Unveiling Heritage in XR: The Role of Immersive Technology in Redefining Virtual Museum Experiences and Heritage Sites

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Abstract

The advent of BIM technology has changed our perception of buildings, which are now viewed as digital entities encompassing all their components and associated information. This paradigm shift from 2D CAD drawings to 3D models has facilitated interdisciplinary collaboration and enabled the storage, documentation, and sharing of heterogeneous content. Moreover, BIM techniques have been extended to the built heritage, which has opened up new avenues for communication and sharing through Heritage Building Information Modelling (HBIM) models. The current challenge is to explore new levels of interactivity and immersion in digital worlds to enhance the knowledge and sharing of built heritage values.

Keywords: Virtual Heritage; Building Information Modelling (BIM); Virtual Museum; Interactive Virtual Objects (IVOs)

Abstract

L'avvento della tecnologia BIM ha cambiato la nostra percezione degli edifici, che ora sono visti come entità digitali che comprendono tutti i loro componenti e le informazioni associate. Questo cambiamento di paradigma, dai disegni CAD 2D ai modelli 3D, ha facilitato la collaborazione interdisciplinare e ha permesso l'archiviazione, la documentazione e la condivisione di contenuti eterogenei. Inoltre, le tecniche BIM sono state estese al patrimonio costruito, aprendo nuove strade per la comunicazione e la condivisione attraverso i modelli Heritage Building Information Modelling (HBIM). La sfida attuale è quella di esplorare nuovi livelli di interattività e immersione nei mondi digitali per migliorare la conoscenza e la condivisione dei valori del patrimonio costruito.

Parole chiave: Virtual Heritage; Building Information Modelling (BIM); Museo Virtuale; Interactive Virtual Objects (IVOs)

Archaeological sites, historical buildings, and museums are on the verge of transcending conventional platforms that merely exhibit tangible and intangible heritage and collections through static images and descriptions. In this age of digital progress, the landscape of museums is evolving. No longer constrained by passive showcases, virtual museums emerge as vibrant platforms, embracing sophisticated modalities such as 3D digital surveying, Building Information Modelling (BIM), Virtual Reality (VR), and Augmented Reality (AR). These advances redefine the essence of engagement, crafting a captivating, interactive, and deeply personalised learning environment. The goal is to create virtual realms where physical interaction intertwines seamlessly with 3D digital representations of heritage sites and museums. This initiative caters to a digital audience, particularly those less inclined toward traditional museum visits. The success of this interaction hinges on the fusion of cutting-edge technologies: state-of-the-art 3D modelling, advanced digital surveying techniques, Visual Programming Language (VPL), and the developmental capabilities of Extended Reality (XR) platforms. Immersive technologies come alive, orchestrating real-time human-computer interactions that extend far beyond mere representation. They weave a tapestry of experiences, melding the worlds of VR and AR into the realms of gaming and virtual museums. Accessibility stretches across devices, from VR headsets to web-based AR platforms, mobile devices, tablets, and personal computers. This enriched encounter transcends the boundaries of traditional museum presentations. It is a transformative intersection where art, culture, and history converge, inviting audiences on a narrative-driven journey through time and heritage.

1. Digital Transformations in Cultural Heritage: From Preservation to Immersive Experiences

As defined by the European Union:

> Cultural heritage is a rich and diverse mosaic of cultural and creative expressions, the legacy of generations of Europeans who have preceded us and bequeathed it to future generations. Cultural heritage encompasses natural, architectural, and archaeological sites, museums, monuments, artworks, historic cities, literary, musical, audiovisual, and digital works, as well as the knowledge, practices, and

> traditions of European peoples. [...] Cultural heritage enriches the individual lives of citizens and, in addition to being an important resource for economic growth, employment, and social cohesion, offers the opportunity to revitalise urban and rural areas and promotes sustainable tourism as a driving force for the cultural and creative sectors. ("EU Policy for cultural heritage" n.d.)

In the cultural domain, the significance of both tangible and intangible heritage is paramount, serving as a testament to the historical and cultural evolution of humanity. Tangible heritage includes objects, monuments, buildings, and sites of cultural, historical, artistic, or scientific value, serving as vital testimony to the past and acting as cultural and touristic resources for local communities and the global population. This category encompasses diverse institutions such as museums, libraries, archives, archaeological sites, historic parks and gardens, churches, palaces, castles, villas, and more.

In contrast, intangible heritage encapsulates values associated with representations, practices, historical memories, knowledge, and skills that communities construct, utilise, and transmit. It includes practices, representations, expressions, knowledge, and techniques that communities, groups, and, in some instances, individuals recognise as part of their cultural heritage. This is transmitted across generations and continues to evolve over time. Examples of intangible heritage include oral traditions like stories, legends, and poems; artistic expressions such as music, dance, theatre, and craftsmanship; social practices like festivals, celebrations, rituals, and games; as well as knowledge and practices related to nature and the universe ("What is Intangible Cultural Heritage?" n.d.). The value of intangible cultural heritage is substantial as it represents a critical source of cultural identity for communities and individuals. Moreover, its recognition and promotion can foster cultural diversity, stimulate creativity and innovation, and help build more inclusive and sustainable societies.

Within this framework, through the Horizon 2020 research and innovation program, the European Commission invests in developing cutting-edge digital tools and technologies to support cultural heritage:

> Digital technologies will play a cross-cutting role in the following areas: *(i)* the preservation and restoration of cultural heritage, *(ii)* the sustainable financing of museums and cultural institutions, *(iii)* the revitalisation of traditional crafts, and *(iv)* the strengthening of the innovative potential of cultural and creative sectors. However, adopting digital tools for promoting and disseminating cultural heritage still poses a challenge for various sectors that still need to fully grasp the value of such instruments ("Shaping Europe's digital future" n.d.).

Technological revolutions profoundly influence the course of human history, triggering major changes in social structures. (MacKenzie & Wajcman 1999). Beginning with the era of the agricultural revolution, which saw the rise of the first settled communities, and progressing through the industrial age, characterised by mass production and mechanisation, to the contemporary information age, marked by the proliferation of computers, the Internet, and social media, these shifts have revolutionised communication and increased access to novel forms of knowledge (Bojanova 2014). This transition has profoundly impacted the transmission and preservation of information, rendering both more efficient and expeditious through advanced tools such as cloud computing, big data processing, machine learning, artificial intelligence, extended reality (XR), and virtual museums (Huhtamo 2013). Multimedia tables, multi-user touch tables, video mapping, apps, and totems are the primary tools for enhancing knowledge while taking part in a multimedia journey. However, they might be considered less advanced in terms of their level of interaction and immersion. On the other hand, cutting-edge tools based on VR and AR enable an exploration of new levels of interactivity, allowing visitors to immerse themselves in virtual environments and gain new insights (Schweibenz 1998).

As of today, VR and AR offer a wide range of possibilities. AR is considered an enhanced reality capable of enriching our visual perception through a mobile device such as a tablet or a smartphone. Tim Sweeney, founder and CEO of Epic Games and creator of Unreal Engine, states: "Once you have an augmented reality display, you don't need any other form of display. Your smartphone does not need a screen. You don't need a tablet. You don't need a TV. You just take the screen with you on your glasses wherever you go" (Takahashi 2015). In contrast, VR is an interactive three-dimensional environment that "replaces" reality, allowing users to navigate in the first or third person (Kassahun and Champion 2019).

According to Tom Furness, a pioneer in human interface technology and the "grandfather" of virtual reality, this technology offers the opportunity to experience what would otherwise be impossible. It allows us to explore distant and unfamiliar places and engage in activities that we could never otherwise perform (TaotiTalks 2024). In contrast to AR, creating a VR environment requires extensive knowledge and commitment in digital modelling, development, integration of VR devices, and identification of suitable technologies.

In this context, the recurring question is whether Building Information Modelling (BIM), AR, and VR can evolve from simple management tools and occasional accessories to true customisable technological platforms capable of disseminating heritage values. Another question arises as to how the use of Historic Building Information Modelling (HBIM) through digital surveying, archival research, and digital representation can play a crucial role in the integration of these technologies into cultural heritage.

2. From Physical to Virtual: Transforming Museum Experiences in the Age of Technology

Museums serve as bastions of cultural heritage, preserving objects and memories that define a community's identity and historical narrative (Falk and Dierking 2016). These institutions engage in rigorous scientific research, communication, and conservation efforts, undertaking activities ranging from collection and safeguarding to documentation, research, and dissemination of knowledge to diverse audiences (Soren 2009). A museum is conventionally structured with separate rooms, each housing a variety of artworks. These exhibits are typically accompanied by informational aids like descriptions, captions, audio guides, or on-site personnel providing insights into the works displayed. Recently, virtual museums have emerged alongside their physical counterparts. This paradigm offers a means to engage a broader audience and promote the dissemination of historical and cultural knowledge, ultimately revitalising interest in the artworks displayed (Woods et al. 2004).

The origin of virtual museums is attributed to Nicolas Pioch, a student who, in 1995, conceptualised and established the WEB Museum, an online platform dedicated to sharing artworks (Bowen 2010). Subsequently, numerous museums worldwide established their digital presence, spanning various disciplines, including artistic, archaeological, anthropological, and scientific-technical domains. These online platforms often mirror the structural and content attributes of their physical counterparts (Huhtamo 2013). Furthermore, several established museum institutions and non-profit organisations operating through consortiums and multimedia databases have undertaken significant endeavours in the digitisation of cultural heritage, thereby making a wealth of digitised cultural artefacts accessible to the public (Schweibenz 2019). While various types of virtual museums have emerged over the years, ranging from replicas of physical museums to exclusively online platforms, featuring virtual tours based on 360-degree panoramas, they often do not facilitate high levels of interactivity between users and the museum itself. This limitation partly arises from the necessity for technical expertise in diverse fields such as computer graphics, programming, advanced modelling for digital representation, restoration, and archaeology. Recent advances in software and computer graphics have streamlined processes, reduced costs and expanded their application into previously underutilised areas (Sundar et al. 2015). For instance, digital surveys generate point clouds, which can be seamlessly integrated with 3D data from laser scanners, total stations, and GPS. This integration creates a unified 3D environment, allowing professionals to work with diverse data inputs while maintaining consistent georeferencing. The structure from motion (SFM) technique, reliant on point collimation from images, facilitates object shape reconstruction (Özyeşil et al. 2017). This involves extracting key points, inferring photographic parameters, cross-referencing identifiable points across images, and computing spatial coordinates using computer vision algorithms. The resulting key points aid in processing the point cloud, culminating in textured digital models. A number of studies have refined digitisation and modelling techniques, assessing the merits and limitations of mesh models. While digital photogrammetry excels in creating textured mesh models, they are not automatically recognised as BIM objects by major applications like Autodesk Revit and Graphisoft ArchiCAD, due to their being composed of dense polygons. Grades of generation (GOGs) 9 and 10[1] have introduced techniques like HBIM digitisation and scan-to-BIM, capable of converting basic points from 3D surveys into BIM parameter objects (Banfi 2021). These modelling requirements use geometric entities to create informative models conveying material, physical, and historical attributes. This graphic approach integrates survey drawing and interpretative synthetic drawing, gathered by means of the scrutiny of archival and bibliographic sources, juxtaposed with the current status of dimensional and formal-compositional verification. Subsequently, this foundational bedrock undergoes further processing to generate digital models that communicate the discerning intent underlying the reworking of sources. Identifying, analysing, and discerning stratigraphic units, materials, and historical occurrences is imperative in procuring an accurate and informative volumetric representation. The conception of intelligent parametric objects and their reciprocal interrelations is instrumental in information mapping and in the constant sharing of intricate scenarios. This succinct overview reveals the pivotal role that graphic and iconographic representations assume as highly effective communicative tools, particularly for built heritage. We can reach a deeper understanding of the external environment by gathering the multiplicity of forms that constitute reality. This evolution heralds a new era in the conservation and accessibility of our shared cultural legacy.

Integrating XR in a scan-to-BIM process can significantly elevate the levels of interaction possible in digital environments, enhancing communication through digital forms capable of sharing diverse data types and formats. This paradigm shift in understanding and IT management of digital models, coupled

1 GOGs 9 and 10 facilitate the conversion of laser scans and point clouds from digital photogrammetry into BIM models using specific scan-to-BIM requirements. BIM applications typically struggle with generating complex elements, such as historical buildings with vaulted systems, arches, damaged walls, and decorative features. GOGs 9 and 10 overcome these limitations by utilising specialised Non-Uniform Rational Basis-Splines (NURBS) algorithms. GOG 9 identifies key geometries using the slicing technique, creating a 3D wireframe model from point clouds, which is then interpolated with NURBS algorithms to produce a BIM object in Autodesk Revit without further remodelling. GOG 10 simplifies and accelerates the modelling of complex elements by directly interpolating scan data without the slicing technique. The primary requirements for creating a BIM model include determining the outer edge of the element and the internal points that define its geometry.

with the use of leading XR development platforms, unveils new prospects for professionals working in the fields of architecture, engineering, restoration, archaeology, and history, as well as students, virtual tourists, and museum curators, many of whom may not possess specialised IT application development skills (Hammad et al. 2021). To this end, this research paper endeavours to establish a methodology which can be adapted to any artefact, demonstrating how various 3D objects derived from digital surveying, laser scanning, photogrammetry and 3D modelling can be dynamically rendered in different XR modalities. Key elements in effecting this transition encompass 3D modelling, visual programming language (VPL), and model interoperability (Ray 2017). It is crucial to consider how the use of digital technologies can influence human communication and interactions, not only on a physical level but also on a cultural and social level. Proxemics[2] thus represents a tool for the comparative analysis of non-verbal inter-human communication modes, wherein different behavioural systems presuppose distinct sensory worlds that can remain separate and unintegrated. In this regard, an in-depth exploration of proxemics proves crucial for creating interactive digital representation experiences that consider the centrality of both the user and the information. Creating virtual environments based on a scan-to-BIM process aims primarily at offering immersive user experiences in which the sensation of "being part of" the virtual environment is as realistic and interactive as possible. Managing space, distance, and interaction between the user and virtual objects has proven crucial to achieving this goal. The constituents of reality are transformed from atoms into signs and then into bytes, making the relationship between the user and Interactive Virtual Objects (IVOs) essential for effective 3D spatial-virtual representation. In this context, proxemics takes on a new form: the "digital" form (Banfi et al. 2023).

Virtual heritage represents an evolving interdisciplinary field that transcends the mere application of virtual reality to cultural heritage. In Banfi (2023), digital proxemics is examined so as to establish sustainable and practical parameters for developing interactive virtual representations. To enhance awareness of these interactions, it is essential to explore how representation, visual factors, interoperability paradigms, interactivity, and immersion of digital models influence the perception and understanding of virtual environments. This exploration reveals how variations in these factors, whether related to the "container" or "content," induce different spatial sensations and affect user experience. The application of a scan-to-BIM process and subsequent computer implementation can lay

2 The American anthropologist E.T. Hall introduced in the 1960s the term "proxemics," derived from the word "proximity," to denote the study of interpersonal distance and human space in their signifying nature (Hall 1968). Proxemics investigates the meaning individuals attribute to the distance between themselves and others, objects, and, more broadly, the cultural and historical value of how individuals position and organise themselves in space, considering psycho-sociological and ethnological factors.

the groundwork for addressing European needs to extend the utility of digital models to built heritage and the digitisation of archaeological sites, museums and collections. Specifically, emphasis should be placed on how drawing (in its various 2D and 3D forms), representation and digital models can "come to life" through user-model interaction, transitioning from static 3D representations to dynamic models capable of sharing different types of information and fostering experiences related not only to architecture but also to archaeology and museology. At the same time, the need for proper management of digital technologies to enhance cultural heritage through primary representation techniques is highlighted, to avoid the risk of excessive trivialisation and detachment from real cultural heritage. Therefore, it will be essential to strike a balance between the use of technologies, drawing, and digital representation to protect and enhance cultural heritage in its authenticity and integrity.

3. From Static Scan-To-BIM Models to Interactive Virtual Objects

The scan-to-BIM process has seen significant improvements in recent years, benefitted new construction, and proven particularly valuable for preserving built heritage. Prominent articles in the field of HBIM highlight the importance of developing Advanced Modelling Techniques (AMT) and creating informative models characterised by high levels of detail (LOD) (Lovell et al. 2023; Yang, et al. 2020). These models aim at capturing irregular architectural and structural elements not typically included in standard BIM libraries. The primary objectives of this specific research field include reducing the production costs of HBIM through the refinement of AMT and the effective management of conservation plans for surveyed artefacts. As Volk highlighted, it is evident that BIM was the most widely researched area from 2005 to 2012 across various disciplinary and application domains (Volk et al. 2014). This study further demonstrates that the most beneficial applications of BIM are directed toward maintenance and "BIM Creation and Modelling" rather than design and data management. The rationale behind this is that modelling requires in-depth studies to enhance the generative aspects of heritage buildings and their ongoing management. Therefore, the true challenge lies not in BIM, with its advantages for new construction, but rather in research fields oriented towards built heritage, as stressed above. Since 2012, research centres such as Autodesk Research and Bentley Systems have enabled the integration of digital survey data into their CAD and BIM software, fully seizing this market opportunity. The surveying sector has been revolutionised with the widespread adoption of laser scanning, which can rapidly capture very large quantities of 3D points and produce digital point clouds of surveyed surfaces (Slob and Hack 2004).

Advantages observed in the use of these tools include:
1. Reduced time for data acquisition.
2. Rapid collection of all necessary information, eliminating the need to revisit the site for integration with new 3D surveys.
3. Non-invasive surveying ensures no direct contact with the surveyed building, by integrating laser technology into instruments.
4. Higher measurement accuracy is achieved through the integrated use of total stations.
5. Cost-effective data acquisition phase, reducing costs and time necessary for the 3D survey campaign.
6. Surveyed spaces can be analysed using innovative software compared to traditional 2D representations.

Identifiable drawbacks include:
1. High initial investment in acquiring new tools.
2. Using the software requires extended learning and practical training phases, and post-survey data processing necessitates the use of various applications and an in-depth understanding of modelling techniques.
3. Output processing formats for post-processing are commonly called "dumb" files, as they are simply a vast quantity of points in space and lack any intelligent parametric function intended for three-dimensional reconstruction.

Several studies published in recent years have sought to outline the state of the art in the scan-to-BIM field, analysing techniques and procedures that emphasise the integration of HBIM with other technologies such as VR, AR, GIS, and with virtual museums (Lovell et al. 2023; Yang, et al. 2020; Xiucheng, et al. 2020). Through systematic reviews of international literature, these studies have reported the main trends and present and future potentials in the field of heritage digitisation. Today, the integrated use of digital photogrammetry (terrestrial and aerial) and laser scanning could allow for the development and application of an approach that converts point clouds and meshes into an environment capable of interacting with state-of-the-art environments, such as Web-VR (Banfi and Mandelli 2021). The osmosis between digital environments and information has defined new spatial experiences in which users can immerse themselves and actively discover new digital worlds composed of IVOs (Interactive Virtual Objects) that can "come to life" and respond to user input (Fig.1). In this specific domain, key elements identified are: data collection; 3D modelling (scan-to-BIM process); information mapping; information sharing.

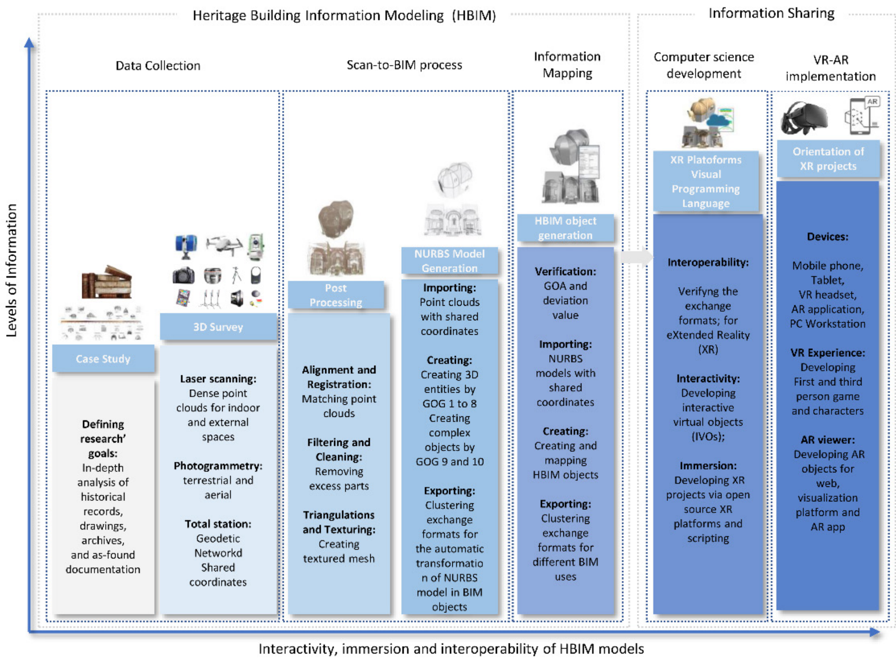

Figure 1. Proposed approach: from data collection and HBIM uses to VR-AR implementation in Banfi 2023.

Digital representation in graphic, infographic, and multimedia languages has evolved into 2D, 3D, and XR dimensions, becoming a vital tool capable of managing morphological and typological complexity paradigms. It analyses existing values and enhances visual communication, oriented towards different dimension scales. This includes the geometric descriptive foundations of drawing and digital modelling based on surveys as tools for understanding the surveyed reality. In this scenario, 3D modelling is understood broadly, encompassing the expressive and cognitive aspects of formal structures. The need to increase the information level of HBIM models is directly proportional to their subdivision into sub-elements capable of representing theoretical and semantic decompositions, not necessarily dictated solely by geometry. Determining "granular objects" can prove vital for subsequent mapping and sharing of information in complex scenarios such as archaeological sites, historic buildings, and museum collections. Geometric model verification also involves applying an automatic verification system (AVS) to communicate the standard deviation value between point clouds and the HBIM model. Assuming that the geometric reliability of each model derives not only from the accuracy of the survey but also from the interpretation and modelling phase of each element, the scan-to-BIM process and HBIM projects have achieved highly faithful accuracy values with respect to the established representation scale. Each element can be returned with a Grade of Accuracy (GOA) of approximately 2/3 mm, starting from an error value of about 1/2 mm related to the photogrammetric survey precision. The geometric reliability of the model in terms of accuracy can be conveyed within the HBIM project by developing specific parameters. The identification of each data point used, and its corresponding GOA should be specified in the property windows based on the principles of "transparency" and "reliability" of HBIM models (Bianchini et al. 2021). Once the modelling phase is completed, it is also possible to optimise the use of digital models to define virtual-visual storytelling (VVS), transitioning from static forms to interactive digital representations capable of communicating the tangible and intangible values of heritage.

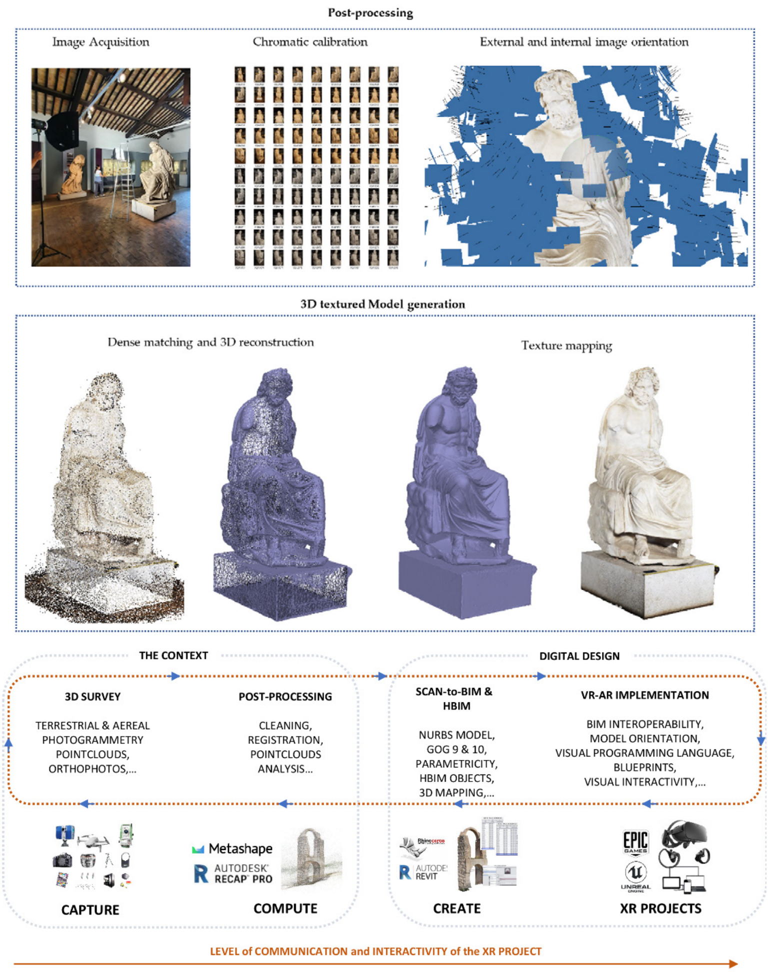

Figure 2. From digital surveying to the scan-to-BIM-to-XR process.

To achieve maximum credibility, an XR environment must exhibit specific characteristics, including *(i)* highly detailed models corresponding to real-world exhibited objects, *(ii)* high-resolution textures displaying authentic material properties, and *(iii)* accurate scaling in the virtual environment relative to the user. These requirements are precisely addressed through adept 3D modelling, which must be coupled with VPL in its most advanced forms, enabling the transition from a static mesh to IVOs.

Navigation through an avatar in an interactive virtual environment (IVE) and interaction with IVOs are essential elements that enrich the user experience and elevate levels of interactivity and immersion. Combining advanced 3D modelling techniques with virtual reality tools like VPL to support XR development enables new levels of interactivity between the user and IVOs[3]. These objects can be animated and brought to life, providing novel forms of human-computer interaction. The quality of the experience offered relies on modelling techniques and exchange formats that facilitate the generation of hyper-realistic objects and genuine interaction between avatars, IVOs, and IVEs.

An innovative approach involves creating customised IVEs and IVOs, significantly simplifying the phase of modelling the scene and objects. Thanks to growing interoperability between modelling applications and XR development platforms, it is possible to develop more detailed experiences in less time, aided by real-time rendering, blueprints, and the FBX format.

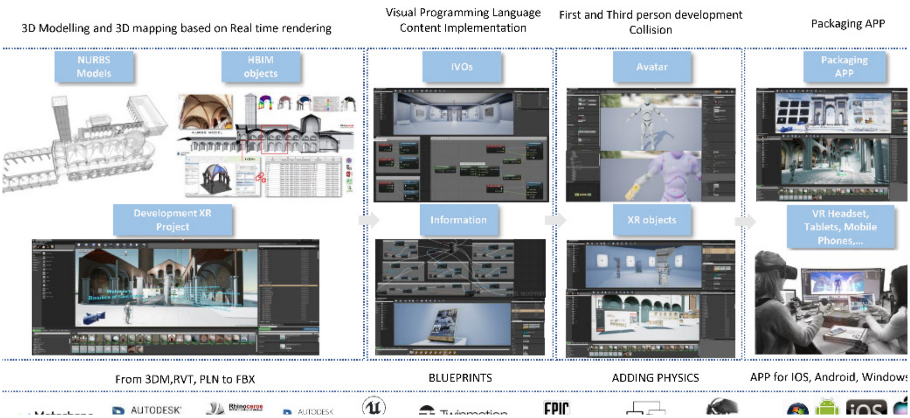

Figure 3a. The Scan-to-BIM-to-XR project of the Basilica di Sant'Ambrogio, Milan, IT in Banfi 2021.

3 Specifically, IVOs consist of a mesh geometry composed of vertices, edges, and triangles/polygons, taking various forms such as informational panels, fantasy characters, interactive guides, flip-through books, level changes, or teleportation points, and features which serve to alter weather and other conditions.

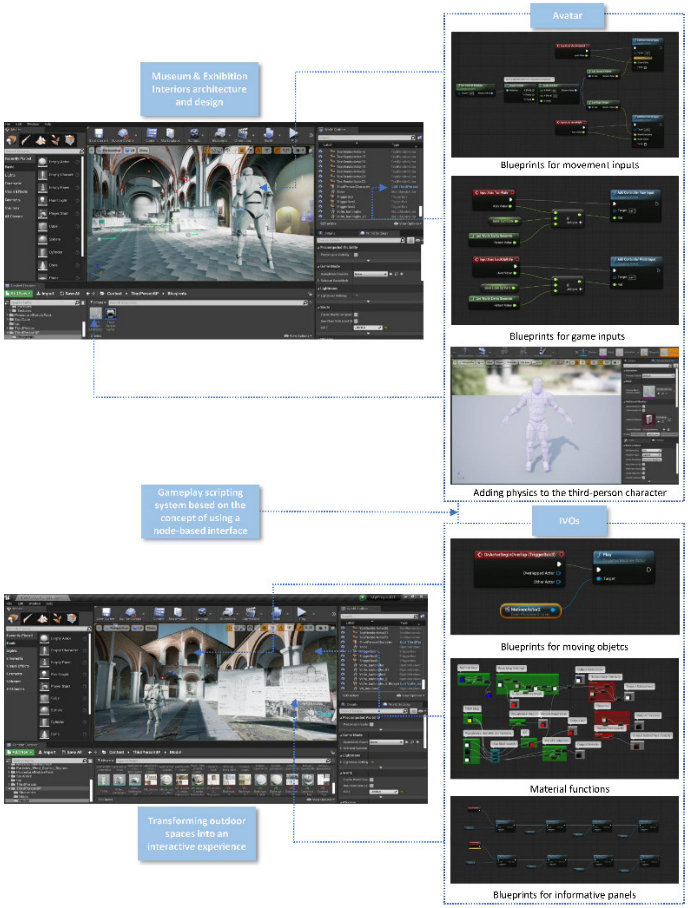

Figure 3b. The Scan-to-BIM-to-XR project of the Basilica di Sant'Ambrogio, Milan, IT in Banfi 2021.

Recent technological advances have streamlined the development process, incorporating the use of modelling software or BIM platforms alongside XR development platforms. Specific add-ins facilitate real-time synchronisation between these two types of software, allowing them to work simultaneously and benefiting from the unique features of both without the need to save and import mesh models. In the context of AR and VR, VPL represents a crucial element for creating interactive environments and engaging experiences. It serves as a primary tool for scripting and adding interactivity to AR and VR projects (Fig. 4).

In XR projects, script files are integrated resources alongside textures and models, playing a fundamental role in creating dynamic objects. XR development platforms support the use of various programming languages, including C#, JavaScript, and Boo, with C# being the most widely used programming language in environments like Unity and Unreal Engine. However, its adoption often involves lengthy generative development times, limiting development possibilities. On the other hand, the scan-to-BIM-to-XR process can emerge as a promising alternative, particularly for individuals who lack expertise in traditional coding. It has facilitated the development of interactive environments using a visual interface based on a graph of interconnected elements following a node-logic structure. This simplified approach has allowed the transition from static models to dynamic objects, associating specific behaviours with each scene element, thereby enhancing direct or indirect interaction with the user through an avatar. Using nodes, events, actions, and conditions that are visually connected, various Blueprints can be implemented to code in C++, creating dynamic 3D objects that bring to life static mesh models derived from photogrammetry.

Figure 4. The development process applied to the digital interactive representation of the virtual museum: from textured models to the VR headset in Banfi, et al, 2023.

Furthermore, the effective use of exchange formats, transitioning from modelling software to XR development platforms, is crucial for ensuring precise visualisation, navigation, and interaction inside the digital environment.

In line with contemporary technological capabilities, the proposed digitisation process integrates diverse forms of photogrammetric digitisation (both terrestrial and aerial) with AMT and GOGs to create VR-AR environments. This integration seeks to facilitate user interaction with innovative IVO forms where representation serves as a driving force for knowledge transmission, fostering the creation of web-VR projects and educational experiences related to architecture, archaeology, museums, and the environment (Fig.5).

Figure 5a. The web-VR project of Villa dei Quintili, Rome, IT in Banfi 2023.

Figure 5b. The web-VR project of Villa dei Quintili, Rome, IT in Banfi 2023.

4. Conclusions

Within the scan-to-BIM-to-XR continuum, creators of digital worlds serve as both architects and storytellers, crafting immersive and interactive experiences that redefine human interaction with the realm of the virtual. Their expertise in transforming digital representations into engaging virtual spaces is invaluable, creating experiences that transcend the limitations of the physical world. These experiences, incorporating new forms of interactive representation such as VR and AR, merge seamlessly with the real world, paving the way for innovative approaches to communication, learning, and entertainment.

The expertise of creators in translating concepts and ideas into Interactive Virtual Environments (IVEs) and Interactive Virtual Objects (IVOs) is crucial for making digital content both accessible and engaging. By meticulously selecting visual, audio, and interactive elements, they shape the atmosphere, narrative, proxemics, and emotions that define the overall user experience. At the core of this creative process is digital representation, which transforms data, concepts, and visions into three-dimensional models and interactive spaces that extend beyond mere visualization. These models become interactive scenarios where users can explore, interact, and experiment. Attention to detail in creating elements such as NURBS, mesh, texture, avatars, VPL, lighting, VVS, and animations is essential in making these digital worlds realistic and engaging.

Interactivity and digital proxemics are fundamental to this paradigm. Creators devise that interactivity which allows users to manipulate objects, perform actions, and fully participate in the experience, resulting in dynamic scenarios where user decisions shape the course of events, enhancing the overall impact.

The approach proposed here can significantly enhance XR ecosystems. The ability to convert digital representations into engaging and interactive virtual spaces enriches experiences that surpass the limitations of reality, offering captivating scenarios that shape the future of human interaction and exploration of limitless virtual worlds. Those experiencing this generational shift have the privilege and responsibility of inheriting and advancing the knowledge and methods of their predecessors for future generations.

Furthermore, this approach serves as an integrative framework for the contemporary museum system, opening new possibilities for implementation and interactive representation techniques. The aim is to create immersive experiences that support the digital transformation of museums. Drawing, 3D modelling, and XR have proven to be highly effective communication tools, capturing the diverse forms that constitute reality and powerfully conveying the tangible and intangible values of our cultural heritage.

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