a set of tools to create Augmented Reality applications without coding.The first step consists in choosing the "scene understanding", which is the method to align the virtual model to the real scene. Plane-tracker and target-tracker appear to be the most significant tools (Fig. 3). Following the logic behind the funcioning of any parent/child software, they are called "parent object" as spatial element that build the environment surrounding the content [Eastman 1999]. The fist method is based on a plane or a planar surface to locate child objects. In the

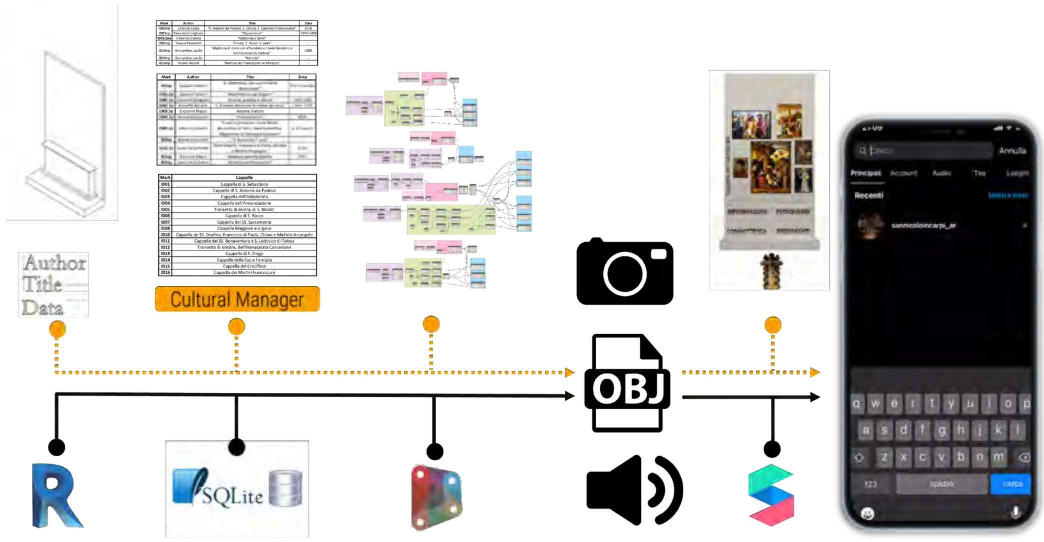

Fig. 2. Methodology process and software used.

Fig. 3 Reality tracking. Target tracker, the virtual scene is aligned to the image-tracker. Plane tracker, the virtual scene is aligned to a plane (i.e. the horizontal.

second one, the experience starts with recognising an image. The relationship between the tracker and the digital content visualisation represents a key point in the methodology. The actors involved in creating digital contents play a central role in the entire process. The proposed methodology here involves the cooperation between the information manager, the cultural manager (i.e. an art and/or architectural historian) and the 3D content manager without programming skills. Even if these figures could collapse in one person, the BIM approach helps us to highlight roles and responsibilities.
The cultural manager establishes which artefacts should be involved in AR applications, checks any contractual constraints regarding their distribution and produces textual information and references.
The information manager builds and populates the database, which summarises the information produced in the forms of texts, images, and documents. At the same time, the information manager creates a BIM model of the building, wich is the container that supports both necessary spatial reconstruction and data integration in the forms of attributes or links to other documentation. The information management may involve scripting through VPL environments to coordinate data among different file formats.
This approach highlights the importance of data structure around a BIM environment, providing the final user with a scalar set of information regarding deepening, filtering, and quantity. The typical concept derived from CDE (Common Data Environment) in BIM methodology represents a key point in the adopted method. The information manager's ability to structure interpretative historical transformation models helps to support content translation to the public.

The Communication of Paintings in San Nicolò in Carpi

The case study of this article is the church of San Nicolò in Carpi and its missing paintings. Thanks to the presence of the Observant Franciscan friars and the activities of the Pio family, the church has hosted important works of art during its history. It was commissioned by the nobles who sponsored the side chapels, and some paintings have a strong relationship with the spaces of the church. Unfortunately, they have been transferred or stolen, and they cannot be visible in their original configuration in terms of chapel placement and altar support.
The case study started from an analysis of the elements hosted in the church to investigate the existing artistic apparatus over time.
In particular, the analysis of the altars suggested that they were significantly transformed or replaced due to the Counter-Reformation. It was therefore essential to consult historical sources, collaborating with a cultural manager and an art/architectural historian to define a hypothetic structure.
A generic-shape altar was then modelled to replace the actual altars, that were not the original ones. This virtual object is parametric since it must adapt its dimensions to the multiple positions within the virtual space of the 4D BIM model of the church that represents the time passing. In addition, this object has a set of parameters designed to compile key information for its identification (Fig. 3). The shape of the altar model is offered by an altar being in a side chapel which, according to the sources, is the only one that currently has its original structure. Therefore, the use of simplified models is necessary not only to abstract their shape but also to optimize the AR solution in terms of file size.
A second step was to create a generic object to host the information about the work of art, such as the image of the painting and a property set that identifies author, title, year, and specific parameters for connection to other databases.
A VPL (Visual Programming Language) script allowed to write the identification parameters based on the values inserted in the database by the cultural manager. A second script then ensured the transformation of some of these parameters, such as author, title, date into graphic elements to place the information in the augmented 3D space.
The part of the BIM model is exported as an OBJ to prepare the virtual scene in Spark AR.

When using the Instagram platform, it is interesting to exploit its potential to fully convey other spatial information: social media play a fundamental role in the emotional involvement of the public. A specific feature of their use for cultural heritage is their ability to involve the user before, after and during the visit. Thanks to posts, a mosaic from the point cloud survey has been created. It allows the user to get oriented, understanding the geometries of the internal spaces of the church. It consists of a central nave and two minor ones, barrel-vaulted spaces, vaulted ceilings, and a central dome. The posts that produce the mosaic are divided

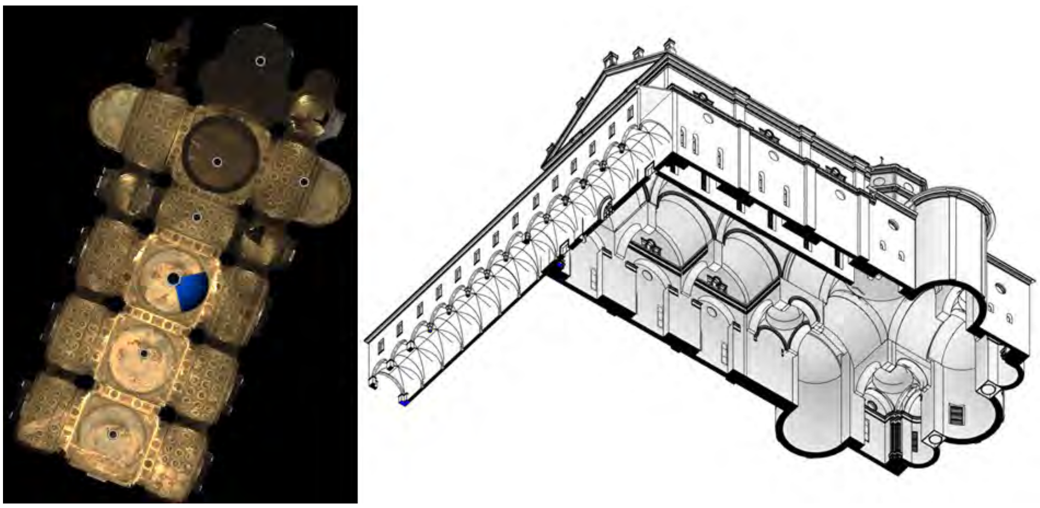

Fig. 4. BIM model as container of information.

into images and slideshows. The latter are in the points of interest where the fifteenth- and seventeenth-century altars were physically located. The others are simple pieces that complete the synoptic image.
The slideshows are composed of a. fragment of the mosaic; b. real-view image from point cloud; c. image of the painting in original place on the altar investigated.
The platform allows the manager to pair each publication with a caption in order to disseminate the main information regarding the painting.
The Instagram stories highlights section allows to fix the presence of the material acquired and published through history over time. In this way they are stable features of the augmented experiences, and the users will be able to learn how the application works and start their experience taking advantage of the Augmented Reality exhibition. The 24 hours Instagram stories can be then used for other scopes such as sharing users' posts or temporary events (Fig. 4).
During the design phase of the filters, the appropriate tracker was chosen among those proposed in the methodology. The first hypothesis was the use of a plane tracker. This type of reality tracking requires a clear horizontal line to recognize a plane or a surface. Since churches present imperfect lighting conditions, this method is unstable. Therefore, a solution based on target or image trackers is better suited to this case study because they could be both reproduced on illustrative panels and properly positioned close to the altar. This method is not as sensitive as the previous one, regarding lighting conditions.
With respect to the position of the digital object, the application does not allow a reference to the object tracker, so it is necessary to establish the exact point of the user. After that, the objects will appear in the correct position. In the present case study, the position is chosen frontally centered to the altar, at a five meters distance.
Each filter provided the following information: a. images of the painting represented on the altar, and of referenced paintings useful for the narratives; b. images of the location of the chapel you are visiting; c. three-dimensional text containing information about the author, title and date, owner, and other references.
The first tests showed a difficult narrative to read, confused by multiple objects within the scene. It was therefore necessary to use audio content. Every object that appears on the scene is a button that can be clicked to start playing the multimedia inserted by the information manager. With this system, the direct interaction with the particular object allows the observer to select the type of content he prefers to consult like basic information such as author, title and date, the description of the painting, the list of characters or other works related to the same author (Fig. 5).

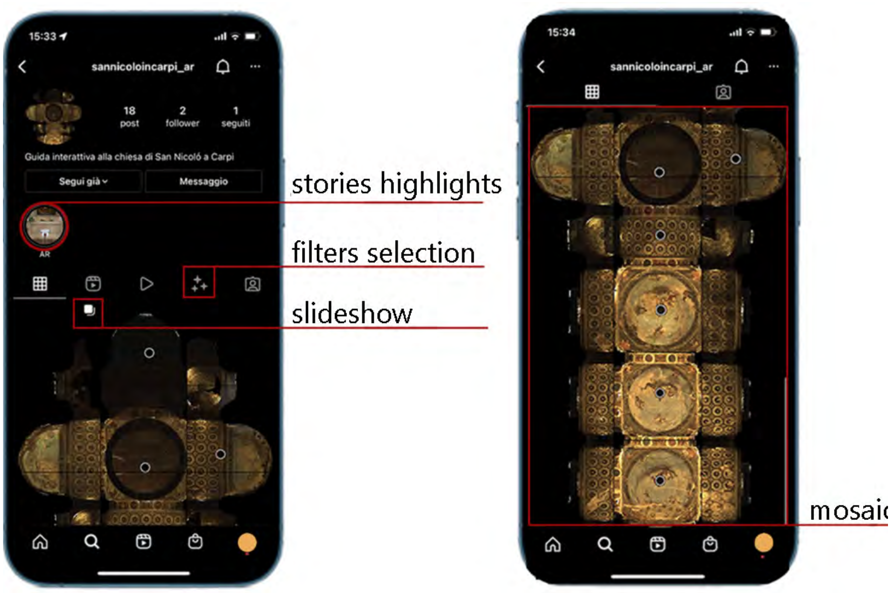

Fig. 5. Instagram first user's interface to access the Augmented Reality experience.

Fig. 6. Example phases of the filters interaction.

Conclusion

The introduced study originates from the lack of models for the dissemination of historical-artistic contents, in reference to the enhancement of cultural heritage. The value of tangible and intangible cultural heritage has been generated by the information typically contained within a documentation from analogical and digital documents, images, maps, etc. Such documentation can often be related to specific location in the built environment. The relationship between the information and its spatial context increases the value of cultural dissemination. Because of this features, 3D digital models become important as they can be linked to different sources of information. In this sense, BIM modeling is a key point, as demonstrated in the present study.
After creating a work environment that can organize the data produced by multiple actors, and after placing it within the digital built environment, it is then possible to structure an information exchange that allows the integration of content with Augmented Reality. Due to economic availability of cultural organizations, the study tried to convey cultural content through Facebook's Spark AR platform. This allows to disseminate information through popular tools, facilitating the use and therefore the understanding of the contents.
The case study of the church of San Nicolò in Carpi has shown the possibility of reading some paintings no longer located in their original position through Augmented Reality. Moreover, since contents were produced by different actors, the example described above highlighted the importance of organizing the information flow.

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Multi-Level Information Processing Systems in the Digital Twin Era

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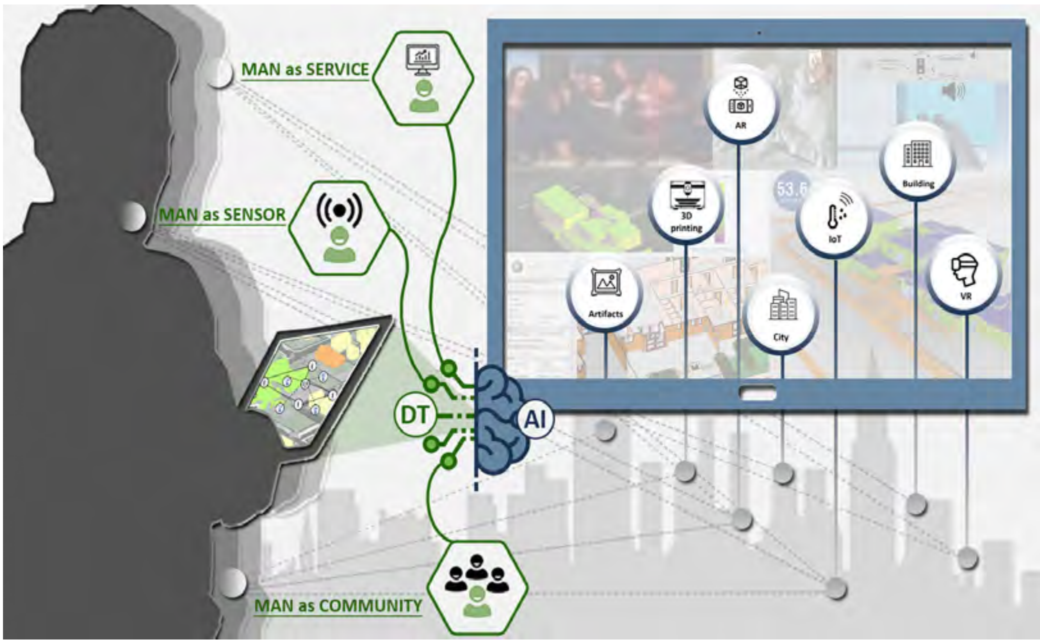
Abstract

The most challenging aspect of the scientific panorama linked to technological innovation is the search for possible connections between Representation, Man and Artificial Intelligence (AI) in the complex ecosystem that defines a Digital Twin. Man plays a crucial role in facilitating communication processes both for the dissemination of knowledge and the accessibility and usability of content and for his ability to become a "sensor" and communicate information, feelings, emotions. The contribution proposes a cross-section of applications that link and decline Augmented Reality and AI differently according to a gradual scale shift from the artefact contained in a building overlooking an urban context of interest. The result is a multi-level information processing system derived from the three-dimensional matrix that links data collection, representation and visualisation techniques and tools with the cultural heritage – city, building, artefact – according to specific use cases.

Keywords
digital twin, BIM, drawing, society 5.0, multi-level information processing systems.



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Introduction

The social and economic changes of recent years have highlighted a new vision of a human-centred society in which people can better manage their quality of life. In this way, users' needs determine the fusion of physical and virtual space to optimise their information and create a new ecosystem of values and high-tech solutions [Atkins 2021]. Thanks to introducing new technologies that improve the control of everyday actions carried out by the digital user, the human-system interaction of Information and Communication Technologies (ICT) provides sustainable and interoperable services.
Social innovation extends services into policies and regulations capable of shaping the decision-making choices of future generations through improved quality of life. In fact, establishing an ecosystem through global and dynamic technological platforms makes it possible to determine new balances between society-technology-human behaviour. The logic that manages societal change is the use of efficient tools that are easily accessible to each individual and the identification of smart platforms [Baheti, Helen 2011]. Enormous advantages can be deduced from this new vision of society: (i) ease of cataloguing information and availability in consulting it; (ii) different contents according to the services required; (iii) dynamic learning modes; (iv) means of communication and visualisation integrated with sensors and real-time monitoring [Deguchi et al. 2020].
The transformation of citizens' lifestyles, cities and artefacts intensify the dynamic properties of their configuration by overcoming static relational barriers. New technologies are best able to govern the intelligent society during the digital process [Del Giudice et al. 2020]. The challenges and paradigms posed by Society 5.0 are overtaken by new tools that must be applied within smart and interconnected cities where a dynamic and social Digital Twin can manage new technological frontiers [Fuller et al. 2020]. The combination of Artificial Intelligence (AI), Internet of Things (IoT), Machine Learning (ML), Deep Learning (DL), cognitive computing and big data analytics allows humans to delineate the real-world boundaries within the virtual model and improve their behaviour in the real world [Fukuyama 2018]. This new development of a digital twin has underlined the need for precise, stable and multi-layer cataloguing and data transmission techniques. Therefore, we can describe the Digital Twin as a virtual model that analyzes real processes to simulate and interpret performance at different scales, generating optimized information flows.
The deployment of the virtual model is closely linked to the integration of platforms capable of automating the flow of information in every social sphere. Therefore, the domains of relevance range from industry and construction to the entire city. It is precisely in the last domain that the diffusion of virtual models has led to effective solutions. The growth of smart cities, develop societies connected with the integration of wearable and non-wearable devices that collect data and determine human choices. The ability to adopt web services that communicate with sensors makes it possible to plan future choices through AI algorithms that monitor and analyse the duality between real and virtual behaviour [Gartner Inc. 202; Gladden 2019].
The main challenges faced by the Digital Twin are related to technological progress, as ICT infrastructures must be able to collect data and analyse them in real time, eliminating data without content. Improving data quality is important for the efficient use of DT. Finally, information security and trust in the reliability of tools guarantee the sharing and implementation of experiences [Grivies 2014]. Thanks to Virtual Augmented Reality (VAR) and AI tools, the integration between different simulated environments and existence is facilitated by innovative methods to calculate and manage process flows [Nair Meghna et al. 2021].
These tools have seen a strong increase in their adoption over the years. According to technology reports, digitisation has changed the traditional systems the user interfaces with by increasingly putting people and their independence at the centre with resilient models. The centrality of humans is linked to digital behaviour in the use of the web, the experience of virtual actions and finally the storage of data [Madani 2020; Marr 2020].
The combination of different technologies not only facilitates information flows, but also

connects the individual to associated behavioural events, changing the society and services of the smart city. There is so much information being generated that precise techniques for managing Big Data are required. In this sense, the IOT evolves into IoB (Internet of Behaviors) where continuous monitoring of the user may or may not encourage choices in a range of well-structured possibilities. The spin-offs are related to the strategy of creating shared experiences that connect to multi-experiential and personalised activities [Mohammadi, Taylor 2017]. Virtual environments that follow these characteristics allow three-dimensional objects and the database to be visualised, modified and reloaded at different scales. The platforms that underpin this utilise reliable web protocols where information is collected, with a decentralisation of machine learning systems. The new technologies of AR and VR are able to improve the perception of places, promote the well-being of society and increase the efficiency of everyday life.
The implementation of these systems with AI algorithms makes it possible to innovate in many areas such as the public sector, industry, education and training, healthcare, and the construction sector.
The adoption of digital technologies can also make the interaction between humans and society more collaborative for the various stakeholders who manage and optimise the decision-making processes of the city of the future.
The contribution analyses the need to investigate concrete actions to be transferred within virtual environments, i.e. a Digital Twin that brings together different scales and objectives. It is possible to define the main actions that Human 5.0 can carry out about cultural heritage, starting from analysing the needs of an artefact. Even at the building level, if connected to a network of sensors, it is possible to self-generate the services humans require, optimising the continuous changes with AI. Similarly, if we investigate the city, each user can communicate data and modify it over time through Deep Learning and Machine Learning techniques. In this way, it is no longer possible to speak of a single type of digital model but of tools that communicate through new systems of visualisation and representation (Fig.1). So drawing, understood as a two-dimensional representation, evolves into advanced three-dimensional information techniques where AI manages its change. Methodologies such as Building Information Modelling (BIM) and District Information Modelling (DIM) allow citizens to manipulate Big Data optimised by AI. Digital components, asset twins, twin units and process twins thus become helpful tools for improving communication, monitoring, simulation and management of knowledge and behaviour in the digital society [Mohammadi, Taylor 2017]. The main challenge of a socie-

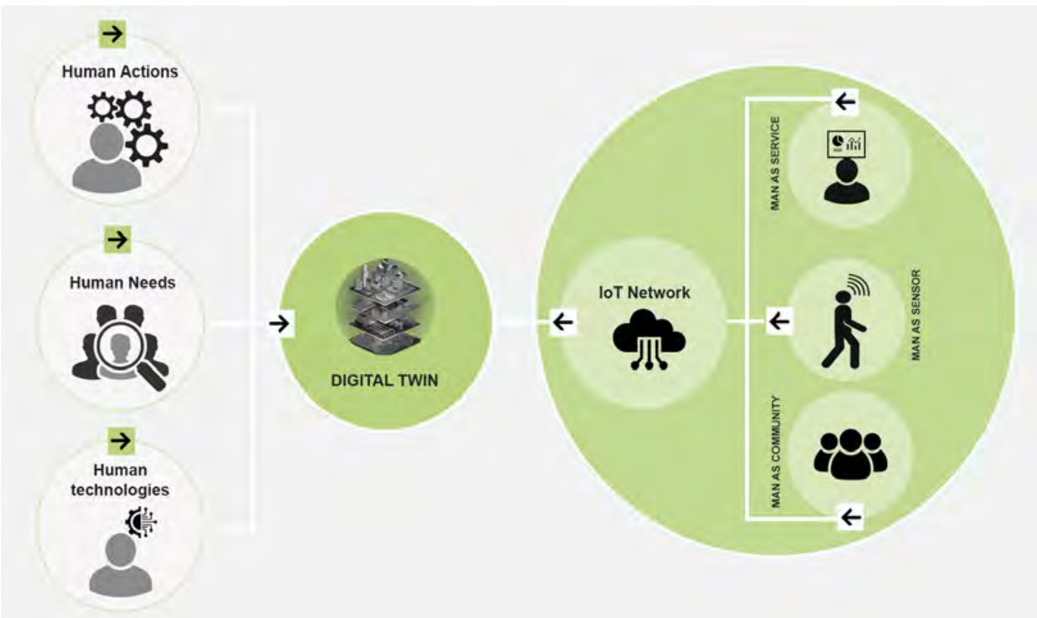

Fig. 1. Workflow.

ty rich in information stimuli is adopting a digital twin that can use sensors to control the effects of the virtual world on reality [Srivastava et al. 2012]. At the same time, the digital model is the means whereby man, understood as a set of social actions and behaviours, becomes a receiver and communicator of information in real-time, like a real sensor. For this reason, a Man-Sensor is defined as a person who can transfer virtual actions to a network of users that improve various domains such as health, mobility, energy, and social relations.

Methodology

The growing need to monitor and manage existing tangible and intangible cultural assets throughout the life cycle provides an opportunity to turn the focus on the challenges launched by ICT for the development of a Digital Twin. It is usually based on three main components:i) the physical world, ii) the virtual world; iii) the data connections that tie them together [Trauer et al. 2020]. The main aspect the paper focuses on is how people can interact with it to extract specific information related to the social and cultural and environmental aspect, from the scale of the individual to the surrounding urban context. Therefore the focus is directed on sharing information between people and their surroundings.
The duality of human-computer interaction is summarized in the methodological framework to define the fundamental characteristics (Fig. 2). The physical world is composed of objects useful to humans, places in which humans live, and cities in which society interacts on a daily basis. The resulting image of reality highlights aspects related to knowledge, cultural identity, behaviour, and policies put in place by the city policy makers. The digital world has the task of collecting data from the physical world to implement monitoring of specific features, to develop simulations of different types and to propose improvement scenarios of wellness. It is composed of i) Sensors; ii) Computing capability; iii) Visualization. Clearly, the feasibility of virtual physical duality must include the creation of an IoT network capable of connecting physical and digital entities. In this case, the approach is that the proposed digital twin is characterized by a multilevel system in which users can connect with different entities including artefacts, the surrounding environment and the people who constitute the community of a district/city. For this reason, three case studies (Fig. 3) were selected to evaluate the usability of data at the social level, the communication of data at the environmental/building level, and the dynamic interaction of data for greater awareness as an active part of a community.

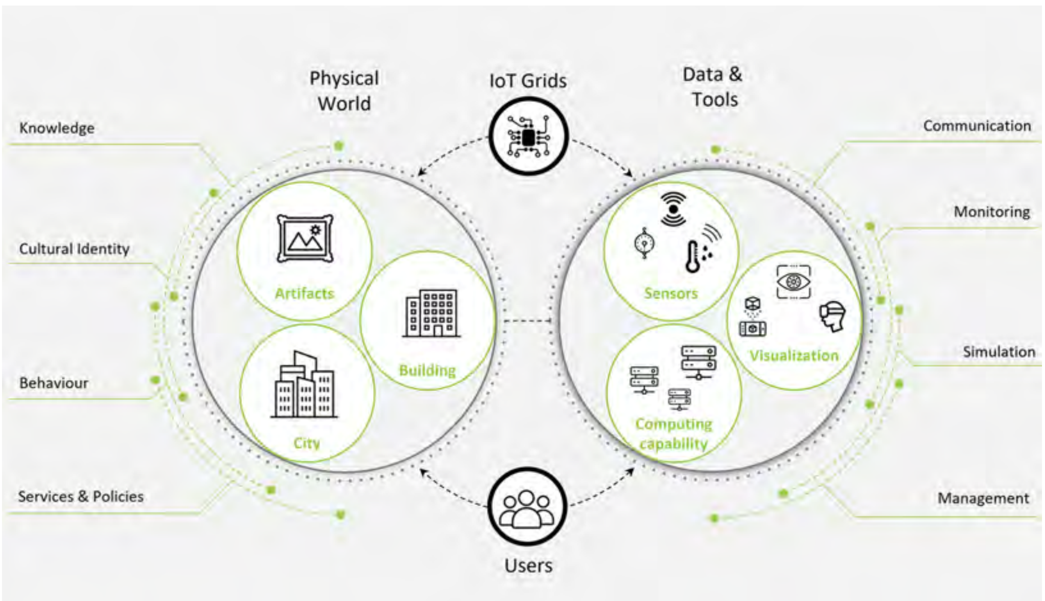

Fig. 2. Methodological framework.

Fig. 3. Case studies.

Level 1 – Man as Community

A first use case relates to user awareness, which becomes social inclusivity beyond disability. The designed tactile experience of a painting is triggered by a proximity sensor that detects the presence of a guest. The artwork, digitally reproduced from point clouds and 3D printed, is divided into parts to which diversified audio content is associated through a mapping system developed with Leap Motion technology. An infrared (IR) sensor tracks the actual position of the hand on the physical replica and transfers the spatial coordinates into the virtual model. In this way, the interaction between the real experience and the activation of the virtual content is managed by an algorithm that activates audio sequences selectively and automatically. 3D printing makes it possible to maintain contact with the artwork, even when it is being restored and inaccessible. In this case, man can make his feelings available with the community.

Level 2 – Man as Service

The second case enables the possibility of creating virtual tours of a building, making information available thanks to the direct interaction of the user with special markers placed in the field. Starting from the development of a BIM model, an informative model is created describing the artificial environment in which humans live. Different sensors (e.g. temperature, humidity) installed in the indoor environment collect information dynamically and are subsequently interrogated by users during virtual tours for the management of indoor thermal comfort. In this case, the digital twin of the building has no relationship with other buildings in the context and no relationship with other people with whom they share the same environments. Therefore, the benefit obtained is only local and is linked to the individual citizen, not producing direct effects for society from a smart city perspective. Buildings incorporate the needs of citizens that become a service to achieve a smart building.

Level 3 – Man as Sensor

The third use case is linked to the possibility of acquiring information from the user immersed in an urban context. Man becomes a receptor of information that he can transmit through questionnaires/platforms that can be retrieved through a QR Code. The data collected will thus feed a cloud database that, once synchronized with the digital models, allows the monitoring of certain parameters and conditions (quality of the environment, maintenance problems, perception, etc.). Through the sharing of various information for the management of the physical world it will then be possible to set up an experiential database in which each user characterises their own way of communicating specific information. This creates the premises for the definition of a smart city that adopts Recommender Systems(RS) [Van Dinh et al. 2020] that employ AI techniques in order to increase user engagement and to guide citizens in the process of finding services that match with their preferences.
Through the three levels described above, it is possible to state how the proposed digital twin is still in an initial study phase. Through the proposed multiscale approach, in the near future it will be possible to activate a multi-scale system in which people are at the center of the virtual physical duality.

Results

This contribution recognizes and affirms the constant need to evaluate the intersections between the real and virtual worlds. The increasing diffusion of Augmented and Virtual Reality technologies has allowed starting more and more challenging research and experimentations that try to go further, widening the boundaries, crossing the domains, and including an ever more vast pool of users. In this context, the discipline of drawing is facing a reflection oriented to meet a significant challenge to improve the quality of human life. The graphic representation of artefacts, buildings and the city can be the starting point to meet the increasingly demanding humans needs. It is essential to elaborate on the different forms of expression through the new visualization, processing, and data collection opportunities. Through this step, the foundations are laid to set up a Digital Twin that is increasingly useful to solve the problems of everyday life.
As described in this paper, the multi-level information processing system enables ever greater accessibility and governance of data. The proposed use cases show a growing potential arising from this framework that places humans at the centre of a super-smart society.
The immediacy of communication reaches the individual but contextually creates an information-based community (Fig.4). While the first use case makes available primarily static and divulgation information, the second expands opportunities through the collection and sharing of dynamic data. In this way, the synergy between human sensor and representation enables a service model covering activities from monitoring to mainte-

Fig. 4. Multi-level information process system for a Digital Twin.

nance and management. In the third case, man is no longer a simple reader of data but becomes himself an interceptor of information, situations, strategies.
The ability to report is enhanced by the intervention of the individual and finds strength in the community. The simpler and more immediate the reporting tool, the more it will be used. In this way, the data collected becomes real big data that can be processed for a variety of purposes.
Unlike the second case, where the data is objective, it is also possible to collect intangible information, which can be evaluated with a different sensibility by the user. For example, let's imagine the interesting scenarios that can be opened up by going to collect the emotions that places inspire.
These can be exploited as elements of investigation to improve the urban texture of the city and adopt solutions shared by citizens towards a city that is not only smart but also resilient.
The objective or subjective evaluation derived from the various sensors, human and non-human, with which the city may be equipped, generates ranking or rating that are best managed through machine learning systems that are returned to the user in the form of recommendation engines.

Conclusions

The adoption of artificial intelligence within the evolution process of society has made services that regulate the relationships between users accessible and sustainable and defines the best strategies to optimise the information and behavioural flows. Indeed, in this way, people can communicate their feelings within virtual experiences where specific algorithms process heterogeneous information defining a dynamic and interconnected database.
The use cases analysed have made it possible to evaluate a multilevel system of processable information in which users and tools relate between the virtual world and real environments. Therefore, the interaction between digital models and the 5.0 society today presents a labile process in which the duality between Human, Artefact and Artificial Intelligence requires interoperable tools adapted to the future society.
The advantage of developing capacitive models expresses a high response to the innovative representation of digital environments at different scales.
Thanks to developing a Digital Twin, linked to Artificial Intelligence through a recommendation system, it will return different information. The user will process this information in the form of alerts that, depending on the location, suggest personalised tours to a generic user and convey information on what defines Society 5.0.
Technological progress linked to Artificial Intelligence, Big Data, Robotics, Deep Learning and Machine Learning tools is opening up new scenarios that on the one hand improve man's way of life, and on the other require automation with high cognitive capabilities. Therefore, the establishment of an effective and efficient ecosystem will have to ensure sustainability in economic, environmental, social and political terms where humans determine new social values.
The sensory capacity acquired thanks to the digital infrastructure constitutes a new vision of the smart city capable of developing a digital version of the real world that enables dynamic environments. Augmented reality overlays the real world with virtual data, making the city and its ecosystem observable and tangible by humans in its various forms.
New technologies such as Augmented and Virtual Reality connected to AI will not only become tools for knowledge, behaviour and social and economic policies of the 5.0 community. Still, they will bring about a real revolution in meeting the needs of human beings within a smart city.

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Object Detection Techniques Applied to UAV Photogrammetric Survey

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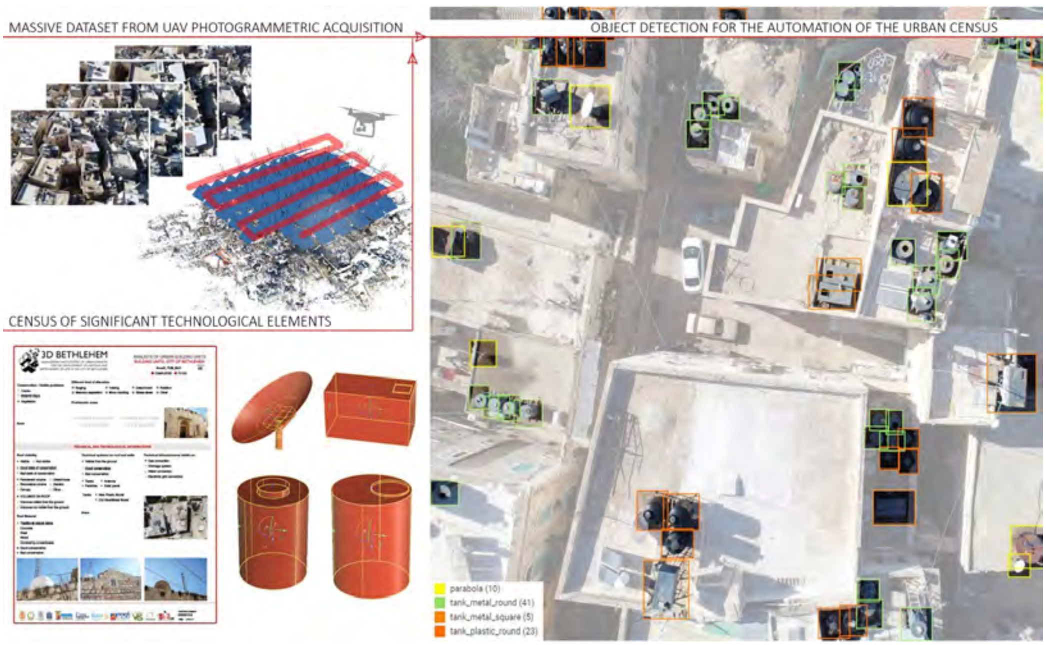
Abstract

This project proposes an automated approach to the census of technological and architectural elements from massive photography datasets. This use case is built on photogrammetric close-range acquisitions performed via UAV over the roofs of the centre of Bethlehem, in order to map the water tanks for civilian use that create loads on historical buildings in a seismic area. The urban census was conducted within "3D Bethlehem. Management and control of urban growth for the development of Heritage and Improvement of life in the city of Bethlehem", a project promoted by AICS. The presented work leverages the project dataset to train Deep Learning models on a Cloud Infrastructure handling model lifecycle from training to deployment. Tests were conducted on historical buildings that show, among objects of interest, multiple spurious elements such as debris and junk. Such density creates complex scenarios for models that are trained to automate recurrent operations to assist large scale monitoring and management of the areas for different teams and municipalities.

Keywords
object detection, architectural census, urban monitoring, UAV photogrammetry, Bethlehem.



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Introduction

The proposed research aims at automating the census process of technological and architectural elements in urban contexts, starting from massive photographic datasets. The use case this is built upon is that of installations on the covering of the historical centre of Bethlehem, selecting the dataset from UAV close-range photogrammetric acquisitions and fits within the scope of the International Cooperation Project *3D Bethlehem. Management and control of urban growth for the development of Heritage and Improvement of life in the city of Bethlehem* [1]. Starting from 2018 researchers from DAda-LAB, from University of Pavia, conducted multiple surveys to build a complete documentation of the historical centre of Bethlehem. This research leverages close-range photogrammetric acquisitions [Picchio 2019] consisting of more than 9000 UAV photographs of the city centre.
While the final goal of the *3D Bethlehem* was that of providing the municipality with a digital tool to improve governance of the urban complex of Bethlehem, the presented piece of work arises from the need of an automated tool for the monitoring of specific elements of the urban environment. The analytical process to understand urban contexts is tied to the construction of reliable data bases to develop strategies for communication and virtual fruition of spaces. Historical centres retain information concerning the numerous events that impacted the city over the years and create an heterogeneous and variable dataset that can be systematised [Bocconcino 2019]. The chosen use case stems from the need to map the water tanks that civilians place on the roofs. Tanks are used as water supplies but create structural criticalities placing localised loads on the coverages in a seismic environment [2]. The urban landscape follows the morphology of underlying hills and is dotted with a high number of tanks that are visible from multiple angles: mapping these elements is one of the intervention priorities for

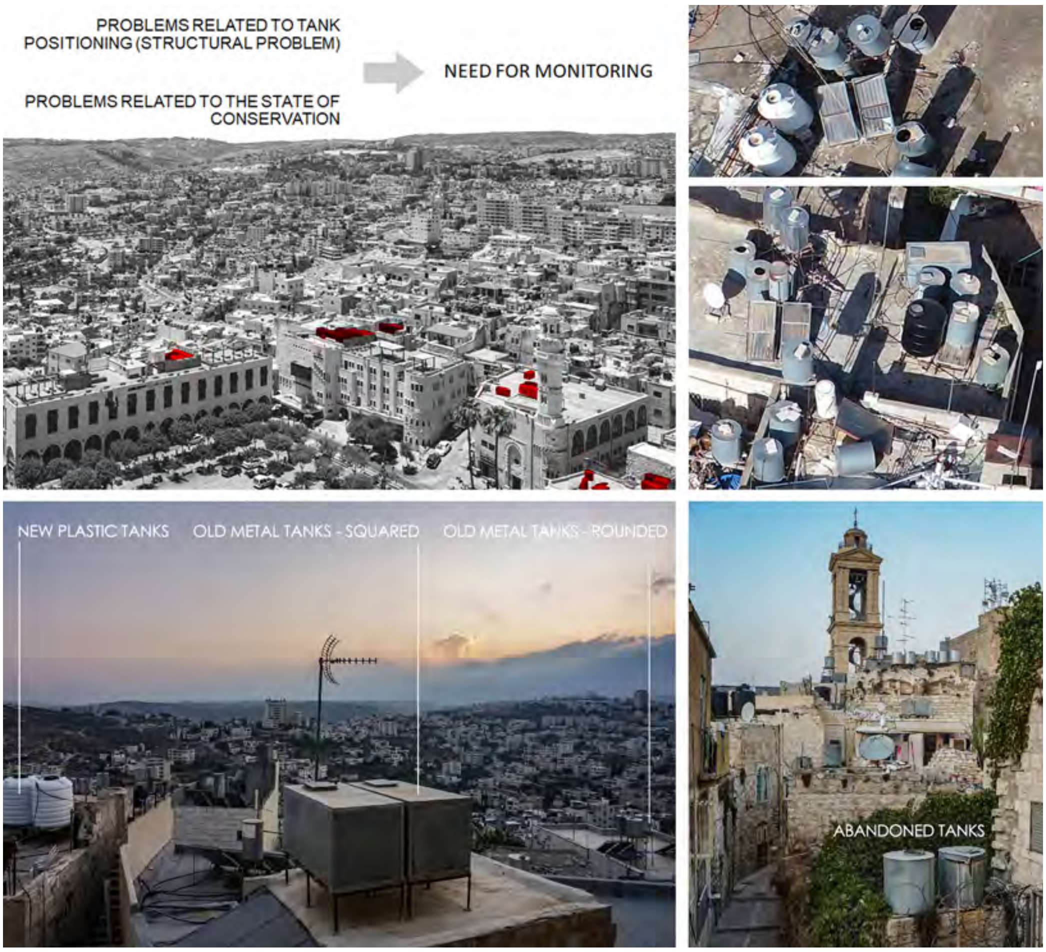

Fig. 1. Different tanks visible on the covering. The majority of surveyed tanks has a capacity of either 500 or 1000 litres, causing high load on the coverings.

Fig. 2. Three-dimensional mesh model of the historic center of *3D Bethlehem* project. Left: Experimental Area R highlighted with respect to the context of the historic center of Bethlehem. Right: cisterns highlighted on the buildings in Area R to understand the high number of elements present on the roofs.

the municipality. This requirement fits in the scope of UNESCO site management plan, in which to develop alternative proposals for the replacement of such infrastructures. Tanks fall in different categories: plastic tanks are the most widespread (54%) and are on average well preserved but have a heavy impact due to colour, either black or white, contrast with the building; metal tanks (46%) on the other side are either cylindrical or box shape and in a worse state of conservation (Fig. 1).
Across the four years span of the *3D Bethlehem* a census of such elements was performed and tank data was structured in a database [3]. During provisioning, the tanks that show flow control issues show leaks on coverings and facades causing material pathologies, vegetation growth and creating moist areas on the walls. Tanks are visible all around Bethlehem, both in recently built structures (that show neither additional elements stored nor debris) and in historical buildings that show complex morphology along with stacked debris and scrap.

Dataset Acquisition Methodology

Studying the historical city centre of Bethlehem was conducted from data surveyed between 2018 and 2021 to detect different building fabrics detectable in the urban context. During the surveying campaign a series of interventions aimed at consolidating and preventing structural damage have been detected across different neighbourhoods. *In situ* studies of Bethlehem city centre led to a subdivision in 20 areas based on historical subdivisions and road patterns across the city. Areas have been progressively named with letters from A (Church of Nativity neighbourhood) to V and different states of conservation can be found across different Areas; newly constructed buildings (V) can be found as well as stratified historical neighbourhoods (Area F) and only few of these Areas have been targeted by projects for renovation and consolidations [4]. Al-Anatreh (Area F), the historical christian neighbourhood was widely impacted by interventions between 2003 and 2005 [Nasser 2005], while the other areas saw targeted interventions on specific building units having high historical and monumental value [5]. Despite interventions for consolidation and rebuilding of the urban fabric there is a widespread portion of built fabric that show the presence of ruins, especially in P and R areas (Al Hreizat e Al Fawagreh Quarter) area U (Al Farahieh Quarter), C and N (Al Najajreh Quarter). This research focuses on Area R (highlighted in Fig. 3), a neighbourhood characterised by high building density with heterogeneous coverings considering both the typology and state of conservation, with some of those showing the presence of debris that hinder automated recognition of objects since partial occlusion may occur [Saleh 2021]. To build the experimental setup the team leveraged the aerial photography dataset to train Deep Learning models on a cloud infrastructure. Photographs from Area R (389 pictures) have been imported and from there a subset was manually tagged highlighting the objects to be detected by the Object Detection algorithm.

Photographic Acquisition via UAV

A fundamental phase of the proposed research was to have a vast photographic archive of close-range coverings available. For the roofs of the historic center of Bethlehem, over 9,000 photographs were acquired to cover an area of over 260,000 square meters, split into neighbourhoods. The photographs were taken with different camera angles:
– zenith photographs of the roofs;
– photographs angled from four different sides that make up the neighbourhood (Fig. 3).
The choice of taking the photos from different angles was necessary in order to generate an SfM model of the roofs, from which it was possible to orient and extrapolate ortho-images [Picchio 2020]. The photographs have an overlap of 65-80% between them. The photographs allowed to obtain a very varied dataset both as urban extension and as a variety of points of view from which the cisterns were photographed [6].
As can be seen in Fig. 3, there are critical issues related not only to environmental conditions such as lights and shadows but also to the deposits of objects present on the roofs that make the urban fabric particularly complex. The goal of the project is that of training an automated recognition system able to detect tanks on the roofs, subsequently feeding a programmed monitoring process. Such monitoring allows to verify the compliance with a series of criteria set by the municipality of Bethlehem such as:
- The reduction of the visual perception of the cisterns from the roads;
- Their positioning in safe points and without structural criticalities.

As regards the structural verification of the criticality due to the presence of cisterns, was carried out a cross-reading of the data with what was acquired in the building census [7].

Deep Learning for Object Detection

Object detection is a branch of computer vision aimed at identifying objects in images. The task is twofold since the algorithm has to isolate the object of interest in a potentially complex scene and then correctly identify the isolated object with the correct class.
Since the introduction of Convolutional Neural Networks [Lecun 1995], Deep Learning (DL) models have become the standard thanks to the high performances achieved [Redmon 2016]. DL models propose a layer based approach in which the image is fed into a series of processing stages that extract features that are then fed to a classifier.
The computational complexity of this problem grows with the number of images in the training dataset and size in pixels of the images. In the simplest case, a sliding window is applied to each portion of the image and slid across the entire frame (convolution) to be subsequently processed by stages deeper in the model architecture. These supervised models require large datasets to provide a wide number of examples of the objects to be identified and multiple executions to train the models via backpropagation.

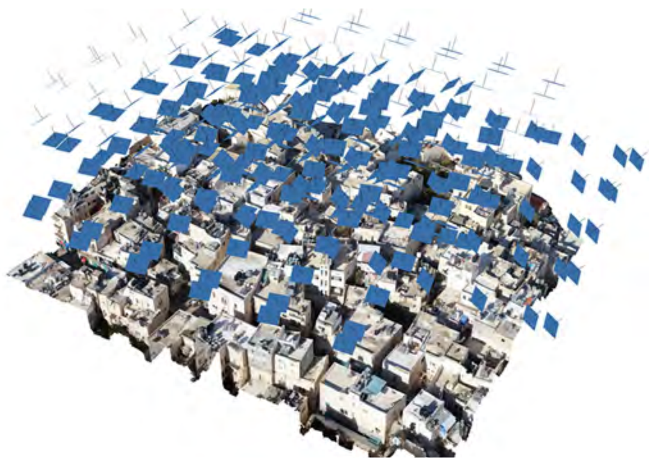


Fig. 3. Example of SfM photogrammetric acquisition of an area with photographs taken at 50 m from the height of the roof from which the survey was conducted. Right: extraction of the ortho image from the photogrammetric model.

The dataset is manually tagged identifying objects of interest, the data is then processed, matched with the ground truth provided and weights that govern the model behaviour are corrected to match the computed and expected result. Execution is repeated until a plateau in performance or a target number of training epochs is reached. With the availability of computing power and acceleration techniques, the complexity of models could grow and new methodologies for learning stemmed from this growth in capabilities. AutoML is a family of models, ensemble of models and feature engineering approaches that leverage ensemble and transfer learning techniques that allow faster construction of ML models and push towards the democratisation of Artificial Intelligence [He 2021].

Cloud Computing – Integrated Machine Learning Platforms

This use case consists of a massive initial dataset and a potentially ever growing one, therefore computational complexity sets a constraint on the available approaches. Abstracting from the computational power available on premises removed the boundaries set by the physical hardware shifting the focus on the problem itself [Rivera 2020]. On premise set ups need to be expanded by buying new hardware if the dataset grows or a new choice of algorithm stresses the existing hardware configuration. Cloud Platforms offer on demand resources in a pay per use fashion, allowing to tailor the needs to the as-is state of the problem and scaling up or down on demand, depending on the computing power and storage required. The presented infrastructure was implemented within the Google Cloud Platform (GCP) set of tools. GCP is a suite of cloud computing tools that offer infrastructure, platform and software as a service tools running on Google data centres. Data storage is performed on the cloud itself allowing for high reliability, fast transfer speeds and resilience to failure. This use case should be considered as a piece of a wider project for surveying, documentation and feeding of an informative system for cultural heritage; this infrastructure provides storage, computing resources, machine learning management, dashboarding and other tools in a unified platform for the entire project lifecycle. This use case addresses a single area of the centre of Bethlehem, but the platform can be scaled to accommodate larger datasets, more complex models or additional components. A Cloud based infrastructure grows and shrinks as a tailored environment built around each of the use cases of the project. The components of this project are: Google Cloud Storage (GCS) buckets to store images, predictions, trained models, and Vertex AI. Vertex AI is a machine learning platform that covers the entire ML lifecycle from dataset tagging and splitting to training, deployment, performance tracking and management of ML models in a serverless environment. The models are accessible via UI and programmatically, and in case a new model outperforms the previous one it can be effortlessly swapped without concerns for the end users. An AutoML model was trained on a subset of 70 UAV images from the aerial photography dataset.

Fig. 4. Figure shows a ortho image with the output of the model overlayed on top. Highlighted examples of Correct Detections, mismatches, competing labels and missed objects. Both images show high precision.Left: False Negative: missed plastic tank close to metallic tanks.
Right: False Negative: missed plastic tank. Black tanks area critical due to the shadows on the roofs.

Results

Initial tests were conducted on a 30 image dataset (UAV photographs), but the model lacked in the recall department failing to identify the correct group of pixels to be classified.
The higher the precision, the fewer false positives predicted, the higher the recall, the fewer false negatives, or the fewer predictions missed. With a threshold set at 0.5:
- 80.5% precision;
- 28.0% recall.

Increasing the size of the training dataset vastly improved performance, to achieve current results the team used 70 UAV photographs for training. Increasing the size of the training dataset vastly improved performance since each image contains tens or hundreds of objects. Tagging a higher number of images increased by an order of magnitude the number of training examples. The second training instance was run on:
- N° parabola: 497
- N° tanks metal_round: 3180
- N° tanks metal_square:695
- N° tanks plastic_round: 188514

Portions of orthoimages of the same area were used for validation. UAV pictures captured from different angles and distances provide a natural data augmentation for the algorithm (Fig. 5). The retrained model, threshold at 0.5:
- 90.8% precision;
- 61.0% recall.

The greatest issues with recall are in dark areas, in which low light reduces contrast between objects and the high amount of cluttering and occlusion on the roofs where wood planks and debris are placed on the covers and on the objects themselves. (Fig. 6)
Since this model is intended as a screening tool to identify criticalities and plan interventions and maintenance, when deploying it for use the team opted for higher tolerance (hence lower threshold) accepting a higher number of false positives but ensuring a higher recall.

Fig. 5. Precision/recall curve - 30 image dataset.

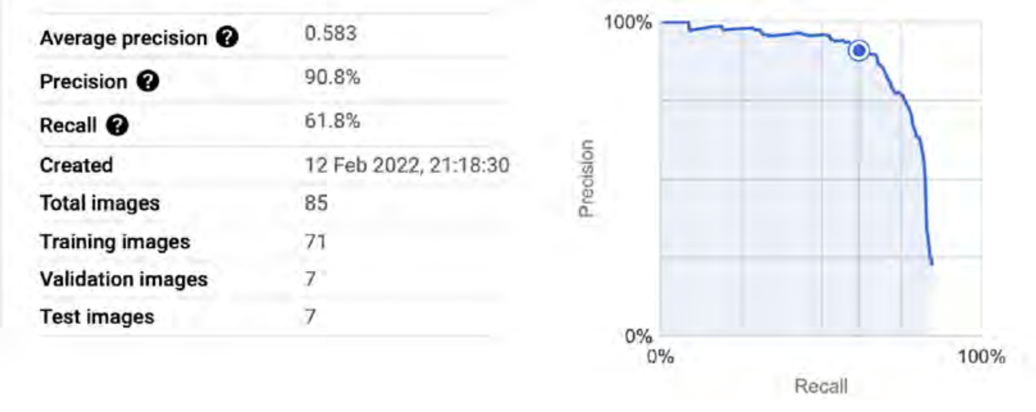

Fig. 6. Precision/recall curve - 70 image dataset.

Conclusions and Future Developments

The research will broaden its scope, extending object detection to different areas of the city to study how the urban setting can alter the results of tests. The algorithm will be evaluated both on morphologically complex historic neighbourhoods and on recent constructions that show a disaggregated morphology, more isolated buildings and regular shapes. This second phase will allow the team to evaluate whether the algorithms should be retrained to handle the entire area of the city. Different elements can be detected and mapped alongside the tanks as well other characteristics of the buildings. Satellite dishes were included in the first phase of the experiments, providing interesting results in both precision and recall. Repeating the same analyses at different moments of time, devising an inspection schedule, will allow to compare the results and map the evolution of the built elements through time, identifying criticalities. State updates are performed thanks to ordinary periodical activities, planned within a management schedule, and extraordinary activities in case of critical events that can vary timings and needs for the inspections.

The field of heritage conservation is tightly bound to best practises for fruition and safeguarding of buildings. Architectural conservation can stem from diagnosing the state of conservation of heritage, within the context it is located, anticipating the need for a procedural and systematic vision [Cecchi 2006]. Management and conservation of cultural heritage, also considering sets of actions that get scheduled and coordinated through time (Intervention time schedule), aims at improving the quality and identity of the elements. Such projects require multidisciplinary contributions, economical and management evaluations, as well as the involvement of the local population in the process of recognising the value and development opportunities of the existing heritage [Della Torre 2008]. The presented research targets the automation of processes in a widespread and complex built environment. Managing such scenario is a challenge for municipalities and automation facilitates the monitoring activities for entities and administrations. This process, if extended to the recognition of different architectural and technological elements, allows to improve the planning of protocols for the preventive maintenance tied to the actions context, maximising enhancement goals for the built heritage.

Notes

[1] *3D Bethlehem. Management and control of urban growth for the development of heritage and improvement of life in the city of Bethlehem* is a cooperation project promoted by AICS, the Italian Agency for Cooperation and Development. The project is coordinated by the Municipality of Pavia, with a partnership made up of the Municipality of Bethlehem, the University of Pavia (scientific coordination), the University of Bethlehem, the Province of Pavia, the Order of Engineers of the Province of Pavia, the SISTERR territorial system of Pavia for international cooperation. APS, ANCI Lombardia, VIS – International Voluntary Service for NGO Development and Palestinian Engineers Association – Jerusalem Centre. The project is scientifically coordinated by Prof. Sandro Parrinello and DAda-Lab laboratory of the DICAr – Department of Civil Engineering and Architecture of the University of Pavia.

[2] The Dead Sea fault is an area subject to the risk of major seismic events. See in particular the seismic risk map produced by An-Najah National University – Nablus.

[3] The GIS-connected building database consists of structural and technological information about the buildings. The percentages relating to the different types of tanks present were obtained from the overall reading of the cards in the GIS system. For an in-depth study on the research relating to the database on the historic center of Bethlehem see: Doria Elisabetta, Picchio Francesca, 2020.

[4] The data refers to interventions mapped during the urban census up to 2019.

[5] Examples of localized interventions are the Syriac Hosh in Hreizat Quarter (2011-2013) in area P; Al-Badd Museum in Najajreh Quarter (2014) in area M and the refurbishment of the road network in area U (2018-2019) and Star Street in area O (2019).

[6] The photogrammetric acquisition of the roofs was conducted by Ph.D. Francesca Picchio during the *3D Bethlehem* project. For specifics on the methods of acquisitions conducted and the tools used, see: Parrinello Sandro, Francesca Picchio (2019).

[7] This research was enforced in a collaboration between DJI Enterprise and the University of Pavia for the development of research activities, and the promotion of the different ways of using drones for cultural heritage. This collaboration is based on the "Agreement for the development of research activities about the digital documentation of cultural heritage and landscape using drones" between the Department of Civil Engineering and Architecture of the University of Pavia and iFlight Technology Company Limited, signed in February 2020, lasting three years.

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Information and Experimentation: Custom Made Visual Languages

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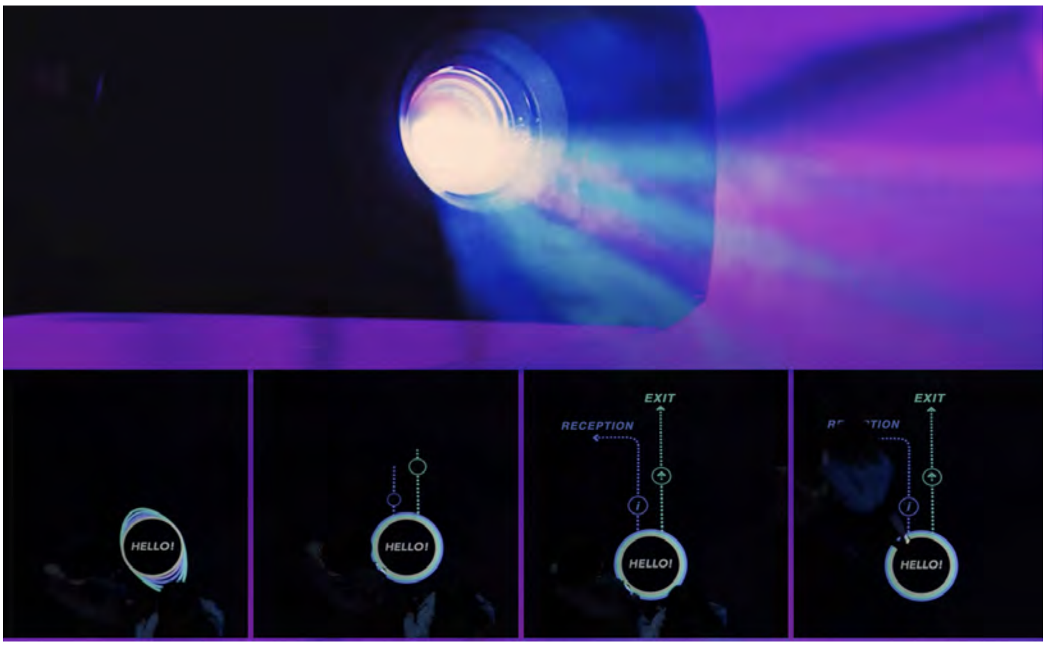
Maria Elisabetta Ruggiero
Ruggero Torti

Abstract

The collaboration between the Architecture and Design department and Grandi Navi Veloci, which began last year from the point of view of setting the visual perception of customer caring on board, was then developed with reference to the issue of communicating the data that are necessary in a certain situation; this occasion was emblematically identified in the often unspoken request for the reassurance of the user in the face of moments of unease or concern. From an initial cataloging of the factors that determine the state of insecurity, we moved on to their possible configuration through AR, with elements that inform passengers of the protection and safety mechanisms that are not immediately perceptible.
The project, therefore, studies visual languages and latest generation applications that, combined with the use of AI, are able to guarantee involvement through the communication of messages tailored to specific situations.

Keywords
visual language, augmented reality, artificial intelligence, perception, ships.



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Introduction

Visual communication always presupposes some methodological and instrumental choices that give sufficient guarantees of effectiveness, immediacy and uniqueness of conveying the message, for the purpose of its optimal understanding: this means, above all, referring to the chosen target, in order to work on languages, compatible with it, in order not to create parallel and unconnected levels among information and transmission modes.
When this should happen, in fact, different hypotheses might occur, all tending to frustrate the design effort, even if well set up and valid in the execution: on the one hand a correct use of the individual elements, on the other the impossibility of incorporating them (such as would happen, for example, if a theoretical text were read by an elementary school child, able to do it from a literal point of view, but unable to understand anything due to the lack of substantial information).
A further possibility is that, on the contrary, of providing information so general to be useless for anyone, since a general target can only receive information that is for the most part generic. Not only, but the media also have an enormous importance, since each communication vehicle makes use of suitable linguistic nuances and, on the other hand, each *medium* is preferable (as preferred for countless reasons) by each target.
In the case of communication on board passenger ships [Falcidieno et al. 2021], all of this is made explicit by the analysis of users, even if summary and carried out in large tranches: adults approaching the elderly, young couples, families. The youth target is a minority.
In essence, this allows us to identify a generalist audience, but in any case with an average computer literacy, accustomed to visual stimuli; consequently, the visual language appears suitable, despite the possible diversification of the media, to be used also at the same time, to satisfy the peculiarities of the individual bands listed above (MLF).

Operative Contest

The amount of visual stresses the passengers of a ship are subjected to is extremely numerous and heterogeneous. Decorative elements, specific elements of the shipping company, messages of various kinds and mandatory signage help to compose the whole interior of a ship, even going so far as to define the identity of a ship, if not even to decree part of its success.

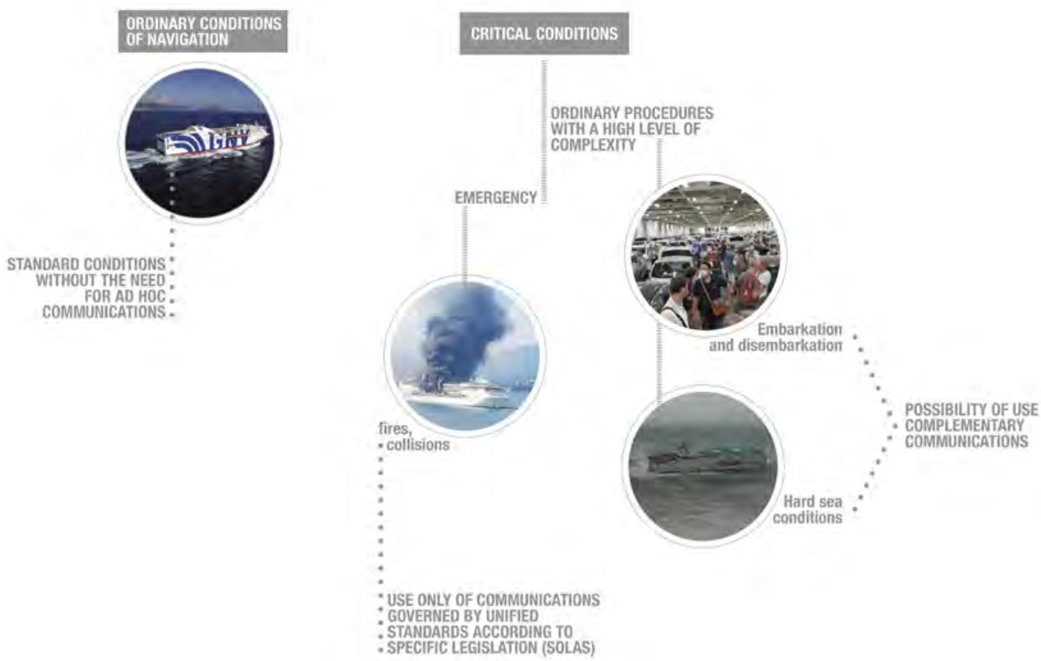

Fig. 1. Outline of possible operational contexts and types of communications.

The "suspended" and out of the ordinary dimension of certain spaces has origins that date back to the first transatlantic liners and still today this heritage is collected by large cruise ships or passenger ferries which, even if compared with them may appear modest in size, easily exceed the length of over 200 meters (with a width of about 40 meters) [Ruggiero, Torti 2020].
The stratification of signs and images that can be seen on board, however, also has functional reasons such as the integration of various types of systems, or the need to diversify spaces that could appear repetitive and uninteresting, or even make less evident the contribution of different companies involved in setting up specific areas is.
This mixture of languages generates a potential situation of disorientation, especially if associated with a further growing phenomenon, that is, the increasingly evident tendency towards gigantism of certain means, where even any references with the outside – which could give an indication at least of the direction of movement and therefore of the position of the stern and bow – are mostly hidden by the formal and dimensional consistency of the ship itself. This condition becomes particularly complex in specific conditions that require, for example, a certain speed of movement or that involve a potential crowding of people with possible consequences in the efficiency of carrying out certain operations.
The aim of the research has therefore been to optimize the articulation of custom made communications for a vessel used for passenger transport relating to specifications with different levels of criticality.
The general method has been oriented towards the definition of languages and methods that can be developed in a complementary way with respect to the mandatory on-board signage complying with specific standards.
From the Methodological point of view the research started from an analysis of the *status quo*, also conducted with specific surveys aimed at passengers of different age groups, as a part of studies for the PhD in Sciences and Technologies of the Sea [1] and subsequently the research had the opportunity to explore some issues in a discussion with the Genoa shipping company GNV as part of a specific research agreement [2].
In fact, from the carried out surveys, it was found that the perception of a difficulty in orientation is not constant but is above all connected to particular conditions.
Precisely in this regard it is therefore necessary to put forward some considerations with respect to the operational context.
In fact, there are mainly two reference conditions, namely: ordinary navigation conditions and critical conditions. The former can be considered as standard conditions without any need for thoughtful communications *ad hoc*, during which actions and directions to be taken can be carried out intuitively (Fig. 1).
The second case, on the other hand, is much more complex: for it further distinctions must be made: we can consider, on the one hand, ordinary conditions with a high degree of complexity, these are – for example – boarding and disembarking conditions, or sea conditions severe, etc. for which it is possible to think about the use of complementary communications. On the other hand, we can consider real emergencies such as fires on board or collisions; for these, obviously, communications take place according to internationally recognized protocols and make use of their own codes such as SOLAS regulation [3].
The communication for complex situations, therefore, referring to sudden or planned changes of a standard condition, can concern: the signaling of specific devices or parts of the ship itself, or, the signaling of specific actions to be undertaken or avoided.
The research project presented here, therefore, aims to establish a sort of dialogue between the ship and the passengers, modulated according to different languages.
The method used to structure these languages takes into consideration two substantial aspects: on the one hand, making the interlocutor recognizable, that is, making it clear who is the sender of certain communications; on the other hand, being able to stand out in the large amount of visual expressions that we find on board. This aspect in particular has to deal with the safety signs already present and that, in no way, they must be overshadowed or confused. Therefore issues related to orientation or to some actions aimed at improving passenger safety or comfort will be expressed in *ad hoc* created language, currently under study (MER).

Fig. 2. Formulation of concepts based on Digital-Out-Of-Home visual communication experiences implemented by Artificial Intelligence and capable of detecting behaviors and emotional state of passengers in order to act consequently with the dissemination of interactive digital content, specifically aimed at contingent situations.

Technologies and Methods

In this context, we intend to focus on the communication problems linked to orientation on board cruise ships as, being conceived both for mobility and for the entertainment of passengers, these "floating cities" are characterized by poles of interest, squares, avenues, wisely studied, from the distribution point of view, to guarantee uninterrupted flows of travelers.
A real naval urban planning consisting of a maze of paths which, despite the presence of internal sorting signs, can confuse even the most experienced travelers.
Today the communication of these horizontal and vertical connection systems is mainly delegated to traditional type signs consisting of totems, posters, brochures and other information systems that are not always effective as they are not immediately understandable or legible.
Hence the need to combine the communication equipment on board cruise ships with an experimental visual communication of a directional and informative type [Falcidieno et al. 2020].
This, in addition to being characterized by the necessary presence of a language for images – therefore potentially universal, intuitive and specifically aimed at cruise passengers as a target of reference – is based on Information and Communication Technologies (ICT), with particular attention to the use of innovative Digital-Out-Of-Home (DOOH) experiences such as Projected Augmented Reality combined with Artificial Intelligence (AI).
This proposal integrates perfectly with traditional signage that is enhanced and implemented by these sophisticated technologies for the creation of engaging communication languages capable of capturing the user's attention, amplifying his emotional involvement, facilitating the use of spaces, as well as allowing analytical insights into the real use of collective spaces [Mongiello et al. 2017].

Specifically, an integrated hardware and software system combined with the application of artificial intelligence would allow – through a series of cameras – not only to analyze a scene, to capture specific information and to recognize the trend of flows, and also to detect automatically facial expressions and behavior of passers-by.
Once the emotional state of individuals has been detected, it is possible to act accordingly by disseminating video and audio content specifically targeted to the contingent situation, needs or target audience, through the reproduction of digital content on LED walls, or Augmented Reality projection of the same (Fig. 2).
We are therefore faced with a communication of targeted and *ad hoc* messages capable of drawing the user's attention to the conveyed message, involving him in an increasingly active and interactive way thanks to a contextualized, rapid, simple and in-depth communication proposal continuously updating [Bistagnino, Falcidieno 2020]. This is a valid alternative to the recent touch screens which, in times of pandemic, have proved to be less safe from a hygienic point of view.
The communication mainly used on passenger transport boats is thus enhanced by technological realities that, thanks to artificial intelligence, are able to automatically analyze and produce statistical data that are considered fundamental.
For example, the data relating to the appropriate use of a route by its users or the actual turnout of a space or the mere subdivision by objective data – such as the age or origin of the various users of a place – constitute the information necessary for the implementation of the planned management of the communications to be disseminated, as well as for the best knowledge of the services to be offered.
In addition to the communication systems on ships based on Artificial Intelligence, we cannot fail to mention the latest generation projected Augmented Reality systems.
Once on board, users are guided by information elements – precisely in projected Augmented Reality – capable of generating a fusion between the real world and the virtual one, with an effective and captivating perceptual yield [Lo Turco 2018].
This is a technology that makes use of the latest generation projectors, combined with high definition 4k video cameras. These are combined with a sophisticated integrated system between hardware and software capable of managing the intelligent scanning of the visible structured light beams projected into the environment, favoring the point of view of the projector. Specifically, in line with the lens of the projector, the camera lens are fixed in order to have the same point of view between the two devices; the projector emits a visible structured light, while the video camera, through the aforementioned integrated system, proceeds to detect the deformations of the structured light beams.

Fig. 3. Example of an orientation idea, in naval interiors, combined with Projected Augmented Reality, created for the transmission of video and audio content capable of capturing the user's attention and amplifying emotional involvement.

In fact, the projection of a series of coded light grids – which usually consist of vertical and horizontal lines – is exploited by the high resolution video camera to evaluate the position and size of the environment and of the present objects, in accordance with the deformation of the lines recorded by the camera itself.
Finally, the video camera captures an image as if it had been taken with the optical parameters and the same point of view as the projector.
The information thus obtained is processed through a computer and converted into 3d maps of the surfaces, on which it is possible to project the light in a timely and calibrated manner. The projector therefore offers a virtual image of the environment perfectly aligned with the real environment [Factura et al. 2018].
This integrated system assumes significant importance, as it allows the processed information to be transmitted, converted into 3D maps directly on the real surfaces, which become possible screens on which to project the information. With the help of dedicated software, in addition to controlling the projection, it is possible to produce captivating and engaging visual experiences through the creative and synchronized design of visual and audio procedural effects (Figs. 3-4).
In summary, the projection of high-resolution plays of light, colors, shapes and images adapts to real surfaces, "increasing" reality with constantly updated contents.
The strengths of this technology lie in the visibility of the contents in both night and day light conditions and in not requiring the aid of devices for viewing the augmented content as is the case, however, for some other forms of augmented reality [4].

Fig. 4. Sophisticated communication system in projected Augmented Reality characterized by the projection, into the environment, of effective information elements capable of generating a fusion between the real world and the virtual world.

This particularity opens its use not only in the field of visual communication on cruise ships – which become a vector of articulated narratives according to the different needs of its users –, but also in many other fields of application, which can range from artistic installations, to the promotion of the territory, from the urban redevelopment of "non-places", to way finding and much more [Torti 2021].

Conclusions

From all the carried out considerations, it is clear that the choice of the visual language for communication is decisive with respect to the information to be conveyed and in this sense the case of passenger ship signage is emblematic, precisely because of its initial articulation and differentiation; as stated at the beginning, in fact, three levels of status are clearly identifiable, from ordinary navigation conditions, to critical conditions, passing through complex situations.
The latter are precisely the object of the research, illustrated in the attached iconographic apparatus: in detail, we worked with the complex situation of the moment of embarkation and disembarkation and with the situation of rough sea, not yet in a state of emergency, but of warning and closure of some spaces of the naval vessel.
In conclusion, these digital "navigation" tools potentially usable inside passenger transport ships make it possible to make on-board communication visible without the aid of touch screens – now obsolete for safety reasons due to the pandemic – or device or, alternatively, directly on the displays of their smartphones, tablets and viewers, thus allowing users to look at the usual horizon to relate to a space that, although delimited, is certainly complex and the object of unavoidably less intuitive knowledge (RT).

Notes

[1] PhD student Dr. Arch Nicoletta Sorrentino is conducting a research entitled *Communication, orientation and wayfinding aboard large boats: towards an integrated and user-centered digital system*; she is at second year of the docotorate courses in Sciences and Technologies for the Sea, University of Genoa, XXXV cycle, Tutor Prof. M.E. Ruggiero. The first part of the study involved the elaboration of specific surveys aimed at passengers on cruise ships or large ferries. The purpose of the survey was to identify critical phases and contexts in the perception of on-board environments.

[2] GNV Grandi Navi Veloci is a Genoese shipping company, founded in 1992. Its fleet is made up of 25 ships used for the transport of passengers, vehicles and goods. Each year it handles millions of passengers within the Mediterranean.

[3] The first international conference on the safety of life at sea was held in London in January of 1914 at the invitation of the British Government. This has been translated into approval, after the accident of Titanic, of the first International Maritime Convention, the International Convention for the Safety of Life at Sea, the SOLAS Convention, and it would certainly have been decisive, years later, to the establishment of the International Maritime Organization. The intention would be to keep the Convention updated through regular amendments so a completely new Convention was adopted in 1974, which included not only the amendments agreed up to that date but also a new amendment procedure – the tacit acceptance procedure – designed to ensure that the changes were made in a given period time, preferably short.
The SOLAS Convention is one of the three most important pillars of the international instruments, which regulate questions relating to maritime safety and pollution prevention, the other two are the International Convention for the Prevention of Pollution from Ships, the MARPOL Convention, and the International Convention on Standards of Training, Certification and Watch keeping for Seafarers, STCW Convention, and undoubtedly the most important convention in the field of maritime transport.

[4] This part of the research is supported by Ateneo 2020 Research Funds of the University of Genoa as part of the study: "Experience design" conducted by R.Torti.

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Collaborative BIM-AR Workflow for Maintenance of Built Heritage

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Abstract

The research proposes a BIM-AR workflow to ensure the monitoring of the built heritage. Indeed, the application of AR might be an extension of the BIM since it allows during the on-site surveys' phases to add and update punctual information within the BIM model overcoming the traditional survey methods based on cards. Consequently, the information models can act as collaborative tools at the service of public autorithies and stakeholders, thus supporting an efficient building management, also from a preventive perspective. The research is a development based on the results of the Fondamenti di modellazione BIM per il settore delle costruzioni [1] academic course of the master's degree course in Ingegneria Edile-Architettura [2] of the University of Padua. Starting from the students' BIM models, the workflow exposes the integrability of the AR during the on-site survey campaigns of a case study to verify the geometric accuracy and the structural problematics of the BIM models overlapped to the real buildings by recording the information directly on them.

Keywords
BIM, AR, maintenance, facility management, education.

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The BIM methodology and the Importance of Proper Sharing Practices

Nowadays the BIM (Building Information Modelling) is an essential aspect in both engineering and architectural practice. Although a simplistic conception of the BIM approach still persists, the stringent regulations introduced in the normative corpus, both national and international, are leading to an ever deeper understanding of the concept. The result consists in a more in-depth informatization of the models created which tend to become databases not only of spatial-dimensional geometric aspects, but also of all the aspects related to the management of the life cycle of the building, whether they are historical or newly manufacts [Volk et al. 2014, pp. 109-127] .
Nevertheless, the deep understanding of the usefulness of BIM is also related to necessary procedures in order to take a full advantage of its use in the most correct and manageable way. Very often numerous personalities are involved within the design team of a project, each one with specific knowledge and skills. This aspect, if not related to proper practices and understanding of the proper manage of the different tools, can cause problems in terms of timing and information sharing within the design process by the various personalities involved [Bosch et al. 2015, pp. 331-343].
Related to the production of documentation by the different parts involved in the project teams, fundamental is also the aspect assumed by the sharing of the models and documentation through proper files formats: this aspect has a key role related to the information exchange inside a more wider collaborative process known with the name of openBIM [Jiang et al. 2019; Jo, Choi 2021]. It is an approach, whether through shared platforms or individual exchange, which guarantees the efficiency of the BIM process, endorsing to the requirements imposed by legislation in favour of a more virtuous one in terms of timing and accuracy of information, especially in terms of public works. Such a practice, if coherently marked through the workflow shared by the different actors involved, as well as by the authorities proposing the works, may lead, to a deep change in the concept of information cataloguing in favour of systems for integrated digital management of artefacts (BMS).

UNIPD BIM Educational Aim

It's precisely the understanding of constant updates within the BIM concept and the teaching of this profound conception that is one of the aims which the University of Padua has been proposing in recent years within the master's degree course of Ingegneria-Edile Architettura, specifically in the Fondamenti di modellazione BIM per il settore delle costruzioni course.
The need to teach the correct practices of BIM, from geometric-spatial modelling to informatization and sharing practices, becomes a precious baggage of knowledge and professional skills for students for their future careers to be able to face efficiently the increasingly demands of the labour market in the architecture and engineering sector, as well as of public administration. In fact, it has been seen how many students, through feedback with former of them, after completing their studies, have found employment in the sector of studies' specialization and particularly within professional firms and companies that require the mastery of BIM as design tool tout court of a broader integrated process.
During the academic year 2020/2021, the Fondamenti di modellazione BIM per il settore delle costruzioni class [3], has offered to the students a knowledge strongly oriented to the aforementioned BIM perspective, paying particular attention to classification and sharing information topics and practices, often underestimated and sacrificed in favour of the only geometric-spatial modelling, in continuity with the common simplistic perspective of BIM practice.
To offer students the most complete and structured possible knowledge, an operational workflow has been equipped to both organize the phases of the course, but also to propose a practice adoptable by the University of Padua for the management of the built heritage. With this purpose, the course proposed real case studies relating to the UNIPD building heritage, as buildings to be modelled and informatized, thus generating operationally valid digital twins that can be used in various phases of the management of the buildings over the years.

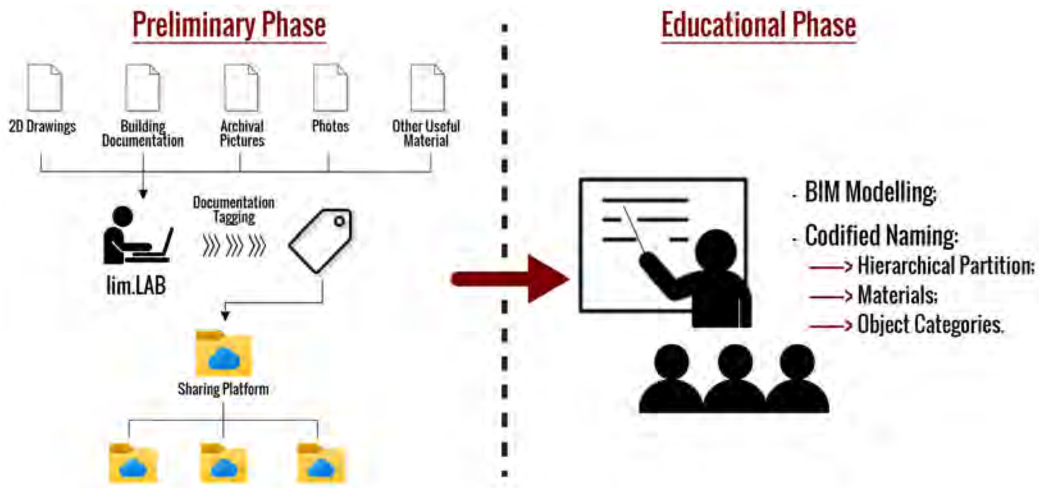

Fig. 1. Operative phases of the first part of the researc.

The academic program was organized in two phases (Fig. 1). The first one had as its purpose the informative systematization of the material according to the documents' typologies made available by the University of Padua and other institutions, according to an alphanumeric code based on the use of the UNICLASS 2015 in order to organize the material through different levels of reading. The cataloguing of the input files obtained therefore provided for the assignment of tags for each individual file in line with the notions contained in reference to the Structural Brakedown System, Role and Project Management for each building. This informative structure then was made available to students for the developments of their projects. The vastness of the documents, which ranges from historical archive files to *in-situ* photographs, from dated and recent project drawings to construction estimates, has thus found a first indexing suitable for the exploitation of easier targeted research paths. In support, a naming was implemented for the same files, which in accordance with the building project, the specific part of the same, the area, the project phase, the specific discipline of the document and the type of document, assigns the name to the file using sequential alphanumeric characters.
The second phase, viewed the teaching of the correct consolidated modelling practices through BIM software for the models' generation, but with it, also the teaching of further best practices aimed at sharing the models and documents generated between students, as well as with the reviewing teachers.
The students, organized into groups, were then assigned the specific case studies with the related input materials already systematized, and the creation of the BIM model was requested, paying attention to the implementation of further information based on precise nomenclatures studied to informatize specific aspects such as spatial hierarchy, materials and types of objects used for modelling. The proposed case studies are existing buildings, some belonging to the patrimony of the University of Padua, but also others of public interest such as provincial school buildings and others of historical, artistic and religious value. The choice of this typological variety has offered students the opportunity to explore different aspects of the digitization BIM process which, although unique from a methodological point of view, requires specific attention strictly deriving from the particular type of building under consideration.

AR-BIM Integration

The outcome of this digitization process is represented by the students' production of BIM models of existing aforementioned buildings which are very heterogeneous in terms of function and levels of architectural value.
The three-dimensional models were used for testing a workflow that involves the integration of Augmented Reality within the BIM methodology aimed at facilitating the management of buildings during their life cycle.

With reference to the first definitions and to the schema published in 1994 by Milgram and Kishino [Milgram, Kishino 1994], AR is defined as a system capable of enriching physical reality by adding virtual content, using a technological tool as an intermediary [Russo 2021, p. 4]. This, in a wider view, is part of the general domain of Mixed Reality (MR), as it is properly inserted at the intersection between the real and the virtual worlds. Thanks to this specific characteristic, the AR is becoming extremely widespread in many fields and among them, the AEC sector is also following this trend.
In recent years, the purposes and use cases related to the implementation of AR in the construction industry have found progressive applications in academic literature and the professional field [Alizadehsalehi et al. 2020]. In reference of the proposal in [Russo 2021, pp. 24-28], these use cases can be divided into three macro-research areas:

• AR for the enhancement of the built;
• AR for the design and construction process;
• AR for professional training and education;

The first category, strictly related to the Cultural Heritage sector, involves all those researches aimed at improving the buildings' knowledge, fruition, and maintenance. In these cases, AR plays a fundamental informative role in making the physical space's impact more effective and engaging to the user, be it a tourist, a designer or a manager. [Russo 2021, pp. 25-26]
The second application area includes all the trials in which AR supports design and construction, both on architectural and urban scale [Katahira, Imamura 2016]. In this way, similarly to VR, AR is part of highly collaborative design approaches, capable of optimizing the design and decisional phase through innovative visualizations of multidisciplinary analyses [Fukuda et al. 2015].
As regards the construction phases, there are many applications proposed to supervise its evolution during the different stages; by exploiting the possibility of overlaying the virtual project on the reality, the researches show extremely positive results in terms of safety [Li et al. 2017], logistics management, prevention and reduction of inaccuracies with consequent reduction of both time and costs [Park et al. 2013].
Finally, the third area involves all the cases in which Augmented Reality is used to guide a learning process [Russo 2021, p. 27]. In AEC sector there are more and more applications in which, through the virtual superimposition of information, AR supports workers in carrying out assembly activities or in implementing directives on the mitigation and safety of workplace's risk [Cuperschmid et al. 2016].
However, despite a richness of contributions, the literature seems to deal in an uneven way with the extensiveness of AR application fields in the AECOM sector, resulting limited with respect to possibilities that might be offered by integrating it with Building Information Modeling and Facility Management approaches.
Based on the literature of recent years, there is a prevalence of research focused on the usage of AR systems during the first design and construction stages, giving limited interest to the subsequent life cycle management of the buildings [Alizadehsalehi et al. 2020; Wang et al. 2013, p. 6]. This consideration points out a partial exploitation of the technological integrability potential and the results, in a broader perspective not only of BIM, but also of the entire construction sector, appear reduced if compared to the effective usefulness that XR could offer.
A wider view in respect of the AR applications would therefore be desirable because if correctly related with BIM, a virtuous support and development process of data sharing would be introduced. This integrated methodology aimed at optimizing the informative organization during the several phases of the construction process, as well as the management of the asset by the manager, avoiding the risk of information overloads and inconsistencies [Chu et al. 2018].
This gap represents a strong incentive for the potential development of hybrid solutions with the common purpose of improving the building process, from design, to construction, to the management of historic and newly built assets.

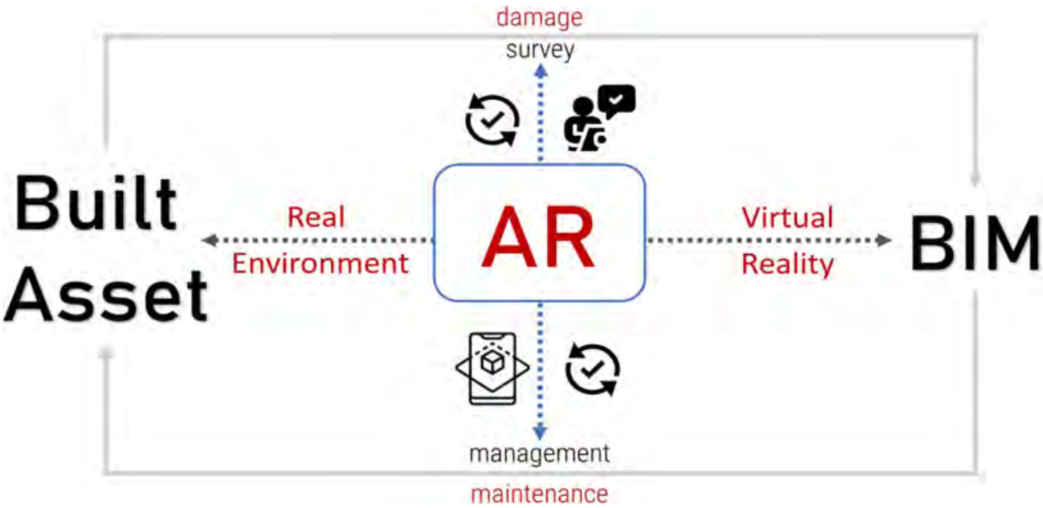

Fig. 2. Milgram and Kishino's schema reinterpretation, adapted to BIM-AR integration

Challenged by these potentials, the research offers the chance to optimize the monitoring activities and consequent management of buildings, allowing the information contained within the BIM model to be updated directly in situ.
In this process, Augmented Reality (Fig. 2) acts as a medium between the virtual and physical environment, becoming a support for interoperability, conveying the informative apparatus from the design to the construction and management phase [Alizadehsalehi et al. 2020].

Aims and Requirements for Suitable AR Software

Starting from this awareness and the purpose to verify the potential of the BIM-AR on a real case study, an operative workflow was aimed at simplifying the information updating activity during the inspection phase and at facilitating the following management phase of existing buildings.
The operative phase was preceded by a preliminary review of the characteristics of the AR systems available on the market in order to satisfying two main needs: information accuracy and interoperability through a collaborative environment.
The first requirement derives from the inherent nature of the BIM collaborative process of consistent data conservation. For this reason, a solution was therefore sought that would preserve the integrity of both the geometric and informative structure, limiting data loss to a minimum during the exchange and export process. This need acquires a key value as the BIM models represent structured coherent databases resulting from careful modelling set on a virtuous organization of the information inputs. For this reason, the conservation of this 'strong' data assumes a key role in the proposed pipeline.
The second constrain is the collaborative approach linked to a central synchronization system of the data flow with the model. Inside a large range of solutions, were considered only the ones that can guarantee a multi-user sharing of the BIM model on several types of devices, ensuring in a single digital environment a complete exchange and communication of information.
In sight of these needs and reasons, the most appropriate software was considered Unity Reflect, a package proposed by developers by the homonymous graphic engine, including plugins and a real-time BIM viewer (Unity Reflect Review).

Proposed Workflow

The workflow (Fig. 3) experimented is developed by considering as a case study the federated BIM models produced using Autodesk Revit software by the students who have been assigned the Mechanical Engineering building complex of the University of Padua.
The first phase of the process involved an "export", through the dedicated plugin, of the complete BIM model within a new Unity Reflect project, shared with the entire research

group. It is essential to point out that this "export" phase takes the form of a multi-platform link in real time between the model in the Unity Reflect project and the starting BIM file. Clarifying this aspect underlines the integrity information key necessity because the link and synchronization process in local and cloud mode of the two models guarantees the reduction of data loss and allows constant updating of the same.
Following the connection process, the model is visualized through a simple app, which can be installed on fixed and mobile devices. This tool offers the main features of a BIM viewer, but also allows navigation modes in augmented and virtual reality, also supporting the use of viewers or other external devices for immersive usage. However, a fundamental aspect of the research is the opportunity of sharing the project between different designers and stakeholders, who can simultaneously access and check the model in real time, from any type of device.
The research then explored, verified and evaluated the applicability of the main available features offered by the Unity Reflect package to support Augmented Reality for the specific case study and which differ according to the scale of representation and the tracking system of the elements in the physical reality.
These are:

- View Match, able to load the model in 1:1 scale, aligning it based on the extraction of features detected by the internal device camera;
- Corner Match, capable to show the model in 1:1 scale starting from the detection of an edge of the building and a horizontal plane near it;
- Tabletop, able to display the model on a variable scale by anchoring it to a flat surface;
- AR Marker, capable of displaying the model in variable scale after scanning a QR code used as a physical marker [4].

After verifying the different approaches related to the objective aimed at defining the research purpose, it was observed that the first two modes are more functional. In particular, the "Corner Match Tracking" approach was opted as it is able to guarantee greater stability and precision in the identification and connection between real and virtual elements through an efficient markerless tracking system in the operative phase.
Once the two realities were connected, by superimposing the BIM model on the physical building during a quick on-site campaign, it was possible to approach the different monitoring operations. We then proceeded to evaluate the accuracy and geometric inconsistencies of the virtual model, as well as the reliability and progress of the students' information modelling and implementation processes.
From the results observed during the survey campaign, the collaborative annotation process was then verified and systematized: specifically, synchronized reporting tests were carried out with respect to some erroneously modelled objects, indicating the conflicts, but also typical problems that can be traced during the verification of the conditions of the real buildings (expulsion of iron covers, detachments, presence of vegetation, etc.).

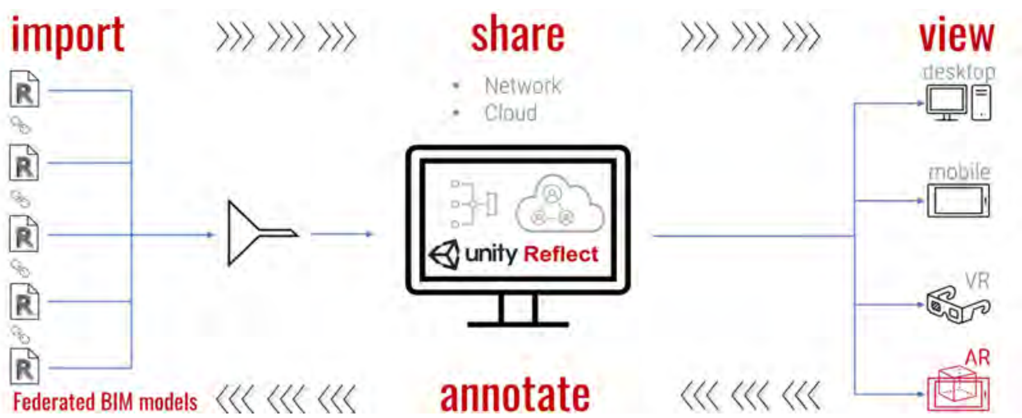

Fig. 3. Operative workflow schema

These annotations, made directly *in situ*, are synchronized in real-time and in-cloud in the BIM model on the sharing platform, updating a specific field that becomes instrumental not only to the expert who is operationally surveying the building, but also of all the professional figures involved in both the technical modelling process and in the management of the asset.

Conclusion and Future Developments

From the results of the research it is evident that BIM-AR integration can become an excellent practice supporting not only the digitalization process of new and built assets, but also for the consequent activities related to the management and maintenance phase. Furthermore, the development of the research highlights the applicability, albeit in the specific case related to a building of relative recent construction, also to buildings of historical and artistic interest. From a hBIM perspective, in fact, where the building is often bound by regulatory protection requirements, the integrability of the AR, through its non-invasiveness, enables more precautionary investigation campaigns, also in relation to the different stages of development of the building investigated. Such an investigation, related to the information update, leads to complete models from a spatial, configurative and informative point of view, giving the possibility to redact documentary and digital apparatuses that are extremely useful for understanding the historical-artistic importance of the buildings.
Thanks to the importance of managing these aspects within the entire AEC sector, the application of the proposed workflow can become an added value to be introduced to the professional knowledge base within university teaching by increasing the level of competence of students. with a view to greater competitiveness in entering the world of work.
An operational proposal for this purpose will be the development of sessions and practical experiences in which students are encouraged to exploit the proposed BIM-AR integration to approach the creation of even more structured and complex BIM models, thus leading to a virtuous process of development of didactics oriented towards advanced digitalization through emerging technologies.

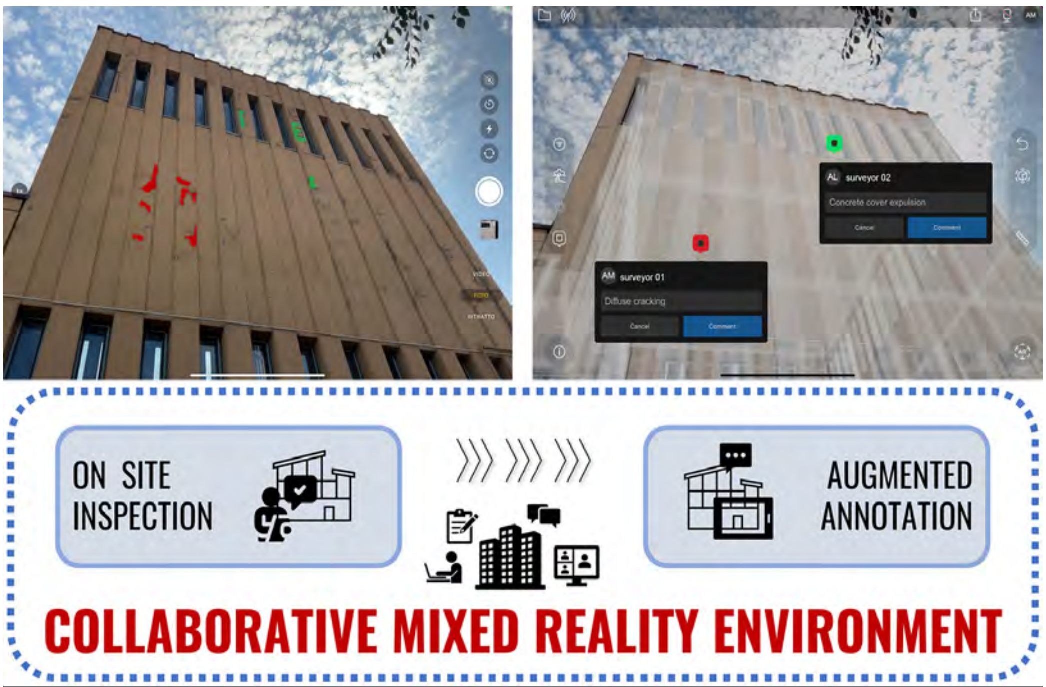

Fig. 4. Screenshots taken during the experimentation of the proposed workflow.

Notes

[1] Academic course of Building Design.

[2] Master's degree course in Building-Engineering and Architecture.

[3] The course was coordinated by Prof. A. Giordano and assisted by the LIM.lab (Laboratorio di Modellazione Informatizzata) research group of the DICEA (Dipartimento di Ingegneria Civile, Edile ed Ambientale).

[4] This tracking method was introduced after our testing phase, therefore it has not been evaluated in this research.

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Connecting AR and BIM: a Prototype App

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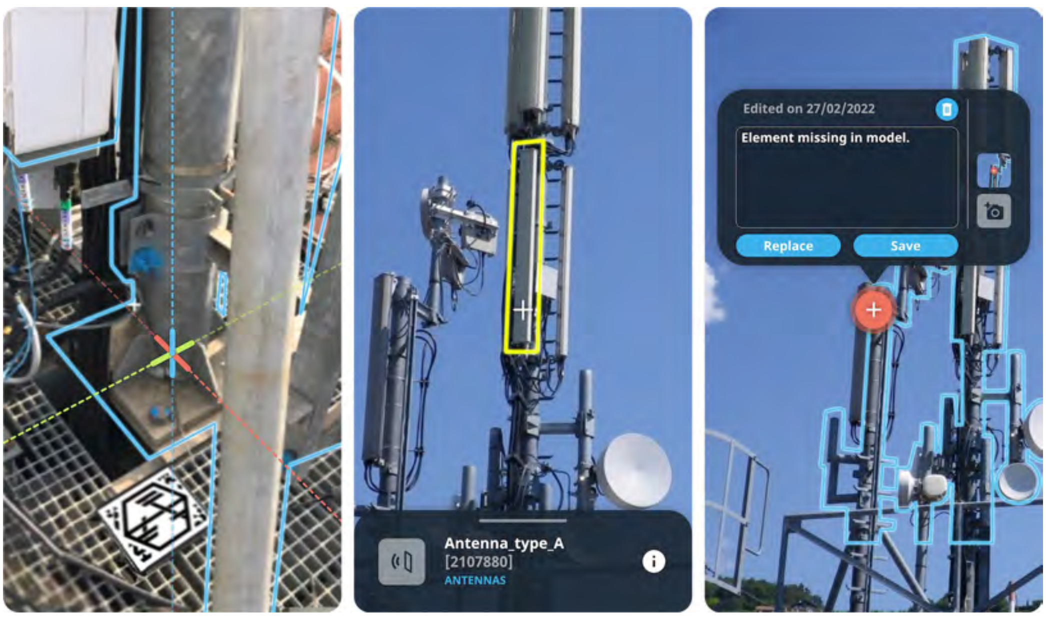
Abstract

This contribution discusses an ongoing project integrating information modeling and immersive technologies for the built space, in particular augmented reality (AR). We examined tools and procedures to quickly recognize the equipment present on telecommunication network sites and access the corresponding components on a digital information model. A first phase of the project, recently completed, produced an app prototype for mobile devices capable of showing a 1:1 scale AR representation on-site. The project highlights current limitations and opportunities in making the interaction between AR and building information modeling (BIM) technologies fully scalable.

Keywords
AR, BIM, AEC, project management.



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Introduction

By making possible an interaction with the digital object closer to the experience of reality, immersive technologies are innovating the management of architectural artifacts. In the architecture, engineering, and construction (AEC) sector, the visual juxtaposition of real and virtual objects can support the comparison of designed and built components, the systematization of on-site progress tracking, and, more generally, the symbiotic evolution of the building and its "digital twin" [Khajavi et al. 2019].
This contribution discusses an ongoing project integrating information modeling and immersive technologies for the built space, in particular augmented reality (AR). The project stems from a research contract between the Department of Architecture and Design of the Politecnico di Torino and the industrial partner INWIT, the first Italian operator of infrastructures for wireless telecommunications. INWIT operates an extensive network of antenna towers and related equipment. These assets have recently undergone a digitalization process, documenting the current state of the sites through building information modeling (BIM) and making data accessible through a corporate cloud platform (Fig. 1).
The partnership studies semi-automatic systems to recognize artifacts and support professionals and non-expert users during site surveys. Technologies such as AR and AI can support data query and update operations [Ahmed 2019; Ma et al. 2019]. In particular, we examined tools and procedures to quickly recognize or search for the equipment present on-site to access the corresponding components of the BIM model. A first phase of the project, recently completed, produced a prototype of an app for mobile devices capable of superimposing a 1:1 scale AR representation onto real-time imagery of the antenna towers site. The app will allow the user to view the 3D models of the company's BIM database, query data and metadata, and send reviews and reports to the BIM management team directly from the site through easy-to-use functions. The research also highlighted the advantages and limitations of solutions using the physical objects themselves as a target for setting the AR experience [Spallone, Palma 2021]. In fact, currently available technologies allow the recognition of architectural structures and equipment as reference points for positioning digital components, accurately superimposing them on real objects.

Background

With the development of mobile computing and the spread of mobile devices, AR shows growing benefits in the AEC sector, where more consolidated experiments and applica-

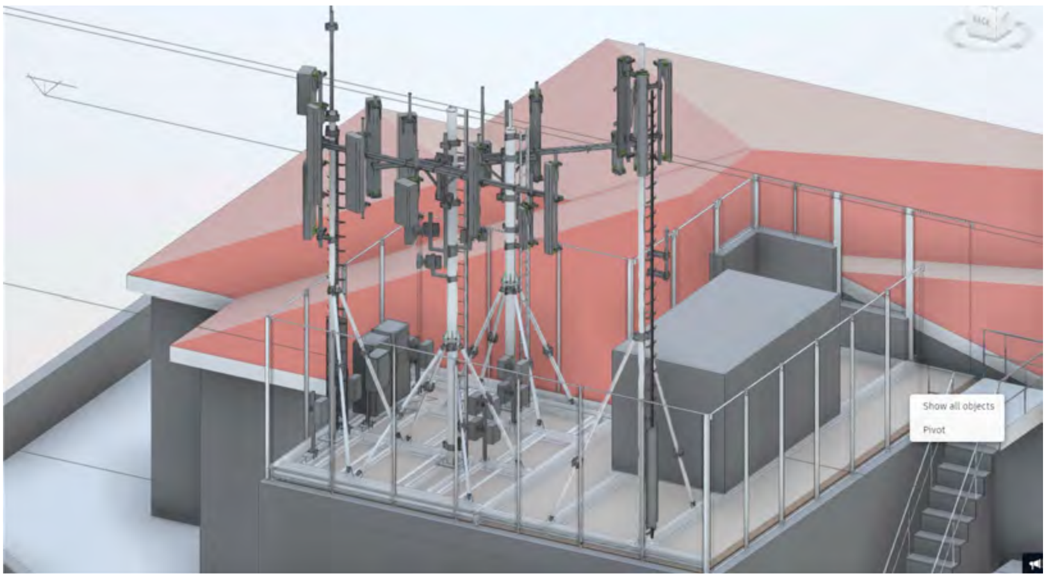

Fig. 1. Axonometric view of the BIM model of a site managed by INWIT (screenshot from the Autodesk Viewer web service).

tions are underway [Song et al. 2021]. AR allows superimposing digital layers onto camera images, simulating the user position relative to the virtual objects by tracking the observer's movements [Milgram, Kishino 1994; Amin, Govilkar 2015]. Hence, AR tools facilitate the search, exploration, and understanding of space-related digital information by making the experience closer to physical interaction. Some of the proven advantages for AEC applications relate to project communication and collaborative work, construction safety, process monitoring and progress tracking [Ahmed 2019]. The continuing development of headsets could make available cheaper and lighter devices than current products, giving new relevance to the use of AR, particularly on construction sites and in other contexts where safety is crucial [Sitompul, Wallmyr 2019].
Despite the high attention paid to these technologies and a recent "renaissance" of AR in construction [Chen, Xue 2020], this research field is still limited, especially when compared with other sectors. Although some experiments have been proposed [Garbett et al. 2021] the integration of AR and data-intensive cloud databases appears rare, notably for the management of BIM data [Chen, Xue 2020]. Features to work remotely on complex projects by accessing data from an immersive interface has yet to be incorporated into consolidated workflows and fully scalable systems. Though AR-BIM interaction is still not very present in literature and applications, researchers have highlighted how BIM and AR technologies can bring mutual benefits [Noghabaei et al. 2020]. For example, AR can improve communication between the different professionals involved in the management of a complex project and can facilitate the exchange of information between construction site and project. Furthermore, many commercial applications and development tools are still based on physical markers. This constrains the creation of a connection between real space and digital model to site-specific projects and design and installation costs, placing further obstacles to scalability.

Methods

The sites managed by the company show a wide variety of typologies, but the project focused on a subset of sites characterized by low-rise towers. Such sites host antennas on poles or small pylons, as well as other ground equipment, which include switchboards and power stations. It is therefore expected that the activities of the operators that we want to facilitate will take place on the ground and without the aid of special equipment. The most relevant elements in terms of standardization (e.g., antennas and electrical equipment) are also the most susceptible to alterations, such as replacement and reconfigurations. This allowed us to hypothesize advantages from automatic recognition tools.
In the first phase of the project, we analyzed different technologies for mobile devices to evaluate the compatibility with antenna sites and their management. We started by identifying a series of relevant parameters, values that can be measured on-site, and types of elements that may vary over time. We considered complex systems, such as those based on computer vision, and more straightforward ones, such as tools to let the user collect images or other data. Although the operational phases carried out so far have focused on augmented reality, the project is oriented to represent a discussion on the role of different technologies in the modeling and maintenance of the studied infrastructures and similar. The team selected two main categories of objects as priorities for the assisted survey functions: data devices and ground electrical equipment, such as switchboards and power stations.
The AR tools were found to be relevant for navigating information given its spatial position on the site, as in the case of BIM component attributes. Focusing on this technology, we have been developing an app for mobile devices that allows superimposing a 3D model onto camera images. The prototype app allows to navigate the company's BIM documents intuitively. We developed two main function classes. The first is composed of tools to identify components on-site, through search functions, or by exploring the hierarchical structure of the BIM model. The second class of functions concerns select-

ing BIM components in the 3D space to obtain data or produce reviews and reports.
Much attention has been paid to the app scalability, which will have to be used on hundreds of different sites. The app and the server that allows it to work required the development of three main modules or components (Fig. 2):

1. The first module concerns the communication between the app and the BIM database.
2. The second is the graphical interface, and its development involves only the app.
3. The third is the AR module, and it too, to be scalable, requires communication with the server, as we will see in more detail.

Based on the solutions already adopted by INWIT to manage the BIM database, the Autodesk Forge platform was used for the model archive and the exchange of information from and for it. The mobile app is built in Unity, a development environment for cross-platform applications, popular in game development and suitable to build applications that make intensive use of 3D models. Finally, we used the Vuforia development kit for AR. This toolkit is compatible with Unity and supports many different anchoring systems.

Backend

The first module, allowing the app to communicate with the BIM model archive, employs the application programming interfaces (APIs) of the Forge platform to interact, in reading and writing, with the models collected on the company's server. Through the APIs, the server can receive requests to which it responds with a text message that can be easily interpreted by the client (in JSON format). In summary, the app will ask the server for information, such as sending changes to some selected parameters.
The workflow we developed specifically employs Forge's Model Derivative APIs. We have verified the possibility of bringing the metadata of a Revit project into the application through scripts in C#, which is the primary programming language for scripting in Unity. At this stage of progress, scripts have been tested with the Postman software. The JSON results have been inserted into the Unity app verifying the possibility of reconnecting the downloaded information to a geometric model for display.
The server will host not only the visualization models (that is, the 3D component of the models) but also the reference objects used for AR anchoring and tracing. Other functions hosted by the server will concern AR and should address the app scalability. For the tool to be usable in the various sites managed by INWIT, the digital models must be accessible through the server instead of being permanently stored on the app. Similar features are still little explored in the literature, and even commercial software tools offer limited possibilities for cloud storage.

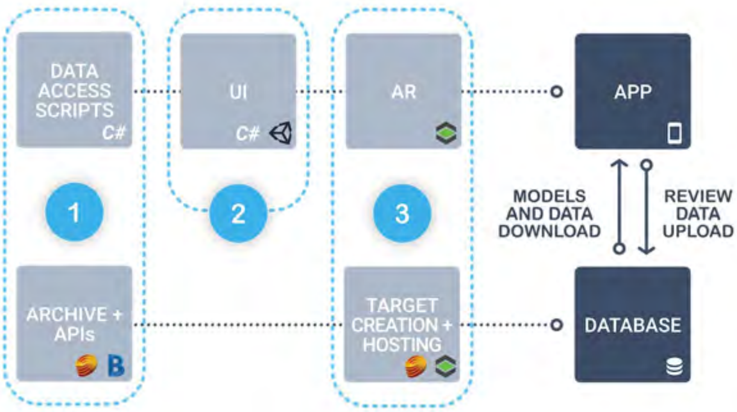

Fig. 2. Scheme of the structure of the app-server system.

AR Targets

AR targets can be images or more complex, large, non-standard targets. In particular, Vuforia allows the recognition of three-dimensional physical structures as reference points for positioning the digital layer (precisely aligning the latter and the actual objects). In this case, the targets can derive from digital reproductions of physical assets (meshes or point clouds). Currently, the project is validating a more typical anchoring system based on bidimensional targets, but we conducted the first tests on compatible 3D targets for Vuforia and carried out some preliminary assessments that may influence the development of the study. Mesh-based target models were the most studied option. The effectiveness was tested using small-sized models as targets. Our tests have found that target generation from BIM documents involves many processing steps. Hence, difficulties arise in automating the task, which, up until now, has been undertaken manually, using the graphical interfaces made available by Vuforia. The functioning of the targets on the site proved to be very sensitive to the discrepancies between the site and the models. We therefore assessed the solution as non-viable due to the accuracy of the models currently available to INWIT. Much work is still expected to identify the optimal targets, especially among markerless solutions.

Frontend

The app will include the following functions:

a. Recognition of the target and fine-tuning of the model position.
b. AR selection of elements through the exploration of physical space.
c. Selection of elements from a list and related AR highlighting.
d. Metadata editing and related AR highlighting.
e. Markup system.

Functions are based on the superimposition of the BIM model on the visualized space. These currently do not supply direct alteration and writing of new information in the BIM document. Only reading operations and the forwarding of reviews to the modeling team are supported. In this way, the communication process with the server is simplified, the risk of affecting the consistency of the database is limited, and modeling is entrusted only to expert personnel.

a. Recognition: at the current state of the project, the prototype employs QR-like bidimensional targets. The alignment of the model to the site is set by framing the target object. By pointing at the marker, the app obtains the identification code of the visited site and automatically starts downloading the correct model. Metadata, i.e. the attributes of the elements, are also downloaded. Alternatively (for example, in the case of damaged or not readable markers), the user will be able to enter the code manually. Once the target is recognized, the pattern appears superimposed on the camera images. Upon target installation, or following displacements or other correction needs, the alignment of the model to the real object can be refined directly from the app (Fig. 3). We have developed a system of sliders corresponding to the three coordinated axes and the rotation on a vertical axis to move the model to the correct position before activating other functions. The user can also confirm the last saved position without making changes. When fully operational, this system will require the association to each target of the relative position of the linked model. To further simplify the alignment procedure, the BIM modelers will first set up the expected model-target relationship. The subsequent on-site installation will take place within a certain tolerance (for example, within plus or minus one meter) and the commands on the app will only allow such slight corrections. One of the main critical issues concerns the management of larger sites, with structures and equipment arranged at distances greater than ten meters and sometimes at different levels. This problem can be addressed by allowing more than one target for each site.

b. AR selection: the ability to easily select elements as modeled in the BIM project is the main feature allowed by the AR tools. The goal is to let the user observe the site and at the same time obtain data from the information model. The developed system features a pointer that selects the element placed at the center of the device screen (Fig. 3). By making the mesh transparent, we can emphasize a single object, such as an antenna or an electrical panel, by showing only its outline. The result is perceived as a highlight around the physical object. In the prototype, a panel shows the identity of the highlighted element in real-time and allows the user to access the complete list of metadata and other related functions.

c. Selection from list: since, together with the geometric model, the app downloads the associated metadata, the user can also identify an object of interest from the list of represented elements. A textual query tool will simplify the search. AR will therefore allow the user to select an object while keeping its outline visible even when it is not under the pointer. In addition, a system of superimposed arrows will show where to move to find the previously selected object, even if it is not in the field of view (Fig. 3).

d. Metadata editing: the app will allow the operator to request modifications to the component's metadata. At the current stage of the work, no solution for the remote editing of instance parameters has been identified. Therefore, the use of a database of proposed alterations is planned. Changes will be shown in the element's attribute list view (Fig. 4). The new values will be displayed as the current attributes of the component, reporting whether the change has still not been confirmed and updated by the modeler. In this way, annotations are necessarily submitted to a second check by the modelers or site managers. Attribute alterations or a removal indication (if a modeled element is no longer present on the site) will also be highlighted in the AR view to keep track of the changes made. The already developed outline system can be used for this purpose (Fig. 4).

e. Markup system: the removal of an element can be managed through the metadata editing function just described. Adding elements to the model (due to a gap or an integration not yet registered) requires a system to indicate a position on the model not necessarily linked to a specific component. For example, to indicate that an antenna has been added, its anchor point on the pole could be selected. Thus, we propose a function to choose a hotspot on the model (Fig. 4). The issuing procedure will allow adding a written comment and some images, including the screenshot of the anchor point and any photographs taken by the user, also from other points of view. This information can be used by the modeler to create a draft of the modeled element, which can be integrated through subsequent surveys.

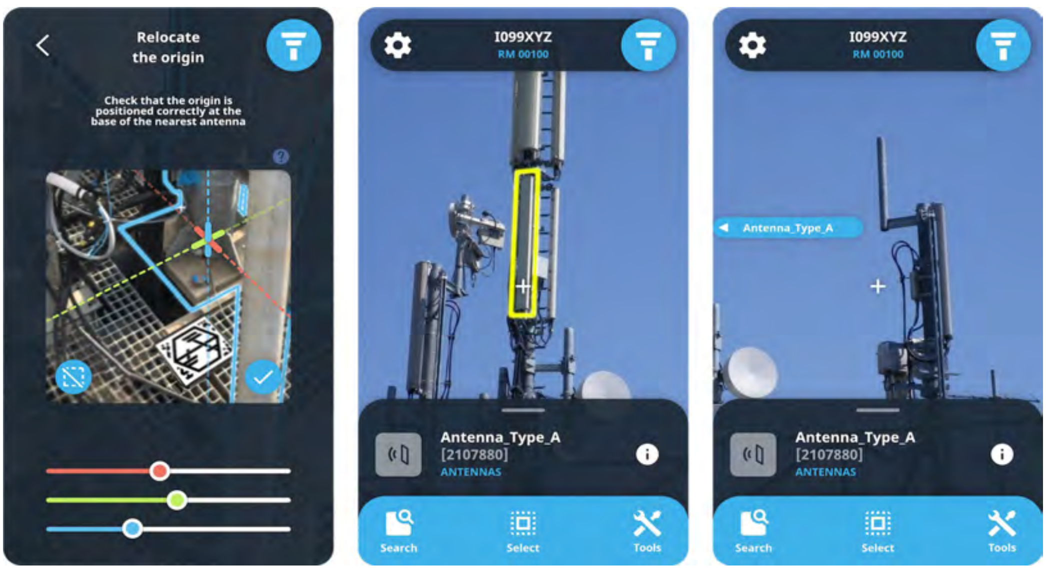

Fig. 3. Representation of the designed app functions. From left: fine-tuning of the model position; object detection and metadata retrieval; arrow indicating the selected object.

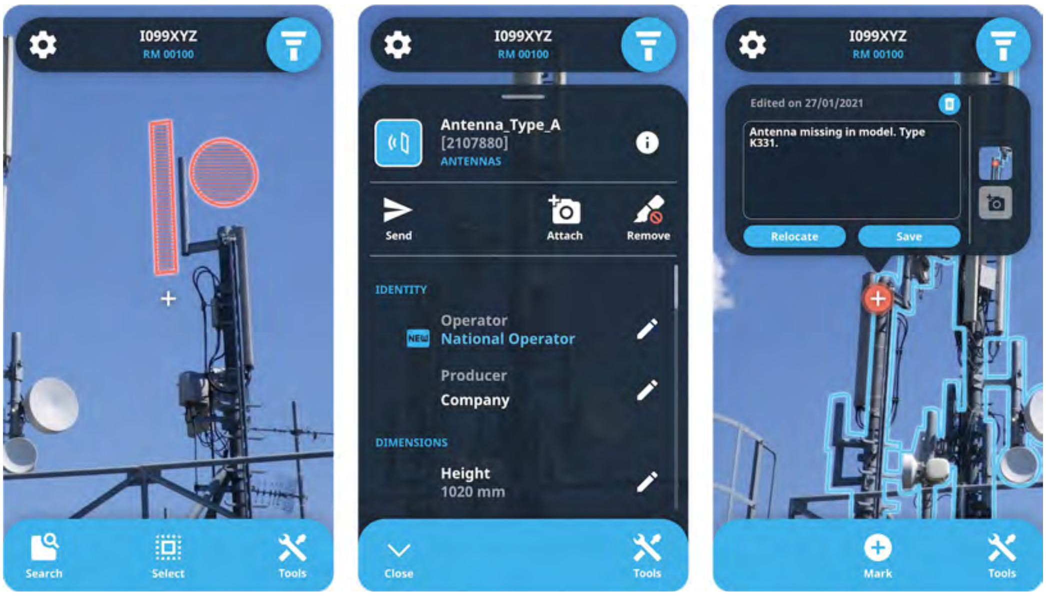

Fig. 4. Representation of the designed app functions. From left: hatching indicating removed elements in AR; metadata and editing functions; markup system.

Conclusions

This contribution described the development of an app prototype for the in situ analysis of 1:1 BIM models via AR, aimed at the management and maintenance of telecommunication antenna sites. The work made it possible to identify software procedures and tools available on the market to create an AR app compatible with a BIM database in the cloud and suitable for easily generated anchoring systems.

Results of the first phase of the project include the validation of three main modules of the app-server system. We discussed the development and compatibility testing of these modules, currently being realized separately. The first module demonstrated the compatibility of the Unity app with the Forge system for exchanging data with a BIM database. Future work will have to make the APIs fully operational on the mobile device to enable scalability. The development of the user interface component sought fluid and intuitive navigation of the model and its metadata. As for the AR module, we verified that the stability of the marker-based anchoring system is suitable for the intended purposes. Furthermore, different functions were tested to highlight elements and indicate if editing occurred.

The main limitation of the developed prototype concerns the use of physical targets produced *ad hoc*. The solution involves costs of design, installation, and maintenance. This choice will have to be re-discussed based on the diffusion of increasingly sophisticated markerless systems in AR development kits. A three-dimensional object recognition system based on natural features will allow defining the relationship between the site and its model remotely and in batch, and to avoid site-specific targets. In the oncoming research phases, we will evaluate in greater detail the targets to be used. In particular, a comparison between mesh targets and point cloud targets should be performed, addressing both the effectiveness of the AR experience and the possibility of batch-generating the targets.

In conclusion, the project laid the foundations for continuing research on critical aspects that still limit the adoption of BIM-enabled, fully scalable AR applications.

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Built Heritage Digital Documentation Through BIM-Blockchain Technologies

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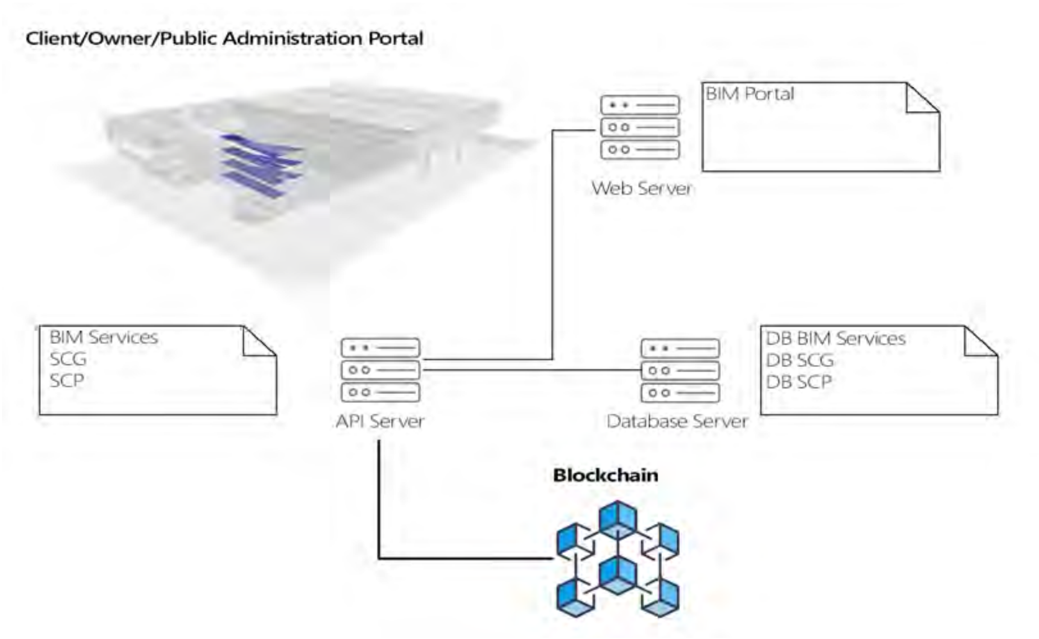
Marcello Balzani

Abstract

Despite rising digitisation, the construction industry continues to be marked by redundancy, multiplication, and, at the same time, a lack of transparency and disaggregation of data and information, resulting in inadequate project life cycle management in terms of time, cost, and quality. This paper presents the results of the development of a TRL 4-5 ICT application based on the integration of Building Information Modeling and blockchain technologies, with the goal of fostering digitisation processes in the supply chain in the direction of greater information flow transparency, knowledge-based organizations, and decision-making processes based on unambiguous ordered data. The initiative, which began as a broader industry research cooperation, now includes a university spin-off, companies that operate as system integrators, and leaders in the customisation of BIM solutions for the built heritage value chain.

Keywords
digital documentation, BIM-blockchain, common data environment (CDE), bigdata.



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Introduction

BIM (Building Information Modeling) tools are increasingly being utilized to show that knowledge can be organized sharing integrated digital information systems that support all phases of the construction life cycle. Following the United Kingdom's lead in initiating the digitisation process in 2009, a number of Member States have taken numerous steps to encourage the use of BIM tools, which are widely recognized as the most effective driver for a more widespread digital transformation of the construction sector [Daniotti 2020]. In the national context, the adoption of the new Public Procurement Code, Ministerial Decree 560/2017, which made the use of BIM tools essential, achieved a similar impact; currently, the compulsory requirement corresponds to contracts with a value of less than five million euros. Furthermore, the aforementioned scenario has sparked a broad drive in the industry to adopt Building Information Modeling tools independent of mandatory requirements, particularly when it comes to interventions on the built environment. Specifically, the Agenzia del Demanio advertised more than 110 BIM tenders worth more than 200 million euros between November 2018 and December 2020. Fifty-five tenders were awarded for architectural, structural, and plant engineering surveys, diagnostics, and a technical and economic feasibility plan for assessing the built heritage's seismic risk.
The use of analogue information tools, as well as redundancy and duplication of data on the one hand, and information gaps on the other, continue to characterize the sector, resulting in inefficiency in design and construction processes, delays, poor risk management capacity [Nawari 2019], and conflictual behavior. Contracts specify how the parties involved will behave. Transparency and clarity of information become crucial needs as a result. The expanding number of testing of blockchain technologies in the construction sector, which are also connected with BIM technologies, demonstrates the supply chain's growing interest in the advances offered by this technology to address structural inefficiencies in the value chain [Autodesk 2020].

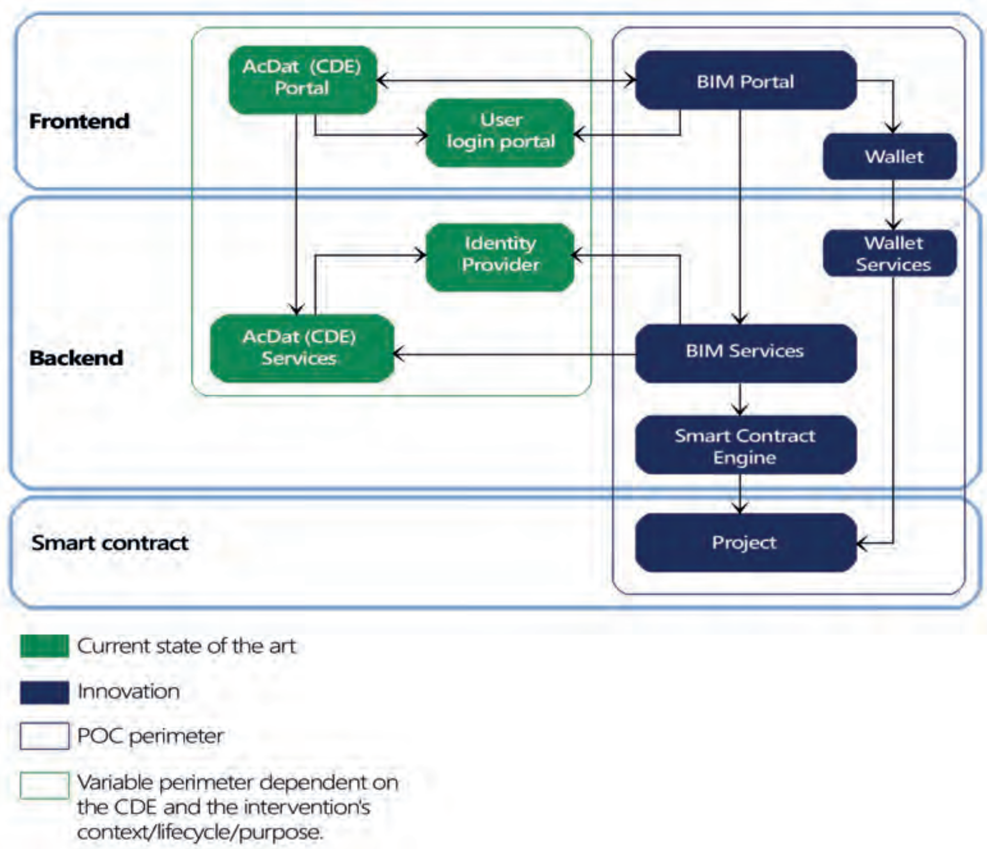

Fig. 1. Benchmarking state of the art and implemented innovation.

Digital Documentation and Built Heritage Management

"Blockchain technology can help overcome stagnant production in construction, with respect to employment, by improving contract management, enabling greater transparency in supply chains and providing the technological backbone needed to combine aspects of the circular economy, BIM, IoT systems and smart sensors. It adds a new layer to tamper-proof network infrastructure for value and information" [ARUP 2017]. As decentralised ledgers [Benahmed 2020], based on consensus mechanisms, incentives, cryptography and peer-to-peer systems, which associate units on the ledger (currency or digital transactions) blockchains shift the aspect of security and trust from a local system, a database, to a global system. The contribution illustrates the results and products of the first phase of a technological roadmap, aimed at the digitalisation of the construction sector, initiated by economic operators and public bodies belonging to the High Technology Network of Emilia-Romagna, which aims at transferring, among others, digital skills to different productive sectors. Raise>up, a spin-off of the University of Ferrara, and the company Harpaceas, a leader in the development of BIM-based solutions for the construction market, have developed an integration solution between blockchain technology and the BIM platform (CDE, Common Data Environment), creating the innovative startup Innovation Chain (Fig. 1). In this sense, the project fits into the primary objective of Emilia-Romagna's S3 smart specialisation strategy, with reference to the objectives of the 2021-2027 cohesion policy and the United Nations 2030 Agenda, as it envisages, in the medium term, the involvement of different enabling technologies: Internet of Things (IoT); Big Data, as an essential requirement for the implementation of analytics functionalities supporting IoT integrations [Campos 2020]; Cloud manufacturing (cloud computing). Surveying, diagnostics, structural and seismic safety analysis, energy efficiency and risk management are just the main areas of investigation that increasingly require the adoption of protocols and standards to assess the quality of results, comparability of outcomes and data analysis, in view of a performance modelling based on Bigdata.

Methodological Approach

The functional analysis used to develop the system requirements took into account the following factors: the amount of digitalisation of Italian businesses, with a focus on cloud computing adoption [Bianchini 2020]; the domestic BIM-based market; the forms of blockchain technology (permissionless or public, permissioned, private).
Similarly, the characteristics of the life cycle of intervention on an existing building have been considered, such as: the numerous and frequent updates to the state of the art, which determine continuous updates of the BIM model; the number of actors involved in the processes of intervention on an existing building, due to the multiple and interdisciplinary specialist knowledge required for the various purposes that the project requires.
According to the authors, the large number of transactions involved in the application of integrated BIM and blockchain technologies makes it difficult to apply the study's goals to the development, implementation, and validation phase – model and code chacking – of architectural, structural, and MEP models, both in the state of art and during the design phase. This is owing not just to the existing high transaction costs on the researched blockchain systems, but also to avoid further overloading the actors' activities. Consequently, it was decided to operate at the level of the data sharing environment, CDE.
BIM is the technology and method for applying project collaboration to the value chain of the created intervention, according to BIM standards.
Moreover, CDE is the standard currently in use that allow professionals with Connecting teams, models, and project data in a single environment, assuring a single, trustworthy source of project information with participants having access to only what they are authorized to see; assuring a highly secure and neutral environment with a complete audit record of the asset to be deployed; reducing the time and effort required to verify, update, and re-issue data; allowing for the extraction of the most recent approved data from the shared area as need-

ed and according to the level of authorization; minimizing the need for ongoing coordination meetings to determine whether models are correct and to address issues such as "clashes" between federated models; allowing information to be reused to assist construction planning, estimating, cost planning, facility management, and a variety of other downstream tasks; reducing the amount of time and money it takes to create shared knowledge.
At a higher level, the CDE ensures the most effective collaboration between all actors in the process, according to current standards, when it comes to the development and implementation of the model for the many disciplines.
The model through which the conformity of the implemented solution is defined, as well as the type and number of actors responsible for uploading, verifying, and validating the starting point for defining the different user categories, is the way in which information is exchanged, verified, approved, and finally stored in the CDE.
Therefore, processes and sub-activities are defined, as follows: project creation; project launch; team definition; project deadline; onboarding; milestones check; BIM model approval; model checking; code checking.

Information Management Thruogh BIM-Blockchain Solution

Blockchain technology has gained acceptance outside of the financial, banking, and insurance industries [Deloitte 2020]. In parts of the literature on low-cost housing, notably non-market rents, there is a rising interest in applying blockchain technologies to the disciplines of social housing and collaborative housing (sometimes known as subsidised housing).
Blockchain technologies were first and foremost used in the management of community services, or proximity, with the opportunity for asset managers to redistribute value within product and service purchasing networks, due to the possibility of certifying the digital identity of information, a document, a contract, or a service [Ethereum 2018].
However, the same opportunity could be provided by applying the same approach to the management of real estate assets, namely, the joint management of services that meet the community's needs in terms of personal services as well as behaviors that influence building performance, particularly energy performance.
However, few investigations in this area have yet to be launched. In this regard, the current research is part of a project to assess the technical and economic feasibility of integrating BIM and blockchain technologies into the asset management of ACER, Azienda Casa Emilia Romagna of the province of Reggio Emilia, Emilia-Romagna, Italy.
The findings of this phase of research led to the identification of: the phase of the intervention's life cycle to which technological integration should be applied; the most appropriate type of blockchain technology to be applied; the conditions, opportunities, and constraints for the development of subsequent implementations.
As a result, the first phase of the study focused on functional analysis in terms of actors, processes, and macrofunctionality, in order to define the activities and digital objects, documents, models, etc., undergoing notarisation.

Functional Analysis: Actors, Processes and Macrofunctions

The following actors have been identified for the Project Management perimeter:
- Project Teams (P1 – Pn), Teams related to different disciplines (Architectural, Structural, Plant Engineering);
- Project Manager (PM), Project manager for the client;
- BIM Manager (BIMm), Responsible for the coordination of the BIM project for the client;
- BIM Coordinator (BIMc), For project team and headquarters (only for large projects);
- BIM Specialist (BIMs): BIM specialist for the project team;
- BIM Specialist (BIMs): BIM specialist of the project team;
- Single Project Manager (RUP), (only for public projects) is in charge of project planning,

design, contracting and execution;
- Contract Executive Director (DEC1 – DECn), (only for public projects);
- CDE Manager: only for large contracts.

Definitely, the design of the platform consisted of the following phases:
- definition of the logical architecture;
- definition of the storyboard for the system actors;
- definition of the integration flows between the components;
- definition of Smart Contracts;
- definition of integration methods.

The verification and validation cycle of the various development phases planned starts after an initial project start-up phase and the onboarding of the actors involved. The delivery and approval of models, the verification of model interference, and the verification of mandatory/contractual requirements are all part of these phases. At the end of each phase, the current phase's status and state of the project are verified and validated. The validation of a phase results in the closing of the current phase and the beginning of the following one until the validation of the final scheduled phase and, as a result, the project's completion. The hash is validated if the check is successful, and the flow proceeds as before. If the hash verification process fails, or the model and code checking technique fails, observations are communicated and saved to BIM resources, where they can be traced. Consequently, the BIMm corrects the problems, and the system gets the repaired models, converts them to hash, and uploads them. The procedure is then re-run (Fig. 2).
Similarly, the functional analysis of the site management phase was carried out.
The innovative component is placed between the collaborative environment in which the various project teams work and share documents and the common data repository (AcDat or CDE) and manages the "gates" of passage between the various processing modes. The new component's features are available as a user interface (web/mobile) as well as APIs that may be accessed by other systems. The component saves the major actions, status changes, and the unique fingerprint (hash) of documents in an immutable and certified fashion (time stamp, cryptographic signature) using Smart Contracts that run on blockchain.
The AcDat/CDE holds its role as a common repository of data and processes, while the Collaborative Environment holds its function as an integrated model viewer and repository navigation interface.

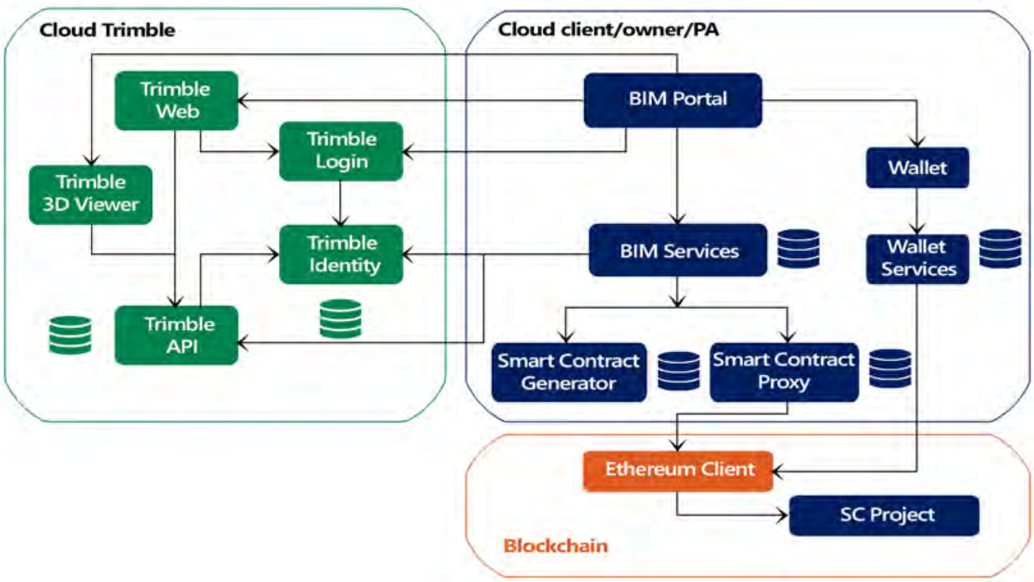

Fig. 2. Software architecture.

Some potential development scenarios were considered when defining the characteristics of the Backend and, in particular, the Frontend. There are three different possibilities for integrating the frontend components, none of which are necessarily alternatives, depending on the CDE to be integrated and the business proposal:
- ACDat Portal and BIM Portal are separate applications but the user can switch from one to the other without logging in again: SSO (Single Sign On);
- BIM Portal includes ACDat Portal (e.g. as iframe);
- ACDat Portal includes BIM Portal functionality (product extension).
While on the Backend:
- BIM Services call ACDat Services (like REST APIs or Web Sevices) to query the repository or modify it using an authorization token issued by the shared Identity Provider.

Sustainability of Integrated BIM Blockchain Solutions

In order to assess whether to construct ad hoc solutions and when to leverage existing goods or solutions to be integrated and/or customized, a "Make or Buy" analysis approach was used for the platform's technical design, with reference to the various components.
It was able to move to the cost evaluation as a result of the choices/assumptions made for the succeeding software and hardware design phases (Fig. 3).
As a result, conditions such as the public or private nature of the actor for whom the solution is developed, the complexity, in terms of the purpose of intervention on the existing heritage and the management of the life cycle, which characterizes the existing building under examination, the phase or ph of the existing building under examination are determining factors in the current context of technological development of both BIM solutions and blockchain technologies.

Components	Make or Buy	Note
AcDat	Buy	Integration with an existing product that provides the essential integration interfaces is suggested for AcDat (API and Identity Provider). If the product does not allow for suitable integration at the user interface level, the API can be used instead, and the integrated interface can be developed in the BIM Portal. Trimble Connect was used as a reference for planning and cost estimation.
BIM Portal	Make	Innovative component to be developed
BIM Services	Make	Innovative component to be developed
Smart Contract Engine	Buy	Smart Contract Generator and Smart Contract Proxy microservices provided by GFT under opensource licence
Project	Make	Smart Contract to be developed
Wallet + Wallet Services	Make/Buy	There are a few possibilities: - Development of a cloud wallet; - Integration of Metamask; - Integration of other third-party wallets. It was decided to create a Cloud Wallet for the design and cost analysis.
Blockchain	Buy	There are a few possibilities: - Development of a cloud wallet; - Integration of Metamask; - Integration of other third-party wallets. It was decided to create a Cloud Wallet for the design and cost analysis.

Fig. 3. Make or Buy analysis.

Consequently, the platform architecture was developed using the functional analysis performed throughout the design and site management phases. The identified solutions differ in the addition of a new AcDat for the construction phase, as well as the introduction of new and unique smart contracts, such as:
- Construction, Smart Contract for site management;
- Checklist, Smart Contract for the management of the technical-professional suitability checklist;
- Rubbish, Smart Contract for waste disposal management;
- Supply, Smart Contract for supply management;
- WorkPackage, Smart Contract for work management.

Conclusions

"Blockchain could help reverse stagnant construction output in relation to employment by simplifying contract administration, enabling greater transparency in supply chains and providing the technological backbone needed to incorporate components of the circular economy, BIM, IoT systems and smart sensors. It offers a new layer to the internet infrastructure for tamper-proof exchange of value and information" [ARUP 2017]. Blockchain technologies allow a higher level of system automation to be integrated into the information infrastructure, which theoretically guarantees immutability, uniqueness and makes it difficult to tamper with information. Therefore, these attributes provide an opportunity for innovation and transparency in the management of the lifecycle of manufactured goods to all production and value chains, with particular reference to the sectors most marked by controversy and corruption.
More specifically, in the construction industry, the technological innovation provided by the integration of blockchain and key enabling technologies [Raed 2019] presents itself as a tool to promote the certification of phase and product quality throughout the project lifecycle, as well as its management. Taking into account the developing field of data collecting, analysis, and modeling for the understanding of existing architectural heritage, which is increasingly characterized by the use of integrated digital technology, it is possible to identify a future application and experimentation area for integrated BIM-Blockchain and IoT technologies.
Definitely, surveying, diagnostics, structural and seismic safety analysis, energy efficiency, and risk management are some of the main research areas that are increasingly requiring the adoption of protocols and standards to assess the quality of information, results comparability, and data analysis in order to model performance using Bigdata. However, it is obvious that there are still significant barriers to widespread adoption of integrated digitization approaches, which are the same barriers that underpin the adoption of the technologies in question. On the one hand, there are regulatory issues, which are a major topic of debate in EU Member States right now.
The costs of a technology that was initially conceived for the financial, banking, and insurance sectors, on the other hand, are still unsustainable for the construction sector, which is dominated by small, medium, and micro enterprises. In the medium term, solid scalable solutions are required so that blockchain technologies can be broadly adopted in markets with weaker economic/financial margins than their origin markets.
Finally, the amount of digitisation of supply chain actors appears to be insufficient, or not uniform, in order to achieve the next step of industrialisation of processes required by blockchain technologies. Once more, the construction industry looks to be the most resistive to the adoption of new process models and procedures.
The construction industry appears to be the most resistant to the adoption of new process management models and approaches, both because of intrinsic characteristics and because of actors' unwillingness to execute a truly collaborative process.
According to the authors, the ability to access specialized resources on a competitive basis in public-private partnerships as well as the scalability of innovation are the main drivers for fostering new and subsequent maturity steps in the transition, which has already begun, from a proto-industrial to an effective industrialised construction value-chain.

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Scan-To-Ar: from Reality-Capture fo Participatory Design Supported by AR

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Abstract

This contribution presents state-of-the-art methods in 3D scanning and augmented reality for public-inclusive architectural programmes through rapid survey, accessible design tooling, and immersive visualisation outcomes. It follows an application case in Cantieri Culturali della Zisa, Palermo, part of a co-design workshop called *Everyday Experiences and Heritage in South European Cities: Digital Tools and Practises*, which invited architects, urban theorists, and local stakeholders to explore public-oriented reclamations of industrial-cultural-heritage sites. This contribution illustrates the benefits of pedestrian-operated 3D structure-from-motion survey for historic urban scenarios and details WikAR; a cloud-based augmented reality app modified for accessible proposal creation and visualisation.

Keywords
ICT, augmented reality, co-design, built heritage, 360 photogrammetry.

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Introduction

Challenged by urbanisation, economy, gentrification, migration, and climate change, the experience of historical spaces and buildings is fragmented, mirroring the disconnected perception of urban societies. Addressing the dilemma of mobilising the right resources for the reactivation of these spaces, the Working Group of the European Research Infrastructure Consortium on Digital Humanities and the Arts (DARIAH) about the use of digital practices for the study of urban heritage (UDigiSH) organised a workshop that focused on new ways of transforming neglected urban spaces and neighbourhoods in historic European cities in the Mediterranean basin. The paper presents a technical workflow developed as part of the novel methodology employed by the workshop [Artopoulos, Martinez 2021]. The event was held at the Cantieri Culturali, Palermo, a site located between a mixed-income residential neighbourhood and the Zisa Palace, a UNESCO-recognized Arab-Norman castle with considerable cultural as well as tourist interest. This campus is a reclaimed early 20th C. furniture factory [Fabrica, Ducrot 1890-1968]; once abandoned, this critical site of Sicilian industrial heritage now hosts a lively campus of university buildings, training schools, art studios, workshops and became home to many cultural institutions (Fig. 1a).

A Co-Design Methodology for Heritage Regeneration

Contributing to the existing literature, the workshop at Cantieri Culturali explored how abundant but disused urban heritage sites can become part of a reflective planning process, resulting in more legible, inclusive, resilient, and enjoyable cities [Rozman 2015]. The workshop offered to city authorities data-driven consultation actions by engaging cultural heritage institutions, scholars and researchers in digital humanities, city stakeholders, professional associations, urban communities, and citizen groups. The principal objective of the event was to enable cultural bearers and local stakeholders to engage with possible future conditions of the site by building on the existing assets and resources available on campus. In detail, the workshop offered to local stakeholders, who were previously mapped by the authors, creative opportunities for visioning [Garel et al. 2021, p. 54] through their engagement with the design process of architectural reuse and functional conversion of the campus. This participatory process drawing from existing literature [Castelnovo et al. 2016; Cruickshank , Deakin 2014] introduced local stakeholders and other users of the campus (e.g., students, passers-by) to a design brief that enquired about the future use and appropriation of the empty uncovered remains of a brick warehouse near the northern campus edge (Fig. 1b). Since the derelict warehouse sits between three campus plazas, the workshop invited design schemes with deeper contextual analysis by incorporating the diverse voices of public stakeholders and accounting for the existing activities around the site. Besides the discussion about its history, the process first introduced the participants to the architectural conditions of the site, such as the boundaries of the space, the spatial and visual continuity with its surrounding sites and open-air spaces, as well as the materiality of the existing remains of the structure of the heritage building on site. Design criteria considered in the conversations that were staged with the stakeholders and current users of the campus included possible functions and uses that are missing from the campus, the kind of form and position of specific interventions they envisioned implemented on-site, how any new structure on-site could be connected with the neighbouring spaces and functions, ways to offer better accessibility to the new proposed space, for all groups and individuals, the role of green spaces, the attractiveness and value of designing a space that would be naturally ventilated for occupant comfort and offering controlled micro-climate, and finally, ways for the space to enable social interaction and provide a sense of community, in the above order.

Using Interactive Visualisation for User Engagement in Co-Design

The overall co-design process relied on the iterative visualisation of alternative design scenarios and architectural function definitions of the site under study, in order for the participants

Fig. 1. a) Cre.Zi. Plus common spaces (site of the workshop). Source: Cre.Zi. Plus Official Fb profile. b) The *Spazio Incolto*, the remains of a brick warehouse.

to engage in a dialogue about their vision for the future of the place and, by doing so, to provide feedback to the authors about possible design interventions. The most popular design interventions were meant to be delivered to the local authorities, as favourable suggestions from the local communities and social groups who appropriate the campus. Central to this dialectic process that facilitated the expression of the needs and visions of the stakeholders mapped, played the use of digital tools that enabled the authors to visualise in an interactive way the spatial characteristics and visual experience of each design scenario implemented virtually on site. This was achieved using two distinct visualisation methods employed in practice, namely, table-top and full scale Augmented Reality interface, respectively.
In 2015, Google and Apple introduced native AR functionality to their mobile phones and tablets, allowing apps to access tracked device motion, camera overlays, and estimated scene geometry. Wikar, a Unity-based mobile app developed between The Cyprus Institute and the University of Illinois, extends these native mobile AR functionalities to visualise dynamically hosted [Marini et al. 2018] geometry in physical space. It is also programmed to support rapid interface prototyping for academic research and cultural events. This section will summarise the creation of Wikar's new proposal-design subsystem and reflect upon augmented reality visualisation outcomes with stakeholders.
In preparation for the workshop, we extended Wikar to create and share lightweight urban design proposals. The inspiration came from creative games like The Sims, which give players grid-based architectural elements to compose scenes. While Wikar already loads industry-standard 3D models at runtime, this simplified tile system was necessary to meet the outdoor workshop's performance requirements: mixed-range mobile devices and no wifi on site. Wikar's tile-based proposals are small JSON files describing tile placements, which reference 3D tile modules pre-bundled in the app. Proposal files are Kilobytes in size,

trivial for syncing between device and cloud server over 2G speeds. We used an open-source JSONObject library to containerize and exchange data between Unity and Clowder, our flexible cloud storage backend [Marini et al. 2018]. Figure 2a shows Wikar's default tile family, including walls, vegetation, and urban furniture. After initial stakeholder meetings, we created additional tile families to ensure we could represent ideal programmatic outcomes – including playgrounds, restaurant seating, urban gardens, and enclosure systems. While 3D model repositories like Sketchfab offer free-to-use materials, we found its offerings too dense, detailed, and distracting for our use case. Instead, we carefully modelled tiles to communicate design intentions without over determining aesthetics.

Figure 2b shows Wikar's tile system employed for two pilot proposals built from stakeholder input; the two extreme outcomes encourage meaningful reflections from participants during the visualisation phase. The top proposal, representing a connected urban common space, shows a shaded park with flexible interior programming and play spaces for children, complementing the site's adjacent public plazas. The bottom is a fully enclosed theatre/office space similar to previous rehabilitation projects. Its flank includes an urban garden for a nearby cafe. Methodological design research by Rosa and Reucker (2020) suggests that greater contrast between prototypes serves a didactic function, opening a wider field of interpretation for reviewers. Local workshop participants, who have been underserved concerning green spaces in the city, were overwhelmingly positive about a shaded park for daytime use, especially when compared with the more conservative alternative.

To show proposals to stakeholders, we used Wikar's QR-code-based placement system. As illustrated in Figure 2c, printed QR codes point to proposal URLs and contain arguments about their position, rotation, and scale relative to the code. During a QR code scan using a Z-Xing library, the device camera and AR tracking subsystems collaborate to anchor a virtual scene origin in tracked space, after which the viewer can explore the loaded content freely. For 1:1 scale onsite visualisations, we placed QR codes in strategic positions around the site, using a Grasshopper script to calculate their offset parameters with a Rhinoceros 3D site model as reference. This digital-twin site model synthesised GIS data, available site plans, and 3D scans from the 360 SFM acquisition. Because minor geometric errors become glaring in a 1:1 overlay, the accurate 360 SFM geometry was critical for validating and unifying all the other materials.

For off-site visualisations, we created QR codes for 1:30 scale 'model-village' walkthroughs. Additionally, a printed campus plan became a 1:500 'table-top' visualisation. Unlike the 1:1 scale walkthrough, miniature visualisations included the 360 SFM model for site context. Each of the three visualisation scales prompted different responses from stakeholders. We found that while miniature model visualisation fostered discussions on overall intentions and cost-benefit analyses, representation at a 1:1 scale invited granular input from participants, who readily offered critiques, additions, and insights for refinement. This observation maps to the traditional modalities of architectural media: diagrams, renderings, and scale models are tools to shape reviewer discourse and reflections toward particular aspects of building proposals. Codesign facilitators should likewise consider the scale of interactive AR visualisation for its effect on viewers in a critical mode.

Crowdsourcing and Data Mapping

One of the most pressing challenges in the current use and application of digital methods in heritage preservation and safeguarding is the availability of reliable data assets. There are numerous efforts to develop the appropriate workflows, standards and guidelines regarding data curation and interoperability, responding to the H2020 FAIR principles presented by the relevant literature [Angelaki et al. 2021]. However, many research practices in heritage face a significant drawback: data generation and sharing. EUROPEANA 3D and subsequently the TIME MACHINE network are occupied with the collection of 3D digital heritage assets made available to the public through open access platforms and standards.

Responding to this need and taking into consideration the particularities and operational cri-

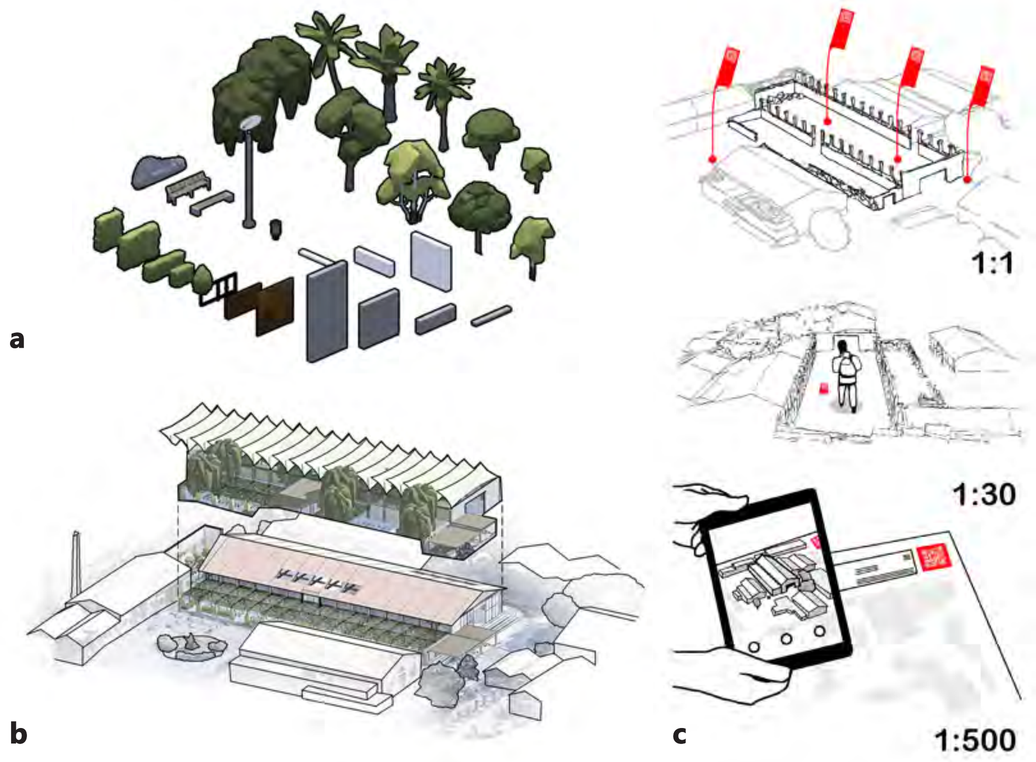

Fig. 2. a) Wikar's default tyle family; b) Two pilot proposals built from stakeholder input; c) QRCode applications.

teria of using 3D digital assets in architectural heritage conservation, as well as for regeneration and reuse, the authors applied in the case of the presented workshop in Palermo a novel spatial asset generation technique that facilitated the rapid acquisition of 3D datasets from the site under study. There are several crowdsourcing platforms for collaborative planning, design and governance tools, as well as for monitoring and evaluation, such as Decide from Madrid (https://decide.madrid. es/), Izboljsajmo Maribor (https://izboljsajmo.maribor.si/), or Wien.at (https:// smartcity.wien.gv.at/site/en/wien-at-live-app-2/) for Vienna. However, most of said tools offer 2D interaction opportunities through maps and metadata generation for crowdsourcing linked information in a semantically structured way [Mirri et al. 2014; Prandi et al. 2014]. Providing to the public and local communities the capacity to interact with geolocated metadata and spatial information through a 3-dimensional interface poses huge challenges in terms of visualisation, as well as in 3D data collection, management and access. As built space can be the result of historical narratives, human actions and events on site, a palimpsest of historical narratives [Merrill, Giamarelos 2019], which is assigned different cultural identities by different groups and communities, its documentation and representation can contribute highly to any public / stakeholder engagement process. Hence the necessity of the presented method for documenting rich representations of historical places under study, including survey of geometric aspects and material conditions.
However, 3D documentation processes can be highly technical and resourceful, and this is where the paper focuses on, in developing an easily accessible workflow of 3D documentation by the public which would accelerate the capturing and sharing of 3D data of built environments. This breakthrough application will multiply and accelerate the 3D documentation of historic sites, built heritage and whole city-scapes by hobbyists who are willing to participate and contribute to extensive, large-scale crowdsourcing operations, coordinated by research groups aligned with the scope of European infrastructure networks, such as the TIME MACHINE, E-RHIS and DARIAH-ERIC. Significantly, the authors aim to develop further and optimise this technique and the performance of its resulting data in order to eventually create a fully documented and replicable workflow of 3D spatial data acquisition for non-expert operators utilising a 360 structure-from-motion, image-based documentation process.

360 SFM Scanning for Rapid Acquisition

The short duration of the workshop required a rapid method of capturing site geometry for use in architectural design proposals and future developments. This section summarises the topic of expeditious digital surveying, describes the state of the art and motivates the choice of using 360 SFM for acquiring the site context.
In recent years, we have witnessed a surge of technologies and sensors for expeditious 3D acquisition [Gonizzi, Remondino, Visintini 2013]. The fastest way to accurately survey urban geometry has typically been vehicle-mounted mobile mapping systems (MMS). This approach enables expeditious mapping campaigns in complex environments. However, their application is limited to automotive-accessible routes, which excludes the narrow streets, pedestrian islands, and irregular forms typical of high-density historic urban centres [Barrera-Vera, Benavioles-Lopez, 2018]. In these cases, it is preferable to adopt pedestrian-scale tools such as spherical photogrammetry (also known as 360 SFM) or Indoor MMS tools, which benefit from their small size and lightweight.
Regarding spherical photogrammetry, Abate et al. (2017) and Barazzetti et al. (2018) have found that accurate metric reconstructions are achievable using low-cost camera sensors. In addition, Teppati Losè et al. (2021) verified compatibility between iMMS and spherical photogrammetry for the survey of the Montanaro bell tower. Although the 360 SFM methodology has thus far centred on interior survey, there are unrealised potentials in outdoor urban capture scenarios. We may visit a few reasons for this: the hardware is less expensive, non-specialists can conduct the acquisition phase, and the results obtained are comparable with iMMS capture, which is acceptable for urban scale representation in design contexts [La Russa et al. 2021].
The methodology's foundation is the acquisition of 360° panoramas, which, through photogrammetric processing, may reconstitute the site as a point cloud. In practice, this starts by setting a 360-degree camera rig to a recurrent capture interval of 2 seconds and subsequently walking through capture routes at a steady pace. The urban scale of the acquisition must take into account time of day and weather conditions to limit the presence of shadows on surveyed surfaces. For 360 SFM acquisitions, we used a GoPro Fusion 360 immersive camera. It has a CMOS 1 /2.3'' sensor and two 9 Megapixel lenses with a 180° angle of view, permitting the acquisition of spherical photos and immersive videos. Its small size (74 x 75 x 40 mm) and lightweight (220 g) present no obstacles to mobility—afterwards, the images.
To define the acquisition path, we considered the 3D model requirements for the AR application. The survey aims to provide viewable assets in the AR experience and provide a usable digital replica to develop the design proposals in AR. Therefore, we defined a path along the building facades around the central open space and the *spazio incolto*. Figure 3c shows the spherical panoramas' acquisition points (in blue). After the acquisition, we processed the data using Metashape software, which supports spherical captures. The results were acceptable for the requirements of the survey (representation scale 1:200). The choice to walk along the facades and not along the axes of the paths improved the resolution of homologous points as it produced adequate photo overlap at multiple distances. The obtained point cloud was scaled to known measurements from other documents and triangulated into a mesh for placement in the model (Fig. 3).

Discussion and Conclusion

The site's 360 SFM acquisition process supports rapid co-design processes. Approximately 5.055 sq. m. were acquired in less than 15 minutes. The tools used are low cost and provide a procedure that can be carried out even by non-experts. Further, it is worth considering how this digital approach can help organise longer-term codesign efforts that are untenable with current methods. Because Wikar QR codes lead directly to app download links, it can onboard users with no supervision, offering new opportunities for long term workshops as stakeholders can visit sites at their convenience and use personal devices. In anticipation of

Fig. 3. a) GoPro Fusion 360 and the acquisition on site; b) perspective view of the sparse cloud; c) top view of the dense cloud; d) focuses of the dense cloud.

such co-design initiatives, an area for future development is a commentary collection system allowing app users to mark up proposals in AR. This commentary, collected at scale, could be instrumental for planning teams and authorities seeking data-driven urban infrastructure design programmes.
In conclusion, the work carried out at the Cantieri Culturali della Zisa campus implemented an expeditious methodology integrating digital surveys and augmented reality to help interested communities explore future urban conditions and realise agency within the planning process.

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AR&AI
Education and
Shape Representation

AR as a Tool for Teaching to Architecture Students

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Abstract

Information and communication technology (ICT) are nowadays an integral part of daily life. Training and educational activities are among the different areas that widely profit from the use of these technologies.
The proposed contribution aims to develop an augmented reality application for accessing documentary sources used in the teaching of drawing disciplines in architecture courses at the University of Cagliari. Much information is produced and collected in drawing classes, primarily in the form of representations, which are either adopted by the professors year after year or elaborated by the students during the classes.
This collection of materials represents a significant legacy that is typically used to enhance instruction, despite certain obstacles in disseminating it among students.
As a result, it was decided to use some of the publications from the core bibliography for a student studying the Castello district and its architecture as an "access point" to the knowledge.

Keywords
AR, education, Cagliari, drawing disciplines, communication.

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Introduction

Information communication technologies (ICT) today play a central role in everyday activities. Among the various sectors that benefit from the use of these technologies there is undoubtedly that of training and educational activities; in fact, there are frequent studies that demonstrate how the application of technologies such as virtual world modelling, augmented or mixed reality, can facilitate the learning process and expand accessibility to information [Mortara, Catalano 2018].

The proposed contribution presents the first stages of an experimentation that aims to create an access application, in augmented reality [Quintero et al. 2019], to documentary sources used within the teaching activities of the disciplines of Drawing in the Architecture courses at the University of Cagliari. In the drawing courses a large amount of information is produced and collected, mostly in the form of representations such as drawings and photographic images, adopted by the teachers themselves from year to year or elaborated by the students in the development of the assigned themes. This "archive of drawings and graphic elaborations" defines an important patrimony normally used to support teaching itself with not a few difficulties of dissemination among students. This information can be easily catalogued and managed thanks to the use of a relational database that can contain the information of individual documents and, if necessary, offer advanced search tools based on links between names, dates, representation techniques, etc. [Chiavoni 2014].

The choice of augmented reality, relying on the database, focuses more on the problems related to access modes; while it is true that the database can be interrogated through forms suitably structured to be used by certain categories of users, such as students, this type of tool lacks a "narrative" of the information that can accompany the student in the discovery. It should be remembered, in fact, that querying the database returns as a result a series of information and documents that, although filterable according to the user's preferences, are not "linked" by an ordered logical thread.

For this reason, it was decided to use, as an "access point" to the information, some of the texts belonging to the fundamental bibliography for a student who is going to study the Castello district and its architecture [Spallone, Palma 2020]; in particular, it was decided to start the experimentation with the text *Forma Karalis* by Dionigi Scano [Scano 1934].

The intention is therefore to "enrich" the paper support with multimedia information, offering the student information and references related to maps, drawings and photographs represented within a certain volume, while preserving the narrative order. For each image of particular interest, framed by means of a mobile device, a series of labels are displayed on the screen that identify the object and, if tapped, open a tab containing additional information on the object.

This is particularly useful when, in the analysed image, objects are not represented in their current state. Typical cases can be photos or historical drawings, where the element is shown in a very different state than it is today, or transformations that have taken place on the urban scale when looking at a historical map; another interesting case is when the represented element no longer exists, such as in the case of demolitions and reconstructions during urban redevelopment or following wartime events. Immediate access to a series of subsidiary or supplementary information via an app facilitates a mode of use that is now consolidated among the youngest, allowing on the one hand a streamlined use of the adopted text and suggesting to students further possible insights and study ideas.

AR Applications for Education

Educational content can be accessed through many types of media. Traditional dissertation involves students to learn interacting and discussing with teachers and colleagues, and using textbooks or non-interactive media. In recent decades, digital media have assumed an increasingly important role in educational environments, providing students with the opportunity to learn through interactive tools. To make this possible, classrooms are equipped

with desktop computers and interactive whiteboards, and more learning experiences are accessible by students using modern portable devices. In parallel with new ways of access, new ways of interacting with learning experiences have also developed; keyboards and mice used to interact with content on the screen are being joined by tools that allow learners to use their whole bodies to interact with educational content that appears to exist in the physical world, thanks to augmented reality technology.
There are several researches illustrating the different possibilities offered by augmented reality (AR), which have led it to be one of the emerging technologies rapidly incorporated in the educational sphere [Akçayır, Akçayır 2017; Johnson et al. 2016]. Precisely, the ease of access to information offered by this tool is, among others, one of the most interesting; this is partly due to recent technological developments that have led to more frequent use of mobile devices in the educational sphere, in the presence of subjects with disabilities or different educational needs [Lin et al. 2016]. Through the combination of the physical and digital environment, AR makes it possible to generate a new reality [Hernández et al. 2015].
However, it should be kept in mind that augmented information can go beyond the sense of sight alone, applying to all senses, such as hearing, smell and touch [Azuma et al. 2001]. Due to this, AR is to be considered extremely promising for facilitating and encouraging processes of educational inclusion [Sheehy et al. 2014]; this technology in fact envisages the support of multiple means of representation, action and the involvement of students in different ways in the learning process [Meyer et al. 2014]. In this regard, Hrishikesh and Nair [2016], in their studies, found that AR facilitates children with disabilities to understand concepts more effectively and quickly. In 2014, Mohd Yusof et al. also demonstrated how AR is able to capture the attention of students with special needs, providing them with educational tools that are fun and enjoyable to use.
Moreover, AR has been shown to have a positive impact on students' educational experience, increasing their trust, level of involvement and interest [Fombona et al. 2017]; it can promote self-learning [Akçayır, Akçayır 2017], but also cooperative learning [Phon et al. 2014], as well as improving the sense of satisfaction and thus motivation in students [Bacca et al. 2018].
However, there are possible negative implications that can be derived from the use of AR systems compared to non-AR systems, which must be taken into account, such as the so-called Attention tunnelling.
Indeed, there are experiments in which students perceived the demand for more attention using AR systems. As a consequence of this, students tend to ignore important parts of the experience or feel inadequate to the demands of the assigned tasks. Furthermore, as observed by Tang et al. [2003] when performing object assembly tasks using AR, users had a greater tendency to ignore previous errors than users performing the same tasks on paper. Attention tunneling can be a source of danger on certain occasions, which is why it is important to study how the system channels users' attention.

Drawing and Representation Llaboratory Materials

The teaching of Drawing is based on both the use and production of works that synthesise and represent physical reality.
From the earliest years, students are taught the techniques and rules for reading and representing architecture and landscape; this is done with the help of images, whether photos, videos or drawings, as well as models, sculptural elements etc., which are the result of the typical activities of a Drawing course (Fig. 1). In response, the students, while carrying out their study activities, produce new works that become part of the Laboratory's materials.
Over the years, therefore, a seemingly vast collection of materials has been created, which are both an aid and a result of teaching and research; furthermore, this collection has become an invaluable heritage in that it represents and bears witness to how the teaching of Drawing has evolved over the years and how it is still carried out today.

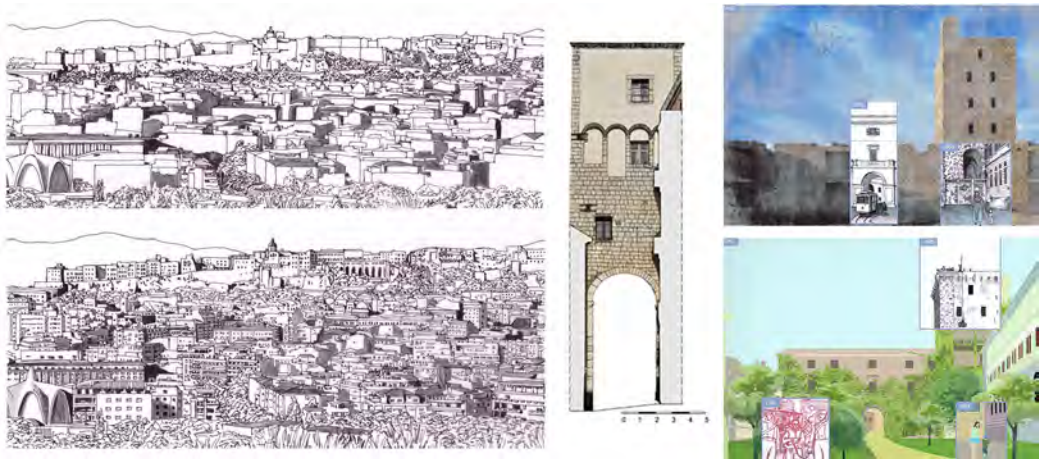

Fig. 1. Some examples of materials belonging to a Drawing Laboratory.

These materials, as already mentioned, are of the most varied natures, from historical cartography to landscape drawing, from study models to plaster casts, from old photographic plates to digital photographs and slides. The study of historical cartography leads to the compilation of new cartography, lightened or enriched with details as needed, just as photographic images are synthesised by redrawing a view during a landscape study or the elevation of a building.
The physical models, which are themselves material reproductions of project drawings, are reproduced or placed side by side digitally by means of 3D models, which offer new keys to interpretation or alternative representations. The drawings or photos produced decades earlier are digitised in order to be preserved; similarly, plaster elements, which were common until the middle of the last century for studying the design of architectural details, now constitute a veritable heritage whose memory can be preserved using modern laser scanning or photogrammetry techniques. To this must be added all the scientific production for the study and interpretation of materials and the subjects represented in them; scientific production that today is practically only digital but increasingly abundant and articulated.
It is clear and undeniable the value that these materials have had and still have in the didactics of Drawing, as well as the support that students can draw from them, if access to this knowledge takes place in a reasoned and structured way.
However, a collection such as the one described involves the problem that it is all the more valuable and difficult to manage and communicate the larger and more heterogeneous it is. Older materials have to be handled with care, thus placing limits on the number and type of users who can be granted access to them; on the other hand, digital materials are often of such a number and nature that effective dissemination is difficult. Cause these problems and taking into account the richness represented by these materials, there is an increasing number of digitised archives of materials related to the discipline of Drawing.

Forma Karalis

Dionigi Scano was an undoubtedly important figure in the architecture and town planning of Cagliari at the turn of the 19th and 20th centuries. Graduated in civil engineering in the Regia Scuola d'Applicazione in Turin, Filippo Vivanet called him back to Sardinia to become his collaborator in the regional office for the conservation of monuments.
Besides having been responsible of the restoration of several important monuments, including the Tower of San Pancrazio in Cagliari, Scano was also very active as an architect, completing buildings of some importance such as the National Archaeological Museum.
In addition to his role as a politician and architect, Scano is also known for numerous essays on medieval architecture in Sardinia and on a variety of other topics.

Of particular importance is his 1934 work Forma Kalaris, already published in previous years with the subtitle '*Stradario storico della città e dei sobborghi di Cagliari dal XIII al XIX secolo*'.
The work illustrates the evolution of the city thanks to photos and numerous maps, which tell the story of its development over the centuries, and provides a valuable description of how it looked at the beginning of the last century. Scano describes the historical quarters as well as the continuous expansion, particularly towards Via Roma in the early 20th century. The wealth of information and images present in Forma Karalis have made it one of the essential texts for any student wishing to approach the study of the city of Cagliari; this is precisely the main reason why Scano's text was chosen as the first object of the presented experiment.

Design of the Database Structure and App Features

Once the types of materials to be made accessible and the channel through which access is guaranteed have been established, it is necessary to proceed with the design of the database and the app; this chapter presents the basic characteristics that the future prototype must have, also proposing some mockups. In order for the designed App to guarantee easy access to information and materials, it is essential that a database containing the main information about the materials to be consulted be developed and populated beforehand. It is therefore necessary to make an initial census of the materials in order to identify the type (paper images, digital files, physical objects, etc.) and the main characteristics; some of the characteristics will have semantics common to all types, such as the name of the author, the date and so on, while other characteristics may be specific to a given type, such as the resolution for a digital image or the type of technique used for a drawing on paper. In addition to the metadata of each type, for which there are precise references to international standards, each object must be accompanied by a series of "tags" that determine its positioning in certain groupings; these tags will then be the basis for the collection and navigation within the app. Some of these tags may include the name of the course during which a particular paper was produced, or its physical location; this will allow the user to view all the materials belonging to the individual course or collected in the same place, useful for example for possible future consultation of the originals.
Another type of tag that is fundamental for effective consultation is the one that concerns the contents of the coursework and what is represented in it; the tags relating to the contents allow for navigation unrelated to the type of coursework and are fundamental for research relating to a single element, be it architecture, an urban space, a district or a person. It is evident that the structure just described for a database is typical of a relational database; this type of database allows an intuitive structuring of the data relating to the individual objects, organised in tables and correlated with each other by means of relations established beforehand, with the possibility of expanding the database at any time by inserting new characteristics or new objects.
Once the characteristics to be attributed to the individual objects and the tags to be used have been established, the objects are inserted into the database. At the same time, the texts to be used as access points to the information are identified (Fig. 2).
This step also includes the study of the works contained in the chosen texts and the attribution of the tags from which to trigger the process of consulting the database. This phase

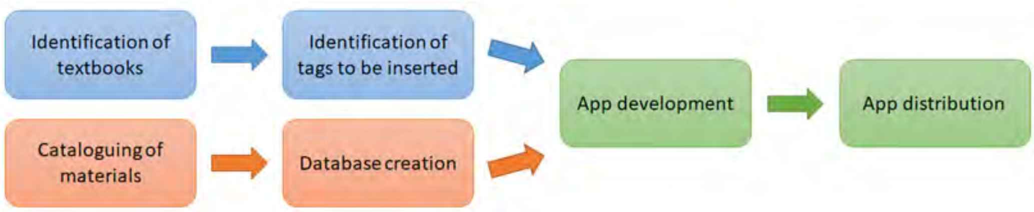

Fig. 2. Workflow proposed.

is of particular importance since the assignment of the tags can have a decisive influence on what information is immediately provided to the user; it is therefore necessary to study and calibrate the tag system according to the type of user and his level of knowledge.
In fact, if tagging a precise element can lead the user to the information targeted on the object of his search, using instead a tag for example of the district, can make the search more articulated but offering more information of the context.
Once the reference texts have been identified, appropriately tagged, and the objects inserted in the database, the next step is the development of the AR consultation App. It is possible to imagine this app as an AR visualiser of the tags on the images present in the reference texts, which, at each tap on one of the tags, triggers a query based on the tag itself. A possible suitable software is the Unity game engine for the development and coding of the application, and its extension Vuforia, designed specifically for the implementation of AR mechanics. In particular, Unity is used to develop the user interface and the database access mechanisms, using simple MySQL code for example; Vuforia is used to create the 'targets', i.e. the images to which the interactive objects representing the tags in the original image are attached.
Once the consultation has started, the user is free to navigate through the digital works, for each of which it's possible to find information on the single object/process, but also other tags to continue the exploration of the contents. At the moment there are three types of element to which specific views correspond: person, object, work. A person is obviously any subject who can be identified as the author of works or the protagonist of events of interest, and is associated with a bibliographic sheet, a works sheet and a bibliographic sheet. Objects, on the other hand, include physical entities such as architecture, an urban space, or a single artefact; they are associated with a descriptive sheet containing the main information, such as author, materials, dating, bibliographic information, etc., a sheet containing the historical materials related to the object, and finally the related works present in the Drawing laboratory. Finally, the elaborate category, which is closely linked to the previous one, includes any catalogued digital product, including photos, graphic works, 3D models, articles and so on; this type is associated with the information sheet containing information on the individual elaborate, i.e. author, dating, techniques used, etc., a sheet containing other elaborates with the same subject or topic, for example. The last sheet relating to the works is that relating to the occasion during which the work was produced, i.e. a course, a research project, a thesis and the like; from this last sheet it is possible to access information regarding, for example, the specific course, with an indication of the teacher name, the course objectives or the reference bibliography.

An Example of Consultation

The logic behind the consultation flow is quite simple and can be schematised as shown in Fig. 03a. Once the user decides which text to consult, if this is among the "augmented" texts, she can use the app for each image in the text or decide to proceed with a standard consultation. If the user decides to use the app, the tags related to the framed image are displayed, allowing access to additional information; for each element displayed, be it a person, a monument or an elaboration, related information is provided and the possibility of moving on to a new element or stopping the augmented consultation. If the user decides to interrupt the consultation, the app goes into standby while the user resumes the classic consultation. At any time, it is possible to resume the augmented consultation following the same procedure.
To better clarify the flow of consultation, an example of access to information is proposed (Fig. 3b). The user decides to consult the text Forma Karalis by Scano and arrives at the map of Cagliari of 1558 attributed to Sigismondo Arquer; she then decides to get more information and frames the map with the app. The app shows her a series of tags linked to some of the main monuments recognisable on the map and, among these, the user decides to click on the tag relating to the tower of San Pancrazio; a tab is then opened

with a brief description of the tower. From here the user can view a second tab containing some historical documents related to the tower of San Pancrazio or a third tab with works produced by the Drawing laboratory; in this last screen the user selects a work related to an experiment on the use of time windows for the narration of urban spaces. A new tab is then displayed, providing information on the selected work, such as the name of the authors, the year in which it was created or the reference course. With regard to the course, the user can open the relevant tab and access the information compiled by the teacher for the course in question, including the course objectives. Finally, on a third tab the user can view further works on the same subject; once she is satisfied with the information received, she can close the enhanced consultation and resume reading the book.

Conclusions

The contribution deals with the difficulties that can arise when the access to a wide collection of materials inherent to the teaching of the discipline of Drawing must be garanted to students. In order to do this, it was decided to design an AR app using as an "access point" the texts that are most frequently consulted by a student of Architecture who is about to study the city of Cagliari. The workflow proposed, easily applicable to a relatively large

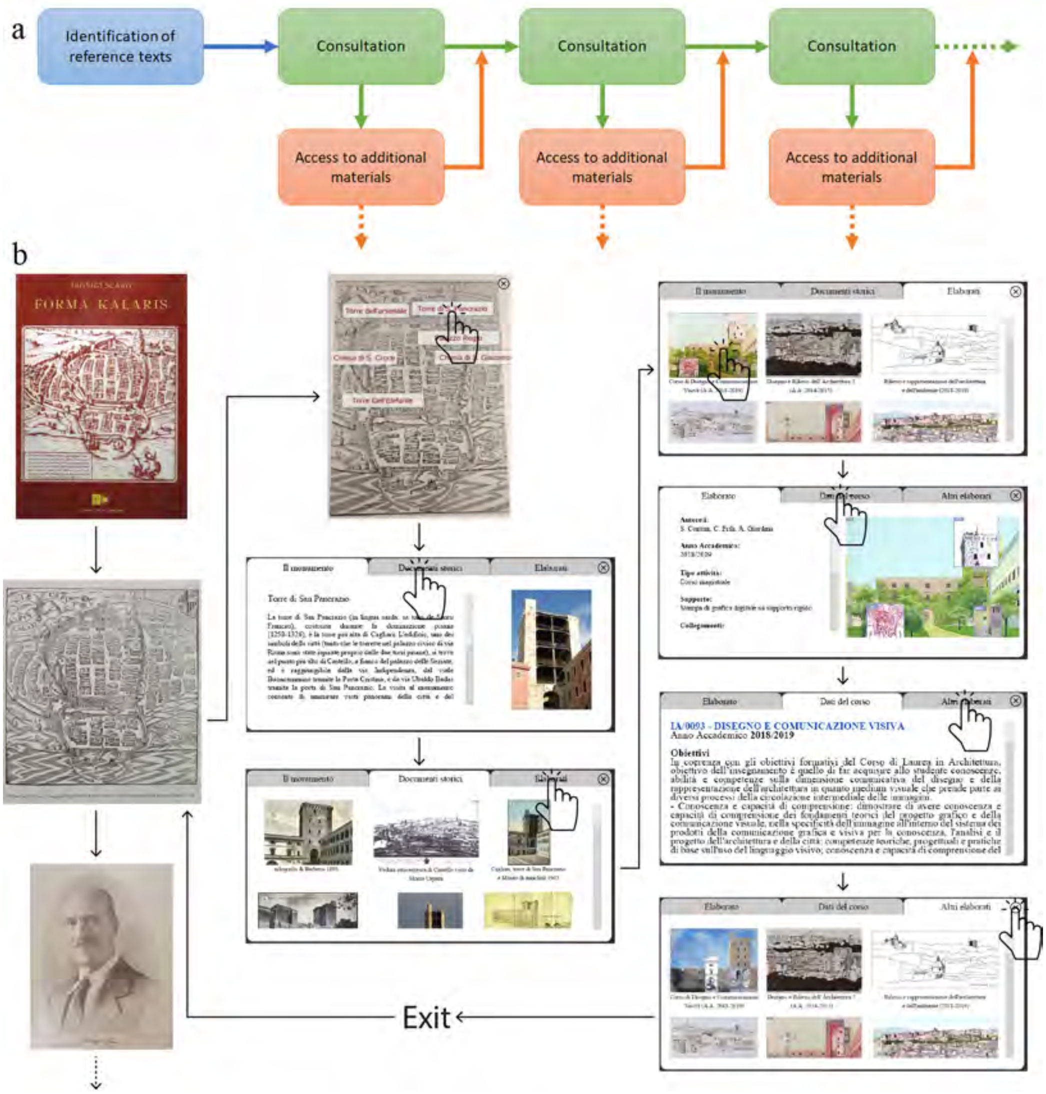

Fig. 3. Consultation flow (a) and a summarized example (b).

number of texts and expandable over time, offers the possibility of structuring a path of learning and discovery of the materials in the possession of the laboratory of Drawing, leaving the text itself to guide the user.
In the future, the research develope a working prototype, extending the range of both "augmented" books and materials that can be consulted. It is also considered necessary to investigate some problematic aspects, such as the attribution of a scale of potential interest for the various materials available for consultation, and to calibrate this scale and the paths of exploration according to the characteristics of the user.

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Architectural Maquette. From Digital Fabrication to AR Experiences

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Abstract

With this paper, the authors want to reflect on how, in the age of the immaterial, a plastic model is a tool still current in the representation and able to connect with the new digital tools of augmented reality (AR). In this context, we would like to present a practical case concerning the realization of two static scale models, realized through Digital Fabrication technologies, aiming to increase the accessibility to knowledge about the architectural project in an exhibition context.
The final goal of this work is to develop a methodology that allows the user to obtain information about the architectural project not only through the real model but also through static and dynamic virtual models overlaid using the current AR technologies. In particular, the following tools were used for tracking: Unity®, a multiplatform graphics engine, and Vuforia®, an augmented reality software development kit.

Keywords
3D modelling, maquette, augmented reality, digital fabrication, multimedia.

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AR Technology for the Enhancement of Architectural Maquettes

This paper reflects on how the narrative of architectural design today requires an increasingly interdisciplinary approach supported using of virtual tools for the simulation of architectural and urban space and by digital fabrication technologies for the construction of physical models. Architectural model is a tool that is still current in the field of representation [Sardo 2004, p. 195] and can be integrated with the new digital tools of AR (Augmented Reality) and AI (Artificial Intelligence).
In particular, the link between maquette, AR and AI is currently articulated along two main lines of research. The first is based on the construction of real information models, the second on 'human-material' interaction through the practices of 'augmented craftsmanship' and 'design by making' [Vitali 2021, p. 62].
The maquette can be considered as a narrative artifact to anchor information and create different levels of interactivity and immersion. The authors propose an approach between amusement and edutainment that aims to convey and understand contemporary architectural design [Meschini 2016, p. 4].
The authors intend to present a practical case focused on the construction of multimedia content and its visualization using AR technologies by anchoring it directly to the maquette. The reference project is a circular logistics center characterized by vertical operation, developed after Politecnico di Torino won the third prize in the international urban design competition "Future *Shanshui* City Dwellings in *Lishui* Mountains" in October 2020. Following the competition, the ModLabArch laboratory, where one of the authors is a research fellow, proposed to create a 1:200 scale model to be exhibited in the *Lishui* Exhibition Centre.
The aim of the research is to reflect on how the new scenarios of craft 2.0 extend and intertwine with the more established universes of design and architecture, and how the practices, processes and methods of project communication are currently changing [Micelli 2016, p. 5]. This process is also happening thanks to the continuing trend of placing new digital technologies alongside more traditional techniques. [Pone 2017, p. 9]
In this case, the maquette is a narrating artefact on which information can be anchored, thus generating different levels of interactivity and immersiveness and proposing an approach between amusement and edutaimnent aimed at communicating and understanding the contemporary architectural project. [Meschini 2016, p. 4]
In the following paragraphs, a methodology will be exposed that allows the user to learn information regarding the architectural project not only through the real model but also through static and dynamic virtual models superimposed on it through current AR technologies.

AR and Architectural and Urban Maquette: the State of the Art

The features and benefits of using physical models in architecture are numerous and well known, while the potential of augmented reality applied to real models is still being explored and developed. Although AR can no longer be considered a novelty, its applications in architecture and the possibilities it opens for representing the architectural and urban environment need to be further explored.
The fusion of physical and digital models creates a powerful tool that can represent the static built environment in a physical, tactile, and three-dimensional way, while allowing the visualisation of dynamic elements such as shadow projections, people and objects in motion, text objects, etc. [Piga 2017, p. 104].
When talking about the interaction between real model and digital model, TUIs – Tangible User Interfaces – are often referred to. A first example is the Luminous Table of the Fausto Curti Urban Simulation Laboratory (LabSimUrb) of the Department of Architecture and Urbanism of the Politecnico di Milano made in 2010. It allows simulating dynamic environmental conditions based on a physical model [LabSimUrb 2010]. Altri esempi sono the In-Form and CityScope projects, each one interactive simulation tools for urban planning aimed at increasing public involvement [Follmer 2013].

In terms of augmented reality applications, reference can be made to the plastic model at Apple Park in Cupertino, in the heart of Silicon Valley (2017), where visitors to the center can see a virtual version of the campus overlaid on the metal model in front of them by using an IPad. They can change the time of day to see how the massive glass structures look when hit by the morning sun. They can also tap on any building to get a small view of the interiors and see how solar energy is collected by cells on the roofs of the buildings and how air moves through the buildings [Cupertino ApplePark 2017].
In the Italian context, we can refer to the monographic exhibition Tex Willer and the project AR, developed by Josef Grunig. A project in which the tracking of the physical model is done through an image and with Apple's ARKit technology, requiring an initial scanning with an iPad, keeping the lighting conditions at the exhibition site constant and not changing during the exhibition day [Tex-70 Years of a Myth 2018] (Fig. 1).

The Case Study: the Logistic Hub of Lishui

The activity presented here started after Politecnico di Torino was awarded the third prize of the "Future *Shanshui* City Dwellings in *Lishui* Mountains International Urban Design Competition" in October 2020.
It is a project developed by 44 teachers, researchers, Ph.D. students, and undergraduates belonging to the research groups of the China Room (DAD and DIST) and the Institute of Mountain Architecture of DAD.

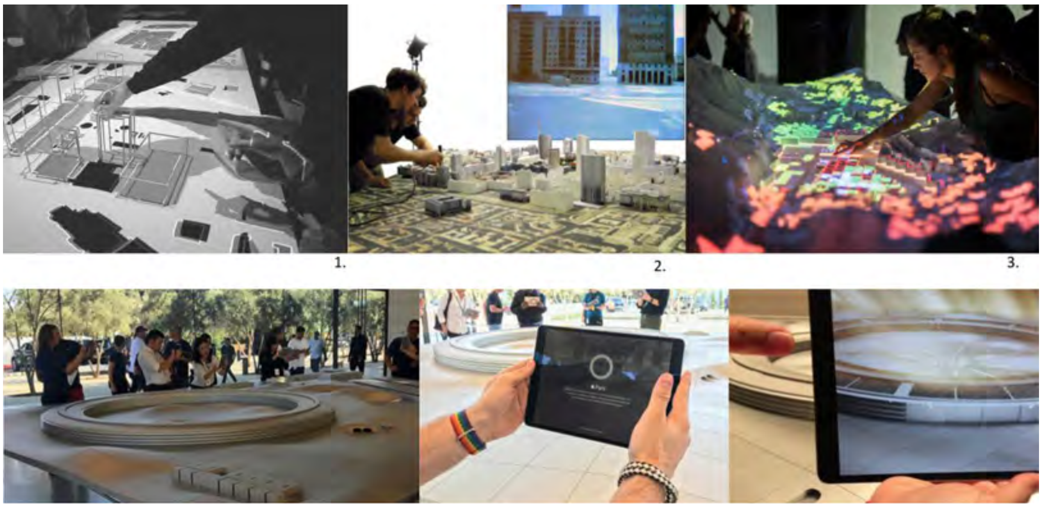

Fig. 1. Luminous Planning Table (LPT), Massachusetts Institute of Technology (MIT), 2000; Luminous Table, Laboratorio di Simulazione Urbana Fausto Curti, Politecnico di Milano, 2010 CityScope, City Science Group del Media Laboratory – Massachusetts Institute of Technology (MIT), 2015; Apple Park, Cupertino, California, 2017.

The work focuses on the *Lishui* Plain, the only plain in southern *Zhejiang*. This area is an important resource for both ecology and agricultural production.
The goal of the master plan was to protect this area and its production by focusing on three project areas: the valley, the housing developments, and the ecological system. Areas that must adapt to the existing city and its main mobility infrastructure without compromising the ecological integrity of the mountains.
The result is a new urban area that shifts its core from the old city to a large central agricultural park designed as a highly specialized and technological platform for production, research, and leisure.
Following the competition, the ModLabArch laboratory proposed to make two 1:200 scale models of two buildings representative of the project to be exhibited in the *Lishui* Exhibition Centre.
The building that is the subject of this case study is a circular logistics center with an area of 192,000 sq.m., located at the crossroads between the air freight system and the road transport system that crosses the valley.

The shape and height of the building are modeled on an air freight system: plants are delivered via cable cars on the upper floor and gradually descend to the lower floors during the various stages of processing until they arrive at the first floor, where they are loaded onto trucks and shipped.
The building has four floors above ground and is organized vertically: the goods coming from the cable cars are deposited in the entrance area, a space dedicated to receiving the goods, unpacking them, and placing them on the conveyors for access to the lower floor; the picking area, where the sorting, storage, and loading of the goods onto containers takes place with the help of overhead cranes; the business district; the commercial area and the public spaces that connect the building with the surrounding villages (Fig. 2).

Methodology Development: from Digital Modelling to Digital Fabrication

For the present work, a workflow has been applied that foresees the coexistence and overlapping of different representation methods, both traditional (drawings and physical models) and modern (3D modelling, integrated CAD /CAM systems, tracking and AR systems). They are all useful for the different communication phases of architectural and urban design (Fig. 3).
These different imaging techniques and the relationships that develop between them are becoming increasingly important in defining the new frontiers of architectural practice [Mitchell et al. 1995]. In particular, the work focused on: the three-dimensional digital modeling of the building, the identification of Digital Fabrication techniques (3D printing and laser cut), the executive design of the individual parts, the printing and cutting of all the elements, the assembly and photo-shooting, the design of the AR experience through the identification of specific types of content.
After defining the aesthetic and scale characteristics of the real model, it was decided to use a scale of 1:200 to represent only a quarter of the building, given its large dimensions. The

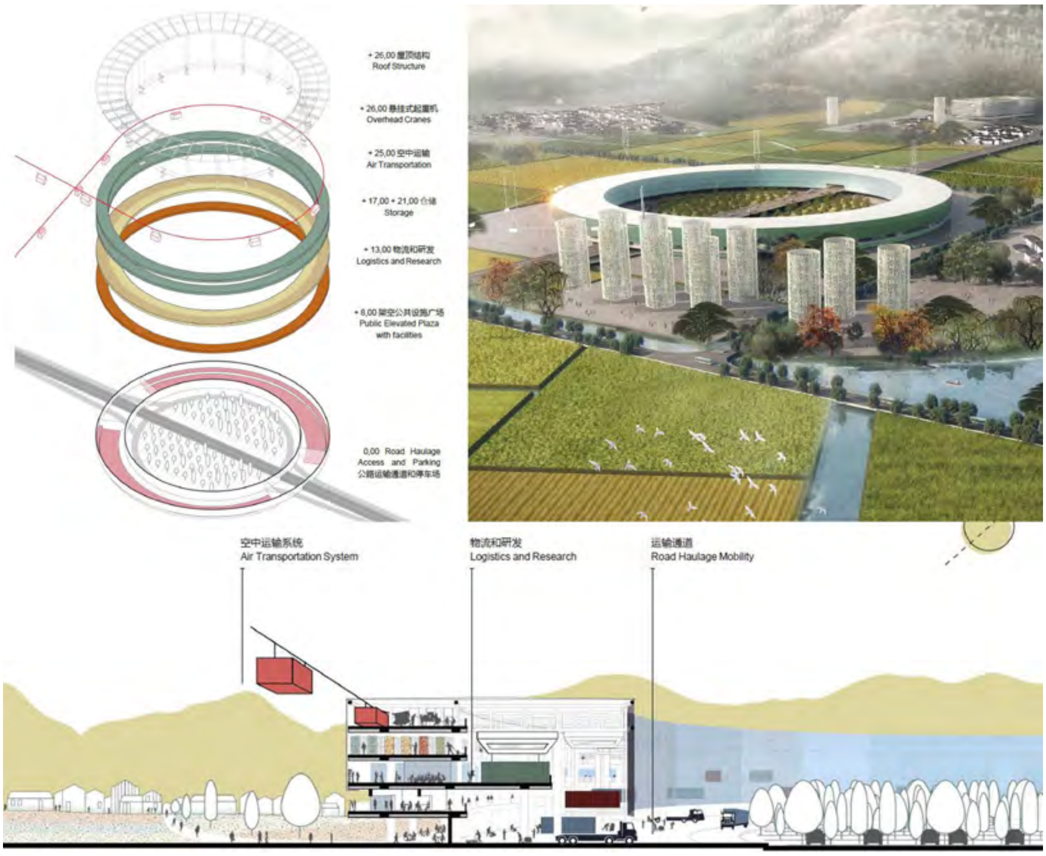

Fig. 2. Prosperous Lishui. South China University of Technology: School of Architecture and Politecnico di Torino, China Room and Institute of Mountain Architecture, Future Shanshui City – Dwelling in Lishui Mountains International Urban Design Competition, 2021.

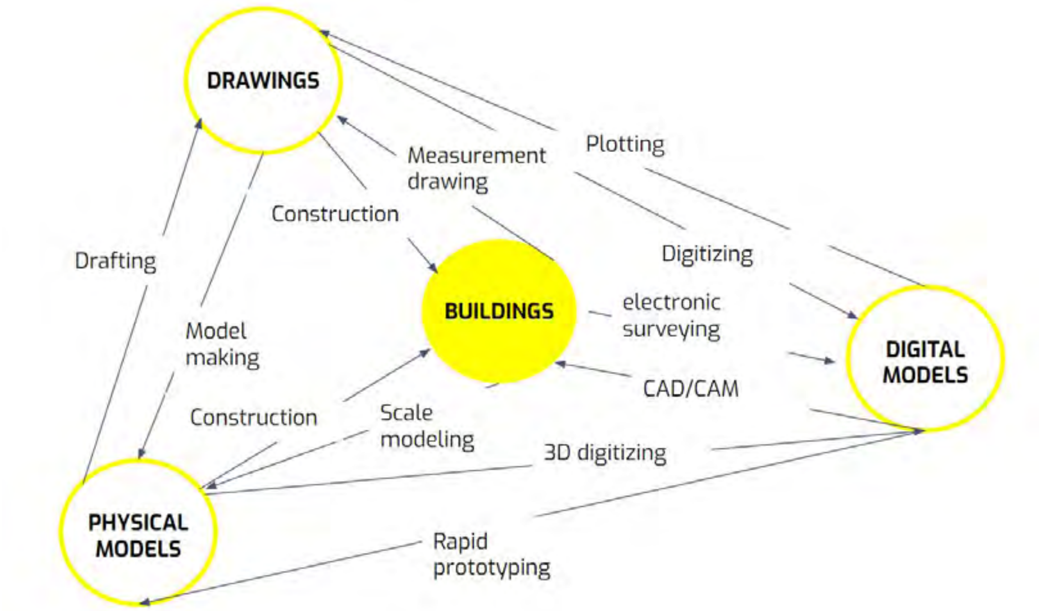

Fig. 3. Mitchell and McCullough, diagram showing the translation paths between physical drawings, digital models, physical models, and the building itself.

model was designed to reveal both the internal and external organization of the distribution, as well as the most representative architectural and structural elements (Fig. 4).
The selection of the dimensions of the different elements was based on the Digital Fabrication techniques available in the ModLabArch laboratory: the Ultimaker S5® 3D printer and the Trotec Speedy 400® laser cutter. Consequently, we proceeded with the choice of materials: colored PLA (polylactic acid) for the structural and distribution components and for the transportation means, grey vegetable cardboard, and opaque and transparent plexiglas for the base and floors. Although for AR experiments it is better to have a solid color and opaque materials, in this case, given the need to have a model that can be understood without digital devices, it was decided to use color anyway (Fig. 5).

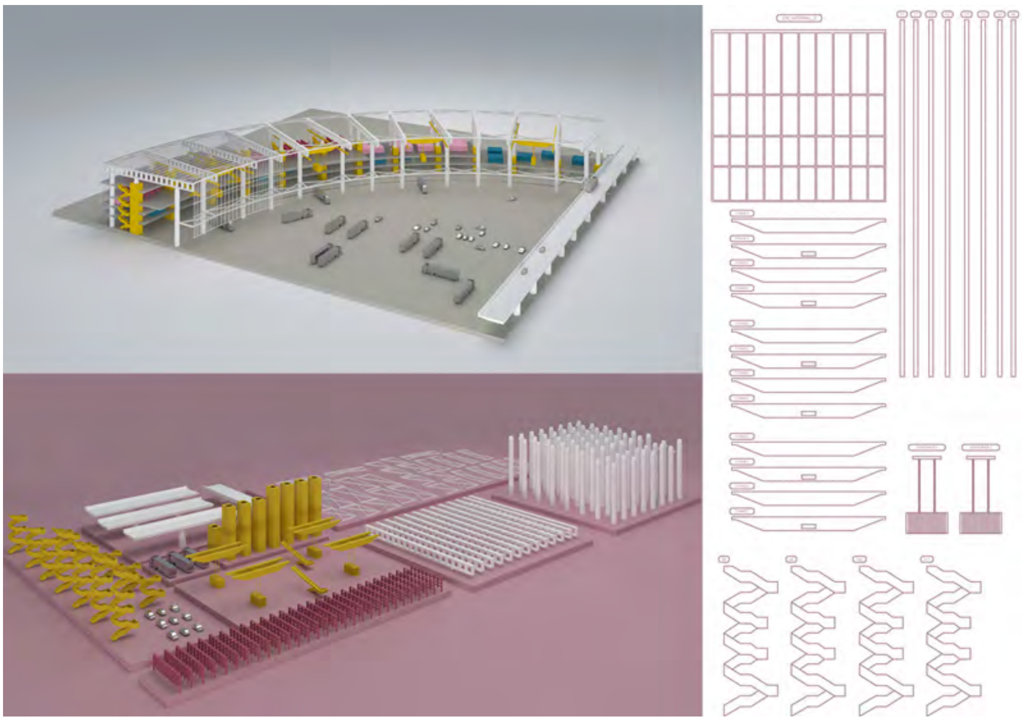

Fig. 4. The 3D model: example of organisation and numbering of some pieces of the model and rendering images. (Project of the Logistic Hub developed by Giulia Bertola, Edoardo Bruno, Alessandro Capalbo, Camilla Farina. 3D model and executive design by Giulia Bertola, Alessandro Capalbo, Enrico Pupi. Rendering and graphics by Giulia Bertola).

Augmented Reality Project

Augmented reality (AR) in the field of architecture and urban planning can be very effective when used to anticipate design projects and their impacts, and to support informed dialogue among the various stakeholders involved in the processes of architectural and urban transformation. This can be done on-site, by acting directly on the area being transformed, or off-site, by using physical scale models [Piga 2017, p. 106].

Fig. 5. The final Hub maquette (3D Printing by Giulia Bertola, Enrico Pupi, assembly operation and photoshooting by Giulia Bertola, Enrico Pupi, Areej Awada).

As for the former, static view content can be created where text documents, meaningful images, videos, project drawings, and conceptual schematics can be linked to the maquette through a system based on the recognition of target images placed directly on the model. Users can access the content through downloadable applications or connect directly to a dedicated website for the project, accessible through devices such as phones or tablets. For this project, however, it was decided to focus on the construction of static three-dimensional content that is dynamically displayed directly on the real model. Starting from the 3D model and using special rendering tools, it is possible to create three-dimensional objects that can provide additional information on structure, distribution, energy, and environmental aspects. When the user frames the model through a device, objects appear on the screen that complement the real model (texts or additional architectural and structural elements that are not present in the plastic model). This process was also made possible by the fact that the real model and the multimedia content are derived from the same virtual model.
Finally, it is possible to make the same content dynamic by simply animating the three-dimensional objects.
As for the choice of tracking tools, the following applications were used: Unity®, a multiplatform graphics engine and Vuforia Engine®, an augmented reality software development kit. Before we could proceed with creating the augmented reality experience on Unity®, we needed to be clear about which model recognition method we wanted to use. One of the best and most popular SDKs (software development kits) for augmented reality is VuforiaTM®, a tool that works very well with Unity® and allows tracking of layers and 3D objects in real-time. A target is a predefined object that the VuforiaTM® engine recognizes in the real scene and tracks in space. The two most common types of targets are the single image and the 3D object.
In this case, since the object to be tracked is directly the hub model, a 3D object target was created. Using the Model Target Generator (MTG), a software from VuforiaTM®, it was possible to upload the digital model exported directly from Rhinoceros® in .fbx format. In general, for the creation of the Model Target, it is necessary that in the transitions between Rhinoceros®, VuforiaTM®, and Unity® there is: a match of the coordinate system, the scale of the object is set 1:1 and there is a general reduction of the complexity of the model. These checks can be performed directly in the Model Target Generator. In the MTG you will then get the auxiliary view, an image file that stylizes the image of the 3D model, in the same position in which it should be framed now of use. Given the complexity of the Hub model, when creating the Model Target, it was necessary to eliminate some components to avoid detection of invisible parts or non-existent features. In the Model Target Generator (MTG),

random colors can also be applied to parts of the 3D model to improve tracking performance. At this stage, colors and textures do not have to be true to reality. On the contrary, the use of photorealistic textures or materials that try to emulate certain physical effects can lead to the opposite effect.
Once the procedure is complete, the Advanced View is created and the Model Target is exported to a .unitypackage file, ready to be imported into the project on Unity®. The first step is to set the device on which the experience will be tested. When you open the Build Setting window, you will find several settings, including the ability to switch between different operating systems.
A preliminary operation to be performed is the setting of the device on which the experience is tested.
Being a preliminary study phase and having a stationary object during the AR experience, it was decided to use the camera of a laptop placed directly in front of the model.
Usually, the use of static movement significantly improves the quality of tracking.
After adding the VuforiaTM package to the project, we proceed with the insertion of the AR Camera, the new Unity® basic camera, the Model Target, and the Child object to be displayed during the AR experience.
The experience takes place when the Game View is activated; in this phase, it is possible to visualize the Guide view (the Model Target), superimpose it on the model, and automatically visualize the Child object (Fig. 6).

Conclusion

This experience intends that the user can acquire additional information about the architectural project. Once the method has been identified, it is planned, in a subsequent phase, to create different types of 3D contents, both static and dynamic, always inserted as Child objects within Unity® and anchored to the Model Target.
The success of modern digital representation technologies is already demonstrated by the rapid spread they are having in various fields of communication. The aim of this study was to show how these applications can have a positive influence on architectural design and the creation of maquettes.

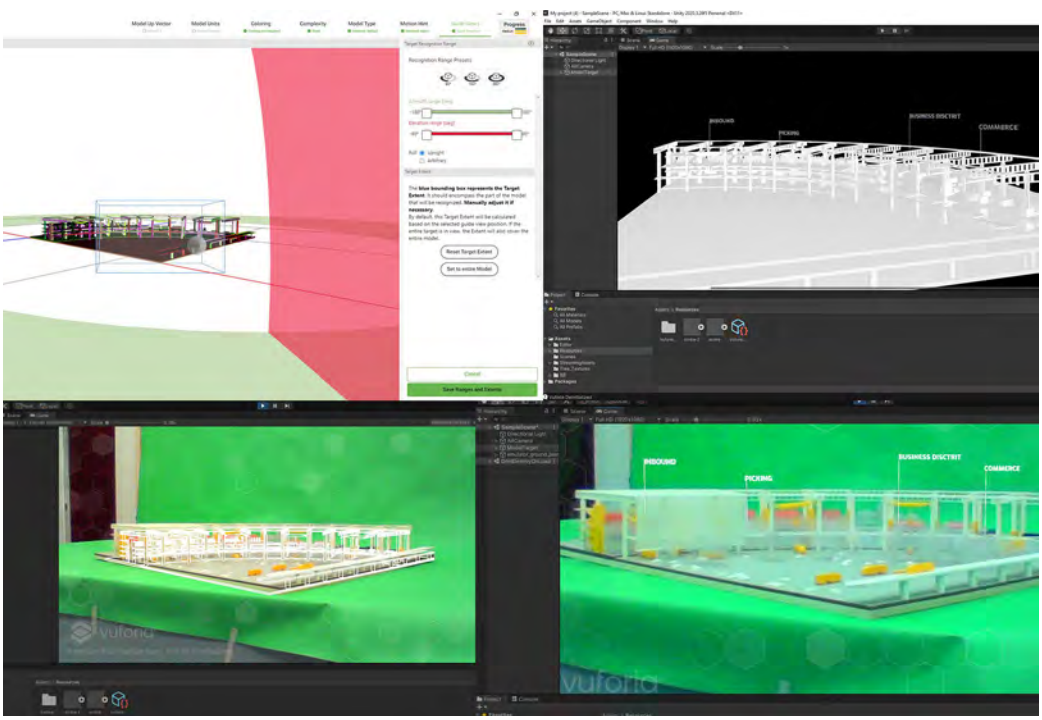

Fig. 6. The Augmented Reality Project. Model Target creations on Vuforia® and the project on the Unity® platform (the recognition of the model target following the overlapping of the real model and the appearance of the Child object in AR). (Design by Giulia Bertola)

Models, even if integrated with such technologies, can still maintain their role as a tangible miniature witness of architectural and urban space and be able to describe the idea of physical space, without simulating its reality but stimulating the critical imagination of the observer [Gulinello 2019, p. 98].
Real models and virtual models can therefore act synergistically even though they come from different approaches: the former maintaining their power to fascinate thanks to the fact that buildings will continue to be designed and built, the latter thanks to their forward-looking approach that helps to achieve other goals such as efficiency in the design process based on the principle of an intelligent process [Schilling 2018, p. 197].

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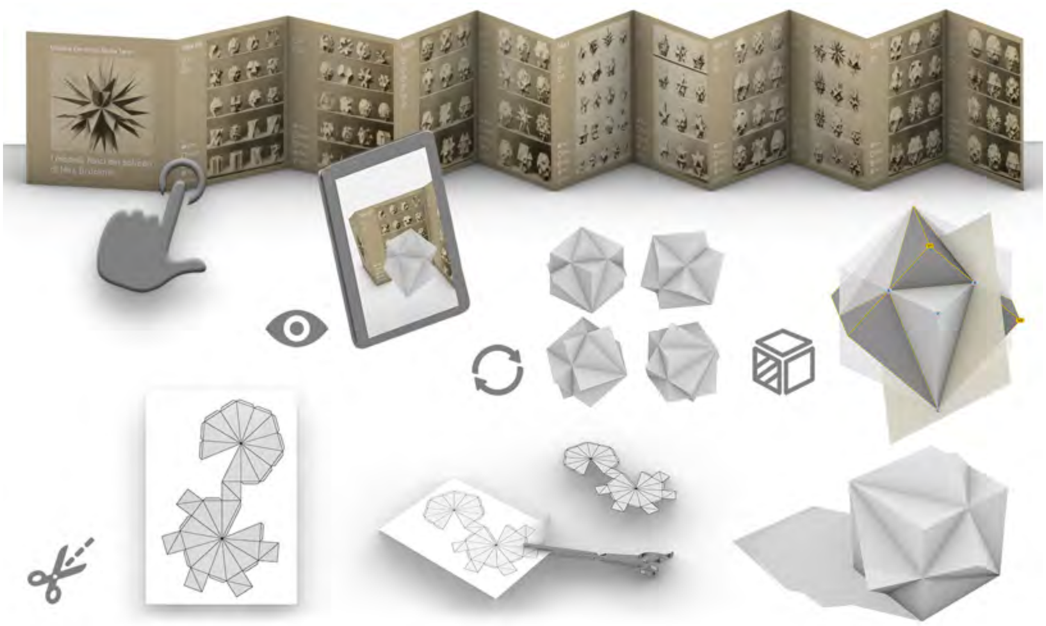
The Renewed Existence in AR of Max Brückner's Lost Paper Polyhedra

Michela Ceracchi
Giulia Tarei

Abstract

This study proposes the realization of an Augmented Reality museum of mathematical-physical models for distinctly educational purposes and capable of explaining mathematical and geometric principles. Augmented Reality, in this context, would render them accessible while interacting with their digital twins would not endanger the preservation of the originals, and furthermore, comprehension would be enhanced thanks to the inclusion of explanatory contents. Following the teaching course proposed from our experience, it is possible to build the replica of one's paper mock-up, thus giving pedagogical value back to the mathematical models otherwise precluded when musealized in a showcase or, worse, safeguarded in storerooms due to limited exhibition space. The first trials concern Max Brückner's collection of polyhedra models, published in 1900 in *Vielecke und Vielflache: Theorie und Geschichte*, which offers the opportunity to evaluate the potentials of Augmented Reality to renew existence to a collection that is now lost.

Keywords
augmented reality, descriptive geometry, physical mathematical models, polyhedra, Brückner.



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Introduction

The present contribution [1] is part of the cultural backdrop of the rediscovery of mathematical-physical models in the context of teaching geometry and the valorization of a fragile cultural heritage, a characteristic due to the type of material used in the creation of these objects. A heritage that has long been almost forgotten due to a lack of interest that took place in a certain historical period [Apéry 2020] but which today is the focus of numerous studies for their valorization and dissemination, both in the physical and the digital world.

In this context, the present research proposes a new musealization of physical mathematical models based on the use of Augmented Reality with the scope, in particular, "to the possibility of recreating collections" [Maniello, Amoretti 2016], integrating an interactive educational experience that concludes with the construction of one's own paper models. This kind of project allows the exploration of Augmented Reality to overcome the limits of the physical model in their not being usable, typical of the traditional museum experience.

The collection chosen for the first experimentation (Fig. 1) is shown in the photographic plates published in 1900 by Max Brückner in *Vielecke und Vielflache: Theorie und Geschichte*, which the author himself defines as a compendium of consolidated knowledge up to that time of the theory of polygons and polyhedra, describing them from a theoretical and historical point of view [Brückner 1900, Preface].

In the Appendix to the treatise, the German mathematician includes seven lithographic Tables and five double photographic Tables with numbered paper polyhedra set and ordered on the shelves.

The importance of physical models on his work is likely due to the influence of Felix Klein, his advisor for the doctoral thesis and one of the principal proponents of the use of images and physical models in the development of mathematical intuition [Hart 2019].

The characteristics of the collection make it an important element to be inserted into the broader musealization project. In fact, it already assumes the aspect of a homogeneous collection but it is a *Wunderkammer* that elicits a nescient curiosity [Hart 2019].

Augmented Reality could add explanatory content to restore the educational value typical of mathematical physical objects. Furthermore, those displayed are paper models, easily replicated with common materials and tools, making them particularly suitable for an education experience tending to the construction of one's own model. But above all the actual collection no longer exists save for the photographic plates in the book [Hart 2019], so it would be possible to investigate the potentials for Augmented Reality to re-establish a rapport with a gone heritage, and furthermore, the replication in the creation of new paper models would bring it back to existence once more.

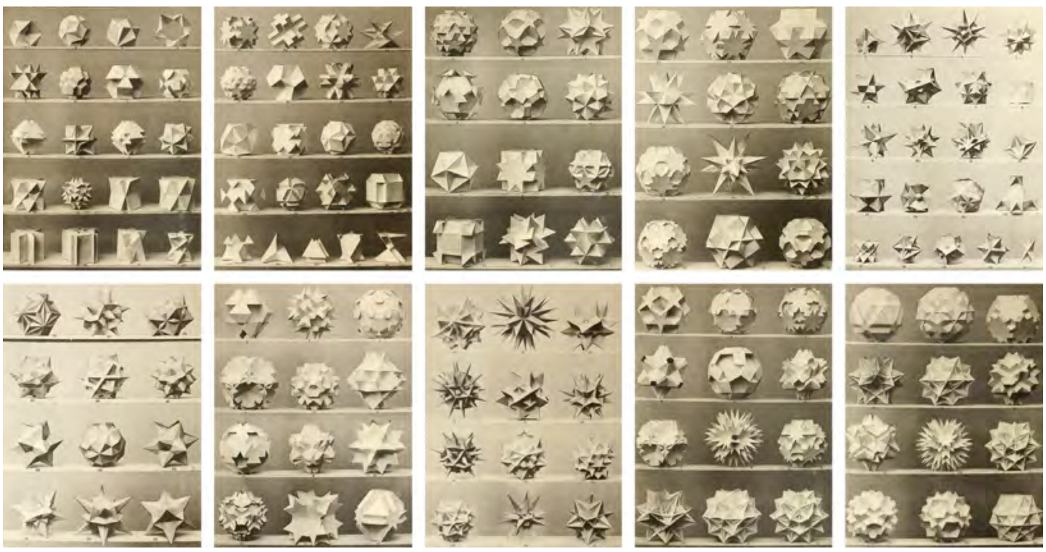

Fig. 1. The photographic plates published in *Vielecke und Vielflache* in 1900 by Joannes Max Brückner, show a selection of the collection of polyhedra created by the author.

The Musealization of Mathematical-Physical Models: Instruments and Prospects

The mathematical-physical models are objects conceived for distinctly educational purposes, representing mathematical laws and principles in space and capable of explaining the features of curves, algebraic surfaces, and complex polyhedra, revealing their spatial genesis. The greatest strength resides in their materializing an immaterial construct of ideas composed of abstract signs on a tangible object [Seidl, Loose, Bierende 2018, p. 20; Pavignano, Cumino, Zich 2020].

The physical models were the main protagonists of the *didactic theaters* [*teatri didattici* Gay 2000] that characterized the teaching of math and geometry between the end of the nineteenth and the first half of the twentieth century. The use of these models spread thanks also to the publication of numerous catalogs, aimed at promoting sales, in which the models were often presented employing text, graphic representation, and analytic description [Pavignano, Cumino, Zich 2020]. It is precisely thanks to these publications and the few surviving collections that the information regarding them has come down to us. Presently the models are preserved in the display cases of university workshops or museum showcases but more often in their storerooms, denying any utilization.

In recent years interest has been renewed regarding these collections, motivated by two main intents. The first has to do with the possibility these objects offer to render mathematics visible [Hart, Heathfield 2017], an aspect of interest for those studies that focus on the leading role of the geometric quality in the definition of the form in architecture [Pottmann, Asperl, Hofer, Kilian 2013; Valenti 2019; Baglioni, Salvatore, Valenti 2020; Salvatore, Baglioni, Valenti, Martinelli 2021]. The other has to do with the aesthetic significance of these objects, able to inspire artistic experimentation even now, as demonstrated by the works of the American artist and mathematician George Hart [Hart 2005; Hart 2005a]. The ability to make the genesis of very complex forms on a physical object clear had already fascinated the vanguard artists who investigated the generative processes, even replicating the formal outcomes [Baglioni, Farinella 2017].

The renewed interest in these collections has led to many experimentations aimed at their valorization. Some concentrate on the valorization of the physical consistency of the surviving collections, as is the case in the vast collection of models created by Alexander von Brill's students at the University of Tübingen [Seidl, Loose, Bierende 2018, p. 15], where others promote the integration of the collections via the modern technique of rapid prototyping, such as the case of the Henri Poincaré Institute in Paris [Apéry 2020]. Still others are directed towards the digitalization of their collections [2], which, however, lack the tactile experience by which the hand which grasps learns, the hand that grasps comprehends [Di Napoli 2004, p. 38].

In this context, Augmented Reality would allow the fruition of the digital model by better simulating the perception of a real object in 3D space; being a link between the real and the virtual, between physical and digital space, it can create the illusion of depth despite it being visualized on the screen of a device. The use of Augmented Reality also has a great impact on educational activity [Lin, Chen, Chang 2015], to improve, optimize, and render both the teaching and learning process more immediate. The success of the use of digital technologies has already been recorded in terms of interest and results in both teaching [Spallone, Palma 2021] and museum [Luigini, Panciroli 2018]. Furthermore, the potentialities of Augmented Reality in the scope of the communication of long gone objects or sites have been extensively investigated [Empler 2019] and results demonstrate how its use can restore their configuration as well as re-establish a rapport with them to a far greater extent than is possible with a virtual reconstruction.

Finally, to understand the three-dimensional configurations of geometric forms or problems of spatial nature, the construction of one's own physical model is the most suitable tool. Studies regarding teaching experiences that make use of the physical model for the understanding of problems of a geometrical nature have shown how this practice is still relevant and fundamental for students' development [Cumino, Pavignano, Zich 2020; Spadafora 2020; Cumino, Pavignano, Zich 2021].

The Collection Through Augmented Reality: an Interactive Pedagogical Experience

The main objective of this museum proposal is to restore life, using Augmented Reality, to a lost collection. To this end it is necessary to know the characteristics of the collection itself; all the models contained in it represent non-convex polyhedra, which, due to their complexity, are not immediately recognizable merely by observing the photographs [Mikloweit 2020]. The lack of organization of the collection [Hart 2019] and any element that helps make the represented polyhedra easily recognizable, render their classification even more arduous. The models are distributed on the shelves according to size, in order to save space [3] [Brückner 1900, p. 183]. In this way, however, the polyhedra belonging to the same category, such as the Kepler-Poinsot polyhedra, are randomly distributed among the plates. The author explains the absence of colour as well, generally used in mathematical models of polyhedra to provide characteristics and genesis of the represented form: the paper models were coated with homogeneous white plaster to avoid problems with the collotype reproduction of the photographs [Brückner 1900, p. 183].
George Hart has identified and classified some of the polyhedra of the collection precisely to show how it is full of interesting and also very complex examples, among which for example the American mathematician identified ten stellations of the icosahedron, many of which were constructed for the first time specifically by Brückner, including the complete stellation [Hart 2019].
The classification was carried out by means of different approaches. Firstly, an analysis of the models illustrated has permitted the identification of some of the best-known polyhedra, some prisms, and antiprisms. With the help of some texts on polyhedra [AA.VV. 1938; Coxeter 1948; Wenninger 1971; Wenninger 1983], it has been possible to classify many other polyhedra, by comparing the models in the collection with those illustrated in some of these publications.
To systematize the contents of a collection of this kind means making it understandable and complete, so as to allow their promulgation. Organizing the collection by categories of affine polyhedra and adding explanatory contents makes the definition of the educational path possible that would restore to the collection its pedagogical value. Furthermore, classifying the polyhedra makes their characteristics and geometric genesis known and therefore makes their graphical, digital, and physical construction possible.
The integration of an interactive learning experience introduces an important issue to reflect upon, that is the pedagogical problem of a balance between traditional and digital instruments [Spadafora 2020]. In fact, this experience was conceived as a series of various activities. The common thread is precisely Augmented Reality.

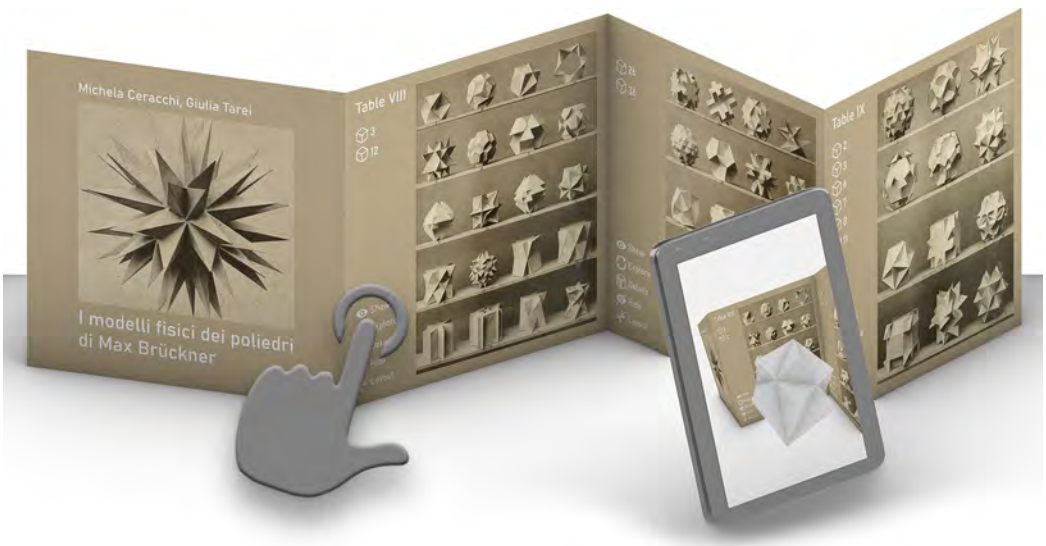

Fig. 2. The photographic plates illustrating the collection become the target by which the Augmented Reality experience is triggered.

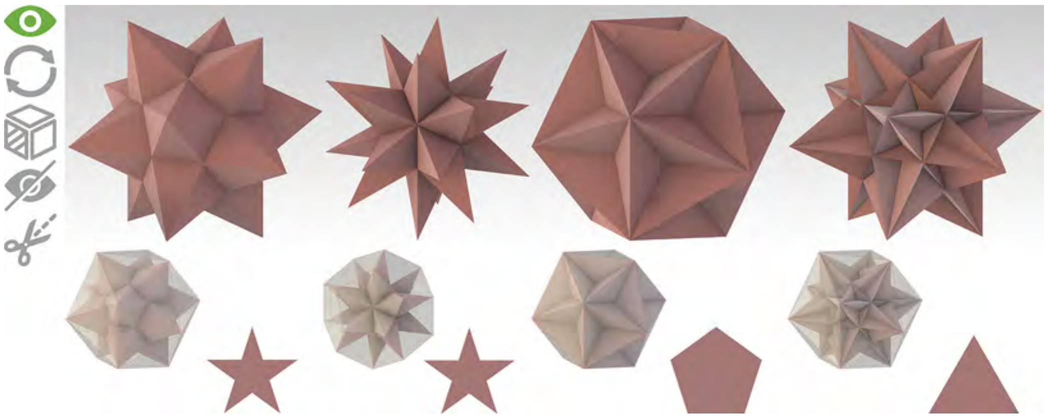

Fig. 3. The first proposed activity: visualization in Augmented Reality of the digital models of the polyhedra.

In this proposal, the tables of the treatise become the means by which the experience in Augmented Reality is triggered (Fig. 2). In that respect, it is necessary to keep in mind the substantial difference that exists between Virtual and Augmented Reality: virtual is synonymous with illusory [Maldonado 2015], whereas, in Augmented Reality, the relationship between the real world and digital content can be consolidated through the target [Bianchini, Fasolo, Camagni 2020].

The activation of the digital content in Augmented Reality permits, first of all, the visualization of the digital model to comprehend the spatial configuration of the polyhedra shown and compare the various models to deduce the relationship. The possibility of visualizing the models together that have been classified in the same category is useful in understanding the relationship between them. For example, this comparison in the case of Kepler-Poinsot polyhedra is useful one can understand the principle of duality that exists between the first two, the small and great stellated dodecahedron, and the following two, the great dodecahedron and the great icosahedron (Fig. 3).

The AR exploration of the digital model to be observed and redrawn (Fig. 4), assimilates it to the plaster models to be copied in drawing exercises, which consolidates the "aptitude in sequential reasoning favoured also by the use of the hands" [Spadafora 2020] because it participates in that rapport mind-eye-hand that if exercised stimulates graphic intelligence, which is the capacity to solve spatial problems through observing, understanding, and representing, as did Galileo regarding the lunar surface [Cicalò 2016], explorable only through observation, exactly as with this collection which no longer exists in its physical form. Orseolo Fasolo, in a letter to Riccardo Migliari, dated August 14, 1987, writes of the need to once more place the physical model at the heart of teaching Drawing because copying a model one learns to draw, especially "if the model is a geometric shape, one learns geometry" [Migliari 2001, p. 277]. These words are still very relevant because drawing is a fundamental passage in the comprehension of a tridimensional shape even when the aim

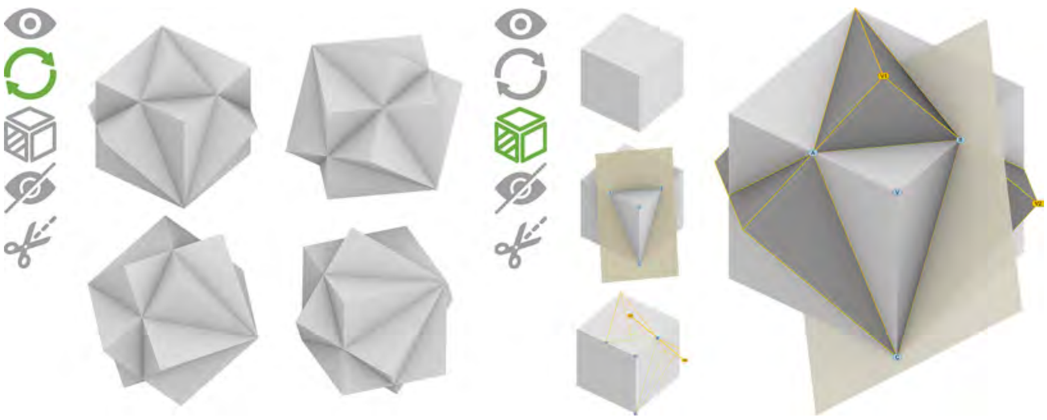

Fig. 4. The second proposed activity: Augmented Reality exploration of the polyhedron, using it as a model to be copied in the drawing to comprehend its configuration (left); the third proposed activity: the study of the characteristics and genesis of the polyhedron in question through the explanatory contents that can be viewed in Augmented Reality on the digital model (right).

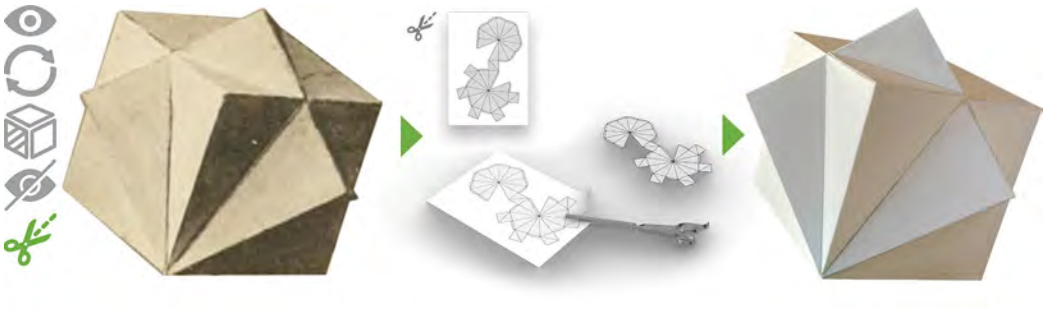

Fig. 5. The last activity: creating one's own paper model starting from the printable planar development, provided as additional material.

is digital or physical modelling so the knowledge and application of Descriptive Geometry are more important than any technological development [Rochman 2020].
The addition of explanatory material integrated with the digital model (Fig. 4), on the geometrical characteristics of the polyhedron and its creation, permits the acquisition of the necessary notions for an autonomous reconstruction of the digital model. For example, in even the simple case of the composition of two cubes, it is possible to investigate the properties of the resulting polyhedron and understand the stages of construction. In this manner, the experience emerges as an auxiliary aid in teaching the theory of polyhedra.
Furthermore, the integration of explanatory material to the digital model convey to these models the distinctive features of the mathematical model to clearly render the geometric characteristics that the form represents, thus far missing for the reasons given by the author himself [Brückner 1900, p. 183], and re-endowing to Brückner's collection that pedagogical value not entirely expressed in these photographic tables [Hart 2019].
Lastly, one's own construction of a paper model starting from the printable planar development, offered as supplementary material (Fig. 5), concludes this itinerary of knowledge of the polyhedra in the collection. The possibility of constructing by hand one's own model has important applicational relevance in the teaching of geometry and of representation because it exploits the educational worth of craftsmanship and manual work [Albers 1944]. Magnus Wenninger, in the introduction to *Polyhedron Models*, invites the reader to build their own paper model to gain a formal proof of the reasoning underlying the creation of polyhedra [Wenninger 1971], but even recent proposals in teaching context encourage the creation,

Fig. 6. Synthesis of the interactive educational experience.

on their own, of tangible objects to understand problems of a geometric nature [Cumino, Pavignano, Zich 2020 ; Spadafora 2020; Cumino, Pavignano, Zich 2021].
At the same time, each paper polyhedron created through this experience will contribute to giving renewed existence to the lost collection.

Conclusion

The originality of this project of musealization and interactive didactic activity consists precisely in the integration of the experiences of a diverse nature in a unitary project. The aim of this proposal is the revival of those *didactic thaters* in which physical models were the protagonists [Gay 2000], modernizing them in communication with the new generations thanks to the continuous interchange with the digital model in Augmented Reality.
The experimentation of this didactic activity and the subsequent validation through consolidated models of learning evaluation would allow to demonstrate its potential in the educational scope.
The broader project of musealization of mathematical physical models could be configured as an autonomous virtual museum, or as an experience to be inserted in a real museum context such as, for example, MoMath in New York – of which Hart himself was a co-founder – where the exhibits and interactive experience were designed to stimulate curiosity and evoke wonder. Linking the collections that can be explored in Augmented Reality to the real exhibits, inclusivity and accessibility can be enhanced – even concerning the recent global situation following the pandemic – and to the true museum experience in museums, it adds an interactive experience between the digital and the real world.
In this manner, Augmented Reality becomes the vehicle for knowledge and, in the specific case of Brückner's collection, the instrument through which the physical models can re-emerge from the two-dimensional condition of the photographic plates in which they are immortalized, bequeathing this cultural heritage now gone.

Notes

[1] The research was carried out jointly by both authors, who, together, wrote the sections "Introduction", "The Musealization of Physical Mathematical Models: instruments and prospects", and the "Conclusion". The analysis in the treatise was carried out by Giulia Tarei. The classification and musealization project in AR were carried out by Michela Ceracchi, who wrote the section "The Collection in Augmented Reality: an interactive educational experience" and created all the images.

[2] By way of example, we note that the digital collection of the University of Rostock, Germany, makes explorable digital models of some mathematical physical models from their collection.

[3] The models, as the author notes [Brückner 1900, Preface], were photographed by the firm Römmler & Jonas di Dresda and printed in the tables by collotype. The author furthermore invites the reader to freely visit the collection he owns.

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Using AR Illustration to Promote Heritage Sites: a Case Study

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Abstract

The Precettoria of Sant'Antonio di Ranverso, property of the Fondazione Ordine Mauriziano, is an extraordinary museum complex recently interested by a global effort to promote the site, an effort that since 2020 has taken a new direction.
Thanks to the site's richness in history, art, and anthropologic elements, for the second year in a row the Techniques in Visual Arts course at the Libera Accademia d'Arte Novalia was able to work on an educational and promotional project aimed at reaching a wider audience, specifically targeting the youngest visitors.
To reach this objective, the course focused on exploiting the possibilities offered by augmented reality, both as a way of spreading the knowledge of the site and to address a younger audience with educational content.

Keywords
augmented reality, heritage sites, Accademia Novalia, educational services.

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Goals

The Precettoria of Sant'Antonio di Ranverso [1] is a museum complex including an abbey, a church, a hospital and a few buildings used for farming; founded by the Hospital Brothers of Saint Anthony of Vienne, it is located not far from Turin, at the entrance of the Susa Valley and along the pilgrim route of the Via Francigena (Fig. 1).
The monastery was built at the very end of the 12th century and the complex was completed in the 15th century, which accounts for the Gothic style of the church and the hospital. Especially interesting, among its many works of art, are the frescoes (Fig. 2) painted by Giacomo Jaquerio, one of the main artist of the International Gothic, active in Piedmont at the beginning of the 15th century, and the polyptych by Defendente Ferrari depicting the *Nativity*, dated 1530. Over the last years, works have been carried on to restore the site, establishing new tour routes and increasing the number of visitors: this project, co-authored by Libera Accademia Novalia and the Fondazione Ordine Mauriziano, is part of that initiative, which has now reached its second year.
Since its outbreak in 2020, the Covid-19 pandemic has affected the Precettoria in different ways: negatively, with the closure and the drop in the number of visitors (above all students), but also positively, giving new stimulus to the digital contents renovation process, leading to small but significant steps.
Before the emergency caused by the pandemic, nobody deemed necessary to update the fruition of the site, which happened almost exclusively in person, with tour guides, printed maps and info pillars, but there was also no drive to reach a new audience, based even far away from the Precettoria.
Now the way the museum complex is interacted with has changed greatly, owing mainly to digital content: thanks to social networks and other channels, the Precettoria of Ranverso is now always accessible, along with its stories, pictures and anecdotes, having now built a stronger and more intimate link with the online users and reaching a much wider audience than the one physically close to the site itself.
Additionally, the forced absence of the vast majority of visitors from schools was the starting point of a new project aimed at spreading knowledge and engaging with the youngest visitors, usually aged 10-18, who would have previously benefited from guided tours tailored on their needs, but instead had soon become the least attracted by and interested in the museum complex.

Fig. 1. Precettoria of Sant'Antonio di Ranverso.

Fig. 2. Frescoes inside the Precettoria of Sant'Antonio di Ranverso.

To this end, a collective decision was made to leverage the potential of augmented reality as a basis for the Accademia's students' projects. This proved beneficial to the diffusion of knowledge about the site on new channels and with new languages: for instance, the symbols and ornamental motives embellishing the doors and the abbey became stylized markers, while events from the life of Saint Anthony were translated to short stories and anecdotes to be shared on Instagram. It is indeed possible to recount the Middle Ages, the saints' lives and the fascinating world of Medieval pilgrims through these means, maybe unconventional but certainly effective.

Methodology

The first project involving the Precettoria, over the course of academic year 2019-20, resulted in the design of a QR-code augmented map to be used as an audio-guide: the map was presented at the Museum Week 2021 and is still proving to be a useful resource.
On that occasion, a preliminary analysis of the needs of the museum complex was carried out, but in the new scenario after Covid-19 an update of the results was due. The huge task of examining and understanding the needs of the visitors, of the Accademia didactics, and of the site has been the first step of our new project, as summarized below.

Precettoria's needs:

- A new, engaging tool aimed at an under-18 audience, to be shared independently and with a greater duration than the time required to visit the site.
- New content for social media channels.
- An increase in online followers, to be translated into new visitors.

Accademia didactics needs:

- Enhance the students' skills while looking for a meaningful way of applying their knowledge of art history and painting techniques to the actual management of a museum.

Visitors' needs:

- Exploring the site, also online, as a mean to prepare for a future visit in person.
- Smart content specifically designed for a younger audience and that can be shared easily on social media.

In the second step, the students had to acquire the necessary knowledge regarding the site and its works of art but also about the new technologies they were going to employ.
The Precettoria management provided us with information, images, maps, and the opportunity to speak with personnel, granting also free access to the site.
In order to master the new technologies, a basic training proved necessary: despite the students' familiarity with augmented reality and social networks, their knowledge of terminology and specific languages was limited.

Our students had to learn the basics of the software Spark AR, distributed by Facebook/Meta to specifically use augmented reality on Instagram and Facebook.
This free software has several strong points: it doesn't require coding as it resorts to block coding, it offers templates and extremely clear documentation, and it is easy to learn.

While studying the Precettoria and its daily activities, our students also researched museums comparable to Sant'Antonio di Ranverso, both in Italy and abroad, understanding the various planned activities and differences in audiences, comparing them, evaluating their effectiveness and their weak spots.
At the end of this painstaking task, our students start the actual design phase:

Fig. 3. Examples of a student-created Personas (Anna Cerato and Alessandro Pietramolla).

- First, they created corresponding to the type indicated in our survey, that is, young people in the age group between 10 and 18 years.
- Second, have they designed the Personas-based filters (Fig. 3).

The final projects presented by our students belong to three categories:

- Markerless in selfie-mode: users can take selfies with the main characters of Sant'Antonio di Ranverso, most notably a black piglet, characteristically attributed to Saint Anthony and for this reason chosen as the site mascot, and share them on social media (Figs. 4a-4b); the aim is to reach an audience that is not yet familiar with the site and increase visits to the Precettoria Instagram profile.

Fig. 4.a. Selfie-mode filter, face decorations inspirited at original Precettoria's paintings (Marianna Luberto's first proposal).

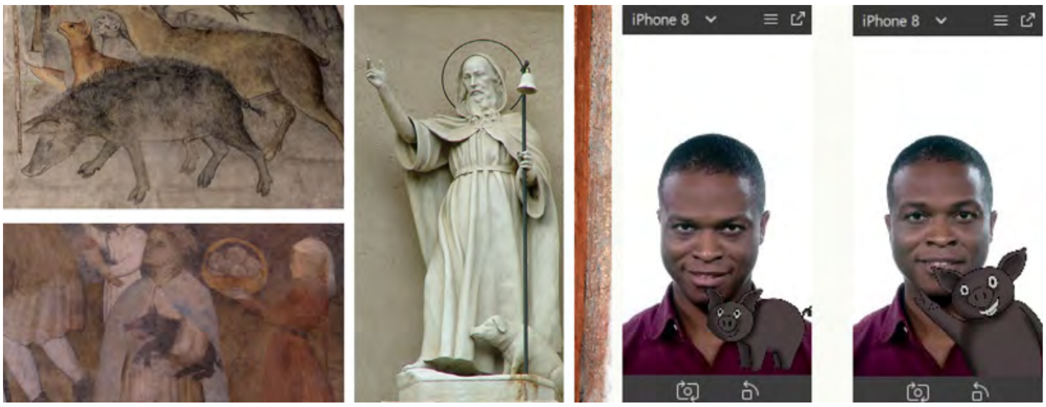

Fig. 4.b. Selfie-mode animated filter, a selfie with Ranverso's mascot: Sant'Antonio's pig (Marianna Luberto's second proposal).

Fig. 5.Markers printed on freebies, first users test (Beatrice Forno).

Fig. 6. Markers printed on freebies, user's journey first test (Anna Cerato).

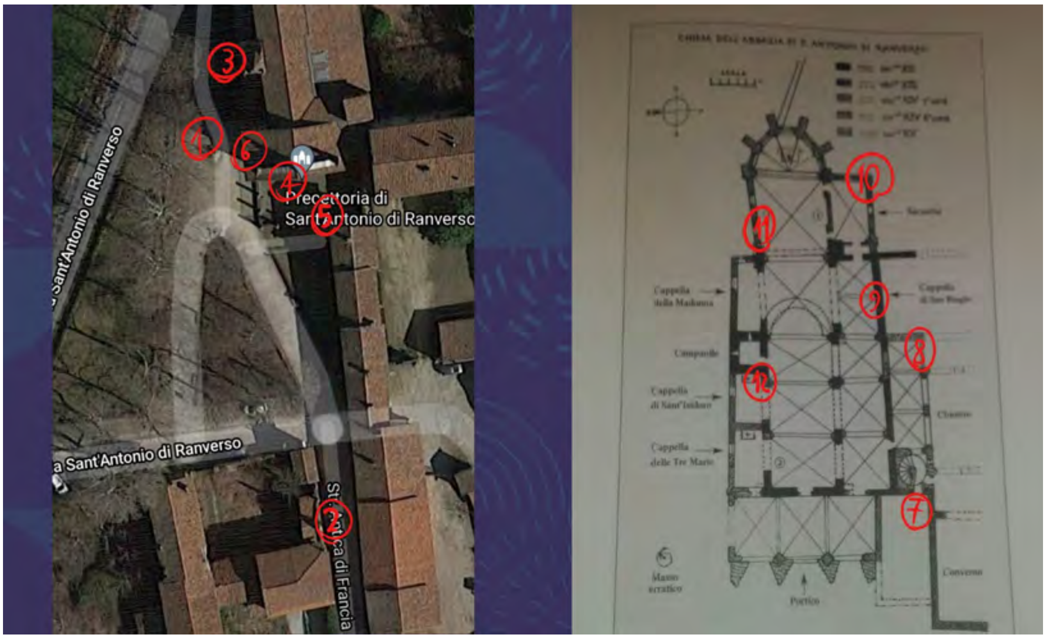

Fig. 7. Treasure hunt in AR, map of the stages (Sacchet Emanuele).

- Markers printed on freebies, such as postcards and posters (Figs. 5-6): the aim is to entertain the audience while teaching them about the site; freebies can be virtually shared on social medias but also printed and gifted to friends.
- Filters for the gamification of the visit route: the AR markers placed on the site in a specific order allow the users to find clues to solve treasure hunts and mysteries (Fig. 7).

Conclusions

By the end of the course, notable projects had been produced (especially for first-year students) while the level of engagement stayed high and Spark AR proved to be a valid and easy-to-use tool.

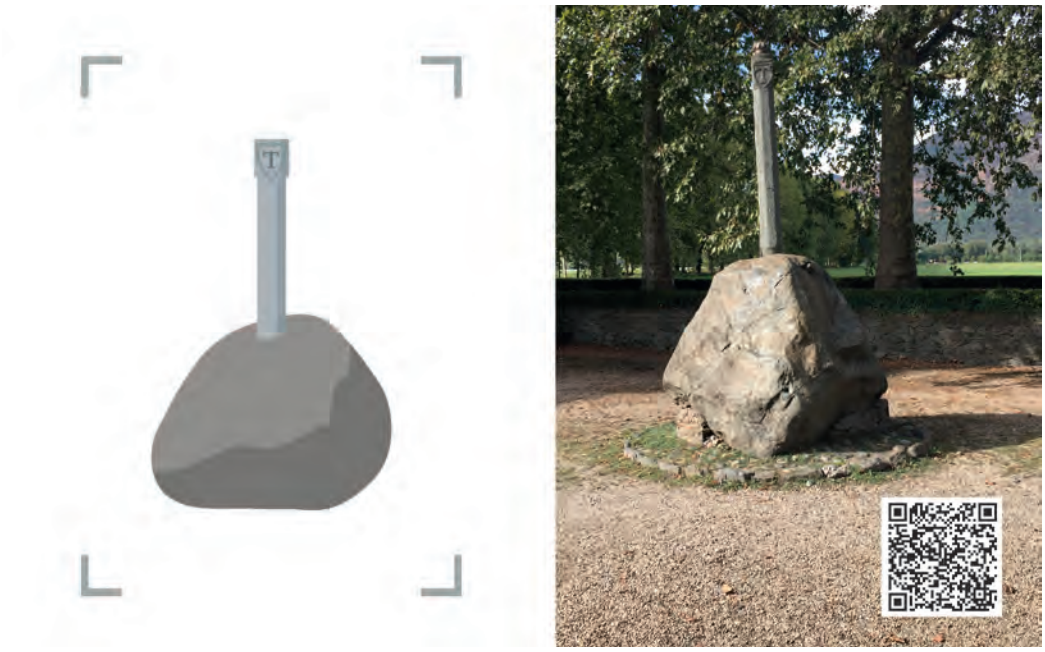

Fig. 8. The original erratic boulder, the marker, and the QR code for the demo filter by Francesca Rocchia.

The SparkAR software, therefore, confirmed the expectations, despite some intrinsic limitations (the use of the filter only on social platforms and the choice to start from a template), allowed the students to independently experiment the whole process of creating a complex digital object (Fig. 8), from the design of the user experience to the final phase of product testing.

The main hurdle was the students' low familiarity with the testing phase and with different devices, and also the general shyness shown in giving a feedback to their classmates, despite being explicitly requested. Unfortunately, the testing phase is still not yet considered a quintessential part of the development of a project and is wrongly perceived as a critique to the quality of the project itself.
Spark's block programming was also a good start to understanding the workflow and logic behind an AR project without the necessity of writing code, a competence not currently foreseen in our study plan.
We are now waiting for the results of the interaction with the users.

Link test:
https://www.instagram.com/ar/700315888010344/?ch=NmU5M2E0OGU2Y2NjNTcxNTRhMzhmNmM1YWZkZjM5NDQ%3D

Notes

[1] The site of the Precettoria belongs to F.O.M. Fondazione Ordine Mauriziano, also owner of the Palazzina di Caccia of Stupinigi and the Abbey of Staffarda (https://www.ordinemauriziano.it).

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SurveyingGame: Gamified Virtual Environment for Surveying Training

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Abstract

This contribution describes the first developing phases of a tool aimed to support field training sessions in topographic survey learning courses. After describing the issue that justifys the proposal of the research, a discussion of similar approaches carried out by researcher from different countries is shown. Thenceforth, the concept and description of the proposed gamified simulator are explained. Finally, the future features and scopes of the research are presented.

Keywords
surveying skills, virtual learning environment, gamification, educational innovation.

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A Need of Innovation in Topographic Surveying Training

During the last decades, new technological instruments have been incorporated into the field of topographic survey, giving rise to different techniques and practices to be developed. Among these instruments it is worth highlighting the GPS and the Total Station, that are widely used in urban projects, roads, bridges, sewage systems, etc. The most relevant changes derived from these advances are evidenced in the process of capturing, storing, calculating, and transmitting the data obtained in the field work, as well as in their graphic representation. Obtaining a final product with greater precision and speed is allowed by using these tools.

The learning of these techniques is highly necessary along the training period of those students who will make use of topography for the performance of their professional activity. However, there are some operational limitations in the educational context of topographical subjects, mainly related to the economic aspect and the insufficient hours for practise training that usually are allocated in the subject programs. The high cost of surveying instruments sometimes implies the shortage of equipment to guarantee adequate learning ratios. On the other hand, environmental factors are decisive. Inclement weather can prevent the correct development of the educational practices necessary for the procedural learning of topographic devices, even delaying or making them impossible. In addition, sometimes the training of students is limited to the surroundings of the educational facilities for security and transportation reasons.

These factors keep down the actual learning performance for students, which is limited in relation to the operational handling of topographical techniques and instruments on-site field. Moreover, we should add the current social and health situation derived from the COVID-19 pandemic. The health protocols applied to educational contexts hinder the effective use of topographical instruments and force the reduction of student ratios, worsening the lack of devices.

The sum of all these factors has motivated the opening of this investigation. The development of a digital tool (simulator) can have a very positive impact on the topographical training of students. It could even replace traditional training sessions in topographic subjects, when environmental or socioeconomic contexts make their development impossible.

State of the Art

The bibliographic review carried out has brought back some experiences prior to this research aimed at the construction of virtual learning environments in the field of teaching topographic surveys. These contributions use virtual reality to enhance the user's immersive experience in different ways. Some are committed to a high-level immersive experience, using peripherals such as VR glasses, gloves, physical spaces set up for the use of the tool, etc. Other contributions are limited to the traditional display of the virtual environment on the screen of the devices. The main contributions studied are listed below, mentioning their main characteristics.

Corresponding to the first group, the "SurReal" simulator [Bolkas et al. 2021] recreates a highly realistic virtual environment for computers, modelled by capturing point clouds of real scenarios using drones (UAVs) and terrestrial laser scanners (TLS). At its current level of development, using the "Oculus Rift" hardware, students can perform pre-configured levelling exercises in different environments. However, the authors point out some limitations in the use of this hardware related to the virtual handling of instrumentation and the performance of certain tasks (tripod leveling, calibration or data recording), for which it has been necessary to enable some additional elements within the interface. In a similar approach, other authors propose a cyberlearning environment designed for smartphones based on virtual reality [Levin et al. 2020] that includes a digital elevation model (DEM), a total station and a virtual reflector. The VR implementation is done using the hardware "Samsung Gear VR". The students recreate the entire workflow of a surveying, emphasising the correct location of the data collection points, that is, the proper interpretation of the terrain to be surveyed. The inclusion of various parameters for the evaluation of the survey is highlighted, taking into account the time spent and the root mean square error (RMSE) obtained by comparing the model obtained with the original. Despite the portability and ease of use offered by this tool designed for mobile devices, it incurs limitations regarding its power and functionalities. This is due to the limited data processing capacity of these devices, having to export the data to other devices.

In a different line to the eminently immersive experiences mentioned above, the Simusurvey tool [Lu et al. 2009] or Simusurvey X (in its latest version) [Kang et al. 2019] consists of a computer-based simulator focused on carrying out virtual surveying projects with a total station. This simulator includes several working modes: leveling surveying, horizontal angle surveying, vertical angle surveying, traverse closed surveying and free mode surveying. The tool is currently available for use on the XBOX 360 console and is compatible with "Kinect" technology, providing a distinctive user experience. However, its replicability within the teaching environment is limited precisely due to the use of such specific devices. Finally, the computer-based tool called "Virtual Environment for Learning Surveying (VELS)" [Dib, Adamo-Villani 2011] introduces some new features compared to the previous ones. It allows the import of digital elevation models (DEM), as well as the real-time generation of 3D terrains, considerably increasing the number of terrains on which to practise [Dib et al. 2013]. It also allows centralised monitoring of student performance, facilitating the later assessment task. The practical exercises that can be carried out with the simulator cover practically all the tasks that are considered minimum content for the training of this kind of professional (chaining, differential leveling, triangulations and coordinates calculations, etc.). It is worth noting that practically all the referenced contributions include a process of assesment of the tool and its impact on student learning, which is reported in the epistemology as very positive.

As a general conclusion of the literature review, it can be deduced that there are already several interesting attempts to create a surveying simulator, but the approaches of each of them differ in different aspects (use of virtual reality, type of fieldwork recreated, instrumentation included, operability of the tool, etc.). It is also surprising that none of the contributions studied has developed a module for the use of GPS equipment, all of them opting for the use of total stations, despite the high use of the former in professional practice. Although it is true that some of them have proposed it in their initial conception phases, none of them have developed it.

In this context, it is proposed to develop a new simulator that takes into consideration the most valuable features of these previous contributions, but which includes a series of distinctive factors. On the one hand, the use of GPS equipment to carry out the survey, in addition to the rest of the tools considered by other simulators. On the other hand, the approach as a learning tool that includes elements of gamification and creative learning (creative or Smart thinking). In this sense, it is also proposed that the simulator should be responsive to the decisions that the student makes during practice, modifying the contents shown and escaping from the idea of a single predefined roadmap. In this way, the aim is to encourage learner autonomy and initiative. Some of the references studied include elements of gamification, but in a secondary way. In this case, gamification occupies a vehicular role in the conceptualisation and development of the simulator. However, given the nature and length of this publication, this concept and its application are not presented in detail, and the interested reader can find more information about it in [Hidalgo-Sánchez 2021].

SurveyingGame. Description and Concept of the Simulator

The proposed gamified simulator, SurveyingGame, is conceived as a support tool, or even a substitute for field training sessions in topographic survey learning courses.

Specifically, it simulates the use of GPS equipment for this purpose. The interface of the simulator has been conceived to make it use as easy as possible. It tries to emulate

student training procedures when using actual devices. As a result, the necessary data to post-process the office work is obtained, just as if it had been obtained in a conventional way.
Regarding the gamification process of training with the simulator, a diagram is included (Fig. 2) that represents the flow of operations that a player/student would carry out from start to finish in the simulator. The conceptual scheme of its development is shown, accompanied by some preliminary images of its subsequent computer development:

• As soon as the simulator is run, the student must enter the username provided by their teacher. This username is associated with a series of specific passwords for each player that they must enter as they obtain them to unlock the different levels.

• When starting to play, the student will appear with an avatar of free displacement within the "Device Room" (Fig. 1a). In it, each student will have to select the necessary device to carry out the land survey Depending on the working procedure, the student will need different devices. Initially, "Real Time Kinematic (RTK)" and the "Differential GPS (DGPS)" work procedure will be included. Students must select the method of work and the necessary devices. After choosing the procedure, the fact that the student obtains each virtual device will be contingent on a correct answer to a series of related questions (Fig. 1b).

• Once students obtain the necessary surveying devices (inventory), they will need to select the difficulty level of the surveying task in the simulator. Initially, only "Difficulty Level 1" will be available. Several levels of difficulty are included. Each of them contains terrain with a different topography and degree of difficulty, which increases in complexity at each level. Level 1 is the simplest, and level 3 the most complex.

• Before starting the topographic survey training, the students will have to configure some parameters in the virtual device and check some key parameters on the work procedure. Once these steps have been completed, they will be able to start the training task, moving freely through the three-dimensional model of the selected terrain, visualizing it with a first-person camera and a top view little map (henceforth "minimap") to assist navigation (Fig. 1c).

• Once the work has started, the timer is activated, and the players can begin to collect those points on the virtual terrain model that they consider necessary. In addition, students will have to check a series of parameters related to the number of satellites captured by the device's receiver and the validity of the positional error obtained. Players will be able to see the points captured on the screen, both in the first-person camera and on the "minimap" (Fig. 1d). Likewise, they may eliminate those that they do not consider necessary.

• When each player completes the data collection, the timer stops. Previously, it is possible to check the data in the field notebook included in the simulator (Fig. 1e). When the work is finished, the simulator calculates the score obtained by the student, which will depend on the time spent and the number of points that the player has estimated necessary to complete the survey. The score obtained can range from 0 to 9999 points. More than 5000 points will be necessary to pass the level. Likewise, if the player passes the level, he will receive a badge, which will depend on the score achieved in the game (Fig. 1f). Having passed the level, the player receives the password to unlock the next one and he will move up to the following level.

• The data related to the captured points (ID, coordinates, positional error and a photograph of the point) are stored in the field notebook and can be exported to a directory on the personal computer. Data is exported in two forms: .csv format (point IDs and coordinates) and .pdf format (survey report with all collected data). The survey report will be delivered to the teacher for evaluation.

• With the password obtained, the students will be able to access the next level, repeating the same process, but in a three-dimensional model of the terrain with greater complexity. The same for level 3.

The overcoming of all the levels implies the overcoming of the complete training. However, the evaluation and final score of the training does not depend only on it. The evaluation of each student depends on several factors: game score, RMSE obtained, and assessment of the survey report carried out by the teacher. Likewise, even if the student has passed all the levels of the game, he can train again to get new badges. In addition, it is proposed that the student can import other three-dimensional terrain models to the simulator to train with. A comparator will also be incorporated to graphically check the adjustment between the original terrain and the terrain obtained by each student through the captured ground points. This comparison by means of the RMSE provided by the simulator itself will be a great indicator to evaluate the training activity of the student, having no necessity to use third party software.

Initial Development of the Tool

The application has been developed for PC Windows 10 operating system, but it can be directly used in Windows 7 SP1+, 8, 10, 64-bit versions only; Mac OS X 10.12+; Ubuntu 16.04, 18.04, and CentOS 7. When released it is aimed to be used by students at the "Higher Technical School of Building Engineering", University of Seville in the subject "Topography

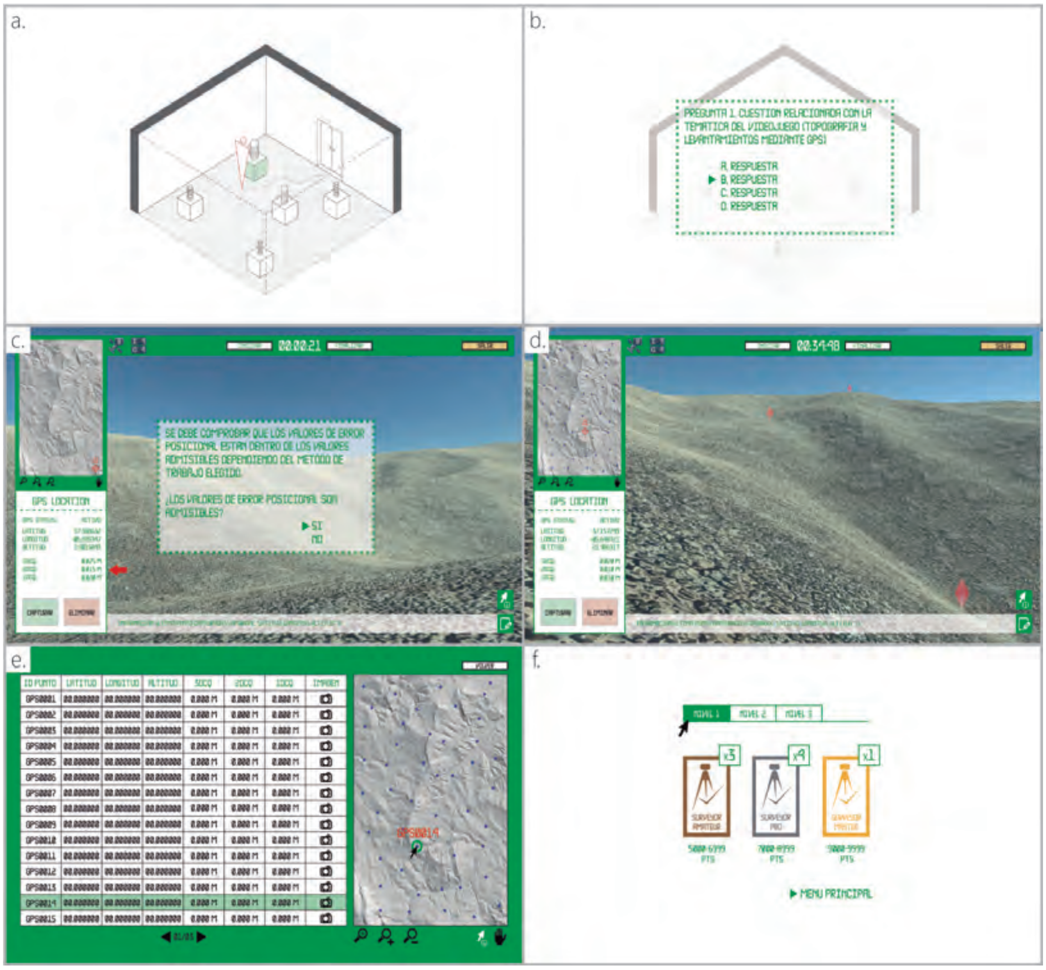

Fig. 1. Some examples of the screens that the student will face during the simulation.

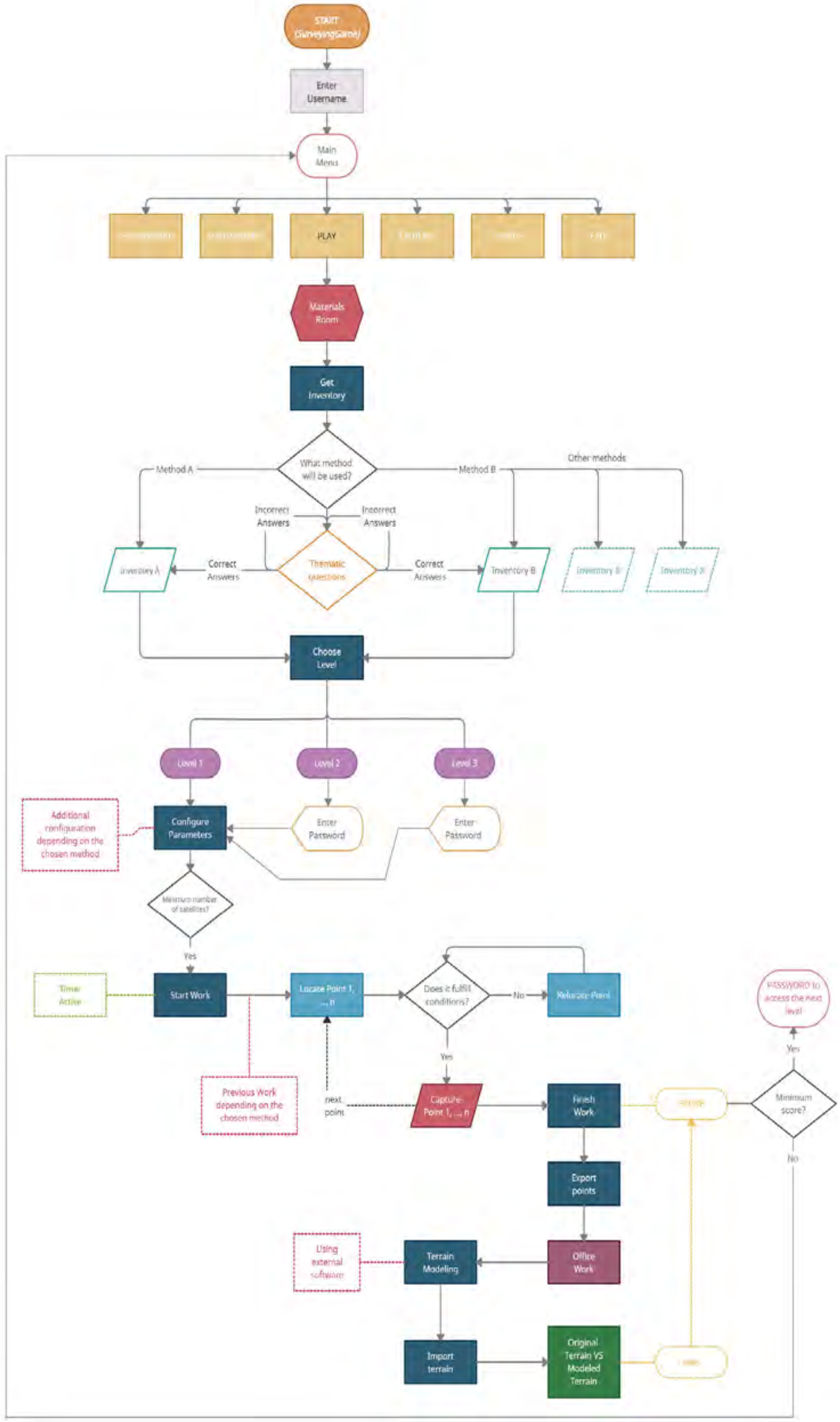

Fig. 2. Flowchart of actions performed by the student within the SurveyingGame simulator.

and stakeout survey" as a testing phase. The hardware requirements for the game are just a personal computer, and peripheral such as mouse, keyboard and speakers. In this way, every student can carry out the fieldwork surveying practice individually by means its own laptop either on screen or by using cardboard virtual reality glasses.
After a perusal review of the different engines for games development, Unity is the platform chosen to program the simulator. It is the most popular gaming engine, and it is the platform that has been used for most of the applications described above. Apart from the gaming engine a code editor is needed to configure the scripts for the interactivity between the different assets of the game. "Microsoft Visual Studio Community 2019" has been the editor used to operate in C# that is the native programming language of Unity.
The development of the simulator is still in progress (Fig. 3). So far, several tasks have been undertaken in this regard: development and operation of the simulator interface (UI); creation of environments and 3D objects with which the student will interact; user movement settings within the virtual environment; control of tracking and position of cameras/views. Each of these tasks has been programmed using specific scripts of different complexity.

Conclusions and Future Research

The SurveyingGame simulator is still at an early stage in terms of its operational capacity. In this contribution, the approach of the tool, its design and some details about the development process have been exposed.
Beyond the necessary computer development to enable the actions defined above, there are some lines of future work that would be interesting to research in order to achieve an implementation. We are working specially in increasing the immersiveness of the application, augmented reality and the automation of the evaluation process by means of artificial intelligence.

This simulator aims to imitate the field work procedure in a real context, but in a virtual way. Therefore, any addition that helps to achieve a more immersive environment in pursuit of a more realistic experience would enrich the project. Beyond that possibility, the inclusion of augmented reality and beacons technology (electronic beacons) seems to be quite appropriate for this proposal. Eventually, this would allow the use of real instruments in a virtual field and vice versa: virtual instruments in actual terrains. In fact, another of the key reasons for

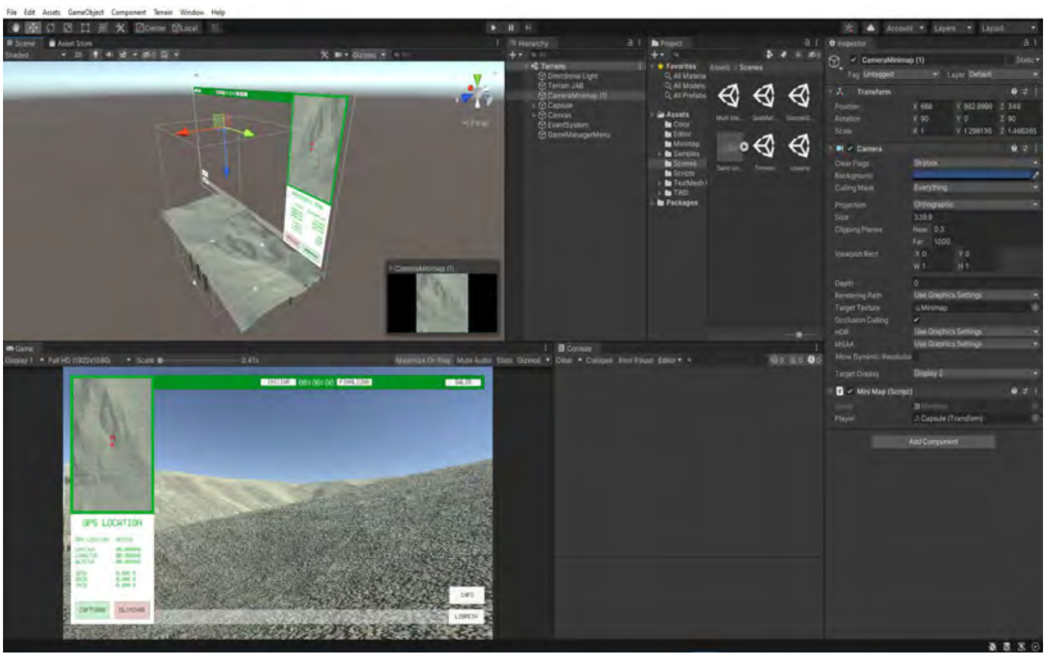

Fig. 3. Development and configuration of the simulator in Unity.

the choice of Unity as the used game engine is that it offers powerful tools to create rich and highly attractive augmented reality experiences that intelligently interact with the real world. It should be noted that its implementation would not imply a very significant cost increase in terms of necessary hardware requirements, since nowadays there are quite affordable solutions, both for beacons and for augmented reality glasses.
As artificial intelligence is concerned, it would automatize the assessment process of virtual land surveying carried out depending on several factors. A database that registers both solutions and given scores would be created. A machine learning algorithm would determine whether the solutions of incoming practices match with found values in the database within a predeterminate threshold, and in that case, it would assign the matched score. Otherwise, the solution would be assessed by the teacher, and it will feed the database. In this way the database will be continuously growing and improving the automatic assessment capability of the algorithm.
Another example of the application of this type of algorithm would be its use to evaluate the suitability of the points captured. For example, an algorithm that detects the terrain break lines (significant points that should be captured) could be implemented in order to evaluate the proximity to the points captured by the student. The shorter the distance from these break lines, the better the assessment.
Just some of the possibilities offered by this proposal are shown above. The mixture of software and hardware under a unified criterion oriented to the virtualization and gamification can greatly enhance the learning process of practical land surveying.

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Artificial Intelligence. Graphical and Creative Learning Processes

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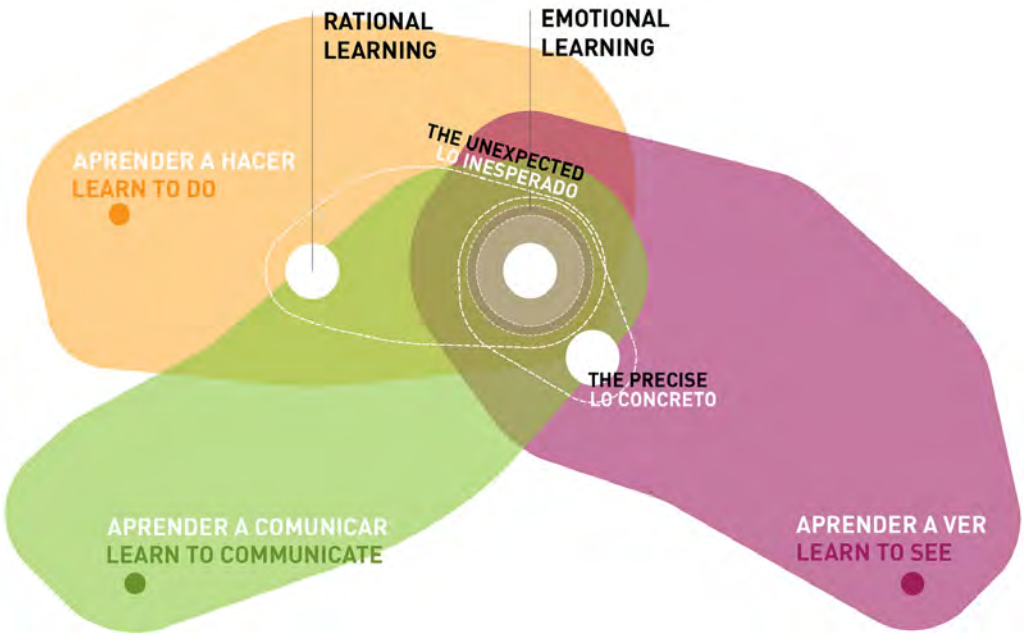
Abstract

Artificial intelligence is responsible for the creation of computer programs that perform operations similar to those performed by the human mind. This is comparable to the traditional procedures used by humans when approaching different disciplines of knowledge. One of the limitations faced by programmers are the non-logical aspects involved in the creative processes of artistic activities.
The relationship between artificial intelligence and creative processes in the field of graphic expression is not only a matter of technological development but must also solve the articulation of logical/rational processes with creative/emotional ones.
The experience based on the teaching methods of drawing at the School of Architecture of Madrid aims to explore how these educational strategies allow the development of work habits which promote aspects that can be used in other environments, including Artificial Intelligence.

Keywords
artificial intelligence, creativity, imagination, education.



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Introduction

The achievements of human beings have been sustained on an imaginary basis, on the maxim that all creation first passes through a state of imagination. Both, society and business, demand creative professionals capable of "imagining" those changes that are yet to come and raise new solutions for the future. A demand that clashes head-on with the decisions that, in education, have drastically limited the presence of teaching methods that promote creativity in recent curricula.

In his writings on creative learning, José Antonio Marina draws attention to the lack of consideration with which this subject is treated in the field of education. Marina points out: "When we talk about creativity we are not talking about artistic activities, but about a way of facing life, its opportunities and its problems" [Marina 2013, pp. 138-142]. In this sense, she alludes to Erich Fromm's postulates on his recommendation for a productive personality orientation [1], understanding this mental productivity as an activity contrary to inertia, passivity or slowness. Understanding creativity as an activity contrary to routine and the inability to face the new, he warns us about the need to educate in productivity in order to educate in creativity. Assuming this to be true, we understand that artistic activities are more permeable to these postulates than the rest of the subjects, which is why it is doubly alarming the progressive elimination of these disciplines in education programs. The need to train students in artistic activities should not be understood as an end to obtain specific results, but to encourage this productivity learning in the search for processes and the opening of new avenues of experimentation.

Since the publication in 2003 of *The Future of employment: How susceptible are jobs to computerization?* in which the authors, Carl Benedikt Frey and Michael A. Osborne, warned of the progressive disappearance of millions of jobs due to robotization, society began to become aware of the magnitude of the challenge, although, contrary to what is desirable, little has been done to meet it.

Only those activities linked to artistic creation are salvaged, since robotics cannot "create" as it is considered a behavior of the human mind. There are several experiments published in this regard, but it is surprising that most of them make a very clear differentiation between the various artistic disciplines, which implies separating musical creativity from literary or artistic creativity.

The article focuses on exploring the advances that artificial intelligence has experienced in graphic-architectural processes of artistic creation, understanding the learning mechanisms of the machine in order to comprehend the keys to these creative processes, as well as their peculiarities and differences. Along the way, some questions will be asked to which there is still no clear answer: is a machine capable of creating and in what terms? Does it make sense to teach the machine to create? What benefit does this learning bring to society? Although it is still too early to answer these questions, some conclusions can be drawn that will make us reflect on creative learning itself.

Artificial Creative Thinking

Professor José Antonio Marina defines talent as "the triumphant intelligence", stating that when we talk about "education for talent, we are talking about something that includes a part of knowledge, a part of feeling, and a third part about the executive functions of the brain" [Marina 2011, p. 7].

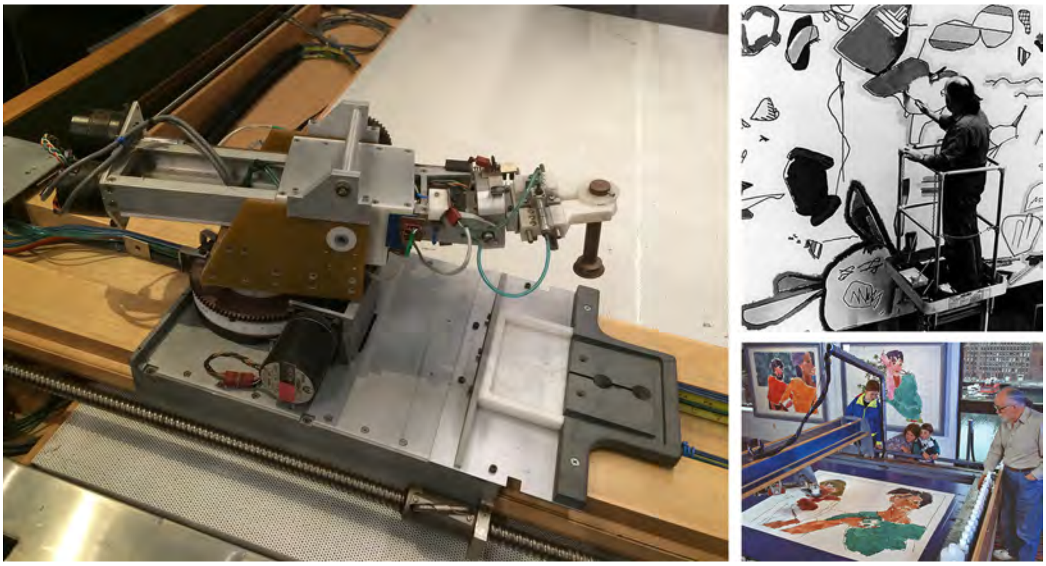
Creativity implies novelty understood as the ability to solve problems by providing solutions that have not been employed by that individual before. Experts such as Ramón López de Mántaras, CSIC's Artificial Intelligence Research Institute (IIIA) director, believe that "human intelligence is versatile, general and that the machine lacks common sense and an understanding of the world" [López 2017], at least for the moment, far removed from artificial intelligences as complex as those suggested by cinema or science fiction in films such as *Ex machina* [2] or *Blade Runner 2049* [3], (Figs. 1, 2).

Fig. 1. Cinematic representations of AI. Still taken from the film *Blade Runner 2049* (2017) directed by Denis Villeneuve.

Fig. 2. Cinematic representations of AI. Still taken from the film *Ex machina* (2014) directed by Alex Garland. Source: Alcon Entertainment, Columbia P. C, Sony (UPI)

This advance seems distant because it is based on the foundations that were laid five decades ago. However, other voices speak of the advances achieved in this field through a technology based on multilayer neural networks or GAN (Generative Adversarial Network), which consist of pitting two algorithms against each other in a zero-sum game framework [González 2018, pp. 36-37].
The algorithms used in the development of Artificial Intelligence (AI) seek to implement automatic machine learning in an unsupervised manner. Some experiments conducted with this technology allow a certain degree of invention from the machine when creating images, musical compositions or texts, based on previously collected data. In the case of music, Artificial Intelligence (AI) has made great advances in the field of machine-assisted composition.
At the last edition of Sónar+D, several proposals were presented that aimed at helping the user compose melodies, such as *Magentea,* an AI designed by Google whose algorithms are programmed to listen to the artist and suggest changes, variations and improvements. Algorithmic advances implemented through Deep Learning applications enable the machine to learn to pick up nuances as the musical database in its library grows, to the point of composing its own pieces [Nadal 2018, pp. 67-71]. Other software that excel in this field are also capable of composing small melodies such as Flowmachines, but still under human supervision, or Xiaoice, a software that generated 10,000 poems in 2,760 hours.
In the visual arts, compared to other disciplines, it is highly disappointing to define an advance in creative intelligence as proposals that, through Machine Learning technology, have managed to program a 3D printer that emulates Rembrandt's style to create a painting that looks like it was painted three centuries ago. Anyone who understands what an artistic process involves, knows that imitating is not interpreting. To interpret is not to reproduce another author's way of painting, nor to compose a work from fragments of other authors.
Another example of an AI prototype applied to the visual arts is AARON, a robotic system programmed over several years by the late artist Harold Cohen, which is apparently capable of painting on a canvas without assistance. Its creator claimed that the system was capable of painting scenes not based on copying one or more existing models, but rather generating a multitude of unique drawings on the same subject (Fig. 3).
Another less predictable attempt regarding its possible implementation through AI is the project presented in June 2017 in the context of the Sónar festival held in Barcelona and entitled "My Artificial Muse". Using software developed by German artist Mario Klingemann, an expert in neural networks and algorithms, which was "capable of imagining" art, his colleague the also artist and researcher at the University of London Albert Barqué-Duran, confined himself to executing for three days a canvas devised by the machine. The human merely "printed" manually what a machine had conceived.
According to the explanations of Klingemann and Barqué-Duran, the use of several neural networks was decisive for the confrontation of an algorithm consisting of a large network of nude images capable of creating a sketch from these data, with another capable of putting it in critique, based on a large database of similar information previously evaluated. Theoretically, both networks learn from each other, until they reach a sufficient degree of sophistication to produce something resembling an image. A third network would formally complete each fragment until it is endowed with lights, shades and textures that allow scaling up to a precision of 60 x 60 pixels for each original unit (Fig. 4).

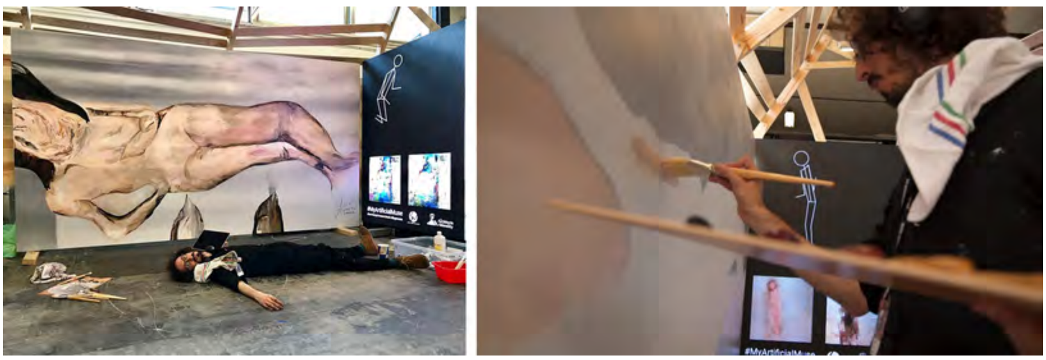
Fig. 3. Harold Cohen. 1995 version of AARON/ Harold Cohen coloring shapes produced by AARON titled "Turtle" at the Computer Museum, Boston, MA, 1982. Source: Collection of the Computer History Museum, 102627459.



Inspiration, Work and Self-criticism. Creative Learning Linked to Graphic Production

Historically, one of the main stumbling blocks we have encountered when considering creative learning is the lack of knowledge on the mental processes that foster creativity. Often this lack of understanding has been justified by alluding to a necessary inspiration without which it is impossible to start, a very weak explanation in our view.
It is surprising that this allusion to inspiration is still so widespread in the collective ideology, especially when most artists confirm the importance of work. We are reminded of some famous phrases expressed by various architects, painters or writers, such as the one attributed to Miguel de Unamuno when he declared that "the way to hit the nail once is to hit the horseshoe a hundred times" [Palomo 2013, p. 23]. Pablo Picasso himself conceived his pictorial work as a continuous process, an endless becoming of variations from an initial subject [4]. In one of his most famous phrases Picasso stated that "inspiration exists, but it has to find you working" [Palomo 2013, p. 169]. Both quotes allude to the two aforementioned aspects with which creative intelligence is built, the work and the decision making derived from this work, based not so much on data analysis, but on random and surprising aspects, which implies a very complex cognitive development more linked to emotion than to reason. All this points to a concept that is difficult to associate with the machine, but essential in the creative process, which is the assumption of error as a tool for exploration and discovery of new ways of creation. Humans learn from our failures through trial-and-error procedures, and we take advantage of them to develop this creative learning through surprise, reinterpretation and reformulation. When a machine makes a mistake, it is not aware of it, unless this variable is introduced into its algorithm.

Fig. 4. A. Barqué-Duran. My Artificial Muse. Sónar + D 2018. Source: A. Barqué-Duran. Source: https://albertbarque.com/myartificialmuse/. (30 August 2018).



In his essay on aesthetics, the philosopher Immanuel Kant alludes to artistic processes, which he defines as an activity of the spirit whose result comes from the imagination [5]. Regarding the process, Kant draws a parallel between nature and the artist, stating that, when creating, both follow an established itinerary. Unlike a technician or a scientist who can establish these guidelines or itineraries in his work process, the artist is not able to explain what he does or how he does it. The artist does not follow rules, but they emerge as the work progresses. The creative process is not linear, it is multidirectional and contemplates learning through error.
In the teaching processes that we carry out in the subjects of Drawing, Analysis of Ideation in the Degree in Foundations of Architecture at the School of Architecture of Madrid (ETSAM), we try to encourage an approach to graphic work which is free of preconceived ideas and without finalist vocation, emphasizing the importance of the process versus the result.
The underlying idea is the learning of drawing as a thinking tool to project, in a productive orientation of the creative personality. By identifying the graphic processes of "architectural drawing" and "architectural design" as processes of architectural research methodology, we validate situations based on graphic operations, which seek to interpret observable realities (Fig. 5). It also allows us to "handle a certain degree of uncertainty and unclear conclusions, validating in a remarkable way as fundamental content the applied method (methodological processes) and not the conclusion" [Raposo 2010, pp. 102-111].
The thinker Giulio Carlo Argan pointed out that "projecting is a provocation, a leap into the future. It is born from an internal obsession, from a very clear and assumed vital purpose" [Argán 1965]. As architects, we experience this urgency. The need to design implies a productive attitude that leaves a graphic record of what is being produced. This way of thinking by drawing implies not only a continuous movement of action-reflection on the traces of what is produced, but also a permanent learning process that helps to internalize the transition from the intuitive to the reflective (Fig 6).
It is a learning process based on the search for its own creative process through the production of graphic artifacts, which requires a series of phases that must be implemented and intertwined in the same way that the different layers of algorithms on which AI is currently based are superimposed.
These phases are not always linear and involve human qualities such as memory linked to experience, skill, curiosity, intuition, emotion and language. During this learning process the student must "learn to see", to encourage graphic research on the project, "learn to do" by experimenting with different graphic techniques that enhance their imaginative abilities and, finally, they must "learn to communicate" to promote the interaction of the project with other agents. This learning is completed with a process of self-knowledge and emotional management, which through the practice of this "drawing to project", tries to deal with concepts such as error, frustration and uncertainty (Fig. 7).

Fig. 5. Patricia Romero. Spatial graphic processes developed in the subject Drawing, Analysis and Ideation 1 of 1st year of Fundamentals in Architecture at ETSAM, during the 2017-18 academic year. Source: Javier Fco. Raposo; Mariasun Salgado; Belén Butragueño. Drawing, analyzing, projecting (2017), 2018. Madrid: Arcadia Mediática, p. 25.

The Unexpected and Specific. A Comparative Reflection on Creative Learning

We can establish that rational and emotional aspects coexist in the learning process. Visual learning feeds on images, observing and documenting as many visual references as possible, in order to create a context that allows them to be critiqued, interpreted and ultimately reformulated. The rational component of this learning, whose data collection is cumulative, would, in first instance, place us at a disadvantage compared to AI if we consider that machines "learn to see" through the elaboration of huge databases to which they have massive access, but we should not underestimate the importance of the emotional component. The criteria by which they interpret these images depend on search algorithms that sift through a series of parameters established in the programming. The interpretation of these images is a very complex process that is not free of conflicts.

The differences in the interpretation of the content of each image, which occur between humans and machines, lie in the literalness of their reading. While humans rely on a memory that alters its meaning according to their experience, the machine can similarly analyze fragments and the whole, converting them into data that it interprets in an unalterable way without paying attention to the message, which, from a creative perspective, is not very flexible. The most important part of "learning to see" in the construction of a creative learning process is not based on analyzing in detail quantities of color, shapes or techniques, it consists of reinterpreting, incorporating what has been visually apprehended into our own process. That is why it is fundamental to reinforce that "visual memory", trusting in a memory that we know will not be faithful to reality, but it will be faithful to our way of seeing.

"Learning to do" poses a similar problem to the previous one. From the point of view of execution, the machine is much more precise than human beings. We have been living for decades with machinery that transforms our designs into perfect executions. But learning to do is not execution, it is the ability to approach work processes on which to experiment and evolve. We learn to do by making mistakes, once again, taking advantage of error. Experiments such as AARON or My Artificial Muse are attempts to approach this field, but they remain at the rational level, trying to make up for the emotional with human interventions. But

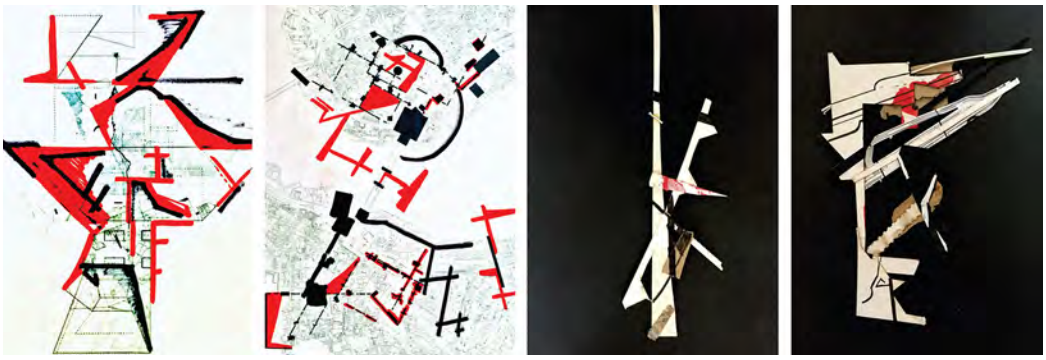


Fig. 6. María Sevillano. Graphic processes of intervention on an urban space developed in the subject of Drawing, Analysis and Ideation 2 of 1st year of Fundamentals in Architecture of the ETSAM, during the course 2017-18. Source: Javier Fco. Raposo; Mariasun Salgado; Belén Butragueño. Hybrid Structures. City, architecture and landscape, 2018. Madrid: Arcadia Mediática, p. 125.

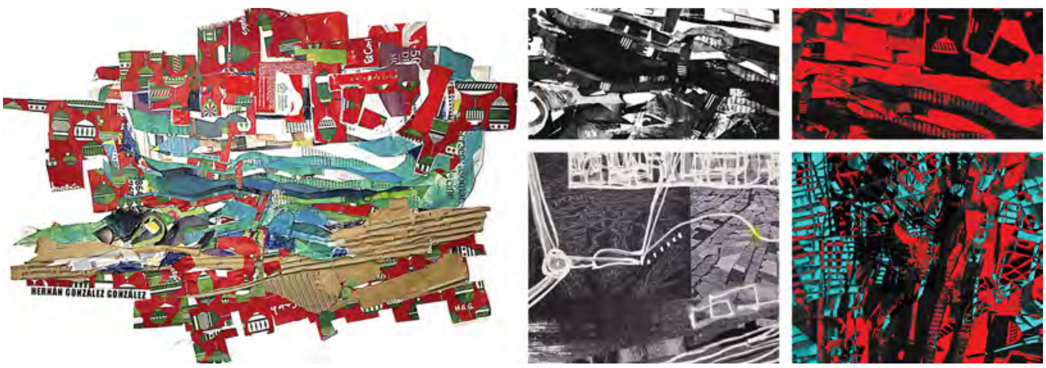


Fig. 7. Héctor González. Graphic processes of intervention on an urban space developed in the subject of Drawing, Analysis and Ideation 2 of 1st year of Fundamentals in Architecture of the ETSAM, during the course 2017-18. Source: Javier Fco. Raposo; Mariasun Salgado; Belén Butragueño. Hybrid Structures. City, architecture and landscape, 2018. Madrid: Arcadia Mediática, p. 25.

the fact is that the emotional and the rational are not placed in watertight compartments, but should intermingle and change shape, like two liquids of different densities.
"Learning to communicate" is the weakest aspect so far for AI, because it consists of empathizing and interacting with other human beings. In this sense, there are games of interpretation on which much of the artistic construction from modern times to the present day is based, for which it is difficult to propose an algorithm. In these cases, the understanding of the message does not always follow preset rules but is built through new rules that have certain emotional components of the sender and receiver. It is enough to recall Magritte's painting "This is not a pipe".
One of the keys to creative learning lies in its singularity, to the extent that its development depends on the pace of each individual to self-formation. This level of self-learning is based on a process of self-knowledge applied to one's own work. To conceive, to design, to create are actions that are not always conscious, that imply a decision-making process that responds to rational and emotional impulses, in which a series of objective data coexist with a mixture of experiences and desires that can hardly be assimilated to a programmable environment.
Despite warnings from Elon Musk or Stephen Hawkings of the risk to the human race posed by uncontrolled advances in AI by private companies, many experts are impressed with the progress made in this field, recalling how inconceivable it was for a computer to win at "go", (a Chinese game of logic that dates back 2500 years), in which Google, in a few years of programming, managed to beat the best, forever changing the way the game is played. Musk warns that "until people see robots killing people in the street, the dangers of artificial intelligence will not be understood. [Machines] could start a war by publishing fake news, stealing email accounts and sending out fake press releases, just by manipulating information" [Musk 2017].
We find it hard to believe in true creative intelligence if we look at the results associated with machine learning. Unlike Musk or Hawkings, we believe that we are still far from dystopias in which a HAL [6] can hatch a creative plan to get rid of the humans around him, much less to design a space, because such constructions require a certain emotional component, which we have yet to see.
In the meantime, it wouldn't hurt to reflect on our own learning processes so that we don't fall behind.
In our experience, the dynamics of collective work between teachers and students has made it possible to establish the relationship between artificial intelligence and creative processes in teaching activities throughout the different phases of learning, solving the relationship between artificial intelligence and creative processes through the articulation between logical/rational processes with creative/emotional ones rather than with the use of technological tools.
Imaginary skills have been developed with the creation of specific exercises designed for this purpose, enabling the establishment of the appropriate connections between the skills to be acquired, the cultural areas of exploration for transversal learning and the tools necessary for the development of these skills.

Fig. 8. Drawing, Analysis and Ideation 2 of 1st year of Fundamentals in Architecture of the ETSAM. Source: Javier Fco. Raposo; Mariasun Salgado; Belén Butragueño.

The course exercises have been articulated and designed to acquire certain capabilities by covering and reinforcing logical and emotional areas, as variables that must establish a certain balance in this linkage between artificial intelligence and graphic and creative learning processes. It should be noted that the verbal/linguistic, bodily/kinetic, and visual/spatial capacities are a further contribution to the theory of Multiple Intelligences [Gardner 1995], as a further contribution to the theory of talents, being in this case these three (of the nine described by Gardner) the most suitable for learning, supported in the generation of artistic processes, so that students have shown specific skills, dedication and creativity in these specific areas.
As for the teaching requirements of the subjects, these have been pleasantly surpassed by the development of the group dynamics proposed, and by the exercises elaborated by the students throughout the course.

Notes

[1] Fromm, Erich (1986). *Ética y psicoanálisis*. México: Fondo de cultura económica.

[2] Ex Machina. DNA Films, Film4, Scott Rudin Productions. 2015. Director: Alex Garland.

[3] Blade Runner 2049. Alcon Entertainment, Columbia Pictures, Bud Yorkin Productions, Torridon Films3, 16:14 Entertainment3. 2017. Director: Denis Villeneuve.

[4] Ramírez, Juan Antonio (1999). *Guernica: La historia, y el mito, en proceso.* Madrid: Electa.

[5] Kant, Immanuel (1919). *Lo bello y lo sublime: ensayo de estética y moral.* Madrid: Calpe.

[6] HAL era un proyecto de software que proveía una capa de abstracción de hardware para sistemas Unix-like.

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