

Three Dimensional modelling in Archaeology

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ABSTRACT

The rapid development of digital documentation technologies has created new opportunities for the recording, interpretation, conservation and dissemination of archaeological heritage. Among these technologies, close-range photogrammetry and 360° imaging provide comparatively accessible approaches for generating detailed three-dimensional representations of archaeological structures and objects. This expanded study examines three complementary applications of digital heritage documentation: the Temple of Apollo Pythios at Gortyn in Crete, the archaeological site of Nora in Sardinia, and archaeological artefacts from the Museo Civico agli Eremitani in Padua. The three cases represent different documentation requirements: metric 3D reconstruction and stratigraphic interpretation, immersive virtual-tour development, and high-resolution digitization of small and medium-sized museum objects. The workflow integrates image acquisition, photogrammetric reconstruction or spherical imaging, quality control, model optimization, metadata organization and web-based visualization. The case studies demonstrate that digital documentation can supplement conventional archaeological recording by preserving spatial, geometric and visual information in a reusable digital form.

At Gortyn, close-range photogrammetry supports the analysis of architectural and stratigraphic elements and displaced architectural members. At Nora, 360° imaging supports a navigable virtual-tour environment that extends access beyond the physical site. At the Museo Civico agli Eremitani, photogrammetric models provide a digital representation of objects that can be examined remotely and catalogued with contextual metadata. The study also identifies practical limitations, including lighting conditions, reflective surfaces, image alignment, large point clouds, texture management, geometric gaps and the need for model simplification. The expanded framework provides a reproducible basis for future archaeological digitization projects and highlights the importance of combining technical accuracy with archaeological interpretation and sustainable digital dissemination.

Keywords : Archaeological heritage; photogrammetry; Structure-from-Motion; 3D documentation; virtual reality; 360° imaging; digital museum; cultural heritage; low-cost digitization; virtual tour

INTRODUCTION

Archaeological investigation is fundamentally dependent on the preservation of information that may be altered or lost during excavation, conservation, environmental exposure and subsequent interpretation. Conventional field documentation—such as measured drawings, written descriptions and photographic records—remains essential, but the increasing availability of digital imaging technologies makes it possible to complement these approaches with spatially explicit three-dimensional documentation. A digital model can preserve relationships among surfaces, architectural components, archaeological layers and artefacts in a form that can be inspected repeatedly without requiring continuous physical access to the original heritage resource. Photogrammetry is particularly relevant because overlapping photographs can be processed to reconstruct three-dimensional geometry and associated textures. In archaeological applications, the resulting point clouds, meshes and textured models may support measurement, visualization, comparison and interpretation.

Previous research has demonstrated applications ranging from field documentation to museum artefact digitization and web-based dissemination. However, photogrammetric quality is influenced by image overlap, camera geometry, lighting, surface reflectance, object scale, texture quality and processing decisions. The purpose of this expanded study is therefore not simply to present 3D models, but to examine how different forms of digital acquisition can serve different archaeological objectives. Three case studies are used as a comparative framework. The first focuses on the Temple of Apollo Pythios at Gortyn, where detailed metric documentation is required for architectural and stratigraphic analysis. The second focuses on Nora, where immersive 360° imaging is used to communicate a large archaeological landscape through a virtual tour. The third concerns museum artefacts at the Museo Civico agli Eremitani in Padua, where object-level digitization supports remote study and public dissemination.

2. RESEARCH OBJECTIVES

- To examine the applicability of photogrammetric and spherical imaging methods to different archaeological documentation problems.
- To develop a structured workflow from image acquisition to processing, quality control, metadata organization and online visualization.
- To evaluate the benefits of 3D digital documentation for archaeological interpretation, conservation, research and public access.
- To identify technical and operational limitations that should be addressed in future archaeological digitization projects.
- To propose a transferable framework that can be adapted to archaeological sites, architectural remains and museum collections.

3. BACKGROUND AND STATE OF THE ART

Three-dimensional cultural-heritage documentation may employ laser scanning, structured-light scanning, image-based photogrammetry, macro-photogrammetry, spherical cameras and other sensors. The choice depends on the scale of the object, required accuracy, accessibility, surface characteristics, environmental conditions and intended dissemination platform. Photogrammetry is attractive where a relatively lightweight and economical system is required, while its image-based nature also provides high-quality texture information.

For archaeological work, the value of a 3D model is not limited to visual appearance. A properly documented model can become part of the research record by linking geometry to excavation units, stratigraphic observations, architectural components, object identifiers and historical interpretations. This makes digitalization part of a broader knowledge chain: acquisition produces the digital record processing converts images into measurable or navigable representations; interpretation relates the representation to archaeological questions; and visualization communicates the resulting knowledge to specialists and the public.

At the same time, digital models are not automatically accurate merely because they are visually realistic. Camera calibration, image overlap, scale control, control points, reconstruction settings and quality assurance determine metric reliability. For this reason, future journal-level studies should report quantitative accuracy indicators such as control-point residuals, check-point errors, scale verification, ground sampling distance, point-cloud density and mesh quality whenever these data are available.

4. MATERIALS AND METHODS

4.1 Overall workflow

The expanded workflow is organized into six stages: (1) definition of the archaeological research question; (2) acquisition
 "planning and image capture; (3) photogrammetric or spherical-image processing; (4) geometric and visual quality control;
 "(5) model optimization and metadata enrichment; and (6) dissemination through interactive web or virtual-reality platforms.
 "The workflow is intentionally modular because the three case studies require different forms of output.

Case study	Primary objective	Acquisition approach	Main output
Temple of Apollo, Gortyn	Metric and archaeological documentation	Close-range DSLR photogrammetry	3D point clouds, meshes and textured architectural models
Nora archaeological site	Remote interpretation and visitor access	360° spherical imaging	Navigable virtual tour
Museo Civico agli Eremitani, Padua	Object documentation and remote study	Photogrammetric object digitization	Optimized 3D artefact models with metadata

4.2 Case Study I: Temple of Apollo Pythios at Gortyn

The Temple of Apollo Pythios at Gortyn is an important archaeological and architectural complex in Crete. The site contains architectural remains and inscriptions that require detailed spatial documentation. Earlier documentation included historical surveys and two-dimensional manual recording, while more recent archaeological investigations created a need for renewed spatial analysis. A total-station survey was used for the planimetric organization of the sacred enclosure, while close-range photogrammetry was introduced to capture the three-dimensional structure. The documented area was divided into manageable survey zones so that each zone could contain both an overall view and detailed records of individual architectural elements. A Nikon D750 full-frame camera with a 35 mm lens was used for image acquisition, with emphasis on obtaining sufficiently detailed textures for later inspection.

The resulting three-dimensional representation supports examination of preserved masonry, stratigraphic relationships and architectural elements that are no longer in their original positions. This is particularly important for columns, capitals and entablature components that can contribute to reconstruction studies. The model therefore acts as both a visualization environment and a research dataset from which individual elements can be isolated and examined.

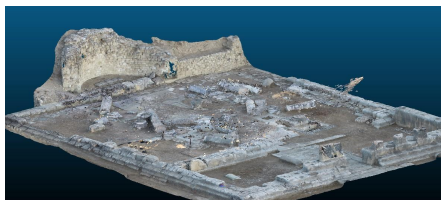


Figure 1. Photogrammetric reconstruction of the excavation area Apollo Temple in Gortyn (Crete).



Figure 2. Photogrammetric reconstruction of a detail of the apse of the temple.



Figure 3. Photogrammetric reconstruction of architectural elements inside the temple.



Figure 4. Kandao Obsidian R 8K camera positioned along the tourist route of the excavation.

4.3 Case Study II: Nora, Sardinia

Nora represents a major archaeological landscape associated with Phoenician, Punic and Roman phases. Because the archaeological area is extensive and contains locations that may be difficult or impossible for ordinary visitors to access, the documentation objective differs from that of Gortyn. Here the primary goal is immersive visualization and remote accessibility. A Kandao Obsidian R 8K 360° camera, incorporating six fisheye lenses, was used to acquire spherical imagery. Camera positions were selected along significant viewpoints so that the resulting sequence would reproduce the logic of an on-site visit while remaining visually continuous. The spherical images were processed using Kandao Studio, where image overlays and alignment could be checked and corrected when necessary. The virtual tour was assembled using the Kuula web platform. A site plan was used as an entry point, and interactive hotspots linked different panoramic viewpoints. The navigation structure supported both sequential movement along the tourist route and direct selection of locations from the map. Additional viewpoints represented areas that are not normally accessible to visitors, thereby providing a form of remote spatial interpretation.

4.4 Case Study III: Museo Civico agli Eremitani, Padua

The third case study addresses the digitization of archaeological objects in the Museo Civico agli Eremitani in Padua. The collection includes material from Egyptian, Greek, Roman, Venetian and medieval contexts. The digitization initiative focused on small and medium-sized archaeological finds, including material associated with necropolises and places of worship. Photogrammetry was selected because it can capture geometry, colour and surface information while avoiding the need for prolonged physical handling or repeated access to objects. The digital workflow generated detailed point clouds and textured models. However, the very high resolution of the raw output created a second problem: models that are appropriate for research may be too large for efficient online visualization. Mesh cleaning and optimization were therefore carried out using MeshLab. Defective or missing portions were addressed where appropriate, texture quality was managed, and model complexity was reduced to improve visualization and computational performance. The resulting models were catalogued with information concerning acquisition technique, material and museum location, and additional tags were used to facilitate retrieval. Models were also disseminated through an online "physical museum environment 3D platform, enabling access beyond the "



Figure 5. Panoramic view of the archaeological site of Nora.



Figure 6. Panoramic view of the archaeological site of Nora.



Figure 7. Processing of the panoramic view using the Kandao Studio software.

5. RESULTS

The three case studies demonstrate distinct but complementary outcomes. At Gortyn, the principal result is a detailed spatial record that can be interrogated at architectural and stratigraphic scales. The 3D model provides a basis for examining relationships among masonry, collapsed architectural elements and preserved structural components. Compared with a purely two-dimensional record, the model retains spatial relationships that can be revisited during later analysis. At Nora, the principal result is an immersive navigation system rather than a conventional metric mesh. The 360° panoramas create a continuous visual environment in which users can move between selected viewpoints. The integration of the tour with a site plan allows users to understand the relationship between individual viewpoints and the archaeological landscape. At the Museo Civico agli Eremitani, the principal result is an object-centred digital archive. The models allow remote inspection of artefacts that may otherwise be difficult to examine closely because of display cases, handling restrictions or physical distance. The combination of 3D geometry, texture and catalogue metadata increases the research value of the digital collection.

6. COMPARATIVE DISCUSSION

The three cases show that the term '3D digitization' encompasses more than one technical product. The appropriate representation depends on the research question. When architectural geometry and stratigraphic relationships are the priority, close-range photogrammetry and metric control are appropriate. When the primary objective is visitor experience and remote site access, spherical imaging and virtual-tour technology may be more suitable. For museum artefacts, object-scale photogrammetry provides detailed geometry and texture that can be integrated with collection metadata. An important common feature is the transition from a raw digital capture to an interpretable and distributable dataset. Image capture alone does not constitute a complete archaeological digitization workflow. Processing, error checking, model cleaning, metadata creation, file management and dissemination are equally important. A visually attractive model with undocumented scale, unknown acquisition conditions or poorly preserved metadata has limited long-term research value. Another major issue is optimization. High-resolution archaeological models can contain millions of points or polygons and very large texture files. Such datasets are valuable for research but can be difficult to display on standard web devices. A two-level strategy is therefore recommended: preserve a high-resolution archival master and create one or more optimized derivatives for web, mobile and virtual-reality use. The derivative should retain sufficient visual and geometric information while reducing computational load.

7. TECHNICAL LIMITATIONS AND QUALITY-CONTROL CONSIDERATIONS

Lighting variability can reduce texture consistency and affect feature detection during image matching. Reflective, translucent, monochromatic or texture-poor surfaces can reduce photogrammetric reconstruction quality. Incorrect image alignment in spherical imaging may produce visible seams or unrealistic geometry. Very dense point clouds and high-resolution textures may exceed practical limits for web-based visualization. Mesh holes, duplicate geometry and irregular surfaces require systematic cleaning and quality control. For metric archaeological research, scale control and independent accuracy checks should be documented explicitly.

Long-term preservation requires standardized file formats, metadata, persistent identifiers, backup strategies and version control.

Online platforms improve access but may introduce dependency on proprietary services; archival copies should therefore remain under institutional control.

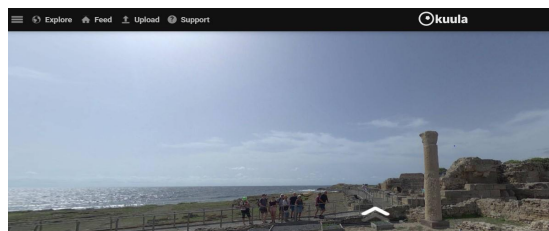


Figure 8. Viewing spot not accessible to tourists.

Protocol for Future Studies

1. Define the archaeological question and required spatial resolution before acquisition.
2. Prepare the site/object, lighting and camera configuration to maximize stable image matching.
3. Use sufficient image overlap and consistent camera-to-object distances.
4. Record camera model, lens, focal settings, image resolution, acquisition date and environmental conditions.
5. Use scale bars, coded targets, control points or independent measurements when metric accuracy is required.
6. Record processing software and major reconstruction settings to improve reproducibility.
7. Inspect point clouds and meshes for holes, noise, misalignment and incorrect surfaces.
8. Preserve an archival master and create optimized web/VR derivatives separately.
9. Attach standardized metadata to each model, including object/site identifier, provenance, acquisition method and processing history.
10. Document accuracy using quantitative checks wherever possible and clearly distinguish measured results from visual interpretation.

9. IMPLICATIONS FOR ARCHAEOLOGY AND CULTURAL-HERITAGE MANAGEMENT

Digital documentation can contribute to several stages of archaeological practice. During excavation, repeated 3D recording can preserve changing spatial conditions. During post-excavation analysis, models can support comparison of architectural elements and surface features. For conservation, digital surrogates can provide a baseline against which future changes may be compared. For education and public engagement, interactive models and virtual tours can communicate archaeological information without requiring physical travel.

The most important implication is that digitization should be treated as an information-management process rather than merely a visualization exercise. Archaeological interpretation depends on context, provenance and chronology; therefore, 3D models should be connected to excavation records, object catalogues, drawings, photographs and scholarly interpretations. This integrated approach can transform a collection of digital models into a research infrastructure.

10. CONCLUSION

This expanded multi-case study demonstrates the potential of low-cost and image-based digital technologies for archaeological documentation and dissemination. The Temple of Apollo at Gortyn illustrates the value of close-range photogrammetry for recording complex architectural and stratigraphic information. Nora demonstrates how 360° imaging can transform an archaeological landscape into an interactive remote-visit environment. The Museo Civico agli Eremitani demonstrates how object-level photogrammetry can support digital collections and remote scholarly access. The cases also demonstrate that successful archaeological digitization requires a balance between geometric fidelity, visual quality, computational efficiency, archaeological context and long-term data stewardship. Future research should strengthen the quantitative validation of photogrammetric products, investigate challenging materials and small objects, evaluate user interaction with virtual heritage environments, and establish interoperable metadata and archival standards. With these additions, photogrammetry and related immersive technologies can become not only tools for visualization, but durable components of archaeological research and cultural-heritage management.

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