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HBIM-based Virtual Reality for Serious Games: A Review and Research Directions Oriented to Built Heritage Dissemination

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Abstract

In the past decade, Historic Building Information Modeling (HBIM) has become a valuable tool for digitally documenting and conserving Cultural Heritage (CH). However, while HBIM excels in precision and archival value, it often remains static, complex, and inaccessible to non-expert users. This limits its broader potential in public outreach, education, and engagement. In contrast, Virtual Reality (VR) offers immersive environments that can transform HBIM from a technical dataset into a compelling virtual heritage experience. Serious Games (SGs) and gamification present an effective strategy to combine education and entertainment, enhancing user interaction, motivation and comprehension. Yet, despite growing interest, structured and integrative applications of HBIM within gamified VR environments have remained relatively limited. This research therefore aims to explore the map of SGs and gamification implemented in HBIM-based VR systems. The paper is structured into three parts: (1) analyzing gamification approaches in CH and their impact on behavior and usability; (2) conducting a bibliometric analysis of the current research on HBIM-based VR for SGs; and (3) addressing key questions regarding tools used, game design dimensions, conveyed knowledge, project goals, effectiveness, and future directions.

1. Introduction

In the past decade, Historic Building Information Modeling (HBIM) offers a rigorous framework for recording and preserving historical assets, rooted in advanced surveying, parametric modeling, and information management techniques. However, despite its disciplinary robustness, it still presents several critical limitations—particularly when it comes to sharing information with a broader, non-specialist audience, such as virtual tourists or casual users unfamiliar with the domain of heritage conservation.

The platforms on which HBIM typically relies, such as Autodesk Revit or ArchiCAD, are designed primarily for professionals and thus remain complex, technically oriented, and financially inaccessible to the general public. Their interfaces are not optimized for intuitive exploration or narrative-driven experiences, which are essential to engaging non-expert users. Furthermore, HBIM models often contain highly technical data that lack immediate readability for lay audiences. There is also a significant lack of integration with web-based environments, mobile applications, and immersive platforms such as Virtual Reality (VR) or Augmented Reality (AR), which could otherwise render these data more engaging and explorable.

File size, interoperability issues, and the absence of standardized formats for open dissemination further hinder the broader diffusion of HBIM content. Ultimately, without contextual information or storytelling layers, HBIM models risk remaining static and opaque—effectively "silent" to digital tourists and educational audiences. Therefore, transforming these static datasets into interactive, accessible, and narrative-rich environments is a crucial step toward democratizing Cultural Heritage (CH) and extending its value beyond the professional sphere.

In this context, the adoption of VR offers a powerful solution to overcome the limitations of the HBIM system and make CH more inclusive and engaging. VR allows HBIM models to be transformed from technical and static tools into dynamic and immersive experiences that can be intuitively explored even by those without specialized knowledge. Through a VR headset or even on more common devices, virtual tourists can "enter" historic spaces, walk through buildings, and discover architectural details in a way that would be unimaginable with a simple 3D visualization.

Moreover, VR offers a unique opportunity to integrate historical and cultural storytelling. Each element of the model can be enriched with multimedia content such as audio, video, and texts that tell the story of the place or explain the significance of specific architectural details. This type of interactive storytelling not only makes the experience more engaging but also helps the audience understand the cultural and historical value of what they are exploring.

Finally, thanks to its accessibility, VR allows a global audience to interact with CH without geographical limits, enabling the sharing and enhancement of heritage in a more democratic and engaging way. VR functions as a medium of expression, taking the form of simulation and gamification, aiming to enhance user engagement and make cultural data more approachable. While simulations often offer predetermined experiences, gamification introduces elements such as roles, goals, autonomy, and playfulness, providing users with a more interactive and immersive experience (Hutson, 2024).

Although VR has been widely employed in CH (Bekele, 2018), the models used are predominantly 3D mesh models, which primarily represent surface geometry without deeper information layers. As a result, the immersive experience is often limited to a virtual tour with only basic science popularization. It is unfortunate that HBIM is not more widely utilized, as it provides rich, multi-level information. Experts could leverage this content for management purposes, while students could benefit from immersive, knowledge-enhanced environments.

Even though the limited use of HBIM in VR, there has still been research progress in recent years. In *"Virtual Heritage: From 3D Modeling to HBIM and Extended Reality"*, Banfi (2023) underscores the growing need for clear methodological guidelines to integrate HBIM with VR. He emphasizes the importance of interdisciplinary collaboration, the interoperability of HBIM models, and the adoption of advanced modeling techniques such as mesh and NURBS. Particular attention is given to the Scan-to-BIM process as a foundation for generating accurate digital reconstructions, advocating for the use of HBIM in conjunction with VR, AR, and web-XR (eXtended Reality) technologies to create immersive experiences that communicate both the tangible and intangible values of Built heritage (Figure 1). A notable case study presented in the study focuses on the archaeological site of Villa dei Quintili in Rome. Here, immersive desktop VR and web-based VR environments were developed, representing both the surveyed ruins and the associated museum spaces. These applications demonstrate how HBIM, traditionally oriented toward a niche group of professionals, can serve as a basis for more inclusive and accessible XR experiences aimed at broader audiences

VR offers the potential for immersive storytelling and interactive learning, yet integrating HBIM data into such environments in a gamified, user-friendly manner remains underdeveloped. One promising direction is the creation of HBIM-based VR Serious Games (SGs), which combine rigorous historical modeling with game design principles to enable meaningful user experiences.

Although the use of gamification in CH has gained attention, systematic studies combining HBIM, VR, and SGs are still limited. To map the research area, this study will be organized into the following three parts:

1. Analyze how gamification technologies are applied in CH environments and how they influence user behavior and system accessibility;
2. Adopt a bibliometric approach to map the current research landscape surrounding HBIM-based VR SGs.
3. Answer the following questions:

Q1: Which tools are used in the projects?
Q2: What game design dimensions are used?
Q3: What knowledge or content is conveyed?
Q4: What are the intentions of the projects?
Q5: How effective are the projects?
Q6: What further directions are proposed?

2. Short Review of Serious Games in Virtual Heritage

SGs are interactive digital applications that go beyond entertainment and incorporate educational, informational, or training objectives as their primary goal. They leverage the engaging and motivating aspects of gaming experiences to facilitate learning, skill development, and behavioral change (Lamb, 2024). They are increasingly being used with interesting outcomes and applications in CH (Mortara and Catalano, 2018). In this context, the definition of SGs extends far beyond merely games, encompassing the idea of ‘edutainment’ in all interactive digital applications. Gamification, as a go-to toolset in CH for various purposes, including marketing, tourist destination, safeguarding and dissonant or challenging aspects of heritage (Marques, Pedro, & Araújo, 2023), often serves as a key strategy within SGs to enhance user interaction, motivation, and comprehension.

The study *"A Systematic Literature Review of Gamification in/for Cultural Heritage: Leveling up, Going Beyond"* written by Marques, Pedro and Araújo (2023) is the most recent comprehensively reviewed gamification in CH field. Analyzing 77 papers between 2017 and 2021, the authors provided a systematic mapping of the current research landscape, revealing a predominant focus on European contexts—particularly Italy, Greece, and the UK—with initiatives primarily aimed at tourists and children, and centered on historical, architectural, and archaeological heritage.

Importantly, in evaluating gamification design dimensions, the review adopted the gamification heuristics proposed by Tondello, *et al.* (2016). These heuristics consists of 12

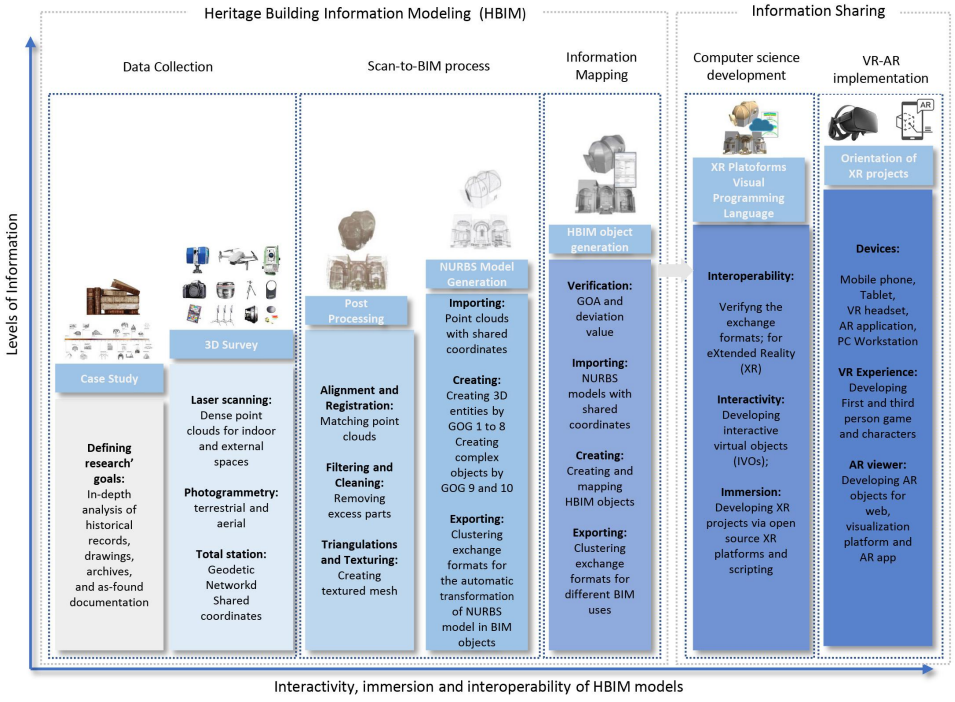

Figure 1. The development approach: from data collection and HBIM uses to VR-AR implementation proposed in Banfi, F. (2021).

dimensions, categorized into:

- Intrinsic Motivation Heuristics: purpose and meaning; challenge and competence; completeness and mastery; autonomy and creativity; relatedness; immersion
- Extrinsic Motivation Heuristics: ownership and rewards; scarcity; loss avoidance
- Context Dependent Heuristics: feedback; unpredictability; change and disruption

The results showed intrinsic motivation was prioritized across the reviewed studies. On average, 2.8 heuristic dimensions were identified per publication. Among these, immersion, completeness and mastery, autonomy and creativity, relatedness and ownership and rewards were the most frequently implemented dimensions.

The study *"Gamifying cultural heritage: Exploring the potential of immersive virtual exhibitions"* by Wang *et al.* (2024) proposed a set of gamification principles based on an analysis of 78 selected studies. These principles include: immersive technologies, multimodal data integration, a balanced education and entertainment, interactive narrative, cultural sensitivity, personalized experiences, advanced interfaces and assessment mechanisms.

Empirical investigations, such as Di Paola *et al.* (2019) employed Unreal Engine 4 designed an immersive virtual museum that embeds AR within a VR environment. For instance, players must reach certain goals to earn AR glasses that unlock new narrative layers.

In parallel, Bagnolo *et al.* (2021) utilized Unity to design a SG grounded in HBIM-derived models, targeting youngsters in the 10-15 range. The game integrated educational puzzles and a progressive unlocking mechanism, allowing players to interact with objects to obtain historical and cultural information while gradually revealing a sharper visualization of architectural components step by step.

Lazarinis *et al.* (2022) presented a game app developed in Unity using models of a Greek temple and a Roman statue, showing that learning about CH through gaming, especially in VR, is more engaging and realistic than traditional methods.

Díaz-Kommonen *et al.* (2024) demonstrated gamification's robust capacity to significantly enhance participant engagement and collaborative dynamics, even in virtual and hybrid settings. Looking ahead, the convergence of gamification with emerging technologies—including AR, VR, and artificial intelligence (AI)—promises transformative impacts on CH interpretation and conservation.

Notably, Martusciello, Muccini, and Bucchiarone (2025) proposed an advanced reference architecture that integrates generative AI and AR to deliver personalized, immersive, and adaptive gamified heritage applications. Such innovations are poised to facilitate bespoke user experiences that dynamically adapt to individual preferences and learning styles, thereby broadening accessibility and deepening engagement with built heritage.

Despite these advances, few studies concretely integrate HBIM models within gamified extended reality (XR) environments. To address this gap, the present study underscores the necessity of an integrated bibliometric and content analysis to comprehensively map the evolving intersection of HBIM, gamification, and immersive technologies in built heritage.

The following bibliometric analysis will quantitatively identify key research trends, influential authors, and collaborative networks, providing an objective overview of the field's structure and evolution. Concurrently, content analysis will qualitatively explore thematic patterns, theoretical frameworks, and methodological approaches within the literature. By combining these methods, the study aims to deliver a holistic understanding of both quantitative and qualitative research dimensions, revealing gaps, emerging topics, and interdisciplinary linkages. The subsequent section specifically focuses on evaluating the effectiveness of research sources, studies, and methodologies employing HBIM models as foundations for VR development, highlighting the critical role of integrated analysis in steering future innovations in gamified built heritage applications.

3. Integrated Bibliometric and Content Analysis

In order to analyze the current state of research, a bibliographic search was conducted using the Scopus and Web of Science (WoS) databases. Initially, the search was performed using the query TITLE-ABS-KEY: "HBIM AND Virtual Reality," which returned 87 results in Scopus and 58 results in WoS. After eliminating duplicates, a total of 107 unique records remained.

A second search was conducted using the query TITLE-ABS-KEY: "HBIM AND Gam*" yielding 23 results in Scopus and 18 results in WoS. After removing duplicates, 26 unique records were obtained.

These search results reveal that the integration of VR within HBIM has received considerably more attention than gamification. This suggests that visualization demands are currently prioritized over interaction or amusement, potentially influenced by the increasing accessibility and widespread adoption of VR technologies.

Through the bibliometric analysis in Bibliometrix (Aria and Cuccurullo, 2017), the first search results shows the research on HBIM and VR started in 2015. Figure 2 shows the publication numbers in total, presenting a rise trend, in 2023 the number reaches the peak. The most relevant authors are Banfi, F., Brumana, R., and Stanga, C. All of them are affiliated with Politecnico di Milano and maintain close collaboration, making it the most relevant institutional affiliation. Italy and Spain are the most related countries, followed by China, Morocco, USA, Canada, Ireland, Korea, Poland and Portugal.

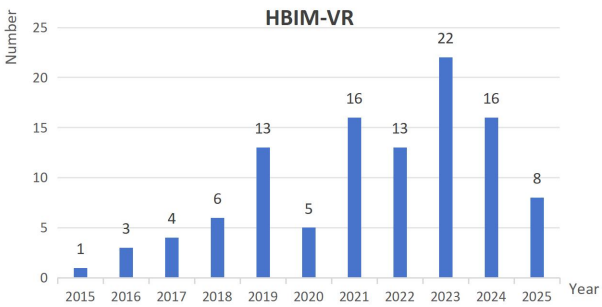

Figure 2. The publications on 'HBIM AND Virtual Reality'.

The second search result shows the research on HBIM and game started in 2017. Murphy, M. and Banfi, F. are the most frequently published authors, and are the only two authors to have published multiple times as first author. Other publications are one-off studies, lacking continuity.

From the collected literature, 14 papers were initially identified that refer to HBIM-VR-Gam*. After careful content review, 10 papers were ultimately selected for further analysis, as their focus aligns with SGs, educational applications, entertainment, or interactivity. Figure 3 shows the proportion of gamified research within the HBIM-based VR domain, indicating a significant lack of such studies. In the following sections, these papers will be referenced by their assigned identifiers (N1 – N10) shown in Table 1.

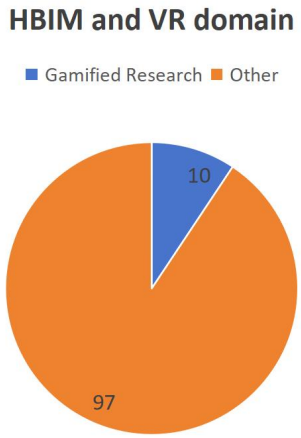

Figure 3. The number of gamification researches within HBIM-based VR domain.

N	Author	Title	Year	Type
1	Murphy M.; Chenaux A.; Keenaghan G.; Gibson V.; Butler J.; Pybusr C.	Armagh observatory -historic building information modelling for virtual learning in building conservation	2017	C
2	Albourae A.T.; Armenakis C.; Kyan M.	Architectural heritage visualization using interactive technologies	2017	C
3	Banfi, F; Brumana, R; Stanga, C	Extended Reality and Informative Models for the Architectural Heritage: From Scan-to-BIM Process to Virtual and Augmented Reality	2019	A
4	Pybus C.; Graham K.; Doherty J.; Arellano N.; Fai S.	New Realities for Canada's Parliament: A Workflow for Preparing Heritage BIM for Game Engines and Virtual Reality	2019	C
5	Banfi F.; Bolognesi C.M.	Virtual Reality for Cultural Heritage: New Levels of Computer-Generated Simulation of a Unesco World Heritage Site	2021	C
6	Meegan E.; Murphy M.; Keenaghan G.; Corns A.; Shaw R.; Fai S.; Scandura S.; Chenaux A.	Virtual Heritage Learning Environments	2021	C
7	D’ Agostino P.; Antuono G.; Elefante E.s	Management and Dissemination for Dismissed Religious Architecture. An Approach Fusing HBIM and Gamification	2022	C
8	Argiolas R.; Bagnolo V.; Cera S.; Cuccu S.	Virtual Environments to Communicate Built Cultural Heritage: A HBIM-Based Virtual Tour	2022	C
9	Banfi F.; Oreni D.	Unlocking the Interactive Potential of Digital Models with Game Engines and Visual Programming for Inclusive VR and Web-Based Museums	2025	A
10	Battista, D., Cecere, L., Colace, F., Guida, C. G., Lorussso, A., & Santaniello, D.	Gamification in Architecture: The Future Interface in Design as an Incentive to Participatory Democracy	2025	C

Table 1. 10 papers research on Serious Games/gamification in HBIM-based VR.

Among the 10 publications reviewed, only 2 are peer-reviewed journal articles, whereas the remaining 8 are conference papers, suggesting that this research area is still in its formative stages.

4. Results and discussion

4.1 Q1: Which tools are used in the projects?

It is foreseeable that Unity and Unreal Engine, as the two most competitive game engines, will be widely adopted. This is substantiated by a literature analysis of the 10 papers, 5 of which utilized Unity and 4 employed Unreal Engine. The exception is N1, where only a proposal was made to create an open access VR immersive model for education purposes. Unity and Unreal Engine were absolutely recommended, while Autodesk’s Stingray Package was also suggested for its superior interoperability with IFC files. However, due to the strong competition from Unity and Unreal Engine, Stingray has ceased service since 2018. Nevertheless, this recommendation inspires us to pay attention to the compatibility question of HBIM models within Game Engine.

One notable example, N7, opted for Autodesk A360 in conjunction with Unreal Engine, leveraging A360's direct query functionality to access technical data.

The rationale for choosing Unity across various studies often includes its ability to handle referenced external files (scripts, textures, models) that can be dynamically reloaded after model changes, its extensive asset store and strong reputation, and its large community of independent game developers providing abundant online tutorials, forums, and open-source scripts for basic video game features. Furthermore, researchers frequently cite Unity's relative simplicity for developing small prototypes,

augmented by a wide selection of free assets, even acknowledging Unreal Engine's superiority in certain aspects.
Conversely, the selection of Unreal Engine is frequently justified by its real-time rendering capabilities, advanced features such as Lumen, Nanite, and the Datasmith add-in, and its foundation in creating immersive environments where developers can directly interact with visual programming languages like Blueprints and Visual Scripting. These features enable developers to create digital environments through an interface structured around functions, events, and nodes, often without resorting to traditional coding. Additional reasons for its choice include its visual fidelity, scripting simplicity, manageable learning curve, and the availability of extensive online resources, including documentation and community support. Its capacity for orienting applications for multiple devices and its facilitation of algorithm and information code development through visual scripting are also frequently cited. Moreover, Unreal Engine is valued for its ability to support both expert and non-expert users in creating innovative digital storytelling, fostering their development and creative narratives.
While both Unity and Unreal Engine 5 are capable of handling dynamic 3D content, Unreal Engine 5, with its robust Datasmith pipeline and advanced rendering technologies, is better suited for high-fidelity HBIM visualizations and interactive projects. However, Unity offers greater flexibility and ease of deployment for lightweight educational applications, particularly on mobile platforms.

4.2 Q2: What game design dimensions are used?

Gamification is best described as a collection of game-inspired design elements, strategies, and process organization methods (Meske *et al.*, 2016). These elements are often integrated into Serious Games (SGs) to enhance engagement and motivation, aligning with their primary goals of education, information, or training. Gamified elements typically include points, badges, leaderboards (PBL), progress bars, streaks, and unlockable content. Game mechanics encompass quests, achievement systems, storytelling, random rewards, and resource management. Gamified design, on a higher level, refers to features such as role-playing, simulation experiences, narrative framing, personalization, and emotional design.
Among the 10 reviewed papers, although terms such as 'Serious Games', 'gameplay', 'game engine', and 'gamification' were occasionally mentioned, the actual focus was on interaction and interactivity. While interaction is a foundational component of games, not all interactions qualify as gamification (Deterding *et al.*, 2011). Gamification builds upon interaction by introducing structured goals, rules, feedback, and rewards, transforming neutral interactions into motivational, game-like experiences (Hamari *et al.*, 2014). In heritage VR applications, many systems achieve a high level of interactivity without adopting comprehensive gamification frameworks.
The two conference papers from 2017 did not reference any gamification strategies; rather, they focused on recommending or implementing game engines solely to enhance interactivity. Since 2019, more detailed approaches to enhance interactivity have emerged. In N3, taking the Basilica of Sant'Ambrogio in Milan as an example, the authors created interactive objects, while Box Trigger, BeginOverlap Event, and Matinee were used to further enhance interaction. Additionally, a virtual subtraction process was implemented to illustrate transformations across historical phases, enriching both storytelling and content. N4 completed the documentation and modeling of Canada's Parliament and emphasized the importance of storytelling in Unity 3D, although this step was not executed. Excessive freedom without narrative constraints can negatively affect users' sense of presence and enjoyment (Tekinbas & Zimmerman, 2005). A well-structured narrative can guide the virtual visitor's gaze, enhancing immersion.
In 2021, N5 identified five basic rules for storytelling: a linear and engaging narrative; reliability of models and source material; identification of suitable VR devices and software; control over project size (in bytes and polygons); and ensuring future development and integration through an open development framework. N6 created Virtual Learning Objects (LOs), consisting of images or photos, live data feeds, video/audio snippets (live or recorded), text, animations, and web-based applications, as both cognitive and interactive elements. Unity was also utilized to visualize a timeline of five historic map models.
By 2022, the field had seen substantial development. N7 highlighted the integration of gamification and edutainment in the HBIM-VR context. The authors designed two types of widgets—pop-up and interactive—for amusement, edutainment, and heritage management, also enabling exploration of different historical periods. N8 developed an HBIM-based virtual tour incorporating multiple game elements, resembling standard first-person shooter (FPS) controls. The tour featured WASD movement, mouse-controlled view rotation, jumping, and climbing. Visitors were rewarded with new information as they explored.
The 2025 studies demonstrated notable advancements over the 2022 HBIM-based virtual tours by adopting explicit gamification frameworks. N9 introduced a VR and WebVR application for the Ospedale Maggiore in Milan, integrating Virtual-Visual Storytelling (VVS) with 3D animations, textual data, and audio. The design featured physics-based interactions, including player controls for movement, jumping, object interaction, and a dynamic camera enabling seamless transition between third- and first-person views. The study also explored types and levels of interaction. N10 implemented participatory design tasks within the VR environment, incorporating voting mechanisms to capture user preferences and real-time object manipulation using hand controllers.
The gamified elements, mechanics, and design features applied in each case are summarized in Table 2. The results indicate that storytelling is the most frequently used mechanism, and N10 employed the greatest number of gamified design components, including storytelling, rewards, personalization, participatory design, Points, Badges, and Leaderboards (PBL) and social features. Besides, N8, and N9 showed advancements in rewards and physics-based interactions.

Gamified elements, mechanics and design	References
Storytelling	N3 N4 N5 N9 N10
Interactive objects	N3 N6 N7
Box Trigger, BeginOverlap Event	N3
Matinee	N3
Narrative Framing	N6 N7
Rewards	N8 N10
Physics-based interactions	N8 N9
Personalization	N10
Participatory Design	N10
Points, Badges, and Leaderboards	N10
Social feature	N10

Table 2. Distribution of the different publications by type of gamified elements, mechanics, and design.

4.3 Q3: What knowledge or content is conveyed?

The transmission of meaningful information is a core objective of SGs. Beyond the textured geometry provided by HBIM models, the integration of historical, cultural, and technical knowledge is essential for raising public awareness of heritage value and supporting expert-level heritage management.

N1 defined LOs, including their history, meaning, quality, and destination. The IEEE Learning Object Metadata Standard was cited as a reference framework, particularly in terms of its levels of detail (aggregation) and classification of learning resource types. N3 emphasized the importance of revealing lesser-known episodes in the history of the Basilica of Sant'Ambrogio, arguing that increasing the level of embedded information enhances public awareness of both the intangible values and the historical complexity of architectural heritage.

N5 illustrated three historical phases to highlight the typological and morphological evolution of the church's main cloister, thereby increasing the educational value of the VR project. It also demonstrated that HBIM can convey a range of information, including the physical and mechanical properties of materials, historical development, and wall stratigraphy. In N6, LOs were treated as knowledge-based, self-contained, and reusable entities, described through metadata tags reflecting their history, meaning, quality, and destination.

N7 adhered to the principle of duality: for professionals, it presented technical-descriptive data, conservation status, and point clouds for asset management; for general visitors, it provided information panels (covering general site data and functional diagrams), photographs of the current condition, and historical narratives designed for amusement, edutainment, and public dissemination. N8 allowed users to interact with architectural elements to access information on materials, styles, mouldings, geometry, and signs of degradation. N9 enabled users to explore analytical content, historical anecdotes, images, and descriptive texts related to damage caused by World War II bombing. VVS is also integrated to provide 3D animations, textual information, and audio to enhance user engagement.

In conclusion, textured geometry appears to serve as a common foundational element across the projects examined, although the level of detail tends to vary depending on the specific goals of each initiative. Several studies have explored the use of storytelling to illustrate different historical phases, though the strategies for conveying educational or meaningful content are sometimes described only briefly or lack depth. While some research highlights the relevance of varying information levels, clear explanations or structured frameworks for their application are relatively rare. Additionally, although HBIM components often contain rich datasets and could potentially be used as interactive elements within virtual environments, the discussion around their granularity and practical use in VR contexts remains somewhat limited.

4.4 Q4: What are the intentions of the projects?

The intentions behind the 10 reviewed papers are multifaceted, encompassing: education, increasing contextual awareness, attracting global tourists, information dissemination and sharing, establishing a Common Data Environment (CDE), public education and promotion, enhancing historical and cultural awareness, maximizing content level, developing Virtual Heritage Learning Environments (VLEs), interdisciplinary information transmission, sharing historical memory with diverse user typologies (from professionals to virtual tourists), public engagement, communication, transforming citizens from passive users to active co-designers, fostering a shared vision of future reuse, and creating an integrated collaborative environment.

These diverse intentions can be broadly categorized into four core aims: education, sharing, engagement, and collaboration, with the overarching goal being the effective transmission of information. The identified target audiences can be segmented into experts, tourists, and students. Specifically, these projects cater to the management needs of experts, facilitate engagement for tourists, and support the study of architecture and history for students.

It is worth noting that N7 proposed a principle of duality, fusing HBIM and gamification. This principle aims to address both the management requirements of professionals and the dissemination, amusement, and edutainment needs of tourists. To achieve this, synchronous and asynchronous augmented knowledge are employed: the former for conveying technical knowledge to regulate and organize information, and the latter as an accessible knowledge base for non-technical users.

Based on these observations, three prominent research laboratories are actively engaged in the HBIM-VR-Gam* field. The first is the Virtual Building Lab at the Technological University of Dublin (TUD), where HBIM proponent Murphy leads work with a primary focus on education. The second is the Carleton Immersive Media Studio (CIMS) at Carleton University, which emphasizes public education and promotion. The third is GICARUS at Politecnico di Milano, which supports both educational and cultural engagement, making its work accessible to both expert users and the general public. These three research groups collectively demonstrate continuity within this field and actively pursue collaborative efforts.

4.5 Q5: How effective are the projects?

Prior to 2025, many proposals and case studies in this domain briefly alluded to benefits such as sharing, education, immersion, and interaction. However, these purported advantages were largely not empirically verified. A notable shift occurred in 2025, with both reviewed papers (N9 and N10) beginning to prioritize the assessment of project effectiveness, indicating a gradual transition towards an empirical phase in research.

In N9, several techniques were referenced for assessing interaction levels, including direct observation, surveys and interviews, data analysis, and usability testing. Despite this, the paper did not report real user testing, participant feedback, or an empirical evaluation of system effectiveness.

In contrast, N10 conducted a series of qualitative and quantitative verifications. The user experience of 34 participants was assessed, with the results indicating that 25 out of 34 users (73.5%) felt comfortable using the VR environment. Furthermore, half of the users (50%) believed that VR added value to the process of democratic participation.

4.6 Q6: What further directions are proposed?

All these papers proposed diverse future directions, which reflect both project-specific improvements and broader developmental trends in the field.

Several studies focus on advancing their respective case studies by refining technical frameworks and enhancing user engagement mechanisms. For instance, N1 aims to develop a web-based HBIM platform accessible via desktop computers, laptops, and handheld devices, enabling individual and group-based student learning. N2 proposes a holistic pipeline combining HBIM, GIS, and immersive VR/AR (AVR) to improve contextual awareness and support interactive tourism and educational experiences. N4 intends to define the direction of the virtual visitor's gaze, potentially controlled by future

narratives. N5 seeks to enrich the storytelling of historical churches by incorporating additional historical records and multimedia content, while also exploring new hardware and software solutions. Finally, N10 outlines an ambitious expansion of its prototype into a web-based platform via the WebXR Device API, aiming to significantly enhance accessibility.

In parallel, several papers expand the discussion toward broader industry-level innovations and future research agendas. N2 further suggests establishing digital libraries of 3D architectural elements to support research, restoration, and gaming/education applications, concurrently offering predictive maintenance solutions for historical structures. N3 highlights the significant challenge of generative modeling for VR projects, with a particular emphasis on developing robust character animation pipelines, including skeletal meshes, player controllers, blueprints, and gamemode configurations. N6 proposes developing Virtual Learning Environment (VLE) design frameworks grounded in Heritage LOs. N7 emphasizes enhancing interoperability with social networks, alongside the introduction of new professional roles such as the "BIM Gamer" to optimize data integration between BIM models and game engines. N8 hopes to explore alternative interaction modalities by incorporating advanced game mechanics. N9 stresses the importance of expanding audiences to include younger and more diverse user groups, alongside future studies addressing user behavior and interface personalization to optimize engagement. N10 advocates for applying these techniques in the restoration sector, where interventions can be performed directly on 3D virtual models derived from ABIM (Archaeological Building Information Modeling), without affecting the physical structures. The authors also anticipate extensive growth in the application of gamification and the metaverse to engage audiences in innovative and educational ways. Specifically, interactive narrative, educational role-playing, and gamification systems with incentives are encouraged as effective strategies. Furthermore, the integration of advanced technologies such as the metaverse, AI, blockchain, and principles of sustainability are identified as future potentials. In conclusion, the future trend is an enhanced sharing, open, interactive, educational, and immersive HBIM-based VR environment. Additionally, advanced techniques should always be incorporated into the field to enhance the multiple experience of various users.

5. Conclusion

The use of VR in HBIM has been explored for several years, primarily in the context of virtual tours. This paper expands on that foundation by examining the potential of serious games (SGs) and gamification within HBIM-based VR environments. A bibliometric analysis reveals that while HBIM-VR integration has attracted considerable scholarly attention, research on SGs and gamification remains limited.

In order to assess the current state of research, targeted searches were conducted in the Scopus and Web of Science (WoS) databases. The query "HBIM AND Virtual Reality" returned 107 unique records after duplicate removal, whereas "HBIM AND Gam*" yielded only 26. This disparity suggests a stronger focus on visualization than on interactivity or engagement, possibly due to the increasing accessibility of VR technologies.

A review of 10 key publications helped map the existing research landscape and informed the following future directions:

- Establish standardized levels of information and interactivity, or at least align them with specific user groups.
- Expand the study and application of game elements, mechanics, and design to fully harness the potential of HBIM-based VR.
- Incorporate community engagement into storytelling strategies and address the issue of cultural narrative ownership within design frameworks.
- Prioritize empirical validation of gamified virtual heritage experiences, moving beyond exploratory phases toward rigorous testing and assessment.

As virtual heritage continues to evolve, the integration of meaningful interaction, community voices, and playful engagement will be essential to shaping immersive experiences that not only preserve the past but actively involve users in its reinterpretation.

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