

Modeling Memory: Ethical Reuse and AI Training with Archaeologist-Produced 3D Reconstructions

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Abstract – This paper explores the application of 3D digital modeling in prehistoric archaeology through three Mediterranean case studies: Haghia Triada (Crete), Borg in-Nadur (Malta), and Polizzello (Sicily). It demonstrates how archaeologist-led virtual reconstructions go beyond visualization, functioning as interpretive tools for understanding spatial organization, ritual practice, and architectural development. The paper contrasts this approach with AI-generated modeling, highlighting the limitations of automated reconstructions in capturing the interpretive nuance essential to archaeological reasoning. It argues that despite advances in artificial intelligence, archaeologist-driven 3D modeling remains vital for producing analytically robust, contextually informed, and methodologically transparent representations of the prehistoric past.

I. INTRODUCTION

In recent years, 3D digital modeling has evolved from a representational tool into a core method for archaeological analysis, conservation, and engagement. Particularly within prehistoric archaeology, where fragmentary architecture, sparse iconography, and complex stratigraphic contexts complicate traditional interpretation, 3D modeling enables scholars to reconstruct and investigate ancient built environments with increased precision and reflexivity. Yet, beyond its immediate heuristic value, archaeologist-generated 3D models now serve a dual role: they constitute ethically reusable digital heritage assets and provide high-quality training data for generative artificial intelligence systems. This paper reconsiders three long-running case studies of archaeological virtual reconstructions, Haghia Triada (Crete), Borg in-Nadur (Malta), and Polizzello (Sicily), developed within the framework of the Archeomatica Project¹ not only as demonstrations of the interpretive power of 3D modeling but also as examples of best practice in the ethical reuse of digital reconstructions [1]. As emphasized in current discourse on responsible AI in archaeology [2], digital heritage assets must be accompa-

nied by transparent documentation, scholarly attribution, and sensitivity to cultural ownership. When properly curated, these legacy models become foundational resources for both human scholarship and machine learning applications. Indeed, with the rise of text-to-image and multimodal generative tools like Stable Diffusion [3], there is growing recognition that archaeologist-authored models, grounded in excavation data, typological reasoning, and contextual analysis, can play a formative role in improving the plausibility and accuracy of AI-generated visualizations. The models explored in this study, developed within the Archeomatica Project framework, not only illuminate past ritual, architectural, and spatial practices, but also exemplify how digital archaeology can intersect productively with emerging generative technologies, provided it is guided by critical reflection, methodological transparency, and ethical reuse.

II. MATERIALS

The selection of these three case studies reflects a deliberate attempt to showcase the adaptability of 3D modeling to different archaeological challenges, site types, and cultural settings. In Crete, the Propylon, House of the Razed Rooms, and VAP House at Haghia Triada were chosen for their stratigraphic complexity and architectural significance during the Neopalatial and Final Palatial periods. In Malta, the focus was placed on the Borg in-Nadur temple, a site that had largely fallen into obscurity despite its historical importance and once well-preserved state during its early 20th-century excavation. For Sicily, the sanctuary complex on the acropolis of Polizzello, dating between the 8th and 4th centuries BCE, provided a rare opportunity to reconstruct a non-Greek indigenous cultic landscape using stratified data from recent excavations. These projects utilized a diverse corpus of archaeological materials including excavation diaries, architectural plans, historical photographs, topographic data, and detailed artifact records. The reconstructions were grounded in archaeological evidence and informed by broader comparative analyses.

¹<https://www.archeomatica.unict.it>



Fig. 1. *Haghia Triada, 3D reconstructive model of the VAP House, view from southwest [6].*

III. METHODS

The methodological approach adopted across the three case studies was grounded in a combination of philological rigor and experimental reconstruction. All digital reconstructions were developed using Blender, an open-source software for 3D modeling, rendering, and interactive content creation. In cases where lighting analysis was necessary, such as Haghia Triada (Figs. 1-3) and Borg in-Nadur (Fig. 4) the Radiance raytracer was employed to simulate solar orientation and assess the impact of natural illumination on ritual space and movement. Multilayered models were developed for the VAP House (Fig. 2) and Polizzello sanctuary to represent successive architectural phases and allow temporal navigation through the history of the sites (Fig. 5-6). The Borg in-Nadur project also relied heavily on image-based modeling, using historical photographs from the 1920s to restore the monument's original layout, which has since been lost to degradation. Interactive environments were a central feature in both the Maltese and Sicilian models. The Borg in-Nadur reconstruction included 17 panoramic viewing stations integrated into a navigable interface, while the Polizzello sanctuary incorporated avatars, digitally recreated votive offerings, and simulations of ritual actions, providing users with an immersive experience of Archaic religious life. These projects emphasized not only the visual realism of the reconstructions but also their heuristic value, allowing archaeologists to test hypotheses about function, intervisibility, architectural sequencing, and site use in ways that traditional methods could not easily achieve

IV. COMPUTATIONAL IMPLEMENTATION

From a computational perspective, the integration of archaeological 3D models into generative artificial intelligence systems such as Stable Diffusion requires the construction of complex pipelines capable of translating three-dimensional digital objects into formats suitable for training and inference. The process begins with the preprocessing of 3D models, which are converted into multimodal datasets including 2D renderings, depth maps, normal maps, and point clouds. This approach increases the variety and semantic richness of the data without introducing interpretative distortions, thereby creating a balanced



Fig. 2. *Haghia Triada, virtual replica of the House of Razed Rooms and architectural study of the wooden floor with trapdoors and of the roof beams system on the model [7].*

corpus for the controlled fine-tuning of generative models.

The next phase involves the application of contextualized data augmentation techniques, such as controlled variations in lighting, angles, and scale, which enable the neural network to learn not only the geometric form of buildings and artifacts but also their perception in different environmental contexts. In parallel, guided prompt engineering is employed, consisting of the creation of textual instructions enriched with archaeological metadata (chronology, function, architectural style, state of preservation), in order to constrain the AI output to recognized and verifiable patterns.

At the architectural level, the integration of extensions such as ControlNet and LoRA (Low-Rank Adaptation) allows explicit structural constraints, such as floor plans, stratigraphic sections, and typological schemes, to be transferred into the generative models. This significantly reduces the risk of hallucinations and ensures greater coherence with excavation data. The pipeline is managed in GPU-accelerated environments to optimize training times and inference capacity, with workflows orchestrated by containerization systems (e.g., Docker) to ensure portability and reproducibility.

Another crucial dimension is the ethical and documentary management of datasets. Each model is accompanied by extended metadata including provenance, bibliographic references, reuse licenses, and interpretative notes. This information is recorded in version-controlled repositories with semantic tracking systems, ensuring transparency, attribution to the original authors, and traceability of modifications over time. In this way, the digital model is not only

a technical resource for AI but also a dynamic epistemic object, retaining the memory of its production context and the interpretative choices underlying it.

Finally, the pipeline is designed to be open and interoperable, encouraging reuse in museum, educational, and scientific contexts. The adoption of open standards and accessible repositories not only improves the quality of training data for AI but also strengthens dialogue between the archaeological and computational communities. In this perspective, the computational component does not merely enhance the visual quality of reconstructions, but becomes a structural element for ensuring the sustainability, verifiability, and ethics of digital practice in archaeology.

V. DISCUSSION

The projects at Haghia Triada, Borg in-Nadur, and Polizzello collectively demonstrate that 3D models created by archaeologists serve not only as interpretive and heuristic tools but also as ethically reusable digital heritage assets, where AI tools fail to deliver on the basis of the mere textual directions and photographic references offered as source (Fig. 6). When generated according to scholarly standards, with transparency in methods, provenance control, and contextual documentation, these models become valuable resources for future research, conservation planning, and educational dissemination. Crucially, their reuse must comply with ethical frameworks that prioritize scholarly attribution, community engagement, and respect for cultural sensitivities [4].

From a computational standpoint, the reuse of archaeologist-produced 3D models highlights the necessity of robust infrastructures for data curation and interoperability. Unlike generic image collections, archaeological datasets must integrate multimodal representations—3D meshes, annotated renderings, stratigraphic metadata—within structured repositories capable of supporting both human research and machine learning. The implementation of containerized workflows, GPU-based acceleration, and version-controlled repositories ensures that models can be efficiently shared, validated, and adapted for new projects without compromising their scholarly integrity. This approach also emphasizes the role of reproducibility, where computational experiments and AI training processes must be documented as carefully as archaeological excavations themselves, bridging disciplinary methodologies through transparent digital pipelines. It is important to note that, although ControlNet and LoRA allow the introduction of structural constraints and styles into generative models, they do not guarantee perfectly accurate results: their effectiveness depends on the precision of input data and the constraints provided. Similarly, using these tools reduces the risk of hallucinations, but does not eliminate it entirely. GPU acceleration speeds up training and inference, but does not affect the correctness of the generated



Fig. 3. Haghia Triada, philologically accurate 3D reconstructive model of the Propylon and the facade of the Bastion and the Stoa. [8]

data. Finally, containerization with systems like Docker improves portability and reproducibility of the pipeline, but does not ensure flawless operation without proper configuration of libraries, drivers, and hardware.

Re-deploying archaeological 3D assets across new projects or platforms, particularly in open-source or museum-based settings, requires clear metadata, versioning, and credit mechanisms to preserve both the intellectual labor and cultural value embedded in these digital representations. In addition to their role as end-products of archaeological analysis, such 3D models can now inform cutting-edge generative AI systems, including diffusion-based models like Stable Diffusion. When curated and annotated accurately, archaeologist-produced models offer robust training datasets for AI systems tasked with synthesizing new reconstructions or simulating ancient environments. As shown in a recent work on archaeological pottery [5], high-quality, domain-specific inputs lead to more accurate, semantically meaningful outputs. In this light, curated 3D models of prehistoric structures can help constrain and improve the visual logic of AI-generated reconstructions, enhancing their archaeological plausibility and mitigating hallucination risks. The procedural knowledge embedded in human-generated reconstructions, such as stratigraphic reasoning, architectural analogies, and cultural logic, is thus not only critical for human interpretation but also a potential corrective for AI workflows lacking domain expertise. This dual value, ethical reusability and generative potential, elevates archaeologist-created 3D models to more than just static representations. They become dynamic epistemic objects, capable of bridging traditional scholarships with next-generation digital methodologies.

VI. CONCLUSION

Archaeologist-driven 3D modeling, as exemplified in the three Mediterranean case studies, continues to offer irreplaceable value in both interpretive archaeology and digital heritage practice. While generative AI models such as Stable Diffusion are becoming increasingly capa-



Fig. 4. Borg in-Nadur, interface of the interactive virtual model (in the upper right corner the interactive map; blue arrows working as link for the navigation stations) [9].

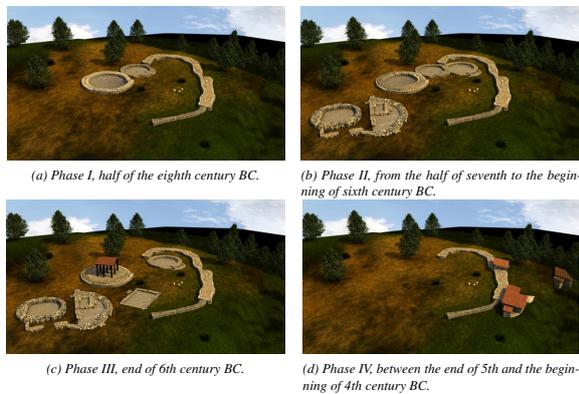


Fig. 5. Polizzello, multilayered 3D model of the Polizzello Acropolis [10].

ble of producing visually striking reconstructions, they still rely heavily on the quality and specificity of their training datasets. Here, archaeologically accurate 3D models serve as foundational ground truths that can inform, train, or constrain such AI systems. Moreover, the ethical reuse of legacy 3D models, when supported by proper documentation, licensing, and scholarly transparency, enables a sustainable digital practice. As emphasized by the latest discourse on AI ethics and cultural data governance, ensuring responsible access and reuse of such models helps preserve the scholarly integrity of archaeological research while fostering new collaborations between human experts and machine intelligence. While AI-enhanced methods may amplify visualization and dissemination capabilities, they cannot replace the contextual understanding, critical reasoning, and interpretive nuance provided by archaeologists. Instead, a symbiotic relationship emerges: the archaeologist curates and interprets, while generative systems extrapolate and visualize. Together, they expand the epistemic reach of digital archaeology, provided ethical reuse and methodological transparency remain central tenets of the discipline.



Fig. 6. AI-generated image of the Propylon of Haghia Triada produced through text-to-image that conflicts with the historical and archaeological reality.

The computational integration of archaeologist-authored 3D models into generative AI frameworks redefines their value beyond heritage visualization. When embedded in reproducible pipelines supported by open standards, metadata governance, and scalable computational environments, these models serve as both interpretive tools and high-quality training corpora. This dual function strengthens the epistemic reliability of AI-assisted reconstructions and demonstrates that informatics is not merely a support layer but a constitutive dimension of digital archaeology. Ultimately, the convergence of archaeological expertise and computational rigor underscores that sustainable innovation in this field depends equally on cultural sensitivity and on the design of transparent, ethical, and technically robust infrastructures. While tools such as ControlNet, LoRA, GPU acceleration, and containerization enhance generative pipelines, careful input preparation and system configuration remain essential to ensure reliable and coherent results.

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