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Augmented Reality-Based Reconstructions in Historical Sites

An Example from Aquincum

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Abstract

The architectural heritage constitutes a vital expression of the cultural and historical continuity of communities. The stratification of historical layers permeates the entire built environment as a complex palimpsest of spatial and material narratives. In favourable circumstances, the physical preservation of historic buildings allows for direct, sensorial engagement with the architectural past. In less fortunate cases, the passage of time has reduced this legacy to fragmentary remains—foundation walls, isolated structural elements, and partial layouts. Lacking specialized knowledge in architectural geometry and historical typologies, most visitors are unable to translate these material traces into coherent spatial understanding, thus limiting their capacity for experiencing architectural space as it once was. By the 2020s, advances in interactive media technologies—particularly in real-time rendering and game engine development—have opened new avenues for architectural-historical reconstruction. These tools allow for immersive, spatially intelligible representations that extend beyond static illustrations and screens, enabling users to engage with reconstructed environments in situ through mobile and augmented reality platforms. These emerging methods enable the experiential presentation of architectural heritage without causing any physical intervention or damage to archaeological sites. They offer new tools to enrich museum pedagogy, enhance social inclusivity, and, consequently, foster greater cultural awareness among the public. In my paper I will demonstrate the theoretical reconstruction of the so called Peristyl House in the ancient roman town of Aquincum, today Budapest, developed as part of an ongoing architectural-historical investigation, along with its implementation as an augmented reality-based 3D model. The discussion addresses key methodological concerns related to the interpretation of fragmentary archaeological data, and reflects on the epistemological limits and potentials of analogy-driven reconstructions within architectural historiography. layouts.

Keywords: Architectural History, Augmented Reality, Aquincum

Introduction

The so-called House No. XXIX—long referred to as the "atrium" or "peristyle" house—is situated in the north-western sector of the civil town of Aquincum. It represents a characteristic and architecturally significant building within the city's industrial quarter. Its importance lies, first, in the fact that it provides a well-defined example of the building type commonly referred to in the scholarly literature as the "long house", a form typical of provincial Roman architecture.

This type is characterised by a layout in which the narrower, street-facing side of the plot opens with workshops or shops. The interior of the plot contains a sequence of residential units, producing the characteristic elongated rectangular plan of the building. The atrium-like spatial arrangement in the residential tract further distinguishes the structure from other known long houses, as the atrium-type domus was not widespread in Pannonia. Between 2004 and 2016, archaeologists from the Aquincum Museum of the Budapest History Museum, under the direction of Dr Orsolya T. Láng, carried out verification excavations on the site. These investigations refined the understanding of the building's construction phases and shed new light on its functional history. They revealed that the complex housed a tanner's workshop over an extended period. The history of research on the building dates back to the late nineteenth century, when Bálint Kuzsinszky excavated its northern part. He identified the structure as a dwelling and documented the atrium-like space, together with its eastern entrance and adjoining hypocaust-heated rooms (Kuzsinszky, 1891). In the subsequent research phase, between 1944 and 1947, János Szilágyi excavated the southern section of the building. Based on the finds recovered there, he interpreted this area as a workshop for wine or oil processing (Szilágyi 1950). During the large-scale conservation programme conducted between 1968 and 1973, Gyula Hajnóczi prepared a theoretical reconstruction of the building and designed its architectural conservation plans. The most recent excavations were again carried out by Orsolya T. Láng. Her investigations established the building's construction phases and integrated them into Aquincum's broader chronological framework. On the basis of new archaeological evidence, she identified the workshop tract as a tannery. My own architectural-historical analysis builds upon these recent findings and adopts this refined periodisation as the starting point for architectural interpretation. In light of the new archaeological evidence, a re-evaluated architectural-historical interpretation of the building is therefore justified. This also includes an innovative mode of presentation designed to meet contemporary museum-educational needs. Accordingly, this study reviews the research history of the building, outlines its construction phases, and explores their 3D visualisation, together with the potential of presenting the monument through augmented reality applications.

Periodisation of House No. XXIX

The reconstruction of the various building phases is fundamentally based on the results of archaeological excavations. Since the city of Aquincum was abandoned relatively early by the Romans (source), the deserted settlement soon fell victim to both natural processes and the stone-quarrying activities of later communities.

In subsequent centuries, the ruins were frequently reused for architectural and representational purposes. A well-known example is King Matthias Corvinus, who had statues and sarcophagi transported to his palace in order to demonstrate his connection with Western cultural traditions (Zsidi 2002).

The surviving remains typically consist of foundation walls and threshold stones. These elements provide the primary archaeological basis for architectural interpretation. They are supplemented by non-architectural finds, which allow archaeologists to reconstruct activities carried out within the building and to distinguish between residential and functional spaces.

Architectural interpretation therefore begins with this evidence, while gaps in the data are addressed through analogies from other excavated sites. The periodisation of Building No. XXIX is based on the excavations and chronological framework established by Orsolya Láng. According to her interpretation, the area initially functioned as a suburban refuse deposit during the first identifiable phase (Láng 2012).
The second phase indicates industrial activity, specifically metalworking. However, due to the depth of the archaeological layer and the high groundwater level, no coherent architectural structures could be identified (Láng 2012). This phase is preliminarily dated to the early to mid-2nd century CE.
The third phase marks the appearance of the first architecturally interpretable structures. Although the northern termination of the building cannot yet be determined, the tract facing the main street already reveals the precursors of the later ground plan. At this stage, the characteristic architectural form of the quarter becomes clearly recognisable. The so-called "long-house" type is defined by industrial and commercial functions along the street frontage, while residential rooms occupy the inner part of the plot. Based on the associated finds, this phase can be dated to the first half or the mid-to-late 2nd century CE (Láng 2012). During the fourth phase, the building was extended approximately three metres to the east, thereby attaining its final width. In the residential tract, an open courtyard-like space replaced the earlier atrium, while post-holes suggest the presence of a simple lean-to roof. The dual residential and industrial function of the building was maintained. However, the nature of the industrial activity changed, and the structure probably continued to operate as a glue-boiling workshop (Láng 2012). On the basis of associated datable finds, this phase can be placed between the Marcomannic Wars and the early 3rd century CE.
In the fifth phase, the southern tract of the building was remodelled into a three-aisled structure. Preliminary field observations suggest that this phase dates to the early or first half of the 3rd century CE (Láng 2012). Significant transformations occurred primarily in the northern, residential part of the building. A more classical atrium was constructed, consisting of a paved space surrounded by a colonnade. At the same time, domestic industrial installations, such as the furnace, were removed.
Access to the building was now provided through a monumental entrance, possibly with a tympanum, featuring a large, wide doorway. This was complemented by a smaller southern side entrance, which also led into the atrium. From the central courtyard, two residential rooms opened to the west, one of which was decorated with frescoes and stucco ornamentation. To the south, additional rooms with terrazzo floors and red-and-black wall paintings were accessible, along with a clay-floored chamber. Beyond these spaces, the workshop tract continued, maintaining the glue-boiling activity attested in earlier periods (Láng 2012).
The associated finds do not allow for precise dating. Nevertheless, this phase can tentatively be assigned to the first half of the 3rd century CE (Láng 2012).

From Archaeological Periodisation to 3D Phase Models

The reconstruction of archaeological plans from two-dimensional projections into three-dimensional models requires appropriate CAD software. The working environment presented in this study is based on Graphisoft Archicad, version 27, together with its specific features and limitations. The DWG survey files provided by the excavation director and the

Aquincum Museum of the Budapest History Museum were imported into Archicad and organised by construction phases on separate layers. This approach enables the creation of an easily manageable and editable layer system through the use of layer combinations. According to the software's internal logic, the individual building components—modelled as 3D BIM elements—are also assigned to dedicated layers. This allows for the creation of additional layer combinations and generally facilitates both the modelling process and subsequent editing or correction. For the purposes of the present study, however, the most important feature is the *Design Options Manager*. This tool allows multiple architectural elements to coexist at identical spatial coordinates within the model. These elements can be switched on or off following a simple logical structure. By assigning separate design options to individual construction phases, a clearly structured and easily manageable sequence of periodised 3D mass models can be generated. Such models are particularly useful for architectural-historical reconstructions. They can also enhance communication between architects, archaeologists, and related disciplines, as has been demonstrated by earlier research (Wang 2007). The phase-based 3D model thus serves as an effective tool for collaboration between archaeology and architecture. A clear and visually coherent model sequence helps to identify and resolve potential misunderstandings or disagreements in architectural interpretation at an early stage of the reconstruction process. In addition, such a model series can assist museums in selecting the construction phase most suitable for potential physical reconstruction. This is especially relevant in relation to existing monument restorations or to the overall character of an open-air museum or archaeological park. From an architectural perspective, the model sequence also enables comparisons between the feasibility and estimated costs of architectural programmes associated with the potential physical reconstruction of individual phases.

Finally, the models offer an immersive, experience-based museum-educational tool for visitors, particularly for younger audiences and children. Users are able to navigate interactively through the construction history of a reconstructed architectural monument, either in a smaller-scale augmented reality model (Chen *et al.* 2009) or in a full-scale AR environment, whether indoors or outdoors (de la Fuente Prieto, Perera and Arroyo 2017).

The resulting model sequence is illustrated in Figure 2. From this point onward, several approaches to 3D representation can be pursued. If the aim is classical 3D visualisation, either static or animated, renderings can be produced directly within the CAD software. The latest versions of such applications generally include integrated rendering engines capable of delivering reasonably high-quality results.

Nevertheless, since these programs are not primarily designed for rendering, they cannot fully compete with software developed specifically for that purpose. Most CAD applications, however, allow the export of 3D files that can be readily imported into programmes offering more advanced texture mapping and rendering capabilities. Should the objective be virtual or augmented reality representation, game engines will be required instead.

Augmented Reality – Based Architectural Reconstruction

The game engine employed in this project is Unreal Engine version 5.4, developed by Epic Games. This software was selected primarily because its Datasmith technology, together with a dedicated plugin—Datasmith Exporter for Archicad—enables direct data exchange with Archicad. In addition, it transfers the visualisation-relevant properties of individual BIM elements (Graphisoft 2025). As a result, the workflow is intuitive and easily comprehensible for architects accustomed to the logic of CAD-based design environments. After the model has been imported, optimisation and texturing can be performed directly

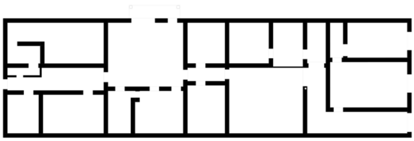

Fig. 1. The reconstructad plan of the House No. XXIX. (András Timár, 2025)

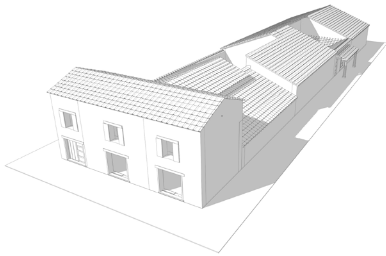

Fig. 2. The final clay model (András Timár, 2025)

within Unreal Engine's own environment, achieving a high level of visual quality. From this stage, several development paths become available. These include, for example, immersive virtual reality applications using optical interfaces. The present study, however, focuses specifically on the use of Unreal Engine's Augmented Reality (AR) Template and its role in the reconstruction process (Epic Games 2025).

Augmented reality applications are typically developed for mobile devices. Their core principle lies in embedding virtual content into the live image captured by the device's camera. The virtual elements respond dynamically to environmental input detected by the camera, such as position, light intensity, and colour temperature.

Since the reconstructed architectural model was imported into Unreal Engine via the Datasmith exporter, and texturing, optimisation, and scaling were completed within this environment, the model can subsequently be referenced in the AR template as an asset. In this context, it functions as a mesh that can be defined as *placeable*. In Unreal Engine terminology, placeables are objects that can be inserted into the AR scene. With regard to hardware, testing was conducted using a Samsung Galaxy Tab S8 Ultra tablet running the Android operating system. Because the AR application operates within an Android environment, the Google ARCore package must be enabled in Unreal Engine. This ensures communication between the device's AR-compatible systems and the game engine. The tablet supports all currently available AR functionalities. Consequently, there are no inherent technical limitations preventing the stable operation of the application (Google 2025).

During testing, however, it became apparent that the application's light management system performed far from optimally. Beyond a basic isotropic illumination, the model failed to respond to changes in ambient lighting conditions. This limitation persisted even under extreme circumstances, such as when the lights were completely switched off in an enclosed space (Fig. 3). Rebuilding and reinstalling the application did not resolve the issue. The next working hypothesis was that the problem originated from the virtual light running

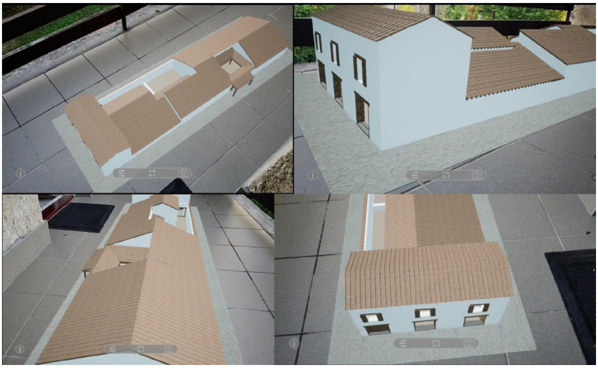

Fig. 3. Screenshots from the running application (András Timár, 2025)

within the game engine's environment. Instead of relying on the pre-defined AR template, I therefore constructed the AR space manually, using the configuration options and logical node connections provided by the software. I linked the *movable Skylight* virtual light source to the light intensity (in lumens) and colour temperature (in Kelvin) detected by the device's camera (Fig 4).

Conclusions

Overall, the research successfully established a workflow capable of transforming the primary input data—namely, the periodised survey drawings from archaeological excavations—into a coherent 3D model. This model can be intuitively constructed within a digital architectural environment according to the identified building phases and their corresponding reconstruction sequences. The resulting models, even when highly detailed and polygon-rich, can be smoothly transferred to software environments specialised in visualisation, or alternatively into game engines, thereby enabling both virtual and augmented reality–based presentations. The game engine employed—*Unreal Engine* version 5.4—proved capable of rendering such complex models continuously and without performance drops at an adequate frame rate. However, within the Android environment, it provides only limited-quality light processing, reducing both realism and user experience. This limitation most likely results from the fact that the engine has not yet implemented the latest functionalities of *Google ARCore*, and thus cannot fully utilise its advanced lighting features. In conclusion, the method outlined in this study has demonstrated its suitability for producing visually engaging augmented reality models that can be applied effectively in both professional and museum-educational contexts. Nevertheless, future work should include testing the proposed workflow within other game engines as well, in order to identify solutions capable of achieving an even more immersive augmented reality experience.

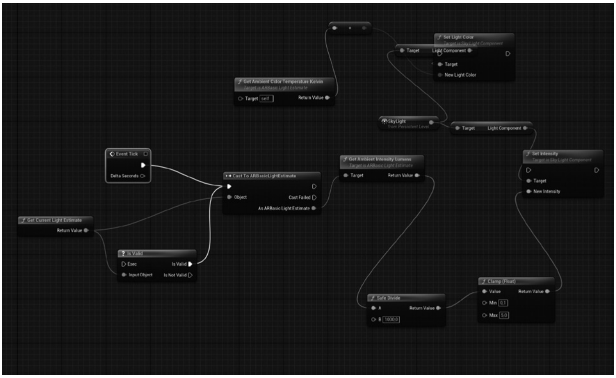

Fig. 4. Unreal Engine node chain for AR lightning (András Timár, 2025)

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