VR APPLICATIONS FOR CULTURAL HERITAGE: HARNESSING PROXEMICS AND INTERACTIVITY FOR HERITAGE DISSEMINATION

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VIRTUAL REALITY
CULTURAL HERITAGE
DIGITAL PROXEMICS
INTERACTIVITY
MUSEUM

Recently, Virtual Reality (VR) has witnessed remarkable growth across various fields, such as education, gaming, and entertainment. In the cultural heritage domain, VR has demonstrated its significance by enabling digital reconstructions of buildings and objects. It allows the public to access virtual representations, interpreting and disseminating cultural heritage through virtual visual storytelling experiences. Despite its potential, VR remains underutilized in the cultural field.
By leveraging VR's extensive capabilities alongside on-site experiences, it offers a comprehensive exploration of architectural and museum environments, becoming a versatile tool for interpretation, learning, and knowledge dissemination. VR introduces innovative paradigms like proxemics, interactivity, and immersion in entirely new digital worlds. The study conducts an in-depth analysis of this ever-evolving technology, with a focus on its applications in two significant case studies: the *Museo Egizio* of Torino and the Basilica of Sant'Ambrogio in Milano. The investigation critically assess VR's effectiveness, highlighting its potential to implement visitors' experience and improve knowledge dissemination of both tangible and intangible aspects embedded in museums' collections and historical buildings.

INTRODUCTION

The architecture and archaeology fields have recently experienced remarkable changes, with methodologies and practices deeply rooted in the theoretical and methodological foundations of these disciplines (Smith, 2020). Globally, diverse research groups have emerged, each adopting different approaches that reflect the influence of scientific and cultural backgrounds, as well as distinct operational methods (Hou et al., 2022; Windhager et al., 2018; Schweibenz, 2019). The advent of visual interactive digital tools has enabled museums and cultural institutions to present their heritage in virtual and immersive environments, thus empowering individuals to become active participants in the cultural domain as 'cultural prosumers', who both consume and produce cultural content (Luigini & Panciroli, 2018; Lanier, 1992).

Recent research in the field of cultural heritage has focused on the design of high quality spatial experiences, with researchers seeking to develop theoretical models that optimise the combination of interaction modes and virtual reconstructions (of either objects, buildings or sites).

Particularly significant, is the work of Baradaran Rahimi, who has highlighted the transformative impact of new media and technologies on museums, transforming them into hybrid spaces where physical artifacts harmoniously coexist with virtual and augmented reality experiences (Baradaran Rahimi et al., 2022). Rahimi's cognitive theory offers a valuable reference model that encompasses key dimensions, such as duration, trigger, scope, significance, interaction, and intensity, which contribute to enhancing spatial experiences. Consequently, understanding how visitors interact with virtual activities and the essential spatial elements becomes of paramount importance.

Along with that, the emerging paradigm of digital proxemics explores the utilization of space within virtual environments and how the presence of other users influences behaviors, interactions, and movements. Thus, the creation of hybrid spaces and the appropriate handling of digital proxemics represent novel challenges for museums and heritage sites. The concept of proxemics, introduced by American anthropologist E.T. Hall, plays a pivotal role in understanding human spatial behavior, interpersonal distance, and the communication process (Hall et al., 1968).

Hall's comprehensive exploration reveals how individuals employ space to create meaning, exchange information, and regulate social interactions. His seminal works, *The Silent Language* (1959) (Hall, 1973) and *The Hidden Dimension* (1966) (Hall, 1966), shed light on the cultural codes that underlie spatial behavior, emphasizing their significant impact on communication and mutual understanding.

Today, proxemics has become an essential field of study in communication and social psychology, providing valuable insights into the intricate interplay between individuals and their spatial environment. Hall contends that proxemics is concerned with the organization of human spaces and the analysis of relationships between individuals, thereby enhancing our understanding of group dynamics. In the realm of virtual environments, developers strive to create immersive experiences that effectively manage the spatial relationships and interactions with virtual objects. This novel area of inquiry has given rise to *digital proxemics*,a field that investigates how individuals relate to virtual spaces and objects, aiming to improve design and redefine the relationship between users and sensory experiences (Williamson et al., 2022). This paradigm opens up new possibilities for extending reality and facilitating exploration of otherwise inaccessible worlds (Mueller et al., 2014). Virtual Reality offers visitors highly immersive experiences that fully engage them with virtual environments, enabling interactions with virtual objects and artworks (Trunfio et al., 2022).

This interdisciplinary approach, incorporating digital representation, 3D modeling, digital photography, and cutting-edge software, augments interactivity and immersion in virtual environments, fostering a transformative process that enhances accessibility and appeal to an increasingly diverse audience. According to these considerations, illustrating two VR applications, the article proposes a reflection on the role of interaction and digital proxemics for user's engagement in virtual environment.

INTERACTIVITY IN IMAGE BASED VIRTUAL APPLICATIONS: THE CASE OF THE *MUSEO EGIZIO*

Due to the Covid-19 pandemic, the sudden lack of physical interaction forced the introduction of virtual connections between people, places and objects. However, it has been shown how these virtual connections can be used productively (Greco et al., 2020). Therefore, with the aim of combining material and digital culture, the *Museo Egizio* of Torino realised a virtual tour of a part of the museum. The development of the virtual tour had the following objectives 1) to guarantee the physical accessibility (off-site) of the museum and its collections; 2) to achieve the cultural accessibility of the museum's collections by offering unprecedented learning and visualisation modalities that cannot be pursued in a real (on-site) visit. The virtual tour developed makes it possible to remotely explore and study some of the Museum's environments, allowing virtual interaction with the objects in the showcases and the multimedia content associated with them.

The virtual tour has been developed with the aim of providing the public with an easy-to-use tool available free of charge on the Museum's website.

THE GENERATIVE WORKFLOW

For the creation of the virtual tour, in the data acquisition phase, the first step consisted in taking 360° photographs. Regarding the tools, a Nikon D850, a 45,7 MPix fullframe camera with a special lens, with the Sigma 8 mm f/3.5 circular fisheye was used to make the panoramic, 360° images. The Agnos RingT and Agnos rotator attached to the lens allowed the camera to rotate around the nodal point of the lens. The whole system is also connected to the Manfrotto 338 leveling base (which allows rotation of the above system on a level plane) and to a sturdy photographic tripod (in our case it is a carbon fiber Sirui N-3204X). This streamlined system has been chosen for its ease use and speed of action, considering the short time to produce the final outcome.

Once defined tools and methods for data acquisition, the second step consisted in the identification of the stationing points (these points correspond to the nodes through which it is possible to move within the virtual tour). Then, the panoramic photographs were shot in the planned stationing points within the selected museum indoor environments. For each stationing points four photographs, one every 90°, were taken. An f/8 aperture, constant in all the shots, was used. It provides an optimal depth of field for this type of shooting, without incurring diffraction and consequent degradation of the final image.

The circular fisheye lens used, having a very wide angle of view (slightly less than 180°) enabled to minimize the number of shots to be taken to rebuild the 360° space. Images obtained with this particular type of lens show marked curved lines as one moves away from the center and a distorted space, but for the purposes of the project this was not relevant.

THE DEVELOPMENT OF THE VR EXPERIENCE AND THE DESIGN OF THE USER INTERACTION

In the elaboration phase, the photographs taken, in .NEF format, were imported and processed in *Lightroom CC* optimizing few parameters such as: exposure, highlights and

Fig. 1 Sample of the panoramic photographs processed and optimized. Software employed: Lightroom CC. Source: authors.

shadows, and removal of chromatic aberrations (Figure 1). After that, images were exported in .jpg format, considering their use for web. The 360° space was reconstructed by joining four photographs, one every 90°. The photographs where joined (stitching process) using *PTGui*, a specialized software application for creating this type of images (Figure 2). The four images were joined according to an equirectangular projection pattern and then exported in .jpg format. Considering that the camera rotates around the nodal point of the lens[1] it has been possible to finalize the stitching process avoiding joining errors. Once all the 360 panoramic photos have been generated, the construction of the virtual tour began. For the development of the virtual tour, the software *3DVista* was adopted (Figure 3). *3DVista* is a proprietary software that allows the insertion of linked panoramic images and, most importantly, the addition of any kind of multimedia content. *3DVista* proved to be a very effective tool in the editing process as it offers a very wide range of customization options. To enrich the virtual tour experience of the museum, several multimedia contents were created ex-novo, specifically for this project.

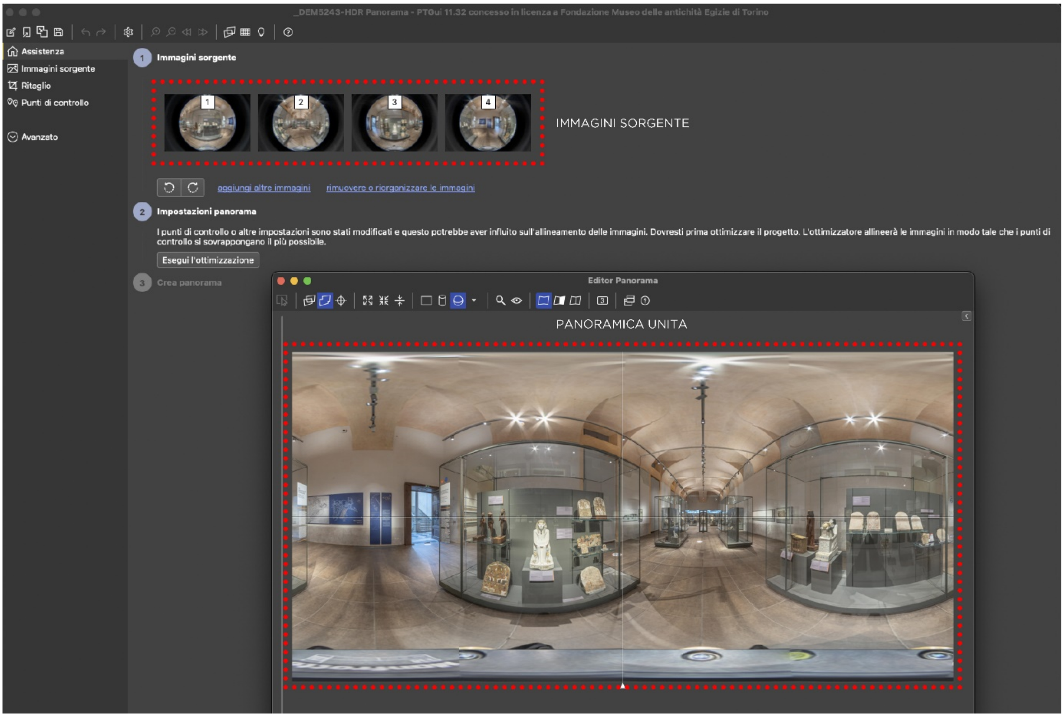


Fig. 2 Example of a 360° image generated by merging four photographs taken every 90°. This process was repeated for each environment to be recreated virtually.

Software used: *PTGui*.
Source: Authors.

For instance, videos dedicated to some of the objects hosted in the showcases, visible within the virtual tour, were created and narrated by the Museum's curators. Several 3D models have also been generated to allow the visitor a 360° appreciation of the modelled artifacts.

Additionally, image galleries have also been created, with a number of photographic campaigns specially carried out for this purpose. These images allow users to appreciate every detail of the archaeological object showed in the Museum's path, taking advantage of the high-resolution photos and the possibility to zoom in catching details otherwise invisible. Further, the historical photographs dedicated to the tomb of Kha and Merit, one of the masterpieces of the Museum's permanent collection, have been made searchable and usable in high definition directly from the virtual tour. To improve the usability of the virtual tour, for texts and videos, multilingual contents were provided.

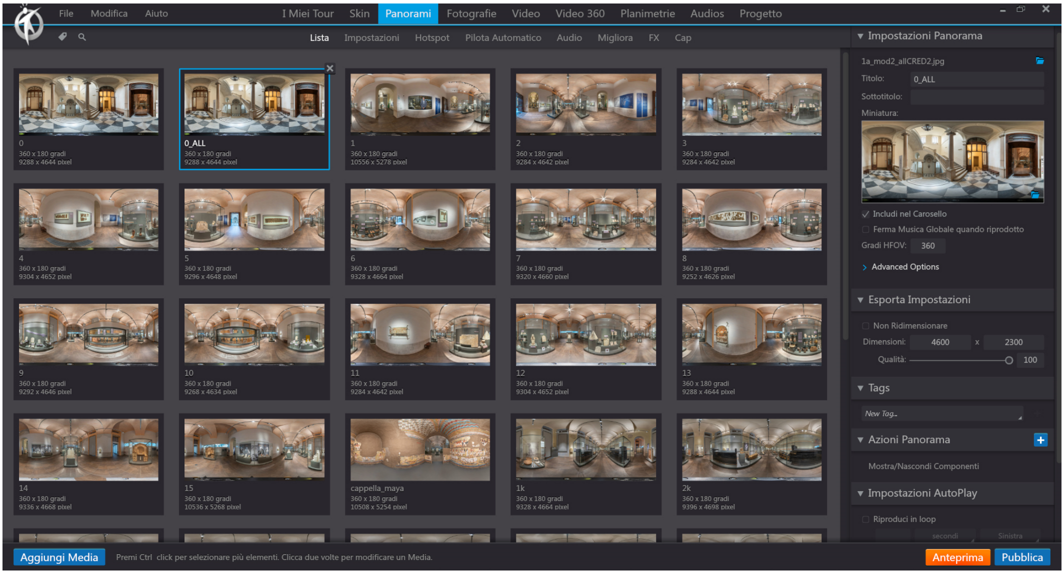


Fig. 3 3DVista software interface showing the definition process of the sequences of the panoramic images for the virtual tour. Source: authors.

More specifically, contents were made available in five languages: Italian, English, French, German and Arabic (Figure 4).

Moreover, most of the artifacts visible in the virtual tour have been linked with the Egyptian Museum's online databases. More specifically, the papyri have been linked to the TPOP *Turin Papyrus Online Platform* (https://collezionepapiri.museoegizio.it), thanks to which it is possible to visualize and consult descriptive sheets accompanied by historical and bibliographical information, high-resolution photographs, and the translation of the texts, in different languages.

The other artifacts have been linked to the Egyptian Museum's online database (https://collezioni.museoegizio.it) where it is possible to retrieve the selected artifact sheets containing basic information and a rich photographic description.

The adopted approach and the software employed, enabled to virtually visualize and interact with some artifacts in a way that would be impossible in a on-site visit (Figure 5). For example, through the 3D models it is possible to explore

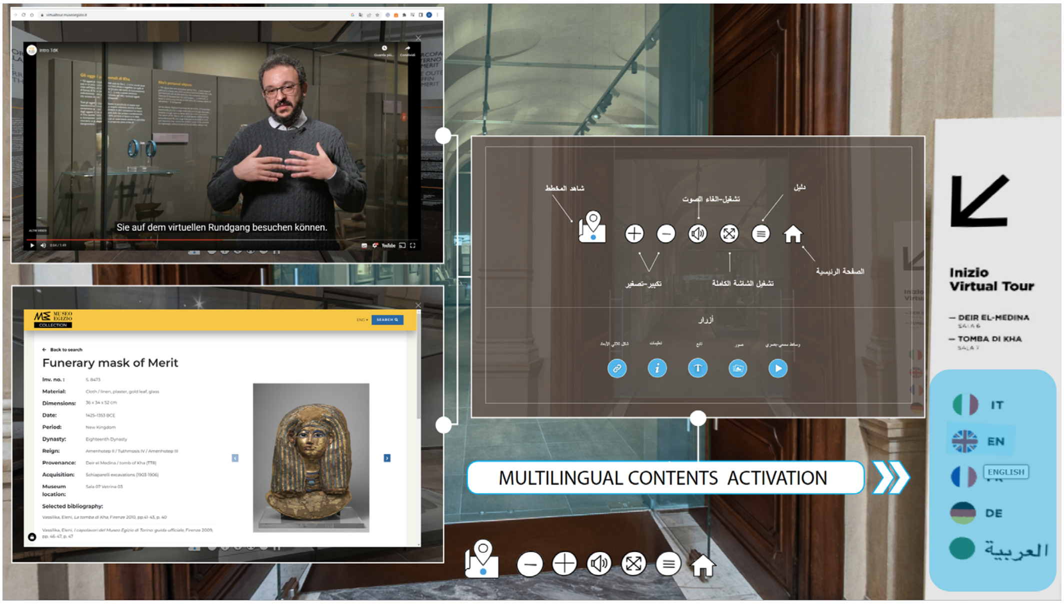


Fig. 4 Graphic interface adopted to activate the provided multilingual contents. Source: authors.

the object in 360°, having the opportunity to grasp details that are not visible when displayed in the showcase.

The possibility to virtually interact with the Museum's artifacts was allowed not only through 3D model of the displayed object but also through its photographic representation. For instance, in the case of *Maya Chapel*, the panoramic photo taken from inside the Chapel, allows to visualize, zoom in and out to appreciate all the details of the decorations of this small, fully painted funerary chapel (also considering that the access to *Maya Chapel*l is forbidden to the public) (Figure 6).

The virtual tour allows to explore its interior and appreciate, from a different perspective, the rich pictorial decoration, enjoy and interact with the numerous multimedia contents associated with it. The perceptual-motor model adopted enabled different levels of interaction within the generated virtual environment.

This approach allowed engaging users to learn through the response they receive from the interaction with digital objects and contents.

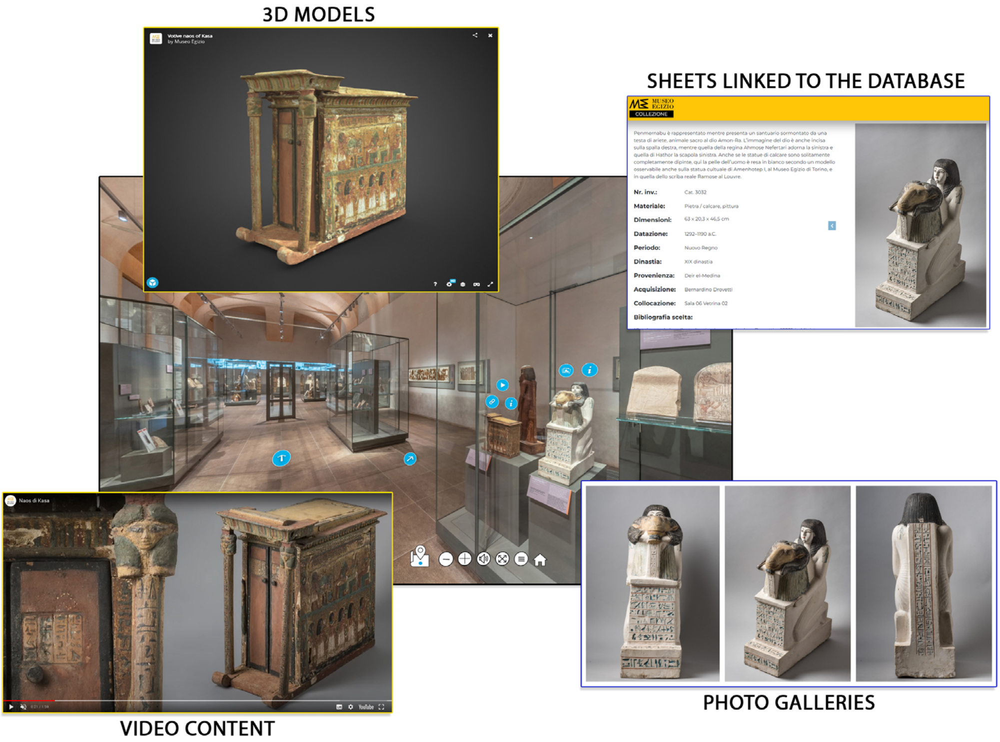


Fig. 5 Interaction available within the virtual tour. Source: authors.

DIGITAL REPRESENTATION OF THE BASILICA OF SANT'AMBROGIO: FROM ARCHIVAL RESEARCH AND 3D SURVEY TO HBIM MODEL

The case study of the Basilica of Sant'Ambrogio in Milan (Figure 7), is representative for its layered history, it complex and stratified architectures as well as for its cultural, social historical and religious relevance. During World War II, Milan was heavily hit by aerial bombings, and the Basilica of Sant'Ambrogio suffered significant damage. After the war, restoration work began immediately to preserve and restore the damaged heritage. Experts focused on repairing the damaged parts and reconstructing the colored stained glass windows. The restoration was a challenging and meticulous endeavor that took years of work (Bella, 2013). Thanks to the joint efforts of art historians,

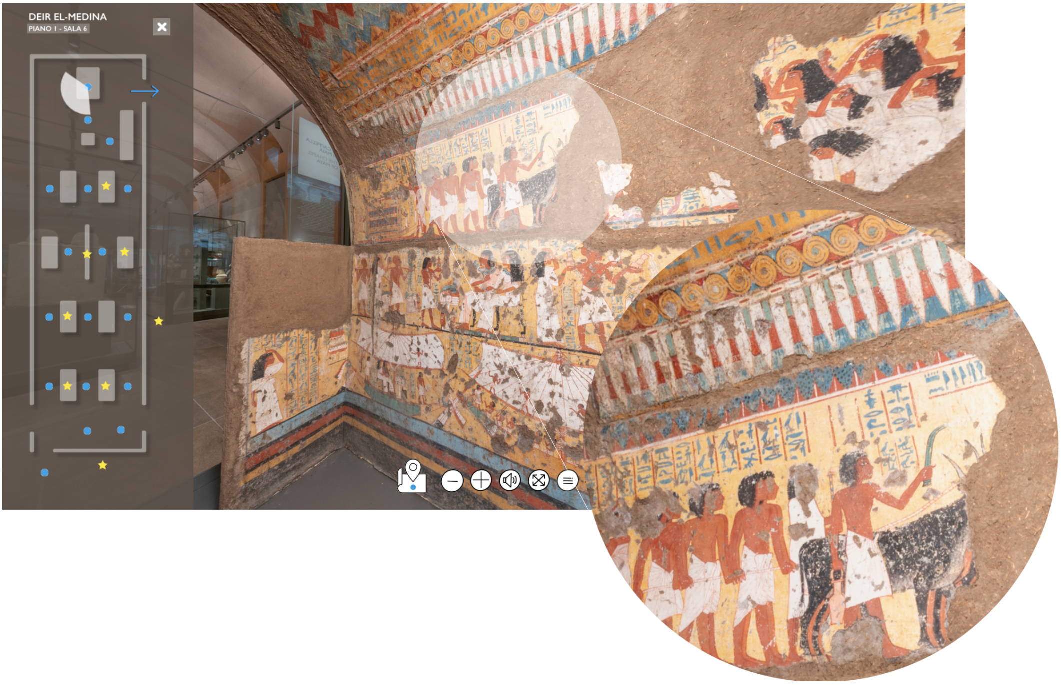


Fig. 6 Possibility to access, explore and visualize, with a high level of detail, artifacts of the *Museo Egizio* not physically accessibleb such as the Maya Chapel. Source: D. Mezzino.

architects, restorers, and local authorities, the Basilica of Sant'Ambrogio was finally restored to its ancient grandeur, preserving its historical and religious importance for future generations (Patetta, 1983). Today, visitors can admire its beauty and historical significance thanks to the subsequent restoration that has preserved this architectural gem.

Recent advancements in VR technology offer exciting opportunities to present its cultural heritage in innovative ways (Boletsis & Chasanidou, 2022). This study adopts a mixed-method approach, combining qualitative and quantitative data collection methods and multiple VR locomotion types to comprehensively assess the impact of proxemics and interactivity within the virtual environment. The study specifically concentrated on the Rectory designed by Bramante between 1492 and 1499 for the Canons of Sant'Ambrogio.

Both edifices (Basilica and rectory) held substantial historical and cultural importance, with the Rectory being promoted by Ludovico il Moro (1452-1508), the Duke of Milan.

Fig. 7 Main views of the Basilica of Sant'Ambrogio: a) the Main façade and Quadriportico; b) architectural details and vaults; c) the Rectory designed by Bramante; d) the vault of the chapel of San Vittore in golden sky.

These structures were chosen as compelling case studies to explore the practical application and potential implications of incorporating proxemics and interactivity in the realm of virtual architectural modeling. The creation of the model-based virtual application involved seamlessly integrating high-resolution 3D scan-to-HBIM models, historical data, and interactive elements. To evaluate the effectiveness of the model-based virtual application, a comprehensive approach was adopted, incorporating on-site observations, 3D surveys, in-depth archival research, and HBIM-to-VR developments. Additionally, spatial analysis and data visualization techniques were employed to assess the impact of interactivity and proxemics on user engagement. The interpretative complexity of the project encompassed various stages. Firstly, archival documents, written sources, historical drawings, images, past surveys, and scholars' reconstructive hypotheses were systematically organized. Secondly, the interpretation of historical transformations was developed based on data and information recorded during the reconstructive modelling process.

Lastly, a communication strategy was devised, catering to diverse audiences, including specialists and the general public. Extensive archival research, including historical documentation and publications by renowned restorers, art historians, scholars, and art critics over centuries, facilitated data collection about the Basilica and its Rectory. Scholars gained insights into its historical evolution and original architectural configuration damaged during WWII. Contributions from esteemed architects like D. Bramante, P. Tibaldi, and F. M. Richini were crucial. These scholarly investigations form the foundation of Milanese and Lombard polytechnic culture, stored at Politecnico di Milano's Historical Library, which houses notable illustrated manuals on civil and industrial construction practices. By the following structured approach, the research achieved a realistic and immersive virtual environment by combining data from different 3D survey campaigns and digital models over the course of the last years.

The workflow was structured into the following systematic steps (Figure 8):

1. Data Collection (2D,3D): Gathering data from multiple 3D survey campaigns and digital models to create a comprehensive dataset for the reconstruction process. Utilizing laser scanning, total station survey, and photogrammetry, data acquisition and processing were conducted and improved to generate a consolidated point cloud.
2. Scan-to-HBIM generation: Ensuring the collected data is accurate and removing any inconsistencies or errors to maintain the quality of the reconstruction; employing state-of-the-art reconstructive techniques to recreate the virtual environment from the compiled data. A non-parametric modelling software (*McNeel Rhinoceros*) was chosen to manage *NURBS* of the complex surveyed geometries effectively; Introducing the results of the reconstruction into a unified and coherent HBIM model.
3. Validation and HBIM Assessment: Conducting rigorous validation tests to ensure the accuracy and realism of

the reconstructed HBIM environment. The application of an automatic verification system (AVS) ensured the accuracy level and checked the modelling process results.

4. VR-Content Implementation: Integrating the virtual model into a VR environment, enhancing the user experience and interaction possibilities; continuously refining the model and implementation based on feedback and emerging technological advancements.

The primary data sources for achieving a precise scan-to-BIM model were Terrestrial Laser Scanning (*TLS*) survey and digital photogrammetry. These non-invasive techniques generated point clouds, facilitating accurate detection and measurement of the Basilica's internal and external elements (Figure 9). Digital photogrammetry addressed data gaps caused by inaccessibility due to scaffolding, barriers, or vegetation. However, some parts, like the extrados of the vaulted systems, remained inaccessible during the 3D survey. 1. *Agisoft Metashape* processed the data, and Ground Control Points (*GCPs*) and Check Points from the laser scanning survey constrained the reconstruction and verified metric accuracy. The geodetic network, measured with Total Station Leica TS30, comprised eight stations, achieving an average precision of ±1,0mm after least squares adjustment. Faro Focus3D facilitated internal

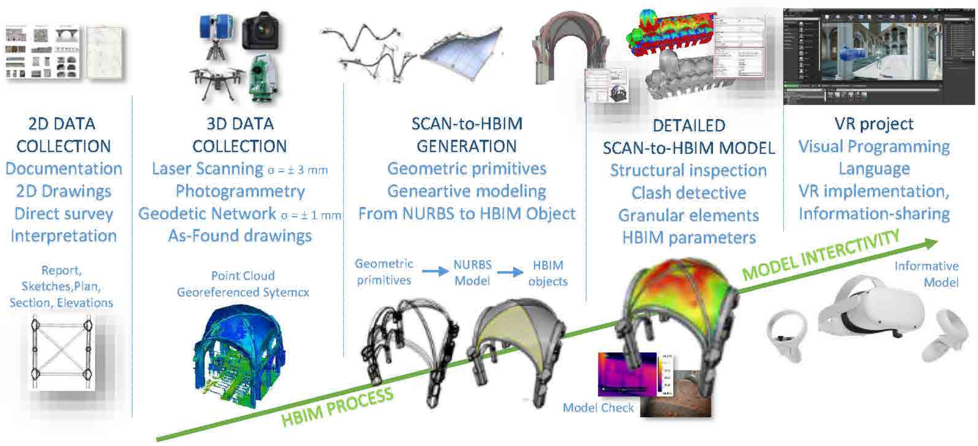


Fig. 8 *The proposed workflow: from data collection to VR implementation. Source: authors.*

Fig. 9 *Laser scanning data: point clouds of: a) the Quadriportico; b) the Basilica; c) the Rectory designed by Bramante.*

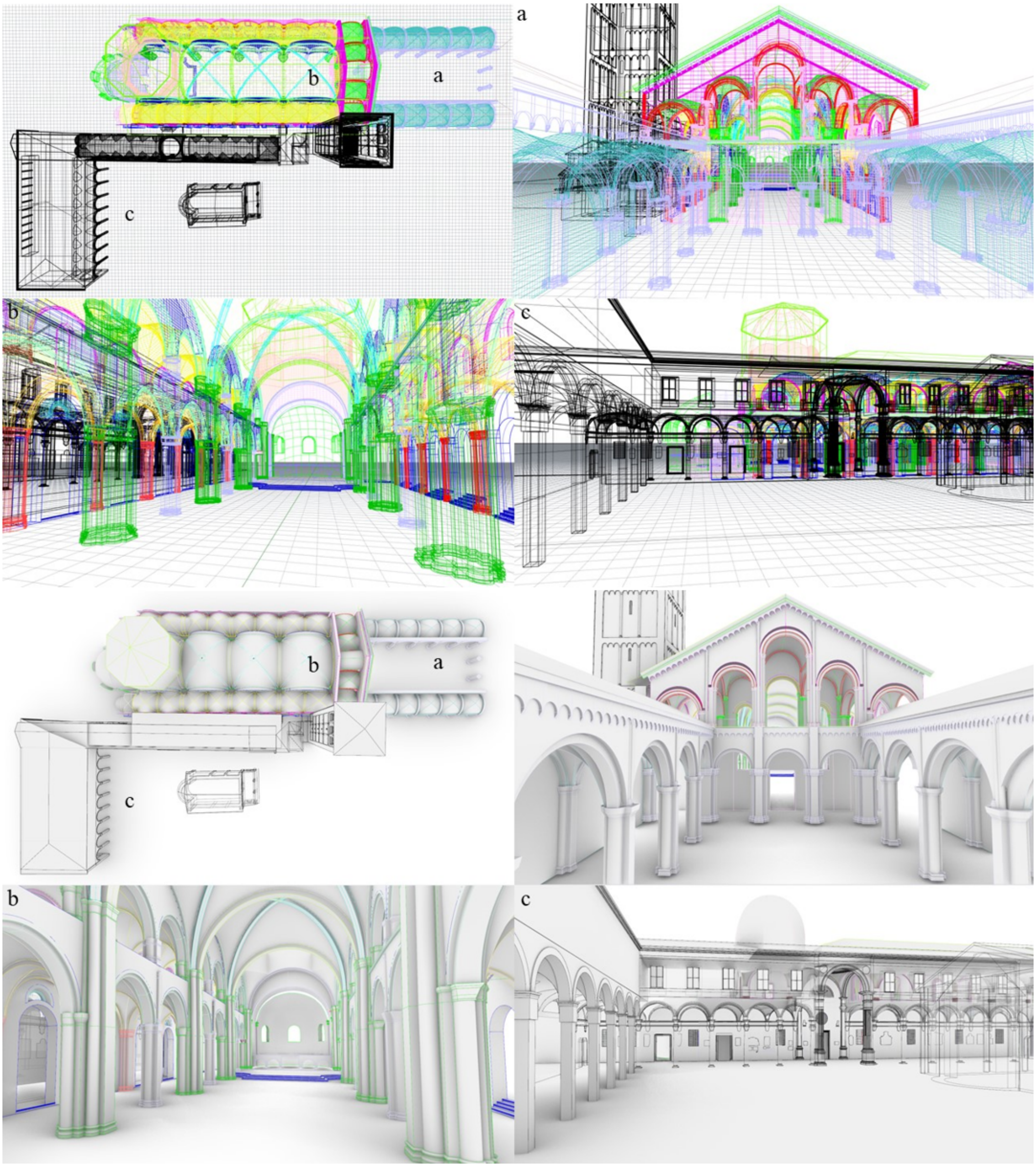
(3300m2) and external (4800m2) scans, with an average precision of ±3,0mm using total station measured chessboard targets and scan-to-scan spherical targets. The data collection phase included multimedia data for geometric/material analysis and enriching VR and AR projects, enhancing cultural richness representation of the Basilica of Sant'Ambrogio.

The utilization of free-form modeling based on *NURBS* geometry was pivotal in interpreting complex three-dimensional elements without the need for manual segmentation and lengthy slicing phases. Different approaches to digital modeling and information sharing were explored, incorporating modeling requirements for Historical/Heritage Building Information Modeling (HBIM). These methods combined mathematical algorithms and *NURBS* modeling with BIM logic, leading to a more efficient and expedited modeling process for as-found-BIM projects.

The generative phase of the model involved the reprocessing of a vast amount of data obtained from laser scanning and photogrammetry. Through an extensive study of archival documents, a deeper understanding of the basilica

Fig. 10 *Model creation: from 3D drawing to NURBS model of: a) the Quadriportico; b) the Basilica; c) the Rectory designed by Bramante.*

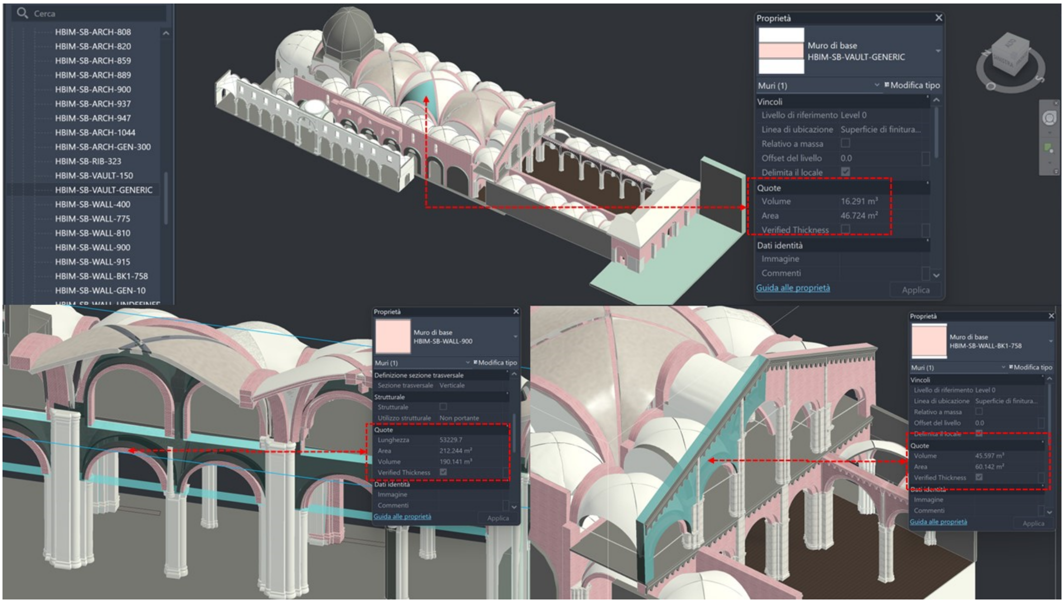
and rectory was achieved, enabling the translation of this knowledge into an interpretive act aimed at createing lines, complex surfaces, and solids corresponding to specific architectural and structural elements (Figure 10).



Heritage Building Information Modeling (HBIM) is a well-known process that involves creating a digital representation of historical structures, encompassing detailed information about their physical elements, materials, and historical significance. This 3D digital model serves as a valuable tool for documenting, analyzing, and preserving the unique features of the building. Moreover, it greatly facilitates researchers, conservationists, and architects in studying and planning restoration, conservation, and adaptive reuse projects.

HBIM models play a vital role in the field of heritage conservation and management, as they foster a deeper understanding of the building's history and construction techniques, thereby aiding in the development of suitable conservation strategies. By integrating historical documentation with modern Building Information Modeling (BIM) technology, HBIM models offer a comprehensive and integrated platform for research, documentation, and decision-making processes concerning the preservation and sustainable management of cultural heritage assets.

Fig. 11 *Unlocking Heritage in 3D: The bidirectional synergy of objects and information in HBIM generation. Tailored parameters ensure the accuracy and reliability of HBIM objects, blending data from historical reports, drawings, laser scans, photogrammetry outputs, and high-resolution textures.*



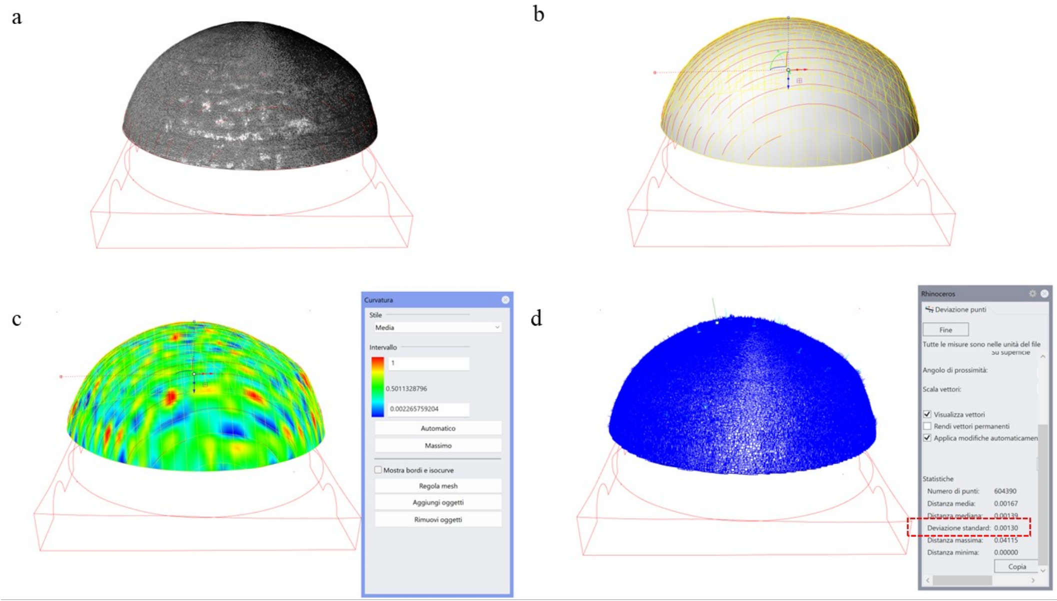


Fig. 12 *The Chapel of San Vittore in Ciel d'Oro. The reliability and transparency of HBIM models: specific parameters have been devised to convey the grade of accuracy (GOA) achieved during the modeling phase.*
a) point cloud and 3D drawing;
b) NURBS model; c)curvature analysis; d) Standard deviation: grade of accuracy about 0,001 m.

It's worth noting that using software like *Autodesk Revit* and *Graphisoft ArchiCAD*, which were primarily developed for managing new construction projects, can result in simplified architectural and structural elements that may not adequately accommodate complex historical details. However, by employing specific scan-to-HBIM modeling requirements, it has become feasible to create highly detailed HBIM objects with various types of information, such as wall stratigraphy and materials, defined in a parametric manner.

This approach forms the foundation for a multi-level information scenario in selected case studies (Figure 11).

The bidirectional information-object relationship typical of an HBIM project is demonstrated. Each element has been developed with parametric logic to expand the semantic value of every created object. Ensuring the reliability and transparency of HBIM models, specific parameters have been devised to convey the accuracy achieved during the modeling phase. For instance, the value of standard deviation allowed for a volumetric representation within 1.5-2mm of the original survey data. Once the semantic enrichment phase of the HBIM model was completed, 3D objects and related information were prepared for the subsequent implementation in virtual reality (VR). This seamless workflow from HBIM to VR ensures a comprehensive and immersive experience, further enhancing the exploration and understanding of the historical building's significance and characteristics (Figure 12).

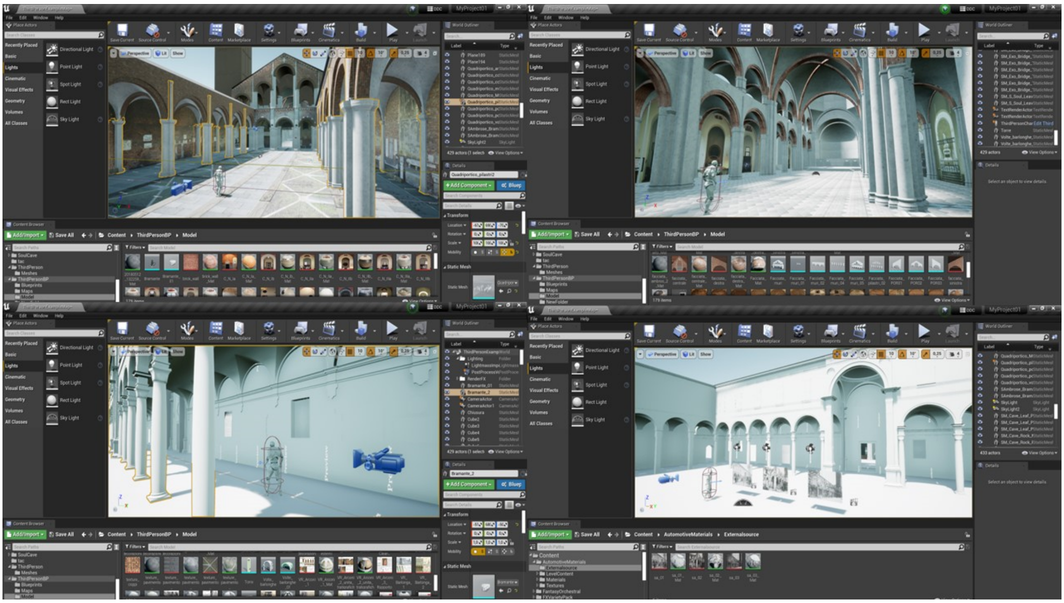
EXPLORING PROXEMICS AND INTERACTIVY TROUGHT MODEL BASED VIRTUAL APPLICATIONS: THE CASE OF THE RECTORY OF BRAMANTE

The reconstructive modelling process has been adopted to develop a sustainable generative process of a digital model able to incorporate and represent the richness of the Rectory of the Basilica of Sant'Ambrogio both from the morphological and typological point of view. The VR project was developed using software applications *Twinmotion* and *Unreal Engine 5* and, enabling real-time synchronization of the 3D model generated in *McNeel Rhinoceros* and *Autodesk Revit* with the VR project. Consequently, any changes made to the model were automatically updated in the VR experience, a critical aspect considering that outcomes of the interpretative 3D reconstruction may evolve over time. Through in-depth archival research, the VR project was iteratively implemented in the last year, allowing for continuous assessment of visitor engagement and cultural understanding achieved through the model-based virtual application. Physical systems have also evolved from the use of concrete anthropometric measures to more abstract models based on VR devices such as VR headset, controllers allowing for an expansion of sensory functions. Users can immerse themselves in and freely navigate the 3D scene through a first or third-person experience, discovering content by constructing an avatar. The avatars a three-dimensional character used to represent the user and enable

Navigation refers to the ability to explore the 3D scene by conducting a true exploration using an avatar. The navigation have been directed by Virtual-Visual Storytelling (VVS) with a predefined and uniform path for all users (Figure 13). The VR project of the Basilica of Sant'Ambrogio has been enriched with an in-depth exploration that narrates the historical background of the Rectory designed by Bramante. This immersive experience conveys the historical complexity through multiple IVOs. Virtual tourists can delve into a VR environment and discover diverse content through video panels, concise descriptions, historical comparisons (from the damages of World War II to restoration efforts and the present state), moving objects, and other types of information. The virtual tourist is introduced to the history through a primary information point, which reveals that the Rectory was designed by Bramante between 1492 and 1499 for the Canons of Sant'Ambrogio, and promoted by Ludovico il Moro (1452-1508), the Duke of Milan.

A second information point describes the construction technique, detailing how the rectory was built on the

Fig. 13 *The main VR development sections. Source: authors.*



northern side of the Basilica. This arcade structure, with 13 bays supporting an unfinished first floor until the 19th century, underwent modest rearrangements in the 17th century. The main arcade, with double height, is positioned in the middle of the structure, signifying the access point to the Basilica. A third information point reports that the Rectory and part of the Basilica apse were demolished during an aerial bombing in 1943.

Fig. 14 *Main views of the VR project and historic content implementation of the Bramante's Rectory: a) Portico of the rectory in the 19th century; b) Portico of the rectory in August 1943; c) Portico of the rectory during twentieth-century restorations. Processing by authors.*

In the latter half of the 20th century, architect Ferdinando Reggiori was entrusted with the restoration of the building complex.

During the restoration, the foundation of an arcade structure perpendicular to Bramante's Rectory was discovered on the east side of the building. Scholars speculated that Bramante's original plan may have included constructing a cloister, where the rectory formed the northern side, and the other three sides were yet to be built. The historical complexity also involves Reggiori's additions (adding a second side to the Rectory) and the 19th-century additions that were destroyed by the 1943 bombing (fourth information point). Other information point are under developing with the main aim to improve the knowledge of this novel integration realized by Bramante (Figure 14).

Digital proxemic rules defined the interaction between the user and the scene, based on a human-centric approach that places the individual at the center of decision-making and interactive experience design, ultimately aiming to satisfy their needs and enhance their experience. In particular, from an operational perspective, the process of creating an avatar was significantly facilitated by 3D design and modeling. Various 3D modeling techniques, particularly organic modeling, offered efficient and effective ways to recreate realistic and detailed characters, streamlining the generative process. The 3D modeling process involved a series of advanced steps that required specialized skills.

The first crucial step was defining the character concept, including style, appearance, abilities, and behavior. The avatar's development starts with selecting from different templates, enabling developers to generate first or third-person experiences. The choice between first and third-person perspectives in a VR experience could significantly influence user immersion and perception of the virtual environment. In the first person, the user views the virtual world through the eyes of the character they are embodying, enhancing immersion and the feeling of being

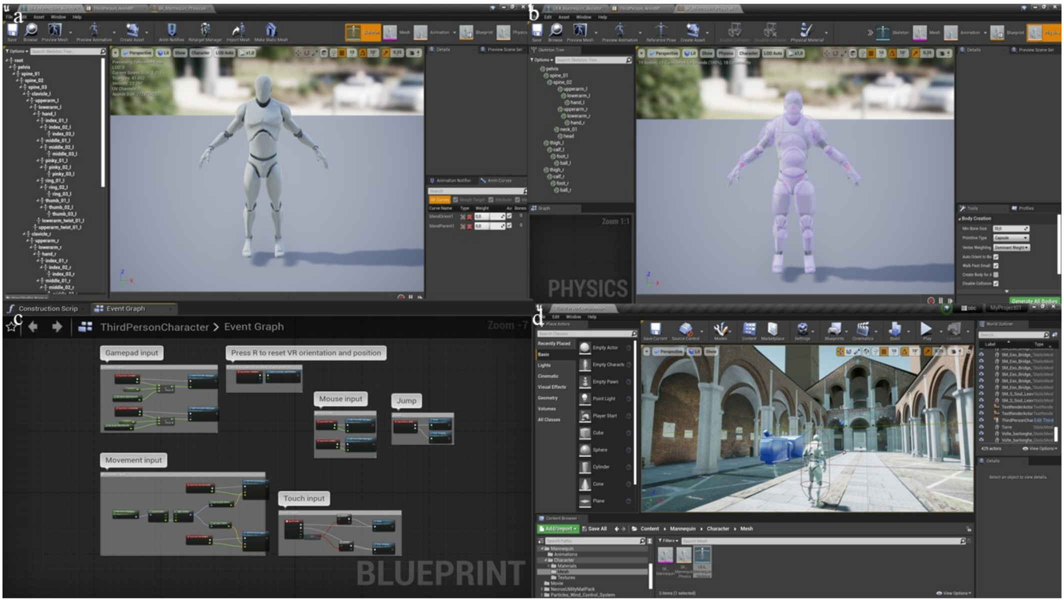


Fig. 15 *Developing third person character: from a) mesh model and b) physics skeleton model to c) VPL and d) final avatar.*

present within the virtual environment. It can also influence the sense of agency and control, as users feel more engaged and capable of directly acting within the virtual environment. On the other hand, in the third person, users see their character from an external perspective, as if watching them through a camera.

This may influence the user's perception of the virtual environment as an external representation rather than an immersive first-person experience. However, the third person perspective can also allow users to see their entire character's body, positively impacting immersion and the feeling of physical presence within the virtual environment. Character animation was achieved using *Visual Programming Language* (VPL) and animation functionality to create realistic movements like walking, running, jumping, and more in *Unreal Engine 5* (Figure 15). Thanks to the camera programming connected to the avatar and the real-time update of the corresponding blueprint, it has been possible to program and alternate the following VR locomotion modes, depending on the device used (VR headset, desktop and mobile devices):

1. Motion-based VR Locomotion: Relies on physical movements for user interaction in expansive and continuous virtual reality spaces. Techniques include walking-in-place, redirected walking, arm swinging, gesture-based locomotion, and reorientation.
2. Room Scale-based VR Locomotion: User interaction occurs through physical movement in VR environments limited by real-world dimensions. Despite spatial constraints, continuous motion is supported, and real-walking locomotion technique is included.
3. Controller-based VR Locomotion: Utilizes controllers for artificial movement in open VR spaces with continuous motion. Techniques include joystick-based, human joystick, chair-based, and head-directed locomotion approaches.
4. Teleportation-based VR Locomotion: Involves artificial interactions in open VR spaces with non-continuous movement. The user's virtual viewpoint is instantaneously teleported to predefined positions, and the point and teleport technique exemplifies this type.
5. Web-VR: Users can experience VR without dedicated hardware by connecting their mobile device to a browser and navigating using the touchscreen. This approach balances immersion and minimizes motion sickness for an optimal user experience, avoiding the installation of specific software.

Finally, to optimize proxemics, interactivity, and immersion, a final phase of research and development was oriented towards defining an Hybrid Locomotion by combining multiple locomotion techniques and hardware offering a more versatile and immersive navigation system as reported in Table 1.

CONCLUSIONS

A particularly pioneering approach in recent times has been the use of virtual reality (VR) as a novel means of disseminating knowledge through visually immersive and interactive storytelling strategies (Cecotti, 2022; Chong, et al., 2022).

VR applications in museums and cultural sites encompass a wide range of interactive experiences, from engaging with artefacts to virtual reconstructions of archaeological sites and historical buildings, thereby increasing awareness and appreciation of cultural heritage (Theodoropoulos et al., 2022; Paladini et al., 2019).

In line with these considerations, the article illustrated two operative workflows in the development of VR experiences with different levels of interaction and digital proxemics.

The image-based and model-based approach (Rossi, 2020) adopted in the development of the two VR experiences are deeply described focusing on the integration of the software applications employed and on the narrative perspective choice, whether adopting a first-person or third-person view, including users' perception and their level of engagement. By the comparison of the two applications (Table 1), it has been possible to derive some reflections on possible implementations of digital proxemics in virtual environments, attentively considering users' spatial relationship with interactive virtual objects (*IVOs*) and the overall user experience.

The case study of the virtual tour of the *NMuseo Egizio* illustrated the methodological and operative approach adopted. The description of this image-based virtual experience focuses on the workflows and tools used as well as on the defined transmedia storytelling and on the developed level of interaction with the users. The virtual tour offers an applicative example of the opportunities of VR for a comprehensive and interactive exploration of museums' environments and collections. The presented project shows the potentials of the developed virtual experience as versatile tool for interpretation, learning, and knowledge dissemination. More specifically, the different levels of interaction enabled by the 3DVista software make it possible to virtually visualise and interact with some artefacts in a way that would not be possible during an on-site visit. The study case describes the operational workflow adopted to build an engaging and iterative mode of edutainment (Luigini & Panciroli, 2018) within a virtual environment. The symbolic-reconstructive learning method, based on the textual component whose symbologies have to be decoded by the individual, is replaced by a new perceptual-motor model in which the user learns through the response he/she receives from the object with which he/she interacts. Additionally, the described experience illustrates the relevance of interactive elements in the design of VR projects for cultural institutions.

The second case study illustrates the model-based approach for the content and interaction implementation of the VR experience of the Basilica of Sant'Ambrogio.

The reconstructive modelling approach promoted the knowledge of the morphogenesis, topology and stereometry of the Basilica.

The virtual experience of the Basilica of Sant'Ambrogio depended significantly on the ability of digital representation techniques to faithfully simulate the real environment. However, the choice of narrative perspective, whether first or third person, had the potential to influence users' perception of the virtual encounter and their level of engagement. Furthermore, the use of avatars or virtual characters introduced the possibility of creating emotional closeness or distance between users and the virtual experience. To create a compelling virtual encounter, it was essential to design virtual environments and interfaces that maximised user interaction and immersion within the virtual realm. This human-centred approach required a thorough understanding of users' individual needs, preferences and limitations. Only through such an approach could a highly targeted and personalised design be achieved to meet the user's specific needs and deliver an exceptionally compelling virtual experience. The creation of an avatar required an in-depth knowledge of specialized techniques and tools such as organic modelling, programming and the ability to

	CASE STUDY 1 **Virtual Tour of the Museo Egizio**	**CASE STUDY 2** **VR project of Basilica of Sant'Ambrogio and Rector**
TYPE OF VR APPLICATION	Image-based	Model-based
TYPE OF MOTION	Non-continous	Continuos
MOTION TECHNIQUE	Point and teleport	Controller/Joystick; Walking-in-Place; Point and teleport; Redirected Walking; Head-Directed; Arm swinging; Chair-Based; touch screen linked to web-VR
ELEMENTS OF INTERACTION	3D models; video animations; 360° photograps; text description; audios; images; websites	Avatar in first or third person template; Interactive virtual objects (IVOs); multi levels; video panels; 3D animations; images; 360° photos; moving objects, audios; text description
VISION MODES	Immersive: VR headsets, web-VR, Non immersive: desktop and mobile devices	Immersive: VR headsets, web-VR; Non immersive: desktop and mobile devices

Table 1 *Comparison of the two different VR applications, focusing on the developed interactions within the generated virtual environment. Source: D. Mezzino, F. Banfi.*

critically evaluate the results of various tests in different modelling environments.

The creation of Avatar was the culmination of a long-standing quest to create a more transparent medium that could faithfully reproduce the visual and sensory experience of the real world. This medium emphasised the importance of the human element and the experiences derived from it. The VR application also aimed at overcoming the limitations of static or moving images by providing an immersive simulation that involved not only sight, but also touch and hearing.

The VR project of the Basilica of Sant'Ambrogio involved the creation of a navigable environment that could be accessed through different devices, ranging from personal computers to mobile devices. The use of the VR headset could be intermittent, with users alternating between interactions on mobile devices, where touchscreens facilitate navigation, and PC interactions, mainly through keyboards and controls.

The resulting VR experience allows visitors to explore the intricate architectural details, artefacts and historical narratives of the Basilica. Users are able to interact with virtual objects and take informative tours, fully immersing themselves in the atmosphere of this historic site. The VR developments were strategically aligned with the implementation of proxemics in the virtual environment, taking into account the users' spatial relationship with the interactive virtual objects (IVOs) and the overall user experience. The study evaluated how the arrangement of human spaces and interpersonal distances within the virtual environment influences the user's sense of presence and emotional connection, thereby fostering interactive environments.

The role of interaction design in guiding users through virtual-visual storytelling (VVS) has been closely examined to enable a more personalized and meaningful experience.

Notwithstanding their heterogeneous aspects, both projects highlight the key role of digital representation techniques in simulating real environments, allowing different levels of interaction with digital objects and multimedia content, with the final aim of implementing cultural and physical accessibility of cultural heritage sites and museum collections.

NOTES

1. This is the point at which the optical cone within the lens is inverted and so rotating the camera around this point is equivalent to recording images with a single point of view.

AUTHORSHIP

Despite methodology and results are shared by the authors, Davide Mezzino wrote: Abstract; Interactivity in image based virtual applications: the case of the Museo Egizio; The generative workflow; The development of the VR experience and the design of the user interaction; Conclusions; Fabrizio Banfi wrote: Introduction, Digital representation of the Basilica of Sant'Ambrogio: from archival research and 3D survey to HBIM model; Exploring proxemics and interactivy trought model based virtual applications: the case of the Rectory of Bramante; Federico Taverni and Nicola Dell'Aquila collaborated in writing: The generative workflow.

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Article available at

DOI: 10.6092/issn.2724-2463/17772

How to cite

as article

Banfi, F., Mezzino, D., Dell'Aquila, N., Taverni, F. (2023). VR applications for Cultural Heritage: harnessing proxemics and interactivity for heritage dissemination. *img journal*, *9*, 74-105.

as contribution in book

Banfi, F., Mezzino, D., Dell'Aquila, N., Taverni, F. (2023). VR applications for Cultural Heritage: harnessing proxemics and interactivity for heritage dissemination. In A. Alfieri, D. Rossi (Eds.), *img journal 09/2023 Metaverse dilemma (pp.* 74-105*). Alghero, IT: Publica. ISBN 9788899586447*