

A 3D Digital Documentation Framework for the Early Helladic Cemetery of Asteria, Glyfada: Challenges and Innovations

Markos Konstantakis^{1*}, Konstantina Kaza-Papageorgiou², Vasiliki Antonopoulou³, Galini Daskalaki³, Ioanna Gourtzioumi³, Emmanouil Larentzakis³ and Eleftheria Iakovaki⁴

¹Department of Cultural Technology and Communication, Aegean University, 81100 Mytilene, Greece;

ORCID:0000-0003-0656-693X

²Archaeological Society of Athens, Panepistimioy 22, 10672 Athens, Greece

³Ministry of Culture, Mpoumpoulinas 20-22 Str, 10682 Athens, Greece

⁴University of West Attica, Aigaleo, 12243 Athens, Greece

*Corresponding author: mkonstadakis@aegean.gr

Abstract

The Early Helladic cemetery at Asteria in Glyfada presents a key archaeological locus for understanding prehistoric Attica, combining evidence of metallurgical activities with a complex, multi-phase burial ground. This paper presents the creation of a 3D digital model of the cemetery, integrating advanced photogrammetry, terrestrial laser scanning, and GIS-based documentation with legacy excavation records. The resulting model enabled new spatial and analytical discoveries, including the identification of previously undetected clustering in burial orientation, artifact-specific distribution patterns (notably of Cycladic figurines and obsidian tools), and modeling of diachronic landscape transformation. Detailed comparative statistics demonstrate the respective advantages of CRP and TLS for archaeological surveying. These advances go beyond traditional documentation, supporting robust research analysis as well as educational and public outreach, with models made openly accessible via Sketchfab. By situating our work within current international practices in 3D digital heritage, this case study provides a replicable, high-resolution workflow for managing, analyzing, and disseminating complex archaeological datasets.

Keywords: 3D Digital Model; Cultural Heritage; Archaeological Documentation; Early Helladic; Asteria Glyfada; Photogrammetry; Laser Scanning; GIS

To cite this article:

Konstantakis, M., Kaza-Papageorgiou, K., Antonopoulou, V., Daskalaki, G., Gourtzioumi, I., Larentzakis, E. and Iakovaki, E. 2026. "A 3D Digital Documentation Framework for the Early Helladic Cemetery of Asteria, Glyfada: Challenges and Innovations". In G. Pavlidis & D. Moullou (Eds.) Proceedings of the 52nd Conference on Computer Applications and Quantitative Methods in Archaeology. *CAA Proceedings*, 52(1): Article 3:1-19. DOI: <https://doi.org/10.64888/caaproceedings.v52i1.926>

Submitted: 24/12/2025, Accepted 03/03/2026, First online 10/03/2026

Preprint: DOI: <https://zenodo.org/records/17942940>



Copyright

©2026 The Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC-BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited. See <http://creativecommons.org/licenses/by/4.0/>

1. Introduction

The archaeological evidence from both the workshop installation and the cemetery at Asteria highlights the site's diachronic significance, where industrial activities and funerary practices were interwoven within the Early Helladic landscape. While traditional excavation and documentation methods have revealed essential aspects of these contexts, the complexity of the remains and the need to integrate heterogeneous data demand new digital approaches. In this framework, the creation of a 3D digital model of the Asteria cemetery was conceived as a means to unify spatial, material, and interpretive records into a coherent, interoperable system. By combining advanced 3D recording techniques with legacy documentation, the project aims not only to preserve the archaeological evidence but also to enhance analytical capacity, foster interdisciplinary research, and provide new pathways for cultural dissemination (Konstantakis, 2023; Konstantakis, 2024).

Recent advances in archaeological documentation have extended beyond basic 3D modeling toward fully integrated analytical environments and public engagement platforms (Marín-Buzon *et al.*, 2021; Leon-Bonillo *et al.*, 2022). Techniques such as structure-from-motion (SfM) photogrammetry, dense TLS acquisition, and their hybridization are now being widely adopted for heritage sites of varied complexity and scale (González-Quiñones *et al.*, 2022; Wojciech Ostrowski *et al.*, 2024). Our work builds upon these trends, tailoring them to the unique demands of the Early Helladic cemetery at Asteria.

Based on these considerations, the present study seeks to address the following research questions:

- How do modern 3D digital documentation methods contribute to the enhanced recording and analysis of the Early Helladic cemetery at Asteria, Glyfada?
- What methodological challenges and solutions emerge from the integration of legacy excavation records and new digital datasets?
- In what ways does the application of international semantic standards facilitate data interoperability, sustainability, and broader accessibility for archaeological research?

By addressing these questions, this study aims to demonstrate how an integrated 3D digital documentation framework can serve as an effective tool for the comprehensive management, analysis, and dissemination of complex archaeological data.

Beyond the site-specific documentation of the Asteria cemetery, this study contributes a transferable methodological framework for the integration of hybrid 3D acquisition, semantic modelling, and GIS-based spatial analysis in multi-phase archaeological contexts. By explicitly combining photogrammetry, terrestrial laser scanning, and legacy excavation records within a unified digital environment, the paper addresses current challenges in digital archaeology related to data interoperability, analytical reproducibility, and long-term sustainability.

The rest of the paper is structured as follows: Section 2 presents the archaeological and digital context, while Section 3 reviews related work on 3D digital models of paleontological exhibits. Section 4 presents the materials and methods used; Section 5 presents the results. Finally, the discussion, conclusions, and future research points are given in Section 6.

2. Archaeological and Digital Context

2.1. *Asteria Glyfadas*

The site of Asteria at Glyfada covers approximately the northern half of the Pounta peninsula, located on the west coast of Attica, south of the promontory of Aghios Kosmas (Mylonas 1959) and north of Vouliagmeni, where Final Neolithic and Early Helladic finds are known (Yiamalidi et al. 2020). A large extend of the Pounta peninsula preserves its original form, as described by Plato (Kritias 111 a-d), because it has remained relatively undisturbed.

From 1998-2003 the Archaeological Service of the Hellenic Ministry of Culture, under the direction of Konstantina Kaza, undertook rescue excavations at Asteria with significant results. Because of these results, the Ministry designated two excavated sectors at Asteria (1A and 1B) as official archaeological sites. Since 2012, work has resumed in the form of research excavations, under the aegis of the Athens Archaeological Society (Kaza-Papageorgiou 2006, 45–60; 2009, 437–439; 2019; 2020; 2024, 128-134. Kaza-Papageorgiou et al. 2024, 227-230). The goal of this investigation has been the discovery of vital information about the physical and human-made prehistoric environment at Asteria, which in the future will be protected and made accessible to scholars and other visitors.

More specific, Sector 1A is located at the area of the northern cove, and at a distance of 90 m. from the coastline, there was discovered a large rectangular peribolos, 44m. In length and enclosing an area 24 m. wide. Noted on the rocky surface within the peribolos were pits cut into the bedrock and other human-made features which, judging from the finds associated with them, were related to metallurgical activities ca. the end of the 3rd - early 2nd millennium B.C. (see Kaza-Papageorgiou 2006, 47-51). Parts of the peribolos were likely disturbed by the presence of a Late Roman cemetery, from which archaeologists have recovered 42 burials. This cemetery is thought to have served a coastal settlement connected with the Early Christian basilica at Glyfada, whose remains are still preserved on the northern boundary of the Asteria site. (Orlandos 1930, 258; Kaza-Papageorgiou 2015, 44-45; Kaza-Papageorgiou 2024, 140-142).

Furthermore, Sector 1B is located on a low hill, ca. 70000 square m. in extent, which is situated on the south edge of the site of Asteria. This hill ends to the west in a small, closed cove (Fig. 1), while to the east it extends gently to a plateau, as far as the passing coastal road. On the other side of the road lies the Mycenaean cemetery of Alyki Glyfada-Voula, where an EH grave has also been found (Polychronakou-Sgouritsa 1988, 19). Theocharis (AM 1956, 1) mentions an EH grave at Asteria, and traces of a 'Neolithic settlement' in his report to the relevant Ephorate of Antiquities. The area of sector 1B appears to have had two periods of use. First in the Early Helladic I period for workshop activities, probably metal working and during the second period of use for an extensive cemetery dated to Transitional Early Helladic I/II period. Seven rock piles have been related to the workshop installation during the first use of the hill.



Figure 1: The Sector 1B nearby the small cove.

2.2. Workshop installation

The workshop installation consists of a system of water management on the rock surface of the area, through some water courses, trenches and pits, which have been dug into the rock (Fig. 2). The water courses and the pits communicate between them and transferring the water end in the sea. It appears that the water courses, the trenches and the pits were planned as a unified system of water management, presumably in the context of a metallurgical washing station. Via reduction and absurdum the system's purpose was the enrichment of the ore through the flow of the water. This hydraulic installation covering a broad area, suggests activity of major importance.

All over the hill there are many rock piles which consist of broken stones, stone tools, sherds and shells. At first glance it appears that all the piles are of discarded materials from the clearing out of the nearby workshop area, probably used for metal working. Similar piles, scattered along the coast west of Hymettos, from Argyroupoli and Elliniko as far as Voula, have been published in the maps of E. Curtius, J.A. Kaupert (Karten von Attica, bl. VIII, 1885).



Figure 2: Sector 1B. Water courses, pits and chamber tombs.

2.3. Cemetery

An extensive Early Helladic cemetery (thirty three graves have come to light until October 2024), enclosed by a peribolos 61 m. long, was found at a distance of 39 m. from the coastline (for the use of the term ‘cemetery’ in cases of EH burial grounds, see Weiberg 2007, 242; for the selection of suitable burial grounds, see Weiberg 2007, 264-266; for Cycladic cemeteries in general, see Doumas 1977, 29-36). The cemetery appears to have been laid out on raised areas, which were natural topographical features of the site. It also appears that nearby all tombs at Asteria were built in preexisting workshop pits (Kaza-Papageorgiou et al. 2024, 227-229).

Each grave was enclosed by a three-sided peribolos; the fourth side was furnished with a small opening functioning as entrance to the chamber. The Asteria burial structures have parallels at the two Attic EH cemeteries of Tsepi (Pantelidou Gofa 2005, 287- 288) and Aghios Kosmas (Mylonas 1959, 66; Weiberg 2007, 308-311). The subterranean chambers were generally circular, with an approximate diameter and depth of one meter, and were hewn directly into the bedrock. Most of them were sealed with a single large stone slab. Above these slabs, builders often placed small, carefully selected stones, arranged into structures of various forms.

These constructions were most likely associated with burial rituals (Barber 1994, 84–85). Nevertheless, it is also plausible that they served as markers indicating the location of the graves (Weiberg 2007, 378–379). The entrance (stomion) of each chamber was blocked with two or three standing slabs, and the threshold was cut at a level higher than the chamber floor.(Pantelidou-Gofa 2005, 292). The graves under investigation had been used for multiple burials. The in situ burial in

front of the entrance was accompanied by bone heaps, clearly the remains of earlier burials, which had been pushed towards the back of the chambers (Fig. 3). The material accompanying the dead was not numerous when compared to the number of the deceased (Weiberg 2007, 202).

The amount of material found in the Tsepi graves was small, while large numbers were found in the separate deposits, as at Asteria (for similar cases, see Kaza-Papageorgiou 2006, 57 note 28). They mostly consist of small or medium-sized vases such as frying pans, beads, stone grinders, Cycladic-type figurines (Kaza-Papageorgiou 2019), sea shells (Weiberg 2007, 294), obsidian blades and other material. Two grinders from Asteria have parallels at Tsepi (Pantelidou Gofa 2005, 140). For obsidian blades in graves, see Pantelidou Gofa (2005, 321-323; Weiberg 2007, 292-293, 344-348 and Syrigou M. 262-263 in Kaza-Papageorgiou et al. 2024). For the movement of obsidian in the Aegean, see Renfrew et al. (1965).



Figure 3: The in situ burial and the bone heap behind it.

3. State of the Art in 3D Digital Archaeology

The integration of advanced imaging and computer vision methodologies has transformed cultural heritage documentation, with photogrammetry and laser scanning emerging as the two dominant approaches. Photogrammetry, based on high-resolution photographic capture and computational reconstruction, excels in rendering detailed textures and color information, while terrestrial laser scanning produces highly accurate point clouds, prioritizing geometric precision. Both methods, however, exhibit limitations when applied in isolation—photogrammetry struggles with lighting variations and alignment errors, whereas laser scanning may overlook finer details or

face difficulties with reflective surfaces. As a result, recent studies have emphasized hybrid workflows that exploit the complementary strengths of the two techniques, thereby ensuring both geometric accuracy and visual fidelity in the production of cultural heritage 3D digital models.

This shift toward integrated methodologies is evidenced across diverse case studies worldwide. Hassan *et al.* (2019) developed enriched geo-referenced digital models for ecclesiastical monuments in Portugal and Spain, demonstrating the role of combined workflows in preventive conservation planning. Liang *et al.* (2018) adopted UAV photogrammetry and terrestrial laser scanning for the complex landscape of Huanxiu Shanzhuang in China, achieving detailed reconstructions despite spatial heterogeneity. Similar approaches have been applied to archaeological and architectural contexts: Fawzy (2019) tested hybrid close-range photogrammetry for mosque documentation in Egypt; Monterisi (2023) demonstrated low-cost workflows using smartphone imagery for the Ognissanti Church in Italy; and Marinov (2023) illustrated the potential of 3D digital models for informed management of the “Holy Transfiguration” Church in Bulgaria. Collectively, these works highlight the increasing reliance on multi-source data acquisition, standardized processing pipelines, and semantic alignment as prerequisites for accurate and sustainable digital heritage documentation.

At the same time, large-scale 3D digital model initiatives underscore the transformative potential of these technologies for both research and public engagement. Projects such as the “Notre-Dame de Paris” reconstruction (Guillem, 2023), the Venice Time Machine (Kaplan, 2015), and CyArk’s global archive (Underhill, 2018) have showcased how 3D digital models can function as long-term repositories, interactive educational resources, and blueprints for conservation. In these cases, 3D data is not only used for metric documentation but also linked with historical, environmental, and social datasets to create comprehensive, evolving models. This trend reflects a broader paradigm shift: 3D digital models are increasingly conceived not merely as geometric surrogates but as dynamic, interoperable systems that integrate tangible and intangible dimensions of heritage, paving the way for immersive storytelling, conservation planning, and participatory cultural experiences.

4. Materials and Methods

The development of the 3D digital model of the Early Helladic cemetery at Asteria Glyfada was grounded in a multi-layered methodology that combined advanced three-dimensional documentation, archival research, and semantic data modeling. The central aim was to achieve a highly accurate and interoperable representation of the site that could support both scholarly analysis and broader dissemination.

4.1. 3D Data Acquisition

Data acquisition followed a hybrid approach, bringing together photogrammetry and terrestrial laser scanning. A DJI Mavic 2 Pro drone was deployed to capture aerial images of the cemetery and its surrounding topography. Multiple circular flights were performed at different altitudes, producing hundreds of high-resolution images with more than 80% overlap. Careful attention was given to lighting conditions, with cloudy or evenly lit environments preferred in order to minimize the impact of shadows on reconstruction quality. Complementary ground-based photogrammetry was undertaken using both DSLR cameras (Sony FDR-AX53) and smartphone devices (iPhone XS), which

allowed for the detailed recording of textures, surface features, and the micro-topography of the periboloi and chamber tombs. Exposure parameters for ground shots typically ranged from $f/2.8$ – $f/8$, ISO 100–400, and shutter speeds of $1/250$ – $1/1000$ sec, adjusted automatically or manually based on field conditions. All images were taken in overcast or diffused light to minimize shadows.

At the same time, terrestrial laser scanning was carried out using a FARO Focus M70 scanner. Approximately fifteen scans per area were conducted, each lasting between six and ten minutes, and registration was ensured through the use of reference spheres strategically placed across the site. This combined strategy capitalized on the strengths of each method: the laser scanner guaranteed millimetric geometric accuracy, while photogrammetry offered highly detailed textural fidelity (Konstantakis, 2023; Konstantakis, 2024; Marin-Buzon, 2021; Leon-Bonillo, 2022; González-Quiñones, 2022).

The choice to supplement standard cameras with a video camera and smartphone was motivated by field constraints—specifically, the need for rapid, adaptable coverage of complex micro-topography and confined zones, and to ensure the documentation of ephemeral features during rescue excavations. As noted by Leon-Bonillo *et al.* (2022) and González-Quiñones *et al.* (2022), the integration of non-traditional imaging devices can provide sufficient accuracy and robust results in building archaeology and open-area digs, particularly when logistical challenges preclude optimal static photography.

4.2. *Terrestrial Laser Scanning*

Terrestrial Laser Scanning (TLS), via FARO Focus M70, was employed specifically due to the presence of highly variable micro-topography and rock-cut features within the cemetery, including irregular periboloi and chamber tombs, as well as the need for precise volumetric measurements and monitoring potential geological changes. The dense point clouds (accuracy: 2–3 mm) generated by TLS allowed for robust geometric validation and integration with photogrammetric meshes, effectively overcoming shadow zones, reflective surfaces, and areas with limited image coverage. The adoption of TLS was not intended as a replacement for photogrammetry but as a complementary solution for selected contexts where centimeter accuracy and geometric completeness were essential for scientific documentation and future conservation assessment. The decision aligns with recent standards in sites where vertical or highly occluded features complicate standard photogrammetric approaches (e.g., Fawzy 2019; Marinov 2023; Ostrowski, 2024).

4.3. *Legacy data, tools and heritage standards*

In addition to the fieldwork, legacy data were systematically incorporated. Excavation diaries, hand-drawn maps, and archival photographs from earlier campaigns were digitized, georeferenced, and cross-validated against the new datasets. This integration facilitated the reconciliation of multi-temporal documentation and provided a more comprehensive account of the site's diachronic use (Kaza, 2006; Kaza, 2009).

The processing and integration phase employed a series of specialized software tools. Photogrammetric datasets were processed in Agisoft Metashape and Polycam Pro, while point clouds generated from the laser scanner were cleaned, registered, and merged using FARO Scene and CloudCompare. The resulting meshes were textured, optimized, and prepared for use across different

platforms. To contextualize these datasets, they were imported into a Geographic Information System (GIS), which served as the backbone for spatial queries and the linkage of archaeological attributes with their spatial coordinates (Konstantakis, 2024).

To ensure interoperability and sustainability, the project adopted international heritage standards. Semantic enrichment was carried out using the CIDOC Conceptual Reference Model (CIDOC-CRM) and its extension CRMdig, allowing the integration of heterogeneous data types such as 3D scans, artefact descriptions, excavation events, and spatial relations. This step established a semantic layer that facilitated cross-referencing, comparison, and long-term reusability of the data (Moraitou, 2022; Moraitou, 2023).

The final 3D digital model was designed as a modular system that combined geometric models, semantic databases, and interpretive metadata within a unified architecture. This structure enabled advanced analyses, such as the spatial correlation of burial typologies with artefact distributions, and supported a variety of applications. For research purposes, it offered new insights into Early Helladic funerary practices and exchange networks. For heritage management, it provided a framework for conservation planning and condition monitoring. Finally, for educational and outreach purposes, the system allowed immersive exploration through virtual and augmented reality environments, thereby bridging the gap between professional documentation and public engagement (Konstantakis, 2018; Aliprantis, 2018).

It is important to note that a 1–2 cm spatial resolution is within the acceptable range for the documentation of archaeological features, as established in recent large-area excavation studies (Marín-Buzon *et al.*, 2021; Wojciech Ostrowski *et al.*, 2024). The selection of accuracy and device configuration balanced site complexity, access, and project sustainability, aligning with current scientific standards for archaeological documentation (Leon-Bonillo *et al.*, 2022; González-Quiñones *et al.*, 2022).

In sum, the methodology of this project illustrates how the integration of cutting-edge 3D documentation techniques, archival sources, and semantic standards can converge into a comprehensive 3D digital model. The approach not only ensures scientific rigor and sustainability but also opens new avenues for interdisciplinary research and cultural dissemination.

5. Results

The implementation of the proposed methodology at the Early Helladic cemetery of Asteria Glyfada produced a comprehensive 3D digital model that integrates three-dimensional spatial data with archaeological attributes and legacy documentation. The photogrammetric campaign, combining aerial and terrestrial imagery, yielded high-resolution textured models of the periboloi, chamber tombs, and associated architectural features. These were successfully aligned with the millimetric-precision point clouds generated by terrestrial laser scanning, resulting in a unified dataset that captures both geometric accuracy and surface detail. The digitized archival plans and excavation records were incorporated into the system, providing diachronic depth and enabling the reconciliation of past documentation with contemporary field data.

The outcomes of the proposed framework can be distinguished into two complementary dimensions. From a technical perspective, the integration of photogrammetry and terrestrial laser scanning achieved both high geometric accuracy and visual fidelity, while ensuring efficient data

management and interoperability through semantic modelling. From an archaeological perspective, the 3D digital model enabled the identification of spatial burial clustering, artefact-specific distribution patterns, and diachronic transformations of the funerary landscape, offering analytical insights that were not attainable through traditional two-dimensional documentation. A comparative summary of the results obtained from photogrammetry and terrestrial laser scanning is presented in Table 1, highlighting their respective strengths and the advantages of their integration within the 3D digital model framework.

Table 1: Comparative results of photogrammetry and laser scanning at Asteria Glyfada.

Parameter	Photogrammetry (UAV + DSLR)	Laser Scanning (FARO M70)	Integrated Dataset
Resolution	~1–2 cm	~2–3 mm	Combined precision
Coverage	Broad (site-scale)	Localized (feature-scale)	Full-scale + detail
Texture Quality	High (color, surface detail)	Low (geometry only)	High + precise
Data Volume	Moderate (GBs)	High (10s of GBs)	Optimized export

Table 2 below presents the statistical comparison between close-range photogrammetry (CRP) and terrestrial laser scanning (TLS) for the documentation of the Asteria cemetery. The data indicate that CRP offered faster acquisition but required longer processing due to image alignment and model generation, while TLS, though involving more setup and longer scan intervals, produced higher geometric accuracy with denser point clouds. The achieved model accuracy for CRP was 1.5 cm, consistent with reported values in Marín-Buzon *et al.* (2021) and Wojciech Ostrowski *et al.* (2024), while TLS reached 3 mm, aligning with best practices for heritage documentation (Leon-Bonillo *et al.*, 2022).

Table 2: Comparative statistics for TLS and CRP models of the Asteria cemetery.

Parameter	Close-Range Photogrammetry (CRP)	Terrestrial Laser Scanning (TLS)
Total Acquisition Time	12 hours (drone + ground images; DJI Mavic 2 Pro, Sony FDR-AX53, iPhone XS)	8 hours (multiple scan stations; FARO Focus M70)
Processing Time	20 hours (alignment, dense cloud, mesh in Agisoft Metashape 1.8.5)	15 hours (FARO Scene + CloudCompare registration)
Model Accuracy (RMSE)	1.5 cm (ground points vs. mesh, measured with scale bars and georeferencing)	3 mm (from manufacturer specs and registration)
Number of Images/Scans	800 images (drone + ground)	15 scans
Output Model Size	2.1 GB mesh (about 8 million faces)	10 GB point cloud (ca. 90 million points)
Resolution	Approx. 1.5 cm/pixel (textured mesh)	2–3 mm/point (point cloud density)

The resulting 3D digital model was uploaded in the [Sketchfab](#) platform and allows advanced analytical capabilities that were not possible through traditional documentation methods alone. Spatial queries and attribute-based analyses enabled the cross-referencing of burial clusters with associated artefact assemblages, revealing new insights into the distribution of Cycladic figurines, obsidian tools, and ceramic deposits within the cemetery. The integration of workshop-related evidence with funerary contexts also offered a more holistic understanding of the site's diachronic use, highlighting the transition from metallurgical activities to ritual and mortuary practices. Moreover, the semantic enrichment of the dataset through CIDOC-CRM facilitated the linking of heterogeneous information, allowing researchers to navigate between excavation events, object typologies, and spatial relations in an interoperable framework.

Usability assessments confirmed the versatility of the 3D digital model across different domains. For archaeologists, the system provides an interactive research environment that supports hypothesis testing and comparative studies with other Early Helladic cemeteries in Attica and the Cyclades. For heritage professionals, it offers a structured platform for conservation monitoring and management planning, ensuring that material traces are documented in a sustainable and updateable format. For education and outreach, the 3D digital models has been adapted into immersive virtual environments and online visualizations, providing students, local communities, and the broader public with access to the site's archaeological heritage. These applications demonstrate the capacity of 3D digital models not only to preserve and analyze complex datasets but

also to foster interdisciplinary research, cultural dissemination, and long-term engagement with the past (Fig 4-6).



Figure 4: 3D model of the cemetery in Sketchfab.



Figure 5: 3D model of part1 of the cemetery in Sketchfab.



Figure 6: 3D model of part2 of the cemetery in Sketchfab.

Our integrated 3D digital model has enabled several new insights into the Early Helladic cemetery at Asteria that surpass those derived from earlier traditional excavation and 2D documentation:

- Spatial clustering and burial patterning: The model's precise georeferencing and spatial query tools revealed previously undetected clusters of graves oriented along natural bedrock ridges, as well as the reuse of workshop-cut pits for multiple interments—phenomena difficult to discern in hand-drawn site plans.
- Artefact distribution analysis: By cross-referencing 3D grave locations with artefact find data, we identified distinctive spatial groupings of Cycladic-type figurines and obsidian tools, suggesting nuanced burial rites or social distinctions within the cemetery that were not apparent in earlier studies.
- Diachronic landscape transformation: Superimposing legacy excavation records onto the new topographic mesh allowed us to quantitatively model erosional processes and document changes in site boundaries since the original investigations—refining prior narratives about cemetery use and landscape evolution.
- Synthesis of funerary and metallurgical contexts: The digital synthesis of workshop and burial data revealed direct spatial relationships between residual metallurgical traces and later mortuary activity, supporting the hypothesis of intentional landscape repurposing (Kaza-Papageorgiou, 2006; Weiberg, 2007).

These analytical advances were only possible through the integration of high-resolution 3D documentation, database linkage, and GIS-based spatial analysis, and they significantly build upon

or correct previous interpretations, as discussed in Kaza-Papageorgiou (2006, 2024) and Weiberg (2007).

6. Discussion - Conclusion

The approach presented here complements and extends existing workflows for archaeological 3D documentation, as documented in international case studies (Marín-Buzon *et al.*, 2021; Leon-Bonillo *et al.*, 2022; Wojciech Ostrowski *et al.*, 2024), by integrating both legacy and new digital data for a unified spatial analysis environment.

The case study of the Early Helladic cemetery at Asteria in Glyfada demonstrates how high-resolution 3D digital documentation and data integration can substantially advance archaeological documentation, spatial analysis, and dissemination. The integration of UAV photogrammetry, terrestrial laser scanning, and archival records addressed persistent challenges of data heterogeneity and enabled the reconciliation of multi-temporal documentation with high-resolution 3D datasets.

The resulting 3D spatial model not only facilitates detailed spatial pattern analysis and integrated artefact distribution studies—which were not previously possible using traditional documentation—but also supports the reproducibility and transparency of archaeological interpretations. For example, our model enabled the identification of previously undetected clusters of burials, the correlation of specific artefact types with distinct spatial zones, and the synthesis of diachronic landscape changes, all of which are presented in the Results section.

Furthermore, the outcome was not only a precise geometric record but also a flexible, semantically enriched platform that supports advanced research questions and interdisciplinary collaboration. By adopting standards such as CIDOC-CRM and CRMdig, the project demonstrated that 3D digital models can function as knowledge-based systems, moving beyond static representations to dynamic archives capable of linking excavation events, artefact typologies, and contextual interpretations. Also, by leveraging recent advancements in 3D digital model technologies, such as those reviewed in Niccolucci *et al.* (2023) and Rossi & Bournas (2023), this project exemplifies innovative approaches to cultural heritage preservation and dissemination. In addition, all 3D models and core datasets are openly available via Sketchfab, providing an accessible platform for future analysis, comparison, and educational outreach; additional contextual data may be made available upon request, in accordance with institutional policies and ethical considerations.

The main limitations of this project derive from fieldwork and environmental constraints: adverse lighting and time pressures limited the optimal acquisition of ground imagery in some areas, and dense vegetation occasionally inhibited TLS coverage in peripheral sectors. TLS registration accuracy was dependent on the number and distribution of reflective targets, sometimes resulting in higher local RMSE in occluded or featureless zones. Balancing file size with processing efficiency for large-area photogrammetry models also required size reduction strategies, with possible minor impacts on textural detail. Despite these challenges, the protocols employed ensured the production of a replicable, metrically accurate dataset suitable for both research and public dissemination. Future work will focus on extending data coverage, integrating additional legacy datasets, and formalizing educational applications of the 3D documentation.

The results confirm that hybrid workflows provide significant advantages by combining the strengths of photogrammetry and laser scanning. This synergy ensured both geometric accuracy and

visual fidelity, while the semantic layer guaranteed interoperability and long-term reusability in line with FAIR principles. The 3D digital model of Asteria offers new archaeological insights into Early Helladic mortuary practices, revealing spatial distinctions in burial patterns and shedding light on the site's diachronic transformation from a locus of metallurgical activity to a funerary landscape. At the same time, it underscores the methodological value of integrated digital frameworks, which can be replicated in other multi-phase archaeological contexts and adapted to diverse heritage environments.

Future work will focus on extending the analytical capabilities of the 3D digital model through targeted enhancements rather than expanding its scope indiscriminately. The incorporation of AI-driven techniques, including automated feature recognition and predictive clustering, will enhance the interpretive potential of the dataset. The development of immersive applications through virtual, augmented, and mixed reality will provide both researchers and wider audiences with new forms of experiential engagement. Linking the Asteria dataset to broader digital infrastructures, such as ECCCH repositories, will allow cross-site comparisons and the creation of interoperable heritage networks. Finally, open-access dissemination strategies will ensure that the 3D digital model continues to serve as a sustainable resource for scholars, heritage professionals, and local communities, reinforcing its role as both a scientific tool and a medium for cultural transmission.

Overall, the proposed framework demonstrates how computational methods and quantitative spatial analysis can be meaningfully integrated into archaeological research, reinforcing the role of 3D digital models as analytical instruments rather than solely as visual representations.

Supplementary Materials

The supporting information of the 3d model of the cemetery can be downloaded at the following link: <https://sketchfab.com/3d-models/cemetery-glyfada-c9c6e26d1ecc40289eb1045a38708ace>

Funding

This research was funded by the non-profit civil company AEGEAS.

Conflicts of Interest

The authors declare no conflicts of interest.

Author Contributions

Conceptualization, M.K. and K.K.; methodology, M.K. and E.I.; software, M.K.; validation, M.K. and E.I.; formal analysis, M.K.; investigation, V.A., G.D., I.G., E.L.; resources, K.K.; data curation, E.L. and K.K.; writing—original draft preparation, M.K.; writing—review and editing, M.K.; visualization, M.K.; supervision, K.K.; project administration, K.K.; funding acquisition, K.K. All authors have read and agreed to the published version of the manuscript.

References

Aliprantis, J., Kalatha, E., Konstantakis, M., Michalakis, K., & Caridakis, G. 2018. Linked open data as universal markers for mobile augmented reality applications in cultural heritage. In *Digital*

Cultural Heritage: Final Conference of the Marie Skłodowska-Curie Initial Training Network for Digital Cultural Heritage, ITN-DCH 2017, Olimje, Slovenia, May 23–25, 2017, Revised Selected Papers (pp. 79-90). Cham: Springer International Publishing.

Barber, R.L.N. 1994. Οι Κυκλάδες στην εποχή του Χαλκού. Athens: Commercial Bank of Greece.

Doumas, C., 1977. Early Bronze Burial Habits in the Cyclades. Göteborg: Paul Åströms Förlag.

Fawzy, H. E. D. 2019. 3D laser scanning and close-range photogrammetry for buildings documentation: A hybrid technique towards a better accuracy. *Alexandria Engineering Journal*, 58(4), 1191-1204.

González-Quiñones, J. J., Reinoso, J. F., Solano, J., Cámara-Donoso, J., León-Robles, C., Linares Matás, G., Jiménez-Arenas, J. M. 2022. Monitoring an archaeological excavation using photogrammetry and digital elevation models (DEMS): the case study of Barranco León in Orce (Granada, Spain). *SPAL Revista de Prehistoria y Arqueología de la Universidad de Sevilla*. 10-30. DOI: 10.12795/spal.2022.i31.18

Guillem, A., Gros, A., Abergel, V., & De Luca, L. (2023, October). Reconstruction beyond representation in Notre-Dame de Paris. In 2023 IMEKO TC-4 International Conference on Metrology for Archaeology and Cultural Heritage.

Hassan, A. T., & Fritsch, D. 2019. Integration of laser scanning and photogrammetry in 3D/4D cultural heritage preservation—a review. *International Journal of Applied Science and Technology*, 9(4), 16. DOI: Hassan, A. T., & Fritsch, D. 2019. Integration of laser scanning and photogrammetry in 3D/4D cultural heritage preservation—a review. *International Journal of Applied*, 9(4), 16.

Kaza-Parageorgiou, K., 2006. Αστέρια Γλυφάδας. Τα πρώτα στοιχεία από μια νέα εγκατάσταση στη δυτική ακτή της Αττικής κατά την πρώιμη και τη μέση εποχή του Χαλκού. *Athens Annals of Archaeology* 39, 45-60.

Kaza-Parageorgiou, K., 2009. Άλιμος, Ελληνικό και Γλυφάδα: Νέα ευρήματα προϊστορικών και ιστορικών χρόνων από ανασκαφές σε ιδιωτικούς και δημόσιους χώρους, in Από τα Μεσόγεια στον Αργοσαρωνικό: Β' Εφορεία Προϊστορικών και Κλασικών Αρχαιοτήτων. Το έργο μιας δεκαετίας, 1994-2003, eds. V. Vasilopoulou & S. Katsarou-Tzevelaki. Markopoulo: Pnevmatiko Kentro Dimou Markopoulou, 433-449.

Kaza-Parageorgiou, K., 2015. Η αρχαία Αστική Οδός και το ΜΕΤΡΟ κάτω από τη Λεωφόρο Βουλιαγμένης. Athens: Kapon.

Kaza-Parageorgiou, K., 2019. Ειδώλια κυκλαδικού τύπου από το ΠΕ νεκροταφείο των «Αστεριών» στη Γλυφάδα Αττικής, *ΑΕ* 158 (2019), 267-285.

- Kaza-Papageorgiou, K., 2020. Αστέρια Γλυφάδας, in Athens and Attica in Prehistory. Proceedings of the International Conference held at Athens, 27-31 May 2015, eds. J.C. Wright, N. Sgouritsa, N. Papadimitriou S. Fachard & E. Andrikou, 309-316.
- Kaza-Papageorgiou, K., Hachtmann V., Prevedorou E., Syrigou M., 2024. Αστέρια Γλυφάδας: Ο κτιστός τάφος 20 της ΠΕ Ι περιόδου, ΑΕ 163 (2024), 227-266.
- Kaza-Papageorgiou, K., 2024. Φάληρο-Βούλα μέσω Αλίμου, Ελληνικού και Γλυφάδας. Παράκτια Διαδρομή με το Τραμ. Athens: Kapon.
- Kaplan, F. 2015. The venice time machine. In Proceedings of the 2015 ACM Symposium on Document Engineering (pp. 73-73).
- Konstantakis, M., Michalakis, K., Aliprantis, J., Kalatha, E., Moraitou, E., & Caridakis, G. 2018. A methodology for optimised cultural user personas experience-CURE architecture. In Proceedings of the 32nd International BCS Human Computer Interaction Conference. BCS Learning & Development.
- Konstantakis, M., Trichopoulos, G., Aliprantis, J., Michalakis, K., Caridakis, G., Thanou, A., ... & Koskeridou, E. 2023. An enhanced methodology for creating digital twins within a paleontological museum using photogrammetry and laser scanning techniques. *Heritage*, 6(9), 5967-5980. DOI: 10.3390/heritage6090314
- Konstantakis, M., Trichopoulos, G., Aliprantis, J., Gavogiannis, N., Karagianni, A., Parthenios, P., ... & Caridakis, G. 2024. An improved approach for generating digital twins of cultural spaces through the integration of photogrammetry and laser scanning technologies. *Digital*, 4(1), 215-231. DOI: 10.3390/digital4010011
- Leon-Bonillo, M.J., Mejías-García, J.C., Martínez-Alvarez, R., Pérez-Romero, A.M., Leon Ortíz, C., Marín-Buzón, C., 2022. SfM Photogrammetric Techniques Applied in the Building Archaeology Works of the Old Cloister of the Monastery of San Francisco from the 16th Century (Cazalla de la Sierra, Seville). *Heritage* 2022 (5), 3901-3922.
- Liang, H., Li, W., Lai, S., Zhu, L., Jiang, W., & Zhang, Q. 2018. The integration of terrestrial laser scanning and terrestrial and unmanned aerial vehicle digital photogrammetry for the documentation of Chinese classical gardens—A case study of Huanxiu Shanzhuang, Suzhou, China. *Journal of Cultural Heritage*, 33, 222-230.
- Marinov, I., Simeonova, G., Mickrenska, C., & Antova, G. 2023. Approach to digital twin of immovable culture heritage. *International Multidisciplinary Scientific GeoConference: SGEM*, 23(2.1), 193-200.
- Marín-Buzon, C., Perez-Romero, A., Lopez-Castro, J.L., Ben Jerbania, I., Manzano-Agugliaro, F., 2021. Photogrammetry as a New Scientific Tool in Archaeology: Worldwide Research Trends. *Sustainability* 13, 5319. DOI: 10.3390/su13095319

- Monterisi, C., Capolupo, A., & Tarantino, E. 2023. Crowdsensing Close-Range Photogrammetry for Accurately Reconstructing a Digital Twin of a Cultural Heritage Building Using a Smartphone and a Compact Camera. In *International Conference on Computational Science and Its Applications* (pp. 234-250). Cham: Springer Nature Switzerland.
- Moraitou, E., Konstantakis, M., Chrysanthi, A., Christodoulou, Y., Pavlidis, G., & Caridakis, G. (2022, November). Supporting conservation and restoration through digital media modeling and exploitation-the example of the Acropolis of Ancient Tiryns. In *2022 17th International Workshop on Semantic and Social Media Adaptation & Personalization (SMAP)* (pp. 1-4). IEEE.
- Moraitou, E., Konstantakis, M., Chrysanthi, A., Christodoulou, Y., Pavlidis, G., Alexandridis, G., ... & Caridakis, G. (2023). Supporting the Conservation and Restoration OpenLab of the Acropolis of Ancient Tiryns through Data Modelling and Exploitation of Digital Media. *Computers*, 12(5), 96. DOI: 10.3390/computers12050096
- Mylonas, G.E., 1959. *Aghios Kosmas: An Early Bronze Age Settlement and Cemetery in Attica*. Princeton: Princeton University Press.
- Niccolucci, F, Markhoff, B., Theodoridou, M., Felicetti, A., & Hermon, S. (2023). The Heritage Digital Twin: a bicycle made for two. The integration of digital methodologies into cultural heritage research. arXiv preprint arXiv:2302.07138.
- Orlandos, A., 1930. La basilique paléochrétienne de Glyphada. *Praktika tis Akadimias Athinon* 5, 258-265.
- Pantelidou Gofa, M., 2005. Τσέπι Μαραθώνος. Το πρωτοελλαδικό νεκροταφείο. Athens: Archaeological Society.
- Polychronakou-Sgouritsa, N., 1988. Το μυκηναϊκό νεκροταφείο Αλυκής Βούλας, αδημοσίευτη διδακτορική διατριβή. Athens.
- Renfrew, C., J.R. Cann & J.E. Dixon, 1965. Obsidian in the Aegean. *Annual of the British School at Athens* 60, 225-247.
- Rossi, M., Bournas, D. 2023. Structural Health Monitoring and Management of Cultural Heritage Structures: A State-of-the-Art Review. *Appl. Sci.* 2023, 13, 6450. DOI: 10.3390/app13116450.
- Theoharis D., 1956. *Atenische Mittheilungen* 71 (1956), 1.
- Underhill, J. 2018. In conversation with CyArk: digital heritage in the 21st century. *International Journal for Digital Art History*, (3). DOI: 10.11588/dah.2018.3.49914
- Weiberg, E., 2007. *Thinking the Bronze Age. Life and Death in Early Helladic Greece*. Uppsala Universitet.

Yamalidi, M., Andreou, A., Lourentzatou, I., 2020. The Northern hill at the peninsula of Laimos in Vouliagmeni. Preliminary evidence from the prehistoric site, in Athens and Attica in Prehistory. Proceedings of the International Conference held at Athens, 27-31 May 2015, eds. J.C. Wright, N. Sgouritsa, N. Papadimitriou S. Fachard & E. Andrikou, 163-174.