VR tools for unveiling a unique hidden Monument

Anna Papatheodorou[1]; Andreas Georgopoulos[2]; Sevasti Tapeinaki[2]; Vassiliki Laspia[2]; Margarita Skamantzari[2]

[1]University of the Aegean, Rhodes, Greece
anna_papatheodorou@hotmail.com
[2]Laboratory of Photogrammetry, National Technical University of Athens, Greece
drag@central.ntua.gr; sevi@survey.ntua.gr; vas.laspia@gmail.com; mskamantz@central.ntua.gr

Keywords: 3D documentation, VR technology, highlighting Cultural Heritage, digital tools.

Commission II

Abstract

The Macedonian Hellenistic Tomb on Troias Street in Drama, Greece, stands as a significant testament to ancient funerary architecture. It is a unique specimen of Macedonian Tombs, located farthest east of the centre of the Macedonian Kingdom. Recognising the imperative need to preserve and reveal to the public such heritage, a multidisciplinary initiative was undertaken to digitally document and highlight the tomb using contemporary technologies and virtual reality tools. This project employed advanced digital methods, including 3D laser scanning and photogrammetry, to reliably create the 3D model of the tomb's structure and intricate details. A multi-sensor approach was employed to overcome the adverse conditions of the extremely confined space, which is an aspect that makes this implementation particularly interesting. Apart from the standard DSLR full-frame camera and a terrestrial laser scanner, a 360° panoramic camera provided overlapping spherical images of the space and an action camera was employed to image the roof of the tomb in particular, as the distance to the basement roof was less than 50cm. In this paper, the workflow for producing the 3D model is described in detail, assessing the use of a variety of contemporary equipment. Subsequently, the 3D model was used to produce a virtual reality application for enabling the highlighting of this hidden monument to the general public. For that purpose, Unity 3D, a well-known game engine, was employed. This VR application will be made freely available through QR code scanning to prospective virtual visitors by the local Ephorate of Antiquities.

1. Introduction

1.1 Historic notes

The protection, conservation, preservation, documentation, and valorisation of Cultural Heritage and, by extension, of the anthropogenic remains of the past investigated by archaeological research constitute key issues engaging a wide spectrum of scholars. In Greece, which is operating in accordance with the principles and directives of international organisations for the protection of Cultural Heritage, archaeological legislation has been accordingly adapted. More specifically, the Law on the Protection of Antiquities and Cultural Heritage (Greek Law 3028/2002) was enacted in order to improve the pre-existing legislative framework, harmonising earlier approaches with more recent international guidelines (Papapetropoulos, 2006). Regarding antiquities discovered *in situ* within urban environments, the competent advisory council responsible (Central Archaeological Council of the Greek Ministry of Culture) for decisions concerning their fate has four principal options for their protection and management (Voskaki and Biza, 2015).

The first option is the preservation of antiquities *in situ* and above ground, at the location of discovery, through the implementation of appropriate protective and sheltering structures. This approach is commonly adopted when sufficient and suitable space is available, allowing the monument to remain visible and accessible without significantly affecting contemporary urban life. The second option concerns the preservation of antiquities in the basement, whereby the remains are retained within subterranean spaces—often beneath the modern urban fabric—which continues to develop above them, rendering the monument not directly visible or even accessible (Figure 1). The third option involves preservation through reburial, following the completion of all archaeological investigations at the site; in such cases, the monument is protectively covered and remains inaccessible and invisible when no conditions or justifications for public presentation or further scientific research exist. Finally, in rarer cases and as a measure of last resort, monuments may be relocated to alternative locations where adequate space is available for their protection and presentation.

Figure 1: Part of the Ancient Wall of Athens in the basement of a building on Dragatsaniou street. (Voskaki and Biza 2015)

The monument under investigation belongs to the second category and is currently preserved in the basement of a residential building, a practice widely applied during periods of intense urban development and industrialisation in major Greek cities. The city of Drama is in Western Macedonia in Northern Greece (Figure 2), and the tomb is situated in the basement of a block of flats built on Troias street in the 70's (Figure 3).

1.2 Description of the Monument

In spring 1976, during foundation works for the construction of an apartment building on Troias street in Drama, a provincial city located in the northern part of Greece, the homonymous funerary monument was discovered (Samartzidou 1992, Koukouli-Chrysanthaki 1984). In parallel with the construction activities, a systematic archaeological excavation was conducted, and the decision was taken to encapsulate the monument within the basement of the apartment building erected directly above it.

Figure 2: The city of Drama

Figure 3: The access to the Macedonian Tomb on Troias street

The Tomb on Troias Street, also known as the Hellenistic Tomb of Drama, constitutes the only *in situ* accessible monument of the Hellenistic period within the modern city of Drama. It belongs to the category of funerary monuments classified by modern scholarship as Macedonian tombs (Mangoldt 2012), which are generally dated to the period of the dominance of the Macedonian Kingdom (mid. 7th – mid. 2nd century BCE). According to surviving historical sources, the region of Drama was incorporated into the Macedonian Kingdom during the reign of Philip II, father of Alexander III, when the former expanded the kingdom's borders from the Strymon River to the Nestos River (Archibald 1998, Archibald 2008). Until that time, the area was predominantly inhabited by various Thracian tribes; nevertheless, it is well documented that from the Geometric period onward, and already attested in the Homeric epic poems, the indigenous populations had come into contact with Greeks from both mainland and insular Greece (Archibald 1998). Particularly during the period of the Great Colonization (8th–6th centuries BCE), intense activity of Greek settlers is observed along the Thracian coast, bringing them into direct interaction with Thracian tribes and creating favourable conditions for the subsequent expansion of the Macedonian Kingdom (Ilieva 2007). Moreover, Thrace, and by extension the area occupied today by the city of Drama, remained under Macedonian control until the dissolution of the kingdom by the Roman Empire (mid. 2nd century BCE).

From an architectural perspective, the funerary monument exhibits all the characteristic features of a typical Macedonian tomb. A description of such funerary architecture is already attested in antiquity, most notably in Plato, who refers to the final dwelling place of the virtuous (Taylor, 1934). The monument comprises a *dromos*, an antechamber (*prothalamos*), and a burial chamber. The *dromos*, equipped with a short flight of steps, leads to the main entrance of the tomb and is constructed of porous limestone blocks coated with white plaster, preserved today in a fragmentary state. The antechamber is the best-preserved space of the monument; it is likewise built of porous limestone and is covered by a barrel vault. All walls, the floor and the ceiling of the antechamber were originally coated with white plaster decorated with wall paintings. A small entrance with a narrow passage connects the antechamber to the soil-cut burial chamber, which contains three built sarcophagi arranged in a Π-shaped layout. Unfortunately, the roof of the burial chamber has been destroyed.

The excavation of the monument yielded significant archaeological evidence, both regarding the funerary structure itself and the broader archaeological record of the Drama region. Although the exact number of individuals interred remains unknown due to the poor state of preservation of the skeletal remains, it is evident that the monument functioned as a family tomb accommodating individuals of both sexes. The grave goods accompanying the deceased on their funerary journey are particularly noteworthy—namely gold jewelry, such as earrings and a necklace, a substantial number of coins, and ceramic vessels including unguentaria and kraters—and they contribute decisively to the dating of the monument. The evidence indicates that the tomb was used diachronically by members of the same aristocratic family from the late 3rd century BCE until the late 2nd century or the early 1st century BCE (Sismanídis, 1997; Samartzidou, 1992).

In parallel, the monument possesses considerable topographical significance, as it delineates the eastern limits of the Hellenistic settlement of Drama. Funerary constructions of this type were typically located outside the city walls and placed in prominent, highly visible positions, often in proximity to a main road leading to the settlement (Kurtz and Boardman, 1971; Drougou and Touratsoglou, 1998; Petsas, 1966; Pandermelis, 1972; Themelis and Touratsoglou, 1997).

Perhaps the most significant aspect conveyed by this architectural type of funerary construction is its strong association with the Macedonian aristocracy (Romiopoulou and Brecoulaki 2002; Sismanidis 1997). Monuments of this kind are predominantly found within the borders of the Macedonian Kingdom, in Macedonia, Thessaly, and Euboea, as well as in more distant regions such as Asia Minor. The earliest examples of this type, dating as early as the 4th century BCE, are in the area of Vergina, Veroia, and are associated with members of the Macedonian royal family (Mastrapas 2003; Bouras 1999; Makaronas 1965). The construction of such funerary monuments appears to have been intensified during periods of pronounced political instability, particularly following the death of Alexander III, when disputes over the Macedonian throne emerged. In this context, the building of Macedonian tombs may be interpreted as one of the means through which the Macedonian elite sought to establish or reinforce symbolic links with the royal lineage.

2. State-of-the-Art

Virtual reality (VR) has become a central tool for valorizing, communicating, and safeguarding cultural heritage, complementing digitization and documentation workflows based on photogrammetry, laser scanning, HBIM and reality capture (Bekele et al., 2018; Banfi and Oreni, 2025; Varol and Öksüz, 2025; Rodríguez-Garcia et al., 2024). Systematic reviews show rapid growth of immersive heritage applications since about more than a decade, with a strong move to consumer-grade head-mounted displays and fully immersive systems (Chong et al., 2021; Innocente et al., 2023; Rodríguez-Garcia et al., 2024; Cecotti, 2022).

VR is nowadays routinely used for:

- Virtual museums and site visits, often built from high-fidelity 3D scans or digital twins (Bekele et al., 2018; Chong et al., 2021; Banfi and Oreni, 2025; Gavalas et al., 2020; Poux et al., 2020).
- Education and edutainment, using narrative, serious games, and interactive tasks to improve learning and engagement (Bekele et al., 2018; Chong et al., 2021; Rodríguez-Garcia et al., 2024; Paulauskas et al., 2023).
- Tourism and digital tourism, offering pre-visit experiences and access to endangered or remote sites (Chong et al., 2021; Varol and Öksüz, 2025; Poux et al., 2020; Hajirasouli et al., 2021).

- Preservation of intangible heritage, particularly rituals, performances, and practices captured via 360° video and interactive storytelling (Boboc et al., 2022; Hajirasouli et al., 2021; Maallem, 2025).
- Endangered or inaccessible heritage: VR-based digitisation frameworks document sites under threat and visualize possible future transformations (Hajirasouli et al., 2021).

Main goal of applying VR techniques is enabling interaction, virtual presence and enhancing user experience. Current state-of-the-art systems strongly emphasize immersion, presence and emotional engagement. Fully immersive VR increases positive emotions, reduces negative affect, and enhances engagement compared to traditional visits (Jangra, et al., 2025). On the other hand, game engines and visual programming are used to transform HBIM or point-cloud models into interactive virtual environments, enriched with audio, text, animations and storytelling for inclusive WebVR/VR access (Banfi and Oreni, 2025; Poux et al., 2020; Paulauskas et al., 2023). Of course, the Virtual humans or avatars acting as guides or characters, improving immersion, social presence and learning when appropriately designed have an important role to play (Machidon, et al., 2018; Rodríguez-Garcia et al., 2024). Finally, user centered design and systematic evaluation for usability, workload, flow, and VR side-effects are increasingly standard in high quality projects (Machidon et al., 2018; Innocente et al., 2023; Poux et al., 2020; Cecotti, 2022; Jangra, et al., 2025).

The Impact of VR supporting Cultural heritage is evident, as many researchers report that VR enhances knowledge transfer and memory in museum and training contexts, especially when combined with narrative and interactivity (Chong et al., 2021; Rodríguez-Garcia et al., 2024; Paulauskas et al., 2023; Jangra, et al., 2025). It also increases visitor motivation and emotional connection to heritage, including empathy toward historical events and endangered communities (Hajirasouli et al., 2021; Maallem, 2025). Finally, VR can broaden access for remote audiences and those unable to visit on site (Bekele et al., 2018; Chong et al., 2021; Varol and Öksüz, 2025; Cecotti, 2022).
The current challenges and research directions include issues to include methodological frameworks for designing heritage-specific VR, balancing realism with interpretive content, motion sickness and comfort, and robust evaluation of long term learning effects (Bekele et al., 2018; Machidon, et al., 2018; Chong et al., 2021; Innocente et al., 2023; Hu, 2023; Rodríguez-Garcia et al., 2024; Cecotti, 2022). Emerging directions highlight extended reality ecosystems (VR/AR/MR), AI-driven reconstruction, and scalable workflows that integrate documentation, conservation, and public engagement in a single digital pipeline (Chong et al., 2021; Banfi and Oreni, 2025; Yu, 2025; Varol and Öksüz, 2025; Rodríguez-Garcia et al., 2024).

In recent years, interdisciplinary collaboration has led to the development of numerous digital applications based both on the results of extensive and long-term archaeological research and on innovative technological advances.

One of the most recent and representative examples is the creation of a digital replica of a Roman-period building (late 3rd–4th century AD), known as the *Villa Romana*, located in the area of Aiano, Italy. Drawing upon excavation data and literary sources, in combination with surveying and photogrammetric datasets, the interdisciplinary research team produced a three-dimensional digital model that essentially constitutes a scholarly hypothesis of the building's probable appearance during its period of use, while simultaneously documenting its successive construction and use phases (Ferdani et al., 2020) (Figure 4).

Another noteworthy attempt to reconstruct the past within a virtual reality (VR) environment originates from the Cherkasy region of Ukraine. The focus of this project was the prehistoric settlement of Talyanki, associated with the Trypillya culture and dated to the first half of the 4th millennium BCE, which covered an area of approximately 450 hectares. The research team employed previously acquired geomagnetic data in conjunction with photogrammetric and photographic data collected both from the archaeological site and from a reconstructed Trypillya building housed in the local museum. Following data processing, a three-dimensional model was generated; subsequently, a game engine was utilised to create a comprehensive virtual reconstruction of the entire settlement (Gorkovchuk et al., 2021) (Figure 5).

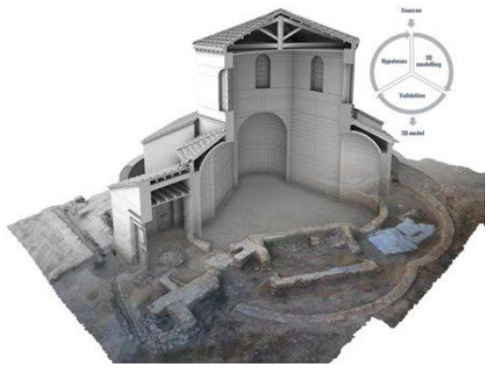

Figure 4: 3D modeling of Villa Romana in Aiano, Italy. (Ferdani et al. 2020)

Figure 5: VR application created based on Talyanki settlement, Trypillya culture. (Gorkovchuk et al. 2021)

3. Methodology

The production of a three-dimensional digital model in the context of the creation of a cultural digital product at a research level constitutes a complex, demanding and time-consuming process, which requires systematic planning and a methodical approach at each stage. The research team decided to proceed with the collection of all possible data within the limited time frame and the technical capabilities provided by the available equipment. This decision was taken in order to serve two main reasons. On the one hand, the most complete and adequately accurate recording of the monument using combined documentation methods. On the other hand, the provision for future processing of all the data, even in the event that part of it is not utilised in the present research work.

3.1 3D Documentation

The monument, as mentioned above, is located in a built underground space of limited space with certain structural elements, mainly concrete walls, of the apartment building, preventing the free movement of the research team in certain points, e.g. on the western and northern sides of the monument (Figure 6). Vertical beams are found that limit easy access for data collection, which, however, did not hinder the collection of data with the necessary care. The eastern and southern sides of the monument are the sides with the easiest access. Around the perimeter of the monument, there is a built corridor with cement mortar covering. Care had to be taken for the collection of data of the burial chamber from the eastern, northern and western sides as the arch is absent and there is no protective railing in the perimeter external corridor.

The instrumentation used included a Topcon 3003 total station, a full frame DSLR Canon EOS 6D camera, an action camera GoPro Hero 8, a XPhase 360° panoramic camera, and a Leica BLK360 terrestrial laser scanner. A 5-point network was established inside and around the tomb to make sure all acquired data are in the same reference system. The accuracy of the survey points was estimated at 10mm, quite adequate, as the result of the documentation was to be used for highlighting purposes in the VR application. The terrestrial scans were carried out on the exterior and interior of the monument. The scan sequence started from the exterior southwest corner of the antechamber and, by gradually moving the scanner, the 45 scans were completed with the scanning of the burial chamber.

The monument was thoroughly photographed using all available digital cameras. The images acquired were of the highest possible resolution, with sufficient overlap between them (60–80%) and stable lighting conditions. More extensive and systematic was the use of the Canon EOS 6D, with which both the exterior and interior of the monument were photographed. For the needs of this process, shots were taken from a tripod or by hand, in small and large-scale shots, and for each shot, the operator took care of the depth of field and sharpness. Lighting is a key issue for the photographic recording stage, and, in this case, the research team faced certain challenges to investigate. It should be noted at this point that the lighting of the monument is realised only by the permanent installation of floodlights. There are three large floodlights attached to the walls of the underground space and a smaller one in the antechamber. This created intense shadows but also, on the contrary, intense lighting in several places, making the photographic process difficult. At the same time, in other places the existing installed lighting was deemed either insufficient or not adequate at all. Consequently, in some cases, the power supply of the respective floodlight had to be interrupted, and a more suitable lighting method had to be created again with the available equipment. Thus, for example, for the photography mainly of the interior of the monument, the use of a digital camera was combined with diffusion umbrellas with adapted synchronised flashes (Figure 7), for simultaneous lighting and reduction of shadows and intensely dark spots. The use of umbrellas was considered necessary in the burial chamber as the area is only illuminated by the installed spotlights, and due to the relief of the object, there were quite dark spots, especially inside the sarcophagi. Furthermore, in places where the painted decoration of the monument is located, in the antechamber, the use of the camera was combined with an XRite colour checker for postprocessing the digital images, but also with the adjustment of parameters in the digital cameras for the white balance, so that, during the processing of the photos and if deemed necessary, the shades of the decorative elements can be rendered in a better and more accurate way.

For the needs of photographing the monument, other photographic means were also used. The outer part of the arch was a key structural element of the monument that had to be photographed with great precision, but there was difficulty in approaching it, especially at its most central point, at the top. An attempt was made to take aerial photographs using a drone, but without success, as there was not enough available navigation space for the device between the highest point of the monument, that is, the arch, and the lowest point of the roof of the apartment building. For this reason, it was chosen to photograph this point using the GoPro Hero 8 action camera attached to a hand-held stick (Figure 8). In total, 861 images were taken with the DSLR, 65 images with the 360° camera and 377 images with the action camera.

(a) (b)

Figure 6: The confined environment for data acquisition

Figure 7: Using artificial lighting for photography

Figure 8: Using a selfie stick to take images of the outer roof with the action camera

Figure 9: Processing data in Metashape and Geomagic

During the data processing phase, the TLS scans were aligned and referenced to the common reference system using the proprietary software. Subsequently, the resulting point cloud was cleaned from noise and unwanted data using the Geomagic Wrap® software. The digital images were processed in Agisoft Metashape Pro® software, taking great care to achieve correct alignment, i.e. orientation of the images, which is a crucial step to accurate results. The resulting dense point cloud was also processed in Geomagic Wrap® software and was combined with the TLS one to produce the completed surface. This product was subsequently inserted into the SfM software to be textured with the high-resolution images. Thus, the final 3D rendered model was produced, which would be used for the development of the VR application (Figure 9).

3.2 Development of the VR application

The development of a digital product in the field of Cultural Heritage constitutes a demanding and time-consuming process, requiring significant resources, specialised expertise, interdisciplinary collaboration, methodological consistency, and careful planning. Once these prerequisites are addressed, a critical subsequent consideration concerns the purpose of such a product and, consequently, the audience to which it is addressed. The fundamental question arises as to whether the digital output is intended primarily as a tool for the scientific and research community or, alternatively, as a means for the dissemination and valorisation of the monument to a broader audience, presented in an accessible, intuitive, and engaging manner while retaining an educational character, available at any time and from any location worldwide.

Guided by the principle of Openness (Kansa 2012; Canellopoulou-Boti and Sitara 2013), namely, the provision of access to cultural assets to the wider public and not exclusively to the scientific community, the research team decided to exploit the entirety of the data collected for the monument, derived both from extensive bibliographic research and from direct documentation of the site itself. In this context, the accumulated knowledge and information required appropriate structuring and adaptation to become readily and efficiently accessible to a broader audience, rather than remaining confined within digital archives on the researchers' workstations. Inevitably, despite the team's existing experience and expertise, new challenges had to be addressed in order to achieve the primary objective: the creation of a digital cultural asset available to the widest possible audience.

Regarding the available time and methodology, the bibliographic research concerning the monument extended over a period of approximately six months, while the data acquisition campaign at the archaeological site lasted approximately three days (Papatheodorou 2025). The development of the prototype digital product by specialized staff required several additional days. At this stage, all collected data underwent processing using specialized software packages, such as Metashape and Geomagic, as previously described. The generation of a digital three-dimensional model was successfully accomplished; however, further processing steps were required to produce the final digital application.

Given that the resulting cultural asset was intended to be made available to the public in the form of a digital 3D virtual tour, accessible at any time, from any location, and independently of the users' physical condition, reference was made to comparable applications offering self-guided (auto-tour) experiences in Cultural Heritage environments. Such applications allow visitors to explore heritage sites through digital tools providing information and guidance without the need for a guide. These solutions are widely adopted in museums, archaeological sites, historic monuments, and cultural attractions. Moreover, they can be accessed through various types of electronic devices, both portable and stationary, either remotely via desktop or laptop computers, or on-site using smart devices.

During the data acquisition phase at the archaeological site, the scientific team employed cameras capable of capturing imagery suitable for the generation of 360-degree virtual tours following processing in specialized software. Nevertheless, the resulting output was not deemed fully satisfactory for the requirements of the final application. For this reason, the use of Unity 3D, a well-known game development engine, was selected. This kind of software environment enables the creation of virtual tours of the auto-tour/guide type and is widely employed in cultural heritage dissemination and promotion. More specifically, Unity 3D constitutes a flexible interactive development platform supporting 2D and 3D graphics, physical interaction, and real-time rendering, albeit requiring programming skills using the C# language. In view of this requirement, previously developed code from an earlier project implementing a similar virtual tour application was reused and adapted (Laspia 2025).

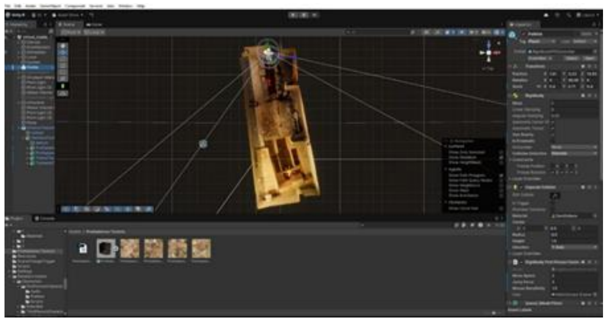

Figure 10: Processing the 3D model in Unity 3D

Based on the above considerations, a deliberate reduction of the polygon count of the three-dimensional mesh was performed during the final processing stage. This decision was motivated by the fact that the model was intended exclusively for a virtual tour application, for which the level of accuracy and geometric detail required in conservation or restoration contexts is not necessary. In parallel, the model was subdivided into three separate sections (chunks), each comprising up to 1.5 million polygons, to improve manageability and processing efficiency within the Unity environment and to avoid delays during loading and rendering (Figure 10).

Subsequently, the model was imported into the development environment, where particular emphasis was placed on scene design and organization, user navigation within the virtual space, the form and mode of interaction with the informational content, and the selection of material presented in the final application. Unity provides extensive possibilities for customization through programming; at the present stage, a simple, standardized navigation scheme was implemented, which may be further enriched in the future through modifications of the original code, an inherent advantage of this category of software.

3.2.1 Virtual Environment Structuring and Visitor Experience: The virtual environment represents the monument and its immediate surroundings as documented at the time of the survey, without hypothetical reconstructions or interpretative additions. Emphasis was placed on maintaining visual fidelity to the existing condition of the Macedonian Tomb, ensuring that the virtual experience corresponds closely to the physical reality of the site. A first-person navigation model was selected to enhance immersion and to simulate the perspective of a human visitor. The virtual visitor is represented by a digital avatar with human-scale characteristics, implemented through a first-person controller, with the camera positioned at an average human eye level. This design choice enables an intuitive exploration of the confined interior space of the tomb, which would otherwise be inaccessible to the public (Figure 11).

User movement within the virtual environment is unrestricted in terms of viewpoint, allowing exploration of areas that are physically inaccessible during on-site visits, such as the western side of the monument and zones affected by spatial constraints. This approach supports both educational exploration and detailed observation of architectural features, while avoiding disorientation through careful scene organisation and scale preservation. Lighting conditions were configured to support clear visibility and spatial perception within the confined space of the tomb. Artificial lighting was employed to simulate uniform illumination, facilitating the observation of architectural details without introducing dramatic or interpretative lighting effects. Although ambient sound or spatial audio could enhance immersion, audio elements were deliberately excluded at this stage due to the lack of documented acoustic data and the scope of the present implementation.

Figure 11: The environment of the auto-tour application

Figure 12. The environment of a pop-up window of the application

3.2.1 Development Workflow and System Architecture: The virtual tour application was developed using Unity 3D, a widely adopted real-time game development engine supporting interactive 2D and 3D applications, virtual reality, and cross-platform deployment. Unity offers advanced rendering capabilities, an integrated physics engine, and extensive scripting through the C# programming language, making it particularly suitable for Cultural Heritage visualisation and dissemination applications.

The development process began with the creation of a dedicated Unity 3D project structured around appropriate asset folders for three-dimensional models, textures, materials, scripts, and user interface elements. The processed three-dimensional model of the tomb was imported in standard mesh format and subsequently optimised for real-time rendering. Given the high geometric complexity of the documented monument, a deliberate polygon reduction strategy was applied prior to import. The final model was subdivided into three discrete mesh segments, each containing approximately 1.5 million polygons, to ensure manageable file sizes and smooth rendering performance within the Unity environment. This subdivision also reduced loading times and prevented memory bottlenecks during runtime, particularly important for deployment on standard consumer hardware.

A first-person controller was implemented to simulate visitor movement and interaction. The controller parameters were configured to regulate walking speed, rotation sensitivity, and camera height, ensuring natural navigation within the constrained interior geometry. Collision detection was enabled through colliders applied to the architectural geometry, preventing the user from unintentionally passing through walls or structural elements. Scene lighting was configured using Unity's built-in lighting system, with adjustments made to intensity and distribution to achieve a balanced and realistic visual outcome. No environmental skyboxes or panoramic background images were included, as the application focuses exclusively on the monument and its immediate spatial context. User interaction was implemented through custom C# scripts adapted from a previously developed virtual tour framework. These scripts handle user input, interaction detection, activation of informational elements, and application exit functionality. The modular nature of the scripting approach allows for straightforward future expansion or modification of interaction logic.

3.2.2 Interactive Content and Extensibility: Interactive informational elements were integrated into the virtual environment in the form of Points of Interest (Info Points). These were visually represented by circular blue symbols bearing the letter "i", positioned at selected locations corresponding to architecturally or archaeologically significant features of the monument. Their placement was determined based on bibliographic research and in situ observations. Each Info Point is associated with a scripted interaction that triggers the appearance of a pop-up information panel upon user selection. The informational content consists of original text adapted specifically for the digital application, based primarily on published archaeological research and documentation provided by the Hellenic Ministry of Culture. In selected cases, supplementary visual material such as plans, drawings, and archival photographs accompanies the textual descriptions (Figure 12).

In the current prototype version, the informational content is provided exclusively in Greek. However, the application architecture enables straightforward adaptation for different audiences, including multilingual support, font size adjustments, and the potential integration of audio narration to improve accessibility for users with visual impairments. No mini map or navigational overview was incorporated in the present implementation, as the spatial scale of the monument and the confined nature of the virtual environment did not necessitate additional orientation aids. Similarly, no audio or audiovisual material was included due to the absence of suitable assets during the research phase and time constraints. Nevertheless, the modular design of the application ensures that such elements can be integrated in future versions without substantial restructuring.

Upon completion, the application was exported as a standalone executable (.exe), enabling distribution as a desktop application. Furthermore, access to virtual experience is facilitated through QR code dissemination by the local Ephorate of Antiquities, allowing prospective visitors to engage with the monument remotely. Finally, a short promotional video captured from within the application environment is available on the YouTube channel of the Laboratory of Photogrammetry of the NTUA. (https://www.youtube.com/watch?v=TJwb5VpmIww).

4. Concluding Remarks

Despite its location in the very center of the modern city of Drama, the Hellenistic tomb of Troias Street has not historically received the level of public recognition and valorization that its archaeological significance would warrant. As demonstrated, both the monument itself and the results of its photogrammetric documentation largely remained confined to institutional archives, in accordance with established international conventions for the geometric recording of Cultural Heritage. While such practices ensure scientific reliability and long-term preservation of data, they often fall short in addressing issues of accessibility, visibility, and meaningful public engagement.

The widespread practice, particularly during periods of intensive urban development, of preserving monuments in situ within subterranean spaces reflects a legislative and methodological framework primarily oriented towards protection rather than interpretation or presentation. In many cases, no parallel strategy was developed for systematic public displays, resulting in monuments that, although legally safeguarded, remain effectively invisible or difficult to interpret for non-specialist audiences. As contemporary heritage management increasingly prioritizes openness and inclusive access, such conditions raise critical questions regarding the suitability of underground spaces for monument presentation and the broader expectations of today's visitors. Nevertheless, this reality necessitates adaptation: monuments located below ground level must be brought, metaphorically, "to the surface" through alternative means of representation, interpretation, and dissemination.

Within this context, the present research demonstrates how the integration of New Technologies, particularly photogrammetry, 3D modelling, and interactive VR visualization, can provide viable and effective solutions. The development of an auto-tour virtual application constitutes not merely technical exercise, but a highly creative process that requires continuous decision-making, interpretative choices, and iterative design. The transformation of raw spatial data into an accessible, navigable, and informative digital environment underscores the interpretive dimension of digital heritage production, where scientific accuracy must be balanced with usability, narrative clarity, and experiential quality.
Moreover, a decisive factor in this process was interdisciplinary collaboration. The successful implementation of the digital application depended on the convergence of archaeological expertise, surveying and photogrammetric methods, computer graphics, and programming knowledge. This synergy illustrates that contemporary archaeological practice no longer operates within rigid disciplinary boundaries, but rather within a dynamic information ecosystem in which diverse forms of expertise interact productively. Importantly, digital technologies do not replace traditional archaeological methods; instead, they complement and enhance them, reinforcing the interpretative potential of archaeological research while expanding its communicative reach.

The choice of a game-engine environment such as Unity 3D proved particularly significant. Platforms of this type, which require programming knowledge, offer substantial flexibility by allowing continuous modification, enrichment, and expansion of the application through direct intervention in the code. This modularity ensures that the digital product is not static, but evolves alongside new research questions, additional content, or changing audience needs. As such, the application can be updated, translated, or augmented with new forms of interaction and media at any stage, reinforcing its long-term sustainability and relevance.

In conclusion, the digital auto-tour developed for Troias Street Tomb exemplifies how photogrammetric documentation can be transformed from a passive archival resource into an active tool for interpretation, access, and public engagement. By combining technological innovation, creative design, and interdisciplinary collaboration, the project contributes to contemporary discussions on Openness in Cultural Heritage and demonstrates the potential of interactive digital applications to render otherwise inaccessible monuments visible, intelligible, and meaningful to a broad audience.

References

Archibald, Z. H. 1998. *The Odrysian Kingdom of Thrace. Orpheus Unmasked*. Martin Robertson, John Boardman, J. J. Coulton, Donna Kurtz, R. R. R. Smith, Margareta Steinby (eds). Oxford: Clarendon Press.

Archibald, Z. H. 2008. "Chapter 9e: Thracians and Scythians". In: D. M. Lewis, John Boardman, Simon Hornblower, M. Ostwald (eds.): *The Cambridge Ancient History, (second edition), vol. VI, The 4th Century B.C.* Cambridge University Press. 444 – 475.

Bouras, Ch. Th. (1999). *Lectures on the History of Architecture*. Vol. I. 3rd ed. Athens: Eptalofos S.A.

Banfi, F., & Oreni, D., 2025. Unlocking the interactive potential of digital models with game engines and visual programming for inclusive VR and web-based museums. Virtual Archaeology Review. https://doi.org/10.4995/var.2024.22628

Bekele, M., Pierdicca, R., Frontoni, E., Malinverni, E., & Gain, J., 2018. "A Survey of Augmented, Virtual, and Mixed Reality for Cultural Heritage". Journal on Computing and Cultural Heritage (JOCCH), 11. https://doi.org/10.1145/3145534

Boboc, R., Băutu, E., Gîrbacia, F., Popovici, N., & Popovici, D., 2022. Augmented Reality in Cultural Heritage: An Overview of the Last Decade of Applications. Applied Sciences. https://doi.org/10.3390/app12199859

Canellopoulou – Boti M. and Sitara M. (2013). "Open Access and Archaeological Data". Presented at the *International conference: Open access @ EKT: Towards common European policies for innovative reuse of public sector & scientific information*, 16 – 18 October 2013. Athens, National Hellenic Research Foundation. (Available at: https://helios.eie.gr/helios/handle/10442/13589)
Cecotti, H., 2022. Cultural Heritage in Fully Immersive Virtual Reality. Virtual Worlds, 1, pp. 82-102. https://doi.org/10.3390/virtualworlds1010006

Chong, H., Lim, C., Rafi, A., Tan, K., & Mokhtar, M., 2021. Comprehensive systematic review on virtual reality for cultural heritage practices: coherent taxonomy and motivations. Multimedia Systems, 28, pp. 711 - 726. https://doi.org/10.1007/s00530-021-00869-4

Drougou, S., Touratsoglou, G. (1998). Hellenistic Rock-Cut Tombs of Veroia. 2nd ed. Athens: Archaeological Resources and Expropriations Fund.

Gavalas, D., Sylaiou, S., Kasapakis, V., Dzardanova, E., 2020. Special issue on virtual and mixed reality in culture and heritage. Personal and Ubiquitous Computing, 24. https://doi.org/10.1007/s00779-020-01377-4

Ferdani D., Demetrescu E., Cavalieri M., Pace G., Lenzi S. 2020. "3D Modelling and Visualization in Field Archaeology. From Survey To Interpretation of the Past Using Digital Technologies". *GROMA: Documenting archaeology*, Vol. 4 (2019), pp. 1 – 21. Archaeopress. https://archaeopresspublishing.com/ojs/index.php/groma/article/view/1344/951

Gorkovchuk J., Gorkovchuk D., Luhmannc Th. 2021. "Integration of complex 3D models into VR environments: Case studies from archaeology". *Proceedings of the joint international event 9th ARQUEOLÓGICA 2.0 & 3rd GEORES, Valencia (Spain). 26–28 April 2021*. DOI: https://doi.org/10.4995/Arqueologica9.2021.12123

Hajirasouli, A., Banihashemi, S., Kumarasuriyar, A., Talebi, S., Tabadkani, A., 2021. Virtual reality-based digitisation for endangered heritage sites: Theoretical framework and application. Journal of Cultural Heritage. https://doi.org/10.1016/j.culher.2021.02.005

Hu, J., 2023. Individually Integrated Virtual/Augmented Reality Environment for Interactive Perception of Cultural Heritage. ACM Journal on Computing and Cultural Heritage, 17, pp. 1 - 14. https://doi.org/10.1145/3631145

Ilieva, P. 2007. "Thracian-Greek "*συμβίωσις*" on the shore of Aegean". In: Iakobidu, A. (ed.) *Thrace in The Graeco-Roman World*. Proceedings of the 10th International Congress of Thracology: Komotini-Alexandroupolis 18-23 October 2005. Athens: National Hellenic Research Foundation, Centre for Greek and Roman Antiquity. 212 – 226.

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*. https://doi.org/10.1016/j.culher.2023.06.001

Jangra, S., Singh, G., Mantri, A., 2025. Evaluating user experience in cultural heritage through virtual reality simulations. *Virtual Archaeology Review*. https://doi.org/10.4995/var.2024.22556

Kansa E. 2012. "Openness and archaeology's information ecosystem". In Mark Lake (ed.) *World Archaeology*, Vol. 44, Issue 4, 2012. P. 498-520. (Available at: https://doi.org/10.1080/00438243.2012.737575)

Khan, I., Melro, A., Amaro, A.C. Oliveira, L. 2020. "Systematic Review on Gamification and Cultural Heritage Dissemination." Journal of Digital Media & Interaction, vol. 3, No. 8.

Koukouli-Chrysanthaki, Ch. 1984. «Drama». Archaeological Bulletin, v. 31 (1976). Part B΄2: Chronicles. Athens: Fund for Archaeological Resources and Expropriations. 303 – 304. (in Greek).

Kurtz, D. C. and Boardman, J. 1971. *Greek Burial Customs*. London: Thames and Hudson.

Laspia, V. 2025. *Charama of Kaisariani: A Three-Dimensional Tour through Space, Time, and Rebetiko Music*. Master's Thesis, National Technical University of Athens, School of Architecture. (in Greek)

Maallem, H., 2025. Virtual reality technology and its role in the valorization of culture heritage: the case of 360-degree video in virtual reality. *Gateway Journal for Modern Studies and Research (GJMSR)*. https://doi.org/10.61856/mq5rn669

Machidon, O., Duguleană, M., Carrozzino, M., 2018. Virtual humans in cultural heritage ICT applications: A review. *Journal of Cultural Heritage*. https://doi.org/10.1016/j.culher.2018.01.007

Makaronas, Ch. (1965). "Tombs in the Vicinity of Derveni, Thessaloniki." *Archaiologikon Deltion*, vol. 18 (1963), Part B2: *Chronika*. Athens: Archaeological Resources and Expropriations Fund, pp. 193–196. (in Greek)

v. Mangoldt, H. 2012. *Makedonische Grabarchitektur, die Makedonischen Kammergräber und ihre Vorläufer – Band: I, II*. Berlin: Ernst Wasmuth.

Mastrapas, A. N. (2003). *Greek Architecture: From the Early Historical Period to the Roman Domination*. Athens: Institute of the Book – A. Kardamitsas.

Pandermalis, D. (1972). "The New Macedonian Tomb at Vergina." *Makedonika*, vol. 12, pp. 147–182.

Papapetropoulos, D. 2006. *Law 3028 on the protection of Antiquities and in general of Cultural Heritage*. Athens

Papatheodorou, A. 2025. *Digital Restoration and Valorisation of the Macedonian Tomb on Troias Street in Drama using Contemporary Technologies*. Master's Thesis, University of the Aegean, School of Humanities, Department of Mediterranean Studies: Archaeology, Linguistics, and International Relations. Rhodes. (in Greek).

Paulauskas, L., Paulauskas, A., Blažauskas, T., Damaševičius, R., & Maskeliūnas, R., 2023. Reconstruction of Industrial and Historical Heritage for Cultural Enrichment Using Virtual and Augmented Reality. *Technologies*. https://doi.org/10.3390/technologies11020036

Petsas, Ph. (1966). The Tomb of Lefkadia. Athens: The Archaeological Society of Athens.

Taylor, A.E. (translation in English) 1934. *The Laws of Plato*. London: J. M. Dent and sons LTD. Available at: https://archive.org/details/lawsofplato01plat_0/page/334/mode/2up

Poux, F., Valembois, Q., Mattes, C., Kobbelt, L., & Billen, R., 2020. Initial User-Centered Design of a Virtual Reality Heritage System: Applications for Digital Tourism. *Remote. Sens.*, 12, pp. 2583. https://doi.org/10.3390/rs12162583

Rodríguez-Garcia, B., Guillen-Sanz, H., Checa, D., & Bustillo, A., 2024. A systematic review of virtual 3D reconstructions of Cultural Heritage in immersive Virtual Reality. *Multimedia Tools and Applications*, 83, pp. 89743 - 89793. https://doi.org/10.1007/s11042-024-18700-3

Romiopoulou, K., Brecoulaki, H. 2002. "Style and painting techniques on the wall painting of the "Tomb of the Palmettes" at Lefkadia." In M.A. Tiverios and D.S. Tsiafakis (eds.) *Color in Ancient Greece: The role of color in Ancient Greek Art and Archtecture 700 – 31 B.C.* Kardamitsa. 107 – 115, Plates 23 – 24.

Samartzidou, St., 1992. «The Hellenistic Tomb of Drama». In: Drama and its Surroundings. History and Culture, Proceedings of the Scientific Meeting 24 – 25 November 1989. Drama Municipality.

Sismanídis, K. (1997). *Klinai and Kline-Shaped Constructions in Macedonian Tombs*. Athens: Archaeological Resources and Expropriations Fund.

Themelis, P. and Touratsoglou, I. (1997). *The Tombs of Derveni*. Athens: Archaeological Resources and Expropriations Fund.

Varol, F., & Öksüz, M., 2025. Use of advanced measurement and reality technologies in cultural heritage sites from the perspective of technology and tourism. *Current Issues in Tourism*, 28, pp. 585 - 603. https://doi.org/10.1080/13683500.2024.2322693

Voskaki, A. and Biza, M. 2015. *Antiquities in the basement*. Athens. (In Greek) Available at: https://www.academia.edu/35854059/%CE%91%CF%81%CF%87%CE%B1%CE%B9%CF%8C%CF%84%CE%B7%CF%84%CE%B5%CF%82_%CE%B5%CE%BD_%CE%A5%CF%80%CE%BF%CE%B3%CE%B5%CE%AF%CF%89

Yu, Z., 2025. Application of Virtual Reality Technology in Digital Protection of Cultural Heritage. *Highlights in Art and Design*. https://doi.org/10.54097/50dekj79