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# XR Technologies for Enhanced Cultural Engagement: from HBIM to a Comparative Analysis of VR and WebVR Development Tools

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**Abstract**

This study presents a novel workflow for the digital valorisation of cultural heritage by integrating Heritage Building Information Modelling (HBIM) with Virtual Reality (VR) and WebVR technologies. The methodology is applied to Villa Arconati—also known as Castellazzo degli Arconati—in the Castellazzo district of Bollate, northwest of Milan, and to a Roman statue traditionally identified as Pompey the Great, which has been recently reattributed to Emperor Tiberius and is currently exhibited within the villa’s museum. A comprehensive 3D survey campaign, combining laser scanning, photogrammetry, and topographic measurements, enabled the creation of a highly accurate HBIM model that captures both the villa’s architectural features and the statue’s spatial contexts: its original outdoor setting in the formal gardens and its current indoor display. To enhance accessibility and deliver immersive experiences, the project developed a VR app and browser-based WebVR application. The HBIM model—created in Autodesk Revit and enriched with detailed semantic data—was carefully optimised for real-time web performance. The resulting application allows users to explore and interact with the statue’s historical and contemporary settings through an intuitive VR and WebVR interface featuring guided narration and interactive informational hotspots. Based on a comparative analysis of Unreal Engine, Unity, Twinmotion, and PlayCanvas, the proposed workflow addresses common VR limitations by offering a sustainable, resource-efficient solution that balances visual quality, interactivity, and accessibility. This study demonstrates how accurate digital documentation, combined with immersive WebVR, can foster inclusive and engaging cultural heritage experiences, supporting the sustainable digital dissemination of historic sites.

## 1. Introduction

In recent years, extended reality (XR) technologies—including Virtual Reality (VR), Augmented Reality (AR), and WebVR—have become increasingly integral to the cultural heritage and museum sectors. These innovations are reshaping how cultural institutions engage with their audiences, both on-site and remotely, by opening up new possibilities to enhance accessibility, communication, and the sharing of both tangible and intangible heritage. Through immersive experiences such as virtual tours, interactive exhibits, and digital storytelling, museums can offer innovative modes of exploration that foster deeper connections with historical and artistic content. Whether through on-site installations or via web-based platforms accessible from anywhere in the world, XR technologies are effectively bridging access gaps. They enable more inclusive and engaging cultural experiences, helping institutions reach broader audiences and support educational and preservation missions. These advancements promote not only new forms of cultural interaction but also new paradigms for the long-term dissemination and safeguarding of knowledge.

Among the most promising developments in this field is the integration of Heritage/Historic Building Information Modelling (HBIM) into XR-based systems. HBIM, traditionally used for the documentation, management, and conservation of historic built heritage, is now being explored as a data-rich foundation for immersive and interactive museum applications. However, research on the synergy between HBIM and VR/WebVR is still in its early stages of development.

Current workflows for converting and integrating complex HBIM models into real-time XR engines such as Unity, Unreal Engine (Albourae et al., 2023; Bagnolo et al., 2021; Andrade, 2015) or WebVR frameworks are often experimental, non-standardised, and technically fragmented. The main challenges in this integration lie in the intrinsic complexity of HBIM datasets, their semantically rich and highly detailed nature, and the lack of native interoperability with VR development tools. This often necessitates time-consuming optimisation and transformation processes, with the risk of losing important semantic or geometric information. Moreover, the absence of established best practices or widely adopted development protocols means that each case study must be approached with custom solutions, demanding interdisciplinary expertise and significant adaptation effort. Despite these challenges, the integration of HBIM with XR offers significant potential.

This research proposes an innovative methodology for transforming 3D survey data, HBIM models, and historical documentation into immersive VR and WebVR environments. The approach adopts a human-centred perspective, placing the user—be it an expert, a student, or a virtual tourist—at the core of the first-person template experience, while ensuring fidelity to the intangible values and narratives of heritage sites. In doing so, the digital museum becomes a medium for both experiential engagement and intellectual discovery, capable of delivering accurate and meaningful representations of cultural heritage. Key to this process is a rigorous foundation built on the principles of surveying, representation sciences, history, and preservation. Techniques such as 3D laser scanning, Structure-from-Motion (SfM) and remote sensing produce high-fidelity data (Genzano et al., 2024; Eskandari et al., 2024), which, when structured within an HBIM environment and enriched with historical sources, enable the creation of detailed and scalable semantic digital models (Lovell et al., 2023). These models, integrated into interactive and immersive XR applications, offer

users the opportunity to embark on virtual journeys that intertwine the past, present, and future in an ongoing dialogue with history (Banfi et al., 2023). A scientific approach to representing cultural heritage ensures that virtual environments are not only visually engaging but also intellectually robust. This guarantees that the knowledge being conveyed is accurate, nuanced, and not oversimplified. Furthermore, by embedding conservation principles into the digitalisation pipeline, the virtual representations remain faithful to the original physical contexts, preserving both form and meaning.
In this context, the study presented in this publication addresses the lack of structured methodologies by proposing and testing a reproducible workflow that integrates HBIM with immersive XR applications, specifically applied to the cultural context of Villa Arconati. This historic villa, with its architectural richness and layered historical significance, provided an ideal testbed for developing and validating a process capable of transforming HBIM-based knowledge into an interactive, accessible, and semantically meaningful virtual museum (Huhtamo, 2013; Shehade et al., 2020). By creating virtual spaces that combine historical rigour with immersive technologies, this work contributes to the development of a new paradigm for museum-based cultural heritage interpretation—one that bridges technical, disciplinary, and experiential domains (Marques et al., 2025)

## 2. The context, historical background and the research case study

The primary case study for this research is Villa Arconati, a historic residence of exceptional architectural and artistic significance (Beltrami, 1907; Cazzani et al., 2003). Located in Castellazzo di Bollate, just a few kilometres from Milan, Villa Arconati stands as one of the most remarkable and emblematic examples of aristocratic architecture in Lombardy. Commissioned in the 17th century by the influential Arconati family, the villa was initially conceived as a country estate, reflecting the socio-economic structure of Lombardy at the time, which was predominantly agrarian. Architecturally, the villa combines elements of Renaissance symmetry with the opulence of Lombard Baroque.
The main façade exemplifies this synthesis, with refined decorative details and elegant proportions that underscore the status and wealth of its original patrons (Figg. 1-3). Over the centuries, the villa has undergone several modifications and restorations, yet it has preserved much of its original character and charm (Ferrarrio, 2001).

Figure 1. Villa Arconati connected to the formal garden and the Diana theatre with the fountain of Tritons.

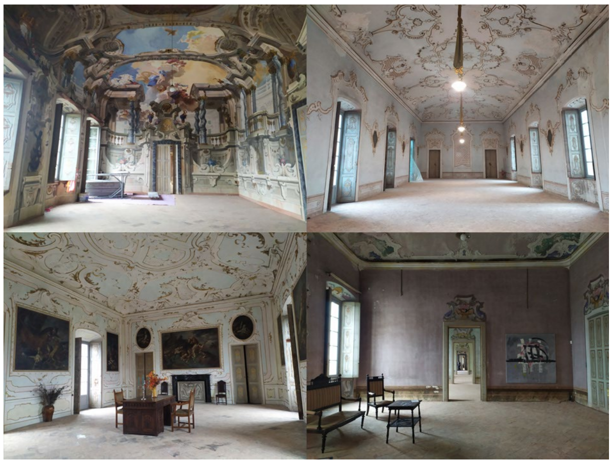

Figure 2. Interior museum rooms open to the public at Villa Arconati.

Figure 3. The room featuring the sculpture of Pompey the Great.

A defining feature of Villa Arconati is its extensive historical park, spanning over 10 hectares. The park includes a formal Italian garden characterised by geometrically arranged flowerbeds, tree-lined avenues, and ornamental fountains, representing a late 17th-century approach to landscape design. A small pond and romantic garden features further enrich the aesthetic and experiential dimensions of the estate (Fig. 4).

Figure 4. Views of the gardens, the Water Tower, the small pond and the stable.

In the 18th century, the villa experienced a period of cultural flourishing. It was expanded and adorned with new frescoes and artworks, becoming a prominent intellectual hub frequented by nobility, scholars, and artists. Today, it is often referred to as the "Versailles of Lombardy," not only for its grandeur but also for its historical and cultural relevance.

Currently open to the public, Villa Arconati serves as a venue for cultural events, concerts, exhibitions, and theatrical performances. Its proximity to Milan makes it an attractive destination for those seeking to engage with regional history and heritage while enjoying the tranquillity of a rural setting. It is widely regarded as one of the most visited and celebrated historical residences in the region, particularly by enthusiasts of architecture, history, and historical gardens.

Despite its cultural significance, Villa Arconati faces ongoing challenges in terms of accessibility, particularly for individuals who are physically unable to visit or reside there due to the considerable distance. Nevertheless, efforts continue to preserve its historical legacy and expand its cultural reach through programming and conservation initiatives. Among the most notable artefacts housed within the villa is a monumental Roman marble statue, approximately 3.5 meters in height. Traditionally identified as representing Pompey the Great, recent scholarship has instead attributed the statue to Emperor Tiberius. The statue was brought to Villa Arconati in 1627 by Galeazzo Arconati, a noted antiquarian and patron of the arts, who also owned the Codex Atlanticus by Leonardo da Vinci.

Originally displayed in the villa's outdoor garden theatre, the statue was replaced with a replica in 1742 and relocated indoors to protect the original (Fig.5). Galeazzo also commissioned an inscription for its base, intended as a moral reflection on the vanity of human ambition.

Figure 5. The replica of the statue in the historic park of Villa Arconati, recently restored.

From an iconographic perspective, the statue depicts a standing Roman commander, draped in a cloak over the left arm and holding an imperial staff in the right hand, which was formerly made of gilded copper. The raised left palm suggests a gesture of command or public oration. For centuries, tradition maintained a mistaken association with the assassination of Julius Caesar, claiming the statue marked the site or figure near which Caesar was killed. This narrative was later corrected with the identification of the figure as Tiberius.

Today, the statue serves as a focal point of the villa's internal museum, which chronicles the transformation of Villa Arconati into one of the most distinguished villas of delight in northern Italy (Fig. 6).

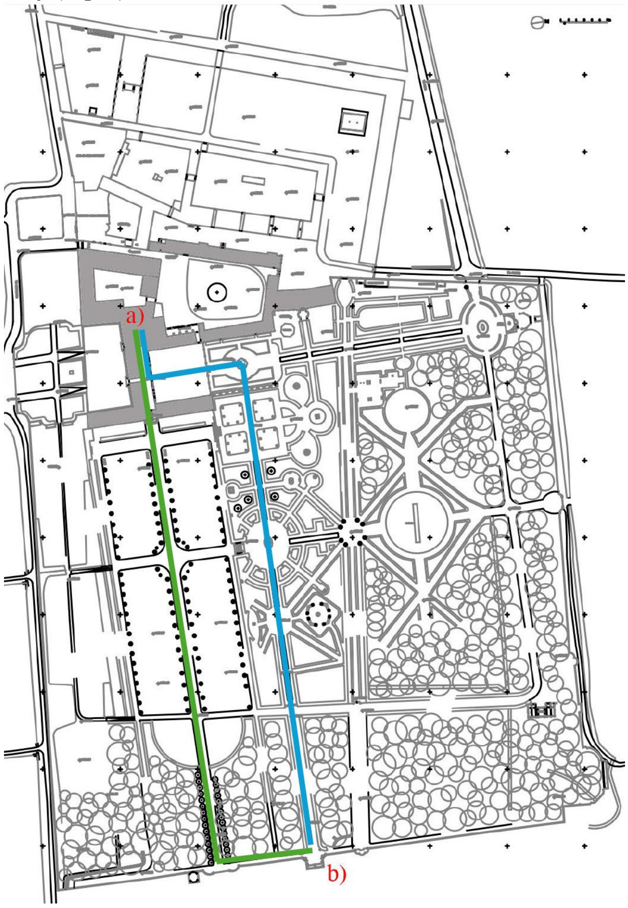


Figure 6. Plans of Villa Arconati and its park, showing the locations of the two Roman statues (a – original, b – replica) and the tourist routes connecting them (blue: along the Fountain Path from the lemonhouse; green: through the southern *Parterre delle Ballerine*. Graphic elaboration based on surveys by the Fondazione Augusto Rancilio.

## 3. Research objectives

In the coming years, a digital heritage initiative will be developed that involves the integration of advanced technologies—including 3D scanning, photogrammetry, digital modelling, visual programming languages (VPL), and XR—to create precise digital replicas of Villa Arconati's architectural structures and landscaped environments. This long-term project aims to enable users to experience the villa's spatial and historical richness in a new, interactive manner, bridging the gap between physical and virtual engagement with cultural heritage.

The broader objective is to create interactive virtual environments (IVEs) that replicate the villa and its grounds, allowing users to navigate and explore them as if they were physically present. By incorporating HBIM and VR technologies, these experiences will provide users with the opportunity to examine rooms, gardens, artworks, monuments, and historical artefacts while engaging directly with the villa's cultural and historical narrative.

The immersive framework developed through this project is strategically designed to support a forward-looking vision for the role of digital technologies in cultural heritage. Five interrelated objectives guide this process, each contributing to the long-term transformation of Villa Arconati into a digitally accessible and educationally rich heritage site.

A primary goal is the future preservation of cultural heritage through the generation of high-resolution 3D replicas. These digital surrogates will play a crucial role in safeguarding the villa's architectural and artistic assets from physical deterioration, while also ensuring their ongoing accessibility to future generations and remote audiences.

Equally important is the ambition to amplify the visibility of Lombard heritage in the coming years. By embracing VR and WebVR technologies, the project aims to establish new models of cultural dissemination that transcend geographic limitations, reaching international users through immersive storytelling and interactive engagement.

Looking ahead, the project envisions creating deeply immersive and emotionally engaging experiences. These will allow users to virtually explore the villa's interiors, gardens, and collections, interacting with digital reconstructions that stimulate curiosity and foster meaningful connections with the past.

In the field of education, the initiative seeks to redefine how cultural knowledge is accessed and understood. The virtual environment will support innovative, learner-centred approaches, offering exploratory and non-linear experiences that can evolve to meet the needs of students, educators, and the general public.

Finally, the project is committed to technological innovation and accessibility. In the years to come, the virtual museum will be developed as a scalable, device-agnostic platform—accessible via mobile and WebVR technologies—to ensure inclusivity and broad public reach.

Through these objectives, the initiative lays the foundation for a sustainable and resilient digital future for Villa Arconati, transforming it into a living laboratory for experimentation in digital museology, immersive learning, and cultural engagement (Gabriele et al., 2023).

In line with these objectives, this study specifically addresses the development of a virtual environment at the museological scale, rather than at the architectural or territorial scale. The focus is on the digital reproduction and enhancement of individual cultural artefacts, with particular attention to the monumental statue traditionally identified as Pompey the Great, now attributed to Emperor Tiberius.

Given its historical, artistic, and symbolic significance, the Tiberius statue represents an ideal subject for a dedicated VR and Web-VR experience. Through high-fidelity 3D reconstruction, users will be able to interact with the statue in a digitally recreated environment that reflects both its original placement in the open-air garden theatre and its current exhibition setting within the villa's museum. This approach highlights the evolution of curatorial practices and deepens the interpretive context for visitors.

Interactive functionalities—such as guided tours, multilingual narration, contextual reconstructions, and layered historical insights—will transform the statue into a dynamic narrative centrepiece, accessible to both on-site visitors and remote audiences.

Ultimately, this museological-scale virtual experience serves as a prototype for broader applications within the digital cultural heritage sector. It aligns with emerging paradigms in virtual museology, enhancing Villa Arconati's educational and artistic offerings while contributing to the sustainable development of cultural tourism using immersive technology.

Despite these advantages, several challenges must be addressed to implement immersive environments within the context of Villa Arconati successfully.

On a technical level, the site's complexity—with its layered architectural evolution, extensive gardens, and large-scale artefacts—requires highly detailed modelling and optimisation processes. This can lead to performance, scalability, and resource-intensity issues, particularly when targeting platforms that must remain accessible across a range of devices.

Institutionally, the integration of HBIM models and VR into a traditional museum framework poses organisational and curatorial questions. There is often a gap between heritage professionals and digital developers in terms of language, expectations, and methodological approaches. Resistance to innovation, lack of digital skills among staff, and limited funding for experimental technologies may slow down or constrain implementation.

From the user perspective, there is also the risk of overmediating the visitor experience, where the digital layer competes with, rather than complements, the authenticity of the physical site. In historically rich locations like Villa Arconati, the challenge lies in achieving a balanced synergy between immersive content and the existing museum narrative, avoiding technological gimmickry in favour of meaningful integration.

## 4. 3D Survey Integrated Survey Methodologies for Digital Heritage: Mapping the Spatial Narrative of the Tiberius Statue at Villa Arconati

As part of the broader digital documentation and heritage valorisation strategy for Villa Arconati, an integrated 3D survey was carried out with the primary objective of digitally reconstructing and connecting two key spatial contexts related to the Roman statue traditionally identified as Pompey the Great, now reattributed to Emperor Tiberius. The statue, currently preserved inside the villa's museum to protect it from outdoor environmental conditions, originally stood in the open-air theatre of the formal gardens, where a replica now occupies its former position.

To document this transition of context, a multimodal survey campaign was conducted, integrating topographic, laser scanning, and photogrammetric techniques to produce a metrically accurate and visually rich digital model that supports immersive interpretation and future XR applications (Fig.7).

Figure 7. Laser scanning, topographic, and photogrammetric survey operations.

A Leica TPS1200 total station and a GNSS GPS unit were employed to establish a geodetic reference framework for the entire site. This foundational step ensured the precise spatial alignment of the data acquired from both the interior (museum) and exterior (gardens) environments.

The topographic control was essential for maintaining metric consistency across different survey techniques and for


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georeferencing the 3D models within the global coordinate system, enabling accurate spatial correlation between the statue's past and present positions.

For the high-resolution capture of geometry, two laser scanning systems were used, each selected for specific environmental conditions and operational strengths (Fig. 8):

The FARO Focus 3D X 130 HDR terrestrial laser scanner was deployed to capture detailed point clouds of the indoor museum space, which houses the original statue. Its high precision and HDR imaging capability allowed for the accurate recording of both geometry and surface reflectance, crucial for documenting the sculpture's current conservation state and its architectural context.

The GeoSLAM ZEB handheld mobile scanner was used in the outdoor garden area, where the replica of the statue is located. This device enabled rapid, flexible scanning in open and uneven terrain, including the surrounding vegetation and architectural elements of the theatre. Its mobility and SLAM-based mapping were particularly valuable for minimising occlusions and optimising time efficiency in complex, outdoor settings.

To complement geometric data with high-resolution imagery, a comprehensive photogrammetric campaign was conducted using a Canon EOS 5D Mark IV, capturing detailed, colour-accurate images with excellent depth of field and dynamic range. These were used to photograph the statue from multiple angles under controlled lighting conditions, producing a dense photogrammetric model of the sculpture and its immediate setting.

A GoPro camera was also used to capture wide-angle contextual imagery, particularly in the garden setting, where environmental elements such as lighting, vegetation, and spatial relationships play a crucial role in understanding the statue's original placement.

The integration of photogrammetric texture maps with the laser-derived mesh allowed for the generation of photo-realistic 3D models, facilitating both curatorial analysis and immersive visual experiences for educational and outreach purposes.

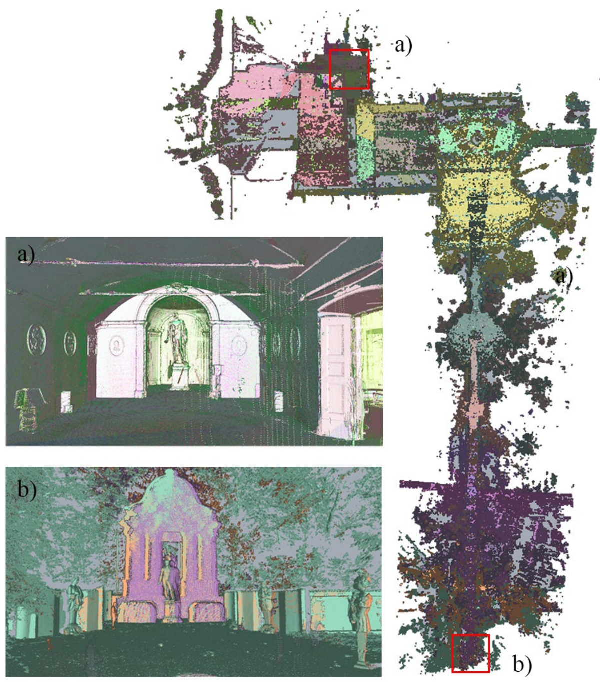


Figure 8. Point clouds obtained through laser scanning and photogrammetry. The surveyed area connects the interior of the villa, where the original statue is currently located (a), with the exterior spot where it was initially placed (b).

The data collected through this campaign forms the technical foundation for the next phase of development, in which the project will utilise XR development platforms to reconstruct and virtually reconnect the indoor and outdoor settings of the Tiberius statue. These environments will allow users to explore, compare, and understand the conservation-driven relocation of the artefact within its broader historical and architectural context.

## 5. Scan-to-HBIM-to-VR Workflow: From Semantic Models to Interactive Virtual and Web-Based Environments

The integration of 3D scanning technologies with photogrammetry and HBIM has emerged as a pivotal methodology in the digital preservation and management of historic buildings. The scan-to-HBIM process involves transforming raw point cloud data acquired via laser scanning or photogrammetry into rich, semantically informed 3D models that accurately represent architectural elements, materials, and construction techniques. While HBIM models provide detailed semantic information essential for conservation planning, maintenance and scholarly analysis, their direct translation into fully immersive IVEs, including VR and Web-based VR, presents significant challenges that currently define the state of the art.

One of the principal difficulties lies in the semantic segmentation and classification of raw survey data. Automating the recognition of architectural components—such as walls, columns, cornices, and decorative elements—with high accuracy remains a research frontier. Manual annotation is time-consuming and requires interdisciplinary expertise, which limits its scalability and applicability. Moreover, HBIM models tend to be highly detailed and complex, reflecting the intricate geometry and metadata necessary for heritage management. However, these models are often not optimised for real-time rendering in immersive platforms, where performance constraints necessitate level-of-detail simplification and efficient data management strategies without sacrificing semantic richness.

The workflow frequently involves heterogeneous data sources and software platforms, including point cloud processing tools, CAD/BIM software (e.g., Revit, ArchiCAD), and game engines (e.g., Unity, Unreal Engine) used for VR development. Ensuring interoperability between these systems is essential but challenging, as standardised data exchange formats (e.g., IFC for BIM, OBJ/FBX for meshes) may not fully capture semantic information or support the dynamic features needed in interactive environments.

The translation of HBIM to VR/Web-VR also requires integration of additional layers—such as textures, lighting, physics, and interactive scripts—which are not inherent in traditional BIM platforms.

State-of-the-art research aims to enhance HBIM-derived virtual environments with interactive functionalities enabling users to query metadata, simulate conservation scenarios, or trigger narrative content. This requires embedding semantic awareness into VR/Web-VR environments, allowing the model not only to be visually accurate but also cognitively meaningful.

Achieving this interactivity requires advanced programming using visual scripting languages, AI-based recognition, and sensor integration to support multimodal interactions, including gesture control and voice commands, which further complicates the development pipeline.

The emergence of WebVR offers new opportunities for widespread access to cultural heritage content without the need for specialised VR hardware. However, WebVR platforms impose stricter limits on model complexity and require careful optimisation of assets for browser-based rendering.
Current research investigates progressive streaming, cloud computing integration, and lightweight semantic modelling as strategies to balance fidelity and performance, aiming to democratize access to heritage virtual environments.
Future developments aim to streamline the entire process—from raw scan data to semantically rich HBIM models and ultimately to interactive XR applications. Key goals include using AI to automate semantic segmentation, standardising data formats to maintain semantic depth across platforms, and applying model simplification techniques that preserve critical heritage details. Additionally, integrating interactive features based on semantic metadata will enhance storytelling and education, while ensuring these experiences are optimised for cross-platform access, including WebVR. Although the scan-to-HBIM workflow provides a solid foundation for heritage documentation and preservation, turning these models into engaging and accessible virtual environments still poses complex challenges. Nevertheless, advances in this area hold great promise for transforming heritage preservation by combining detailed documentation with immersive, user-friendly experiences.

## 6. Toward an Integrated Scan-to-HBIM-to-XR Pipeline

Building on the discussion of the scan-to-HBIM workflow and its evolution toward immersive XR experiences, it is essential to examine the primary software platforms currently employed for developing these virtual environments. Among the most prominent are Unity, Unreal Engine, and Twinmotion—each offering distinct advantages alongside specific challenges.
Unity is widely favoured for its flexibility and extensive asset store, supporting a broad spectrum of VR and WebVR applications. Its user-friendly interface and robust scripting environment make it accessible to both developers and researchers. While Unity excels in cross-platform compatibility, achieving photorealistic rendering often requires additional plugins and considerable optimisation efforts.
Unreal Engine distinguishes itself with cutting-edge graphics capabilities and real-time photorealism, leveraging advanced lighting and rendering systems. It is particularly suited for high-fidelity visualisations of cultural heritage sites. However, its steeper learning curve and higher hardware requirements can limit accessibility for some users and complicate deployment on lower-end devices or web platforms.
Twinmotion, developed by Epic Games, offers rapid visualisation workflows through an intuitive interface tailored for architects and heritage professionals who may lack extensive programming expertise. It enables swift generation of visually appealing scenes and supports VR integration, with notable capabilities for exporting to WebVR formats. This facilitates easy sharing and access through web browsers without the need for specialised software or hardware. Nonetheless, Twinmotion's customisation and interactivity options are more limited compared to Unity and Unreal, constraining the complexity of immersive experiences.
Selecting the most suitable platform depends on specific project goals, balancing factors such as graphical fidelity, interactivity, accessibility, and usability. The effective integration of these tools within the scan-to-HBIM pipeline is crucial for creating immersive virtual environments (IVEs) that are both engaging and accessible to diverse audiences.

This research investigates an alternative approach to defining a sustainable and efficient development pipeline specifically tailored for WebVR experiences. In contrast to traditional platforms such as Unity and Unreal Engine, which typically require substantial computational resources and involve complex workflows, this study focuses on Twinmotion and PlayCanvas. The latter, in particular, has proven to be a lightweight, web-native game engine optimised for browser-based deployment.
PlayCanvas offers seamless accessibility, requiring no dedicated software installation or high-end hardware from users, aligning well with inclusivity and broad audience reach objectives. By adopting PlayCanvas, this research establishes a streamlined, resource-efficient production workflow that enables the direct delivery of immersive cultural heritage experiences online, thereby supporting the sustainable digital dissemination of historic sites, such as Villa Arconati.
The development process begins with creating a detailed HBIM model in Autodesk Revit, which serves as the foundational digital representation of Villa Arconati's architecture and the contextual environment of the Pompey statue. Leveraging high-precision laser scanning and photogrammetric data, the villa's structural elements and key artefacts are modelled with exact geometry and enriched with semantic information, including material properties and historical annotations. Revit's parametric tools enable the production of a highly accurate, information-rich model tailored for heritage management and documentation. Specific scan-to-BIM requirements and Grades of Generation (GOGs), as proposed by Banfi (2017) and applied in multiple case studies, have been utilised to enhance the generative process (Fig. 9).

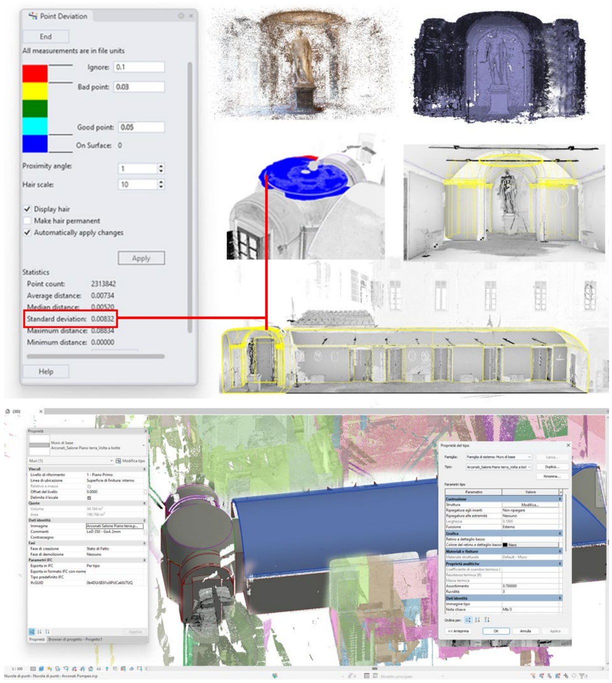

Figure 9. Progression from point clouds to mesh-textured and NURBS-based models, developed according to defined Grades of Generation (GOG), culminating in the HBIM model used to create the WebVR environment.

Once the HBIM model is complete, it undergoes polygon reduction and detail simplification to ensure suitability for real-time visualisation. The optimised model is then exported from Revit in compatible formats such as FBX or OBJ, preserving textures and essential geometric features. In the subsequent stage, the model is imported into 3D editing software such as McNeel Rhinoceros, Blender, or Autodesk 3ds Max for further refinement. This phase includes UV mapping, texture optimisation, and the creation of Level of Detail (LOD) variations to ensure smooth performance within browser-based environments. These preparatory steps are crucial for balancing visual fidelity with the rendering constraints of WebVR platforms. Following asset refinement, the optimised model is uploaded to Twinmotion and PlayCanvas, both of which support immersive real-time rendering directly in web browsers. Within these platforms, the digital environment is reconstructed to accurately position the statue of Pompey in both its current museum setting and its original outdoor location in the villa's garden. This dual-context reconstruction enables users to explore both settings through the WebVR interface seamlessly.

Interactive features are developed using PlayCanvas's JavaScript-based scripting system, enabling elements such as informational hotspots, guided narration, and intuitive navigation controls. In Twinmotion, interactivity and semantic enrichment are achieved through the use of custom interactive functions and pre-modelled, textured objects created in Rhino. The Datasmith plug-in proves essential for real-time synchronisation between the modelling environment and Twinmotion.

Once development is complete, the project is transferred to the cloud, where specific packaging functions facilitate the deployment of both a VR app and a WebVR application (Fig. 10).

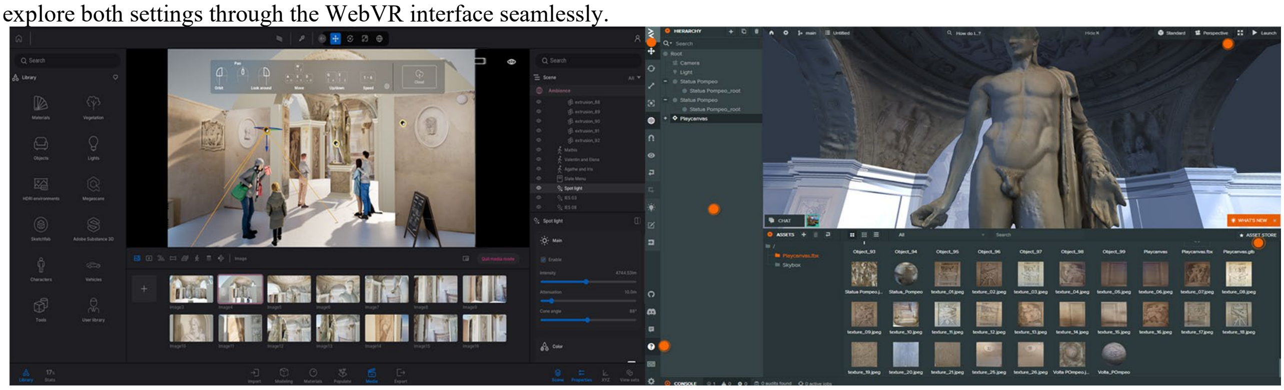

Figure 10. The WebVR environment developed in Twinmotion (left) and PlayCanvas (right).

| Feature / Platform | PlayCanvas | Unity | Unreal Engine 5 (UE5) | Twinmotion |
|---|---|---|---|---|
| **Runtime Platform** | Web browser (WebGL/WebXR) | Desktop, Mobile, WebGL, XR devices | Desktop, Console, XR devices | Desktop app, VR viewer, Twinmotion Cloud |
| **Open Source** | Yes | Partial | Yes (via Epic Games account) | No |
| **Development Environment** | Web-based editor | Local installation (Unity Hub) | Local installation (Epic Launcher) | Standalone desktop app |
| **Model Format Support** | glTF, FBX, OBJ (IFC via conv.) | IFC, FBX, glTF, Revit | FBX, Datasmith, Revit, IFC | FBX, Revit, SketchUp, Rhino |
| **HBIM Compatibility** | Yes (indirect) | Yes (via plugins) | Excellent (Datasmith + Revit) | Native Revit/Datasmith support |
| **Interactivity & Logic** | JavaScript scripting | C# scripting | Blueprint + C++ scripting | Partial (walkthrough UI only) |
| **Visual Rendering Quality** | Moderate | Good | Excellent (Lumen, Nanite) | Good (architectural) |
| **XR/VR/AR Support** | Yes (WebXR ready) | Yes (full XR stack) | Yes (full XR support) | Yes (VR walkthrough only) |
| **Deployment & Sharing** | Yes (instant URL) | Partial (WebGL tuning needed) | No (desktop only) | Yes (cloud sharing, limited interactivity) |
| **Collaboration Tools** | Yes (real-time online) | Partial (needs version control) | Partial (needs Perforce) | Yes (via Twinmotion Cloud) |
| **Scripting Language** | JavaScript | C# | Blueprint, C++ | None |
| **Plugin Ecosystem** | Limited but growing | Very large | Large | Limited |
| **Learning Curve** | Easy | Moderate | Steep | Very easy |
| **Licensing Model** | Free (MIT core) + paid | Free personal + royalties | Free up to $1M revenue, then royalties | Free (students), paid (commercial) |

Table 1. Comparative analysis of XR development platforms.

This ensures compatibility across various interaction levels and device types, including touchscreen mobile devices, VR headsets, and desktop PCs. Throughout the parallel development in PlayCanvas and Twinmotion, various levels of interaction, immersion, and interoperability are tested. The WebVR environment is rigorously evaluated across multiple XR development platforms, devices, and browsers to ensure accessibility, usability, and optimal performance (Table 1).

## Conclusion

This research demonstrates the potential of integrating Historic/Heritage Building Information Modelling (HBIM) with immersive VR/WebVR applications to enhance the digital valorisation and accessibility of cultural heritage sites. Using Villa Arconati and the reattributed statue of Tiberius as a case study, the project combines accurate 3D survey data with advanced modelling and web-based visualisation techniques to create interactive virtual environments (IVEs) that bridge the gap between tangible architectural heritage and its intangible historical and cultural significance.
The development of WebVR applications, designed for browser-based deployment, addresses key challenges related to accessibility and hardware requirements, effectively overcoming many of the limitations of traditional VR platforms. This approach enables remote, hardware-independent exploration of complex heritage assets, thereby fostering broader public engagement and supporting both educational and outreach initiatives. Furthermore, the study underscores the importance of an optimised and well-structured workflow—beginning with precise HBIM documentation and continuing through model simplification and semantic enrichment—to ensure that the final immersive experience is both visually compelling and informative. Future work will focus on extending this methodology and conducting a comparative analysis of XR development platforms at other heritage sites, further enhancing interactivity, and exploring integration with augmented reality (AR) and other virtual reality (VR) technologies. Ultimately, this research contributes to the development of a sustainable, scalable, and replicable model for the digital preservation and dissemination of cultural heritage in an increasingly digital and interconnected world.
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