Implementing VR Techniques for identifying the Authenticity Levels of a Monument

Nefeli Tentoma[1], Andreas Georgopoulos[2], Aziliz Vandesande[1]

[1] Faculty of Engineering Science, Master in Conservation of Monuments and Sites, KU Leuven, Belgium – nefelitentom@gmail.com, aziliz.vandesande@kuleuven.be
[2] School of Rural, Surveying and Geoinformatics Engineering, National Technical University of Athens, Greece - drag@cental.ntua.gr

Keywords: Authenticity, Interpretation, Virtual Reconstructions, Digital Heritage, Virtual Reality, Heritage Presentation.

Abstract

This paper presents a methodology for the virtual reconstruction of an archaeological site through the application of contemporary digital technologies. The research focuses on the systematic identification, evaluation, and representation of authenticity in virtual archaeological reconstructions, aiming to produce models that are scientifically founded and visually informative, while minimizing speculative or purely aesthetic interventions. Authenticity is critically examined as a theoretical construct to establish the conceptual framework of the study, with particular emphasis on transparency and user-oriented interpretative clarity as key criteria for its preservation in digital environments. The main contribution of this research is a workflow for evidence-based virtual reconstructions derived from archaeological data, bibliographic sources and historical documentation, by means of a classification of reconstruction according to distinct levels of authenticity. These levels are explicitly communicated through a Virtual Reality (VR) application using a structured colour-coding system linked to the underlying evidential sources. The development pipeline of the VR application is described in detail, enabling immersive, interactive exploration of the reconstructed site while maintaining a clear correspondence between visual representation and source reliability. The resulting system is evaluated in terms of methodological reliability, interpretative transparency, and usability, and directions for future enhancements and refinements of the VR application are discussed.

1. Introduction

Advances in new technologies and digital tools have opened up alternative approaches to the conservation, preservation, and protection of cultural heritage. Digital visualization and the geometric documentation of archaeological remains, enables reconstructing the envisioned initial state of heritage sites in a virtual way, without causing any physical alteration or damage to the surviving structures. In addition, the introduction of Extended Reality (XR) technologies has greatly enhanced the ways in which cultural heritage can be presented and promoted. These innovative tools provide immersive experiences that not only enable the digital reinstatement of the past but also foster a meaningful virtual connection between users and historical contexts, allowing them to engage with heritage in ways that were previously impossible.

The reconstruction of archaeological remains, whether physical or virtual, is inherently tied to issues concerning authenticity. The advent of digital and XR technologies has introduced new challenges in defining and communicating authenticity, particularly in ensuring that reconstructions reflect scientifically grounded interpretations of the past rather than purely speculative or imaginative visions. The great impact of authenticity in virtual reconstructions is emphasized in international standards and guidelines, which highlight its critical role in the accurate, responsible, and transparent presentation of cultural heritage.

Through this research, various insights and approaches will be presented regarding the perception of authenticity. The primary objective is to investigate the factors that ensure the preservation of authenticity in the virtual reconstructions of archaeological remains, in order to create visually informative representations and not necessarily visually aesthetic ones.

After the formation of the theoretical framework, the findings will be applied to a specific case study of an archaeological site - the Library of Pantainos in Athens, Greece – which will be digitally documented and virtually reconstructed. The virtual reconstruction will have a dual presentation: one focusing on the original materials and one indicating the Levels of Authenticity through colour codes. The final result will be integrated in a VR application, where the user will be able to explore the virtual site as if they were in the actual physical site.

2. Authenticity in Virtual Reconstructions of Archaeological Remains

Authenticity has long been a core element of cultural heritage, first formally emphasized in the 1964 Venice Charter, the first “reference document” (Jokilehto, 1998) shaping international conservation practices and still influencing preservation policies worldwide. With the onset of the digital era, new challenges would emerge from the alternative contemporary means of presentation and interpretation of cultural heritage. The vast implementation of digital replicas and virtual reconstructions of archeological remains would raise concerns about their authenticity. Thus, traditional conservation concepts had to be reinterpreted for digital heritage, prompting the creation of new guidelines.

The first major step occurred in 2003 with the Charter on the Preservation of the Digital Heritage, which was later complemented by more targeted frameworks, including the Ename Charter on the Interpretation and Presentation of Cultural Sites (2008), the London Charter for the Computer-based Visualization of Cultural Heritage (2009), the FAIR Data Principles (2016), the Seville Principles for Virtual Archaeology (2017) and the CARE Principles for Indigenous Data Governance (2018).

These documents reveal a “dynamic relationship” between the original physical object and its digital counterparts. Nevertheless, the primary concern in terms of authenticity is not whether these digital replicas are “an original or merely a copy?” but whether they are “well or badly reproduced?”, referring to sufficient accuracy and transparency (Di Franco et al., 2018). According to the London Charter, authenticity in digital heritage depends on intellectual transparency, clear documentation of reasoning and transformations, and the disclosure of data used. The Seville Principles reinforce this, dedicating Principle 4 to defining “Authenticity” through distinguishing reality from speculation and clarifying accuracy levels. Principle 7, on “Scientific Transparency,” further highlights the need to make documentation practices publicly accessible (Seville Principles, 2017).

Although international documents provide a foundation for indicating Levels of Authenticity in virtual reconstructions, their guidelines remain broad and lack strict rules or standards for field practitioners to follow (Lopez, 2018). This highlights the need for a unified, regulated approach to representing and assessing authenticity in virtual reconstructions of archaeological remains. Authenticity and scientific transparency are essential for both physical and digital reconstructions, suggesting that some principles from guidelines for physical reconstruction could be adapted to establish specialized standards for virtual applications (Lopez, 2018). Across most international charters and frameworks, a consistent conclusion emerges: authenticity is closely tied to heritage values, which are in turn grounded in the reliability of information sources. Credible sources enable a clearer understanding of heritage values, thereby guiding accurate assessments of authenticity (Denyer, 2011).

Furthermore, presenting digital heritage to the public involves ensuring source transparency without producing a monotonous or overly academic outcome. It is crucial to foster a connection between visitors and digital heritage through immersive experiences that evoke emotions. Such engagement should not rely solely on visual effects or aesthetic appeal (He et al., 2017), nor should it create an “idyllic image of the past,” as denoted by the Seville Principles (ICOMOS, 2017, Principle 5.2). The ultimate aim of virtual reconstructions of archaeological sites is to resonate with visitors’ own experiences, allowing them to appreciate both the historical accuracy and the social significance of the monument (Callebaut, 2004). This perspective reflects Freeman Tilden’s foundational principle from 1957: “Through interpretation, understanding. Through understanding, appreciation. Through appreciation, protection” (Callebaut, 2004).

Therefore, a virtual reconstruction of an archaeological site can be characterized as authentic if it complies with two main objectives:

1. Ensure intellectual transparency of the underlying reconstruction process, by indicating the Level of Authenticity and consequently the information sources, their subsequent interpretation and included hypotheses.

2. Enhance user experience by offering an experience tailored to the virtual reconstruction’s target group, in order to accomplish a connection with the users, stimulate feelings and avoid an overly academic outcome.

Finally, the question arises: can a digital replica be considered as authentic as the original physical monument? While digital heritage and virtual reconstructions serve to preserve and protect the original site, they lack its uniqueness. As Petzet (1999) notes, “no matter how faithful in form, material, and scale, a replica is always a new object and merely a likeness of the original with its irreplaceable historical and artistic dimension.” Consequently, a virtual replica is separated from the original location and context (Brumman, 2017) and cannot substitute for the authentic monument.

3. Extended Reality Tools for the Presentation of Cultural Heritage

The recent advancements in XR technology, together with its ability to provide both informative and entertaining experiences, thus ensuring an authentic outcome, establish it as an ideal tool for presenting cultural heritage to the public. XR applications stimulate users’ senses in a “natural and vivid way” (Innocente et al., 2023) and enhance inclusivity and accessibility (Bekele et al., 2018), contributing to their widespread adoption by museums and heritage institutions worldwide (Innocente et al., 2023).

Over time, a wide variety of XR applications for virtual heritage have been developed, each designed to serve distinct purposes and to highlight specific aspects of cultural heritage. Depending on the nature of the application, appropriate tools from augmented reality (AR), virtual reality (VR), and mixed reality (MR) are employed. To better understand the usability and benefits of each tool, cultural heritage XR applications can be categorized by their objective into the following groups:

- Education
- Exhibition Enhancement
- Exploration
- Reconstruction
- Virtual Museums
- Serious Games

This classification was derived from a review of XR applications for cultural heritage conducted within the scope of this study and reflects the predominant application types identified in the literature. Specifically, examples oriented toward education include the “Bramante I-Book” AR application developed by Clini et al. (2017) and the “Sutton House Stories” MR application (Dima & Maples, 2021). In terms of exhibition enhancement, a representative example is the immersive experience offered by the Museo Archeologico Virtuale (MAV) in Ercolano, Italy (MAV–Fondazione C.I.V.E.S., 2024). Applications focused on exploration include the AR project “Revealing Flashlight” (Ridel et al., 2014).

Reconstruction-oriented applications are exemplified by the “ArchaeoFano” project (Quattrini et al., 2016), while “Timeless Museum” serves as a notable example of a virtual museum (Aiello et al., 2019). Finally, the game “Discovering the Stoa of Attalos”, developed in 2016, represents the category of serious games applied to cultural heritage (Georgopoulos et al., 2017).

It should be noted that these categories are not mutually exclusive, as a single application may serve multiple purposes. Consequently, XR applications in the cultural heritage domain often integrate or combine elements from several categories. This review facilitated the identification of suitable XR tools, with a particular focus on the virtual reconstruction of monuments.

4. Case Study: The Library of Pantainos in Athens, Greece

To illustrate the theoretical framework of this research, a case study was selected focusing on archaeological architectural heritage and their virtual reconstructions. Accordingly, the

https://doi.org/10.5194/isprs-archives-XLVIII-2-W12-2026-471-2026 | © Author(s) 2026. CC BY 4.0 License.

chosen site is the Library of Pantainos, a Roman edifice, located in the Ancient Agora of Athens, Greece. The specific building was originally constructed around the 2nd century A.D. (Travlos, 2005), when Athens was under the rule of Romans, along with other cultural and educational institutions (Camp II, 2004).

The principal spaces of the Library comprised the Main Hall, which housed the ermaria containing the scrolls, and the central courtyard with its peristyle (Figure 1). The Main Hall was connected to the courtyard by an opening framed by a colonnade. Together, these two spaces constituted the core of the Library and were enclosed by three stoas (στοά: a freestanding colonnade or covered walkway; Encyclopædia Britannica, 2024). Specifically, these included the West Stoa facing the Panathenaic Way, the Northwest Stoa opposite the Stoa of Attalos, and the North Stoa running along the street leading to the Roman Agora. The stoas were lined with Ionic columns along their entire length and provided access to multiple rooms situated toward the central area of the Library (Camp II, 2013).

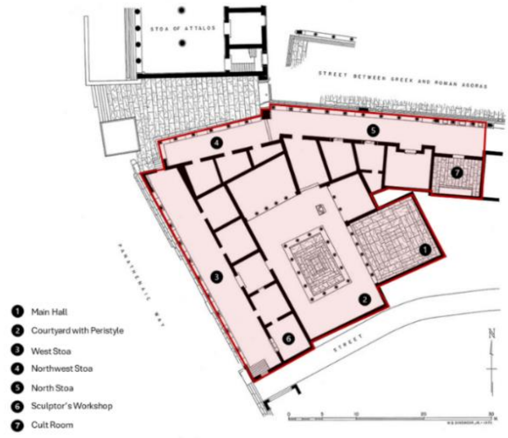

Figure 1: Reconstructed Plan of the Library of Pantainos (indicated in red) © Dinsmoor, 1975 (edited by Authors).

The Library of Pantainos survives today in a dilapidated condition. Although traces of the structure remain visible in their original locations, several architectural elements were relocated or incorporated into later buildings. The remains include the foundations of the Main Hall, sections of the courtyard wall foundations, the partially preserved walls of the surrounding rooms, and the north stylobate with a limited number of column bases from the outer stoas. In addition, the stylobate of the West Stoa has been preserved, as it was reused as the foundation for the Late Roman Fortification Wall (Figure 2).

Figure 2: The Library of Pantainos as existing in the present day © Authors, 2024.

5. Virtual Reconstruction of the Library of Pantainos

5.1 Methodology

Virtual reconstructions effectively convey information about a cultural heritage asset while enhancing both its tangible and intangible values. However, they still represent "possible reconstructions" derived from integrating various sources and remain subject to revision as new evidence or discoveries emerge (Pietroni & Ferdani, 2021, p. 8). Furthermore, the formation of multidisciplinary teams is a key factor for creating scientifically accurate virtual reconstructions (Bakaoukas, 2020).

Taking everything into consideration, the proposed workflow for creating a virtual reconstruction is presented below (Figure 3):

1. Digital Geometric Documentation:

As established in Article 16 of the Venice Charter, the "precise documentation" of a monument is the initial step towards comprehending its current state or preservation. This digital replica is identified as the "reality-based model", which is implemented as "spatial reference" and the primary source of the virtual reconstruction (Demetrescu, 2015, p. 3).

2. Collection of Information Sources:

The subsequent step involves historical, archaeological, and iconographic research aimed at gathering metadata related to the site under study. Integrating diverse types of secondary sources enables a comprehensive understanding of the site's development over time and ultimately results in the formation of a structured database.

3. Data Processing and Interpretation:

Both primary and secondary sources are analyzed in order to formulate a hypothesis for the initial state of the site. The inevitable "lacunas" of the reconstructive proposal due to lack of information are addressed through comparative investigation of similar case studies (same era, architecture style etc.) or subjective interpretation. On this basis, the initial version of the hypothetical reconstructed configuration is developed (Pietroni & Ferdani, 2021).

4. Creation of the 3D Virtual Reconstruction:

The visual output of the stage of data processing and interpretation is the 3D model of the virtual reconstruction of the site. The specific 3D visualization embodies all the previously collected information sources, therefore, it is characterized as the "source-based model" (Demetrescu, 2015). The first version of the reconstructive hypothesis is virtually modelled and simultaneously assessed, a process that may prompt a reassessment of the previous step or result in the validation of the reconstructed 3D model. This stage of the workflow functions not only as a means of visually conceptualizing the imagined past, but also as a tool for synthesizing and verifying analytical data. (Pietroni & Ferdani, 2021).

5. Depiction of Authenticity:

The transition from a "source-based model" to a "semantic model" is accomplished through underlining the decision-making and interpretation process. It is crucial to ascertain the traceability of the implemented sources and analysis by displaying the Levels of Authenticity (Pietroni & Ferdani, 2021). This phase aligns with the principle of intellectual transparency, identified as a fundamental requirement for virtual reconstructions in the Seville Principles (ICOMOS, 2017).

6. <u>Presentation:</u>

The selected approach for the presentation of the virtual reconstruction is fundamental both for its creation process and for communicating the outcome to the public. With regard to production, the format of the final presentation directly influences the technical specifications of the reconstructed 3D model and, consequently, its workflow (Pietroni & Ferdani, 2021). In particular, cognitive aspects must be tailored to the intended audience while ensuring an experience that is immersive as well as informative.

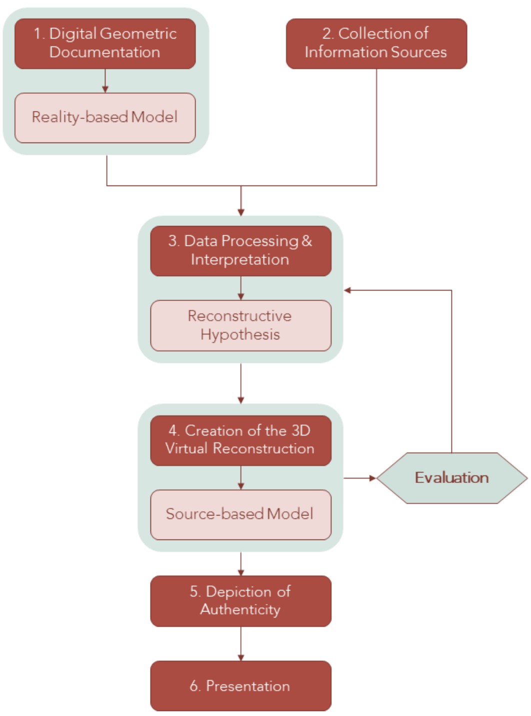

Figure 3: Diagram of the steps for the Virtual Reconstruction Workflow © Authors, 2026.

5.2 Digital Geometric Documentation

As stated in the previous section, the primary step towards the creation of a virtual reconstruction is the "reality-based model" that derives from the site's digital documentation. The location of the Library of Pantainos, however, had been occupied by several structures both prior and after the presence of the Library. Thus, it was eventually decided to document the whole archaeological site related to the Library, which corresponds approximately to 3350 sq. m.

To achieve optimal results in both accuracy and visualization for an archaeological site of this scale, a comprehensive documentation strategy was adopted. The methods employed included geodetic measurements, aerial photogrammetry, and terrestrial laser scanning. Given the relatively low height of the ruins, terrestrial close-range photogrammetry was not deemed necessary for the digital geometric documentation. Data acquisition was carried out in two phases during the summer of 2023 (Figure 4).

Upon the completion of the necessary field work and measurements, the collected datasets would be processed, with the aim of creating a geometrically precise, textured, 3D visual replica of the site of the Library of Pantainos. Initially, two separate 3D point clouds were generated, one from the laser scans and another from the digital images. These point clouds were subsequently merged to create the final digital surface model, while the texture was derived from the aerial photography. It is noteworthy that certain decisions during this process were guided by the intention to integrate the resulting model into an Extended Reality application. Namely, the mesh of the final 3D model was significantly decimated, reducing its triangle count by 50%.

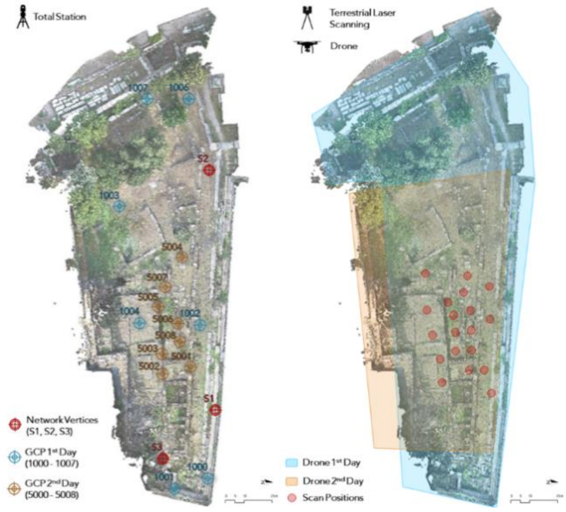

Figure 4: Positions of Control Network Vertices and Targets measured with Total Station (left) and Areas Documented with Drone & Scan Positions (right) © Authors, 2026.

5.3 Reviving a selected part of the Library

In the development of the "source-based model," the virtual reconstruction focused on specific components of the Library's architecture, namely the Main Hall and the adjoining courtyard with its peristyle. Two key parameters of the reconstruction process were the reference date and the intended target audience, defined in this case as 100 A.D. and a combined audience of the general public and field experts, respectively.

A bibliographic review was conducted to gather information sources related to the architectural elements selected for reconstruction. The main source was the digital archive of the American School of Classical Studies at Athens (ASCSA), the institution responsible for the excavation of the Library of Pantainos. Additional scholarly publications were consulted to provide comparative insights into the architectural typology of Roman libraries from the same period. The collected visual and textual data were systematically organized using a "Table of Sources," inspired by the "metafile" tool, which served as a record of the secondary information sources (Boeykens et al., 2018).

The subsequent phase involved the integration, processing, and interpretation of both primary and secondary sources in order to formulate a reconstructive hypothesis. This hypothesis was then visualized through a 3D modeling workflow, resulting in the virtual reconstruction of the selected parts of the Library (Figure 5). Considering the 3D modeling process, the level of detail (LoD) adopted in this case corresponds to LoD 100, representing a conceptual and abstract model characterized by basic geometry and the absence of architectural detail. This output constitutes the initial version of the virtual 3D reconstruction and is intended to be evaluated and refined through comprehensive scholarly assessment and the incorporation of additional archaeological evidence.

Figure 5: The Virtual Reconstruction of the Library of Pantainos (software 3DS Max) © Authors, 2026.

5.4 Visualizing Authenticity in the Virtually Reconstructed Model

To ensure the intellectual transparency of the virtual reconstruction, three key aspects of digital consistency were considered: 1) Shape (dimensions and spatial position), 2) Material (building/manufacturing systems) and 3) Appearance (surface features) (Apollonio, 2015). Moreover, the primary aim of the virtual model was to function as a "Didactic Model," prioritizing the explicit communication of source material, degrees of uncertainty, and existing knowledge gaps, rather than as an "Atmospheric Model" intended to enhance realism and create an "illusion of completeness" (Grellert & Haas, 2016).

In light of these considerations, two models with distinct textures were developed. The first model would convey the "Authenticity of Material" by representing the surface materials of the various virtual architectural elements comprising the structure. The second model would represent the "Authenticity of Geometry and Level of Evidence" through the use of a colour scale, assigning a semantic colour to each reconstructed component.

5.4.1. Authenticity of Material

For the model representing the "Authenticity of Material", both primary and secondary sources were consulted to determine the appropriate textures. Texturing constitutes a critical stage of the reconstruction process and therefore requires careful consideration. Photorealistic textures were employed solely for objects depicted in actual photographs. On the contrary, for disappeared objects, textures would evoke the material in a more generic way (De Fuentes et al., 2010).

Accordingly, this model aims to convey the materials from which the original architectural elements were constructed and should not be interpreted as a fully realistic visualization of the reconstruction. Instead, it is intended to support transparency, enabling both general audiences, who may value aesthetic clarity, and scholars, who seek analytical insight, to understand "why each part of the model has been represented in the way it is" (De Fuentes et al., 2010).

5.4.2. Authenticity of Geometry and Level of Evidence

The model illustrating the "Authenticity of Geometry and Levels of Evidence" was created based on the interpretative decisions and source types employed during the 3D modelling process. To communicate this information, the Graphic Scale of Historic–Archaeological Evidence was adopted. In this scale, each level of evidence is represented by a distinct colour, with the degree of reliability expressed through a gradation of hues: warmer tones indicate higher levels of certainty, while cooler tones denote lower levels of reliability (Cáceres-Criado et al., 2022).

The scale was originally introduced in 2011 by Patrick Clifford, Jan Kostenec, and Albrecht Berger and comprised ten levels of evidence. Subsequent adaptations and refinements were proposed by Aparicio Resco and Figueiredo in 2016, Ortiz-Cordero, León Pastor, and Hidalgo Fernández in 2017 and more recently by Cáceres-Criado, García-Molina, Mesas-Carrascosa, and Triviño-Tarradas in 2023.

This study introduced a revised version of the graphic scale, greatly influenced by the proposal of Ortiz-Cordero, León Pastor, and Hidalgo Fernández, with 8 levels of evidence. Sources were classified in 4 categories: Existing in Situ, Archaeological Reports, Analogy based on Similar Structures and Estimation. Afterwards, each category was divided into subcategories with different degrees of accuracy. The subcategories were represented using varying tones of the respective category's hue, with darker tones signifying greater accuracy and lighter tones signifying lesser accuracy. A supplementary colour scale was employed for indicating combined sources (Figure 6).

Level of Evidence	Category	Subcategory	Color	Supplementary Color Scale	
Level 1	Existing in situ	Existing in situ		Level 1.4.	
Level 2		Existing in situ & Relocated		Level 3.4.	
Level 3		Based on Similar Existing Parts of the Same Structure		Level 3.5.	
Level 4	Archaeological Reports	Documentation		Level 3.5.8.	
Level 5		Hypothesis		Level 2.5.6.	
Level 6	Analogy	Analogy to structures of the same era / architectural style / function		Level 3.5.6.	
Level 7		Analogy to structures of the same era / architectural style / function & estimated geometry		Level 5.7	
Level 8	Estimation	Estimated Geometry		Level 7.8.	
				Level 3.6.	

Figure 6: The proposed Graphic Scale of the Level of Evidence with its Supplementary Colour Scale ©Authors, 2026.

6. Exploring the Library of Pantainos through Virtual Reality

The implementation of XR technology has highlighted its potential to provide alternative means of virtually accessing heritage sites while significantly enhancing visitor engagement (Spallone et al., 2021). Moreover, XR applications foster a more objective approach to cultural heritage by enabling "360° holistic visualizations and multiple levels of perception" (Galeazzi, 2018, p. 269). They thus enable the transmission of multiple "layers of meanings" (Morcillo et al., 2017), supporting their authenticity.

For the presentation of the results of the virtual reconstruction of the selected parts of the Library of Pantainos, the development of a VR application was selected. Although outdoor AR applications are commonly employed for reconstruction purposes, this approach was deemed unsuitable due to limited accessibility to the site. Consequently, the VR application was designed to be experienced on a desktop computer, using a keyboard and mouse for navigation and interaction. This configuration was chosen in view of the widespread availability of such equipment, making the application usable by a broad audience.

The VR application was developed in Unreal Engine, chosen for its visual programming capabilities through Blueprints. It combines the "reality-based model" of the site as documented, overlaid with the “source-based model” representing the virtual reconstruction of the Main Hall and the Courtyard with its Peristyle. Users can navigate the digital environment in first-person view and switch between the “Authenticity of Material” and the “Authenticity of Geometry and Level of Evidence” models (Figure 7).

Accordingly, the primary objective was to enable virtual access to the archaeological site from anywhere in the world while illustrating the probable appearance of the selected parts of the library in 100 A.D. That was accomplished by presenting both their original materials and the interpretative process underlying their geometric reconstruction, thereby ensuring intellectual transparency.

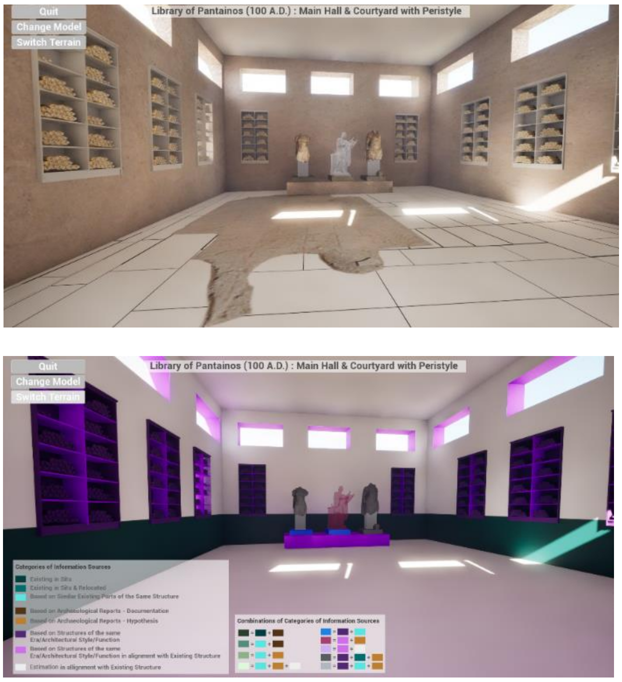

Figure 7: View of the interior of the Main Hall during gameplay mode, changing between “Authenticity of Material” (up) and “Authenticity of Geometry & LoE” (down) (software Unreal Engine) © Authors, 2026.

7. Concluding Remarks

Archaeological remains are prioritized for preservation due to their fragility and their status as the sole surviving evidence of the ancient world; however, their reconstruction as a conservation method remains contested, particularly with regard to authenticity.

Authenticity remains a central concern in virtual reconstructions of archaeological remains. Although international digital heritage principles lack explicit guidelines on its representation, they emphasize intellectual integrity, transparency of evidence, and the communication of uncertainty. Accordingly, authenticity in virtual reconstructions depends on two key factors: 1) ensuring intellectual transparency through the clear presentation of sources, interpretations, and levels of authenticity, and 2) designing user-centered experiences that promote engagement without undermining scholarly rigor.

While tools can help identify authenticity in virtual reconstructions of archaeological sites, authenticity itself remains inherently subjective and shaped by individual values. It is dynamic, differing between people and evolving alongside each person’s changing beliefs throughout life. Consequently, the pursuit of identifying authenticity is an eternal and perpetual endeavour. Its notion was defined in the past, is experienced and revised in the present and will be readapted in the future.

7.1 Future Work

Overall, several aspects of this research require further evaluation and review. To begin with, the virtual reconstruction of the case study represents an initial step towards a reconstructive hypothesis, and the involvement of a multidisciplinary team with diverse backgrounds could provide additional insights and contribute to a more scientifically robust reconstruction.

Subsequently, a revised Graphic Scale of the Level of Historic–Archaeological Evidence was proposed, featuring eight levels of evidence across four categories: existing in situ, archaeological reports, analogies from similar structures, and estimations. A colour palette of green-blue, brown, purple, and white was implemented. Moreover, a supplementary scale was added to indicate combined sources. While this scale effectively depicts the Level of Authenticity for the Library of Pantainos, its broader applicability to other virtual reconstructions of archaeological remains needs to be tested.

Finally, the VR application was designed to provide content that is both engaging for the public and informative for the scientific community. To assess whether this goal has been achieved, a User Study should be conducted with participants from the target audience, using questionnaires and interviews. Considering the application itself, there are multiple possible advancements.

From the technical point of view, some suggestions would be integrating head-mounted displays and interactive hand-held devices for creating a fully immersive VR experience. Furthermore, the application could be converted to Web VR, promoting accessibility, inclusivity and multivocality.

Focusing on the scenario of the application, developing an HBIM in the form of multimedia pop-up windows for presenting the corresponding sources for selected architectural elements would be the next step towards intellectual transparency. What is more, the integration of alternative versions with equivalent "scientific validity," as outlined in the Seville Principles (ICOMOS, 2017, Principle 4.1), or even a 4D VR application of the different building phases, should be considered.

References

Aiello, D., Fai, S. & Santagati, C. (2019). Virtual Museums as a Means for Promotion and Enhancement of Cultural Heritage. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. 27th CIPA International Symposium “Documenting the past for a better future”, 1–5 September 2019, Ávila, Spain. Vol. XLII-2/W15. pp. 33 – 40. https://doi.org/10.5194/isprs-archives-XLII-2-W15-33-2019

Aparicio, P. & Figueiredo, C. (2016). EL GRADO DE EVIDENCIA HISTÓRICO-ARQUEOLÓGICA DE LAS RECONSTRUCCIONES VIRTUALES: HACIA UNA ESCALA DE REPRESENTACIÓN GRÁFICA (The degree of Hirtorical-Archaeological Evidence of Virtual Reconstructions: Towards a Scale of Graphic Representation, In Spanish). Arqueología y nuevas tecnologías. Revista Otarq. Vol. 1. pp. 235 – 247.

http://revistas.jasarqueologia.es/index.php/otarq/article/view/96/0

Apollonio, F. I. (2015). Classification schemes and model validation of 3D digital reconstruction process. Proceedings of the 20th International Conference on Cultural Heritage and New Technologies 2015 (CHNT 20, 2015), Austria. Museen der Stadt Wien – Stadtarchäologie.

Bakaoukas, A., G. (2020). Virtual Reality Reconstruction Applications Standards for Maps, Artefacts, Archaeological Sites and Monuments. In Liarokapis, F. et al. (eds.) Visual Computing for Cultural Heritage, Springer Series on Cultural Computing. pp. 161 – 176. https://doi.org/10.1007/978-3-030-37191-3_9

Bekele, M. K., Pierdicca, R., Frontoni, E., Malinverni, E. S., & Gain, J. (2018). A Survey of Augmented, Virtual, and Mixed Reality for Cultural Heritage. ACM Journal on Computing and Cultural Heritage. Vol. 11. No. 2. Article 7. https://doi.org/10.1145/3145534

Boeykens, S., Maekelberg, S. & De Jonge, K. (2018). (Re)Creating the past: 10 years of digital historical reconstructions using BIM. International Journal for Digital Art History. Iss. 3. pp. 62 – 85. DOI: 10.11588/dah.2018.3.32544

Brumann, C. (2017). How to be authentic in the UNESCO World Heritage system: Copies, replicas, reconstructions, and renovations in a global conservation arena. Corinna Forberg & Philipp Stockhammer (Eds.) The Transformative Power of the Copy: A Transcultural and Interdisciplinary Approach. Heidelberg: Heidelberg Publishing., 269–287. https://doi.org/10.17885/HEIUP.195.C1640

Cáceres-Criado, I., García-Molina, D.F., Mesas-Carrascosa, FJ. et al. (2022) Graphic representation of the degree of historical-archaeological evidence: the 3D reconstruction of the "Baker's House". Herit Sci 10, 33. https://doi.org/10.1186/s40494-022-00670-0

Callebaut, D. (2004) Introduction to Site Interpretation in Flanders. In Callebaut, D., Killebrew, A., E. & Silberman N., A., (eds.) Interpreting the Past: Presenting Archaeological Sites to the Public. Proceedings of an International Conference on New Approaches and Technologies for Heritage Presentation. Belgium, Brussels 2004. pp. 17 – 20.

Camp II, J. McK. (2004). The Athenian Agora: Excavations in the heart of classical Athens (in Greek). National Bank of Greece Cultural Foundation. ISBN: 960-250-267-3.

Camp II, J. McK. (2013). The Ancient Agora of Athens: A guide for the archaeological site (in Greek). National Bank of Greece Cultural Foundation. ISBN: 978-960-250-575-5.

Clini, P., Frontoni, E., Quattrini, R., Pierdicca, R. & Nespeca, R. (2017). Real/Not Real: Pseudo-Holography and Augmented Reality Applications for Cultural Heritage. In Ippolito, A. & Cigola, M. (eds.) Handbook of Research on Emerging Technologies for Digital Preservation and Information Modeling. Advances in Library and Information Science (ALIS) Book Series. IGI Global. pp. 201 – 227. DOI: 10.4018/978-1-5225-0680-5.ch009.

De Fuentes, A. F., Valle Melón, J. M. V. & Rodríguez Miranda, A. (2010). Model of sources: a proposal for the hierarchy, merging strategy and representation of the information sources in virtual models of historical buildings. In Melero, F., J. & Cano, P. (eds.) Computer Applications and Quantitative Methods in Archeology - CAA'2010. Fusion of Cultures, Granada, Spain.

Demetrescu, E. (2015). Archaeological Stratigraphy as a formal language for virtual reconstruction: Theory and practice. Journal of Archaeological Science. 57. 10.1016/j.jas.2015.02.004.

Denyer, S. (2011). Retrospective Statements of OUV for World Heritage Properties: Authenticity & Integrity. Workshop for the 2nd Cycle of World Heritage Periodic Reporting for Western Europe. Prague 27th May 2011.

Di Franco, P. G., Galeazzi, F. & Vassallo, V. (2018). Introduction: Why authenticity still matters today. In Di Franco, P., G., Galeazzi, F. & Vassallo, V. (eds.) Authenticity and Cultural Heritage in the age of 3D Digital Reproductions. McDonald Institute for Archaeological Research. University of Cambridge. ISBN: 978-1-902937-85-4. pp. 1 – 10.

Encyclopædia Britannica (2024). Stoa. Retrieved April 22, 2024, from https://www.britannica.com/technology/colonnade-architecture

Dima, M. & Maples, H. (2021). Affectual Dramaturgy for Augmented Reality Immersive Heritage Performance. Body, Space & Technology, Vol. 20. No. 1. pp. 25–36. DOI: https://doi.org/10.16995/bst.368

Galeazzi, F. (2018). 3-D Virtual Replicas and Simulations of the Past: "Real" or "Fake" Representations? Current Anthropology. Vol. 59. No. 3. https://doi.org/10.1086/697489

Georgopoulos, A., Kontogianni, G., Koutsaftis, C. & Skamatzari, M. (2017). Serious Games at the Service of Cultural Heritage and Tourism. In Katsoni, V., Upadhya, A., Stratigea, A. (eds.) Tourism, Culture and Heritage in a Smart Economy. Springer Proceedings in Business and Economics. Springer, Cham. pp. 3 – 17. https://doi.org/10.1007/978-3-319-47732-9_1

Grellert, M., & Haas, F. (2016). Sharpness Versus Uncertainty in 'Complete Models': Virtual Reconstructions of the Dresden Castle in 1678. In Hoppe, S., & Breitling, S. (eds.) Virtual Palaces, Part II: Lost Palaces and their Afterlife. Virtual Reconstruction between Science and Media. pp. 119 – 48. PALATIUM e-Publications, 3. Heidelberg: arthistoricum.net.

He, Y., Ma, Y. H., & Zhang, X. R. (2017). "Digital Heritage" Theory and Innovative Practice. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLII-2/W5, 26th International CIPA Symposium 2017, Ottawa, Canada. DOI: 10.5194/isprs-archives-XLII-2-W5-335-2017

Innocente, C., Ulrich, L., Moos, S. & Vezzetti, E. (2023). A framework study on the use of immersive XR technologies in the cultural heritage domain. Journal of Cultural Heritage. Elsevier Masson SAS. Vol. 62. pp. 268 – 284. https://doi.org/10.1016/j.culher.2023.06.001

Jokilehto, J. (1998b). The context of the Venice Charter (1964). Conservation and Management of Archaeological Sites. Vol. 2. No. 4. pp. 229–233. *https://doi.org/10.1179/135050398793138762*

London Charter. (2009) The London Charter for the Computer-based Visualization of Cultural Heritage. Retrieved June 3, 2024, from https://londoncharter.org/index.html

Lopez, L. V. (2018). Authenticity and Realism: Virtual vs Physical restoration. In Di Franco, P. G., Galeazzi, F. & Vassallo, V. (eds.) Authenticity and Cultural Heritage in the age of 3D Digital Reproductions. McDonald Institute for Archaeological Research. University of Cambridge. ISBN: 978-1-902937-85-4. pp. 25 – 34.

MAV - Fondazione C.I.V.E.S. (2024). Museo Archaeologico Virtuale. Technology at the service of culture. Retrieved July 26, 2024, from https://www.museomav.it/?lang=en

Morcillo, J. M., Schaaf, F., Schneider, R. H. & Robertson-von Trotha, C. Y. (2017). Authenticity through VR-based Documentation of Cultural Heritage. A Theoretical Approach based on Conservation and Documentation Practices. Virtual Archaeology Review, Vol. 8. No. 16. pp. 35-43. http://dx.doi.org/10.4995/var.2017.5932

Ortiz-Cordero, R., Pastor, E. L. & Fernández, R. E. H. (2017). Proposal for the improvement and modification in the scale of evidence for virtual reconstruction of the cultural heritage: A first approach in the mosque-cathedral and the fluvial landscape of Cordoba. Journal of Cultural Heritage. Elsevier Masson SAS. Vol. 30. pp. 10 – 15. https://doi.org/10.1016/j.culher.2017.10.006

Petzet, M. (1999). Principles of monument conservation, Lipp GmbH Graphische Betriebe, Munich. ISBN 3-87490-668

Pietroni, E. & Ferdani, D. (2021). Virtual Restoration and Virtual Reconstruction in Cultural Heritage: Terminology, Methodologies, Visual Representation Techniques and Cognitive Models. MDPI Information, 12, 167. https://doi.org/10.3390/info12040167

Quattrini, R., Pierdicca, R., Frontoni, E. & Barcaglioni, R. (2016). Virtual Reconstruction of Lost Architectures: From the TLS Survey to AR Visualization. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. XXIII ISPRS Congress, 12–19 July 2016, Prague, Czech Republic. Vol. XLI-B5. pp. 383 – 390. DOI: 10.5194/isprsarchives-XLI-B5-383-2016.

Ridel, B., Reuter, P., Laviole, J., Mellado, N., Couture, N. & Granier, X. (2014). The Revealing Flashlight: Interactive spatial augmented reality for detail exploration of cultural heritage artifacts. ACM JOCCH 7. Vol. 2. No. 1. pp. 1- 17. DOI: http://dx.doi.org/10.1145/0000000.0000000

Spallone, R., Lamberti, F., Guglielminotti Trivel, M., Ronco, F. & Tamantini, S. (2021). 3D Reconstruction and Presentation of Cultural Heritage: AR and VR Experiences at the Museo d'Arte Orientale di Torino. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. 28th CIPA Symposium "Great Learning & Digital Emotion", 28 August–1 September 2021, Beijing, China. Vol. XLVI-M-1-2021. pp. 697 – 704. https://doi.org/10.5194/isprs-archives-XLVI-M-1-2021-697-2021

The Seville Principles. (2017) International principles of virtual archaeology. (2017). Retrieved from http://sevilleprinciples.com/

Travlos, J., (2005). Urban development of Athens: From prehistoric times to the beginning of the 19th century (in Greek). (3rd ed.). Kapon Editions.