3D Technologies and Virtual Reality in Archaeology: Preserving the Kition Ship Graffiti from Late Bronze Age Cyprus

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Abstract

The southern façade of Temple 1 at the site of Kition (Cyprus) is a unique feature of interest for the maritime cultural heritage of the Eastern Mediterranean, representing the largest concentration of Late Bronze-Early Iron Age ship graffiti from a single context in the region. Due to continuous exposure to the elements and their visible degradation in the last forty years since their excavation, in 2024 the graffiti were recorded using digital photogrammetry and terrestrial laser scanning as a means to both digitally preserve and re-study them. The produced dataset has revealed as many as twenty-three previously unknown graffiti, highlighting the efficacy of 3D recording technologies in the study of petroglyphs on highly damaged surfaces. The third component of our multipronged project involves the digital restoration of the Temple 1 complex, with the goal of creating an accessible, immersive, and historically accurate virtual reconstruction of the graffiti in their broader archaeological context.

1. Background

This paper offers the preliminary results of a re-analysis of a remarkable assemblage of ship graffiti etched onto the monumental façade of Temple 1 at the site of *Kition Kathari* (Figure 1), combining a detailed archaeological study with digital photogrammetry, 3D terrestrial laser scanning, and Virtual Reality (VR). Located on the southeastern coast of Cyprus, the sacred precinct of Kition, constructed in the Late Bronze Age (LBA; ca. 1200 BCE), was excavated in the 1970s (Karageorghis and Demas, 1985). The site was quickly recognized as an exceptionally well-connected port of the LBA Eastern Mediterranean, underscored by its assemblage of wide-ranging imports which would have arrived on seafaring vessels not unlike those depicted on the walls of the temple. The Kition graffiti comprise by far the largest assemblage of ship depictions of Late Bronze–Early Iron Age date from a single site in the eastern Mediterranean. The exceptional discovery has offered critical insights into maritime iconography, nautical technology, seafaring practices, and maritime cultural landscapes during a crucial period of intensifying maritime connectivity in the Mediterranean. A group of nineteen graffiti was originally published as schematic drawings based on photographs of the site's excavation reports, only four of which were provided with more detailed illustrations (Basch and Artzy, 1985 in Karageorghis and Demas, 1985). High-resolution laser scanning in 2024 revealed an additional set of at least 23 graffiti, bringing the total to 42. Recent discoveries at two contemporary archaeological sites in the western part of Cyprus have further expanded the field of inquiry, as they suggest a broader island-wide phenomenon for the very first time. Our work is also timely, as there is significant observable degradation of the blocks and graffiti, which is quite obvious from comparisons with older photographs (Figure 2).

Figure 1. South façade of Temple 1. Photo by T. Manolova.

2. Research Objectives

Despite their great significance, the Kition ship graffiti have remained exposed to the elements since their excavation 40 years ago, with no on-site conservation efforts to protect them from ongoing deterioration (Figure 2). In response to this pressing issue, in 2024 our team collected high-resolution scans of the blocks bearing the graffiti using two complementary methods: photogrammetric imaging to generate detailed 3D models and terrestrial laser scanning using a phase-shift scanner to capture precise 3D surface models and data including incision dimensions, tool marks, and surface modifications. In addition to discovering two unpublished graffiti on a block from a later repair phase, the resulting dataset has revealed 21 previously undetected graffiti on the Temple 1 orthostats, while the morphology of some of the previously documented graffiti has been corrected. The resulting dataset thus serves two ends: first, as a means of preservation, ensuring that these graffiti are documented in high fidelity before further erosion occurs; and second, as a means of further analysis of the ships' morphology and the techniques employed in their incision.

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Figure 2. Comparison of orthostat T1.5 during the 1970s (top) versus 2019 (bottom). Courtesy of Michal Artzy (top)

3D recording technology continues to gain ground as an important medium for the documentation, analysis, preservation, and diffusion of archaeological sites and collections (Arnold and Kaminski, 2014; Ekengren, et al., 2021). In Cyprus, significant methodological advances have been made in the documentation of Medieval graffiti through large-scale digital databases (Demesticha et al., 2017; Škrabal et al., 2023). In contrast, Bronze Age graffiti, including those at Kition, have yet to benefit from comprehensive digital modeling and preservation efforts. Our project addresses this gap by developing a methodology for recording and analyzing graffiti and stone carvings through digital technologies that are both accessible to most archaeological teams and adaptable for broader applications, including epigraphy, masons' marks, and toolmarks. With regard to the restudy of the Kition ship graffiti, our multi-pronged approach is guided by three primary aims: (1) to digitally preserve the ship graffiti as the stone surfaces continue to deteriorate; (2) to deepen and enhance the graffiti's archaeological analysis by using advancing methodologies to record and visualize them; and (3) to provide researchers and the broader public with a new form of engagement with the material through a VR reconstruction. Existing scholarship on the graffiti (e.g., Basch and Artzy 1985; Wachsmann 1998: 145–78, figs. 7.32–7.38; Knapp 2018: 140–141, fig. 35) provides minimal consideration of their physical placement. In response, our project foregrounds the significance of viewership, emphasizing how the scale and positioning of the graffiti as part of the wider temple are integral to their interpretation. The VR environment also allows for a dynamic experience of the graffiti, including interactive lighting controls, revealing how the graffiti's visibility shifts with light and shadow over the course of the day. This immersive approach has both interpretive value for archaeologists and also serves as a didactic for public audiences. Presently, visitors to the archaeological site of Kition *Kathari* are unable to view the graffiti up close – the footpath is far from the temple wall and is confined to the unexcavated soil and a wooden bridge built over the excavated area, both of which are high above the architectural remains of the sanctuary (Figure 1). Consequently, the ability to see the graffiti is greatly obscured. By creating a sensory and spatial engagement through VR, our project offers an avenue for viewing the graffiti as they may have been intended to be seen during the LBA, all the while increasing their accessibility (see Steuri et al. 2023; Paladini et al. 2019).

Archaeologists have long considered the role of sensory experiences, especially in terms of the framework of 'phenomenology' (van Dyke 2014 for overview). This approach is grounded in the idea that meaning and experience are borne from the relationships between human actors, objects, and their environment. From this entanglement emerges a dynamic and recursive process in which space is both created by and creates our experience of the world. The development of digitally immersive technologies such as virtual, augmented, and extended reality over the past two decades (best practices for which are outlined in the London Charter 2009 and Seville Principles 2011) aligns closely with these phenomenological concepts, offering opportunities to simulate ancient settings as they would have been experienced in the past. The advancement of digital techniques in recording, analysis, and visualization has made virtual reconstruction an increasingly popular practice in archaeology and heritage preservation. While the range of scholarship on this topic is too extensive to be addressed in full here, several recent studies provide literature reviews and insights that have informed the development of this paper (e.g., Izaguirre et al., 2024; Al shawabkeh and Arar 2024; Theodoropoulos and Antoniou 2022; Falconer et al., 2020; Bekele and Champion 2019).

3. Methodology

In partnership with the Virtual and Augmented Reality Lab in Sofia, we are developing an immersive VR reconstruction of the temple's built environment based on our digital recordings combined with archaeological drawings and architectural plans produced during excavation (Callot 1985 in Karageorghis and Demas 1985).

3.1 Photogrammetry

The Temple 1 orthostats were captured in digital photogrammetry for the purpose of the VR reconstruction. The equipment used was a Nikon Z6 (a full-frame mirrorless interchangeable lens camera), an FTZ mount adapter, a Nikon 50 mm f/1.4 lens, an X-Rite ColorChecker passport, and three scale bars. Due to constraints such as the opening hours of the archaeological site and the sunny weather during the visit, open shade photography conditions were artificially created with the assistance of a student who held an umbrella over the area being photographed. The photogrammetric capture involved two consecutive visits, with a total of 1317 photographs taken in landscape mode, without a tripod. A high number of photographs were taken as these provide better results in the texture quality of the final render. The camera was set to manual (M) for full settings control, with the auto-focus set to a single focus point. The ISO value was set to 100 and the aperture to f/16 in order to increase the depth of field. The post-processing workflow involved the use of Adobe Lightroom, RealityCapture, Zbrush,

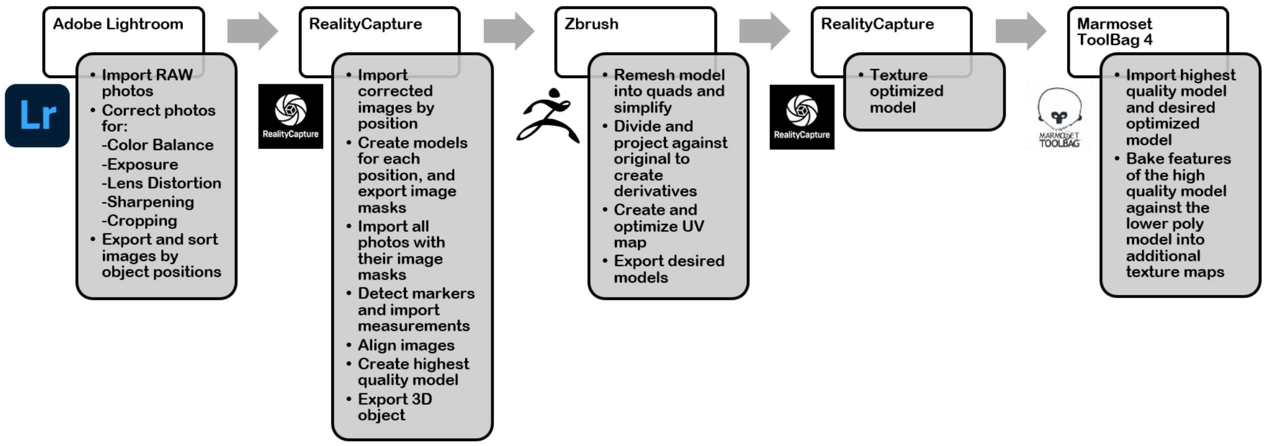

Figure 3. Digital photogrammetry post processing workflow

and Marmoset ToolBag 4, with all steps summarized in Figure 3. The original 3D model produced by Reality Capture for the entire southern façade (all seven orthostats and the later period repair) was 11.8M points and 378.5M polygons. This was reduced down to 60M in order to make the model workable, and was used to bake detail maps for the lower poly models. For optimization purposes, the poly count was further reduced from 60M to 95.6k for the seven orthostats, and from 18.2M to 23.5k for the eight repair block. All textures were produced in 8k.

3.2 Laser Scanning

The graffiti on Temple 1 were also recorded using a FARO Focus^{3D} X330 terrestrial phase-shift laser scanner. Laser scanning allows for the fast and automatic acquisition of points in 3D with high density and resolution and does not require direct contact with the object. Collected spherical coordinates are converted to XYZ coordinates and projected in point clouds. The FARO scanner is also equipped with additional sensors including a GPS, inclinometer, altimeter, and compass in addition to a camera to produce colorized visualizations. Eight scans were collected in 2024 with the scanner set up en face to the middle of block, with the result that the laser hit the middle of the block directly and the edges more obliquely, perhaps leading to slightly lesser point densities in these regions of the blocks. This was a compromise for taking less time per block, as all eight scans needed to be completed in 2.5 days. Scans were nevertheless set to a high quality and resolution, with the settings set to a quality of 3x–4x and resolution between 1/4 and 1/1 (see the FARO Focus3D X330 manual for further descriptions of these measures). These high-resolution scans focused on the blocks were collected following a lower-resolution 360° scan to orient the machine and have a record of the surroundings. The initial scan took about two minutes, while the high-resolution scans took roughly 30 minutes each to complete. The collected points were first processed in the FARO Scene software native to the scanner itself, then meshed and cleaned using open-source applications MeshLab and Gigamesh, the latter of which is developed specifically for the 3D analysis of archaeological materials (for a recent publication by the GigaMesh team, see Linsel et al., 2025; see also Mara et al., 2010; for more information see Mara, n.d.). The resulting meshes (exported as .ply) contained vertice counts of roughly 2.5–3.5 million for each block, with a range of 5–7 million faces produced. This variation is due to the slight variation in the size of the blocks' faces (their lengths range from 238cm to 308cm, and their heights range from 140cm to 148cm), as well as the damage incurred by the block over time, which can cause the laser to hit the block at varying angles and producing varying point densities. This is reflected in the best-preserved blocks having the highest point counts per cm^2. The resulting meshes (exported as .ply) were analyzed using simple but effective functions offered by GigaMesh, namely the Distance to Plane and Angle to Plane functions that allow for consistent geometries to be viewed based on various color ramp options so that details of the graffiti can be highlighted considering depth and angle of their incision (Figure 4). For each scan the ‘plane’ was set relative to a single block in various positions including parallel to the block and bisecting it horizontally and vertically, so that the angle and depth of cuts from the plane are visible based on a hot color ramp. From these visualizations we were able to discern cuts on the ashlar blocks made in order to carve the graffiti, some of which had gone unnoticed and were not visible on-site. These cuts were isolated for better visibility, exported as PNG files and brought into Adobe Illustrator for illustration. Based on the variability of the cuts and the inherent subjectivity in discerning what constitutes a ship, we have created a confidence scale of 1–3. Level 3 represents high confidence that the cuts depict ship graffiti; Level 2 conveys moderate certainty in that these are indeed anthropogenic cuts and seem to represent ships, but their exact composition is not perfectly clear; and Level 1 is the most uncertain, where cuts may be anthropogenic but if and how they represent ships is unclear. Once the ships were drawn in their local contexts, they were compiled into a composite image of the wall as a whole.

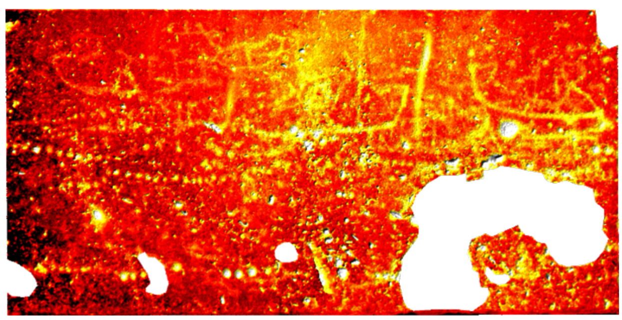

Figure 4. Example of a processed laser scan with Distance to Plane visualization applied. Scan by G. Braun

3.3 Virtual Reconstruction

The digital restoration of Temple 1 was structured into several key phases (Figure 5). The first stage involved a detailed review and selection of the required digital resources, including scientific publications, a 3D SketchUp model of the site layout, high-quality photographs for structural and preservation reference, high-polygon scans of the blocks bearing the graffiti, and reconstructed ship graffiti in vector format. These materials were then processed for optimal use in 3D modeling and VR integration. A block-out of the complex was developed in SketchUp from excavation floor plans of the temple complex (Karageorghis and Demas 1985: Plan VII) to serve as a basis for layout and sizing of the temple buildings. This SketchUp model was then converted to OBJ format, with the exported .obj serving as a geometric reference, preserving the correct proportions and spatial layout of the complex. Albedo textures were extracted from high-polygon scans of the ashlar orthostats, while the provided graffiti images were exported individually as transparent 4K PNG textures. This allowed for planar projection onto each stone block with precise positioning.

To achieve visual consistency across the entire wall, a well-preserved section of the original stone surface was used to generate a seamless texture (Figure 6). This texture retained the qualities of the original material while allowing repeatable tiling without visible seams, contributing to a unified and complete visual impression of the reconstructed ashlar orthostats. Key models were created or rebuilt. Temple 1 and 2 were remade with cleaner geometry for VR compatibility. The south wall was reconstructed as a simplified low-poly model, with missing or eroded sections digitally restored. Special attention was given to the eighth stone block, where additions from a later period were removed and the original texture extended to ensure visual continuity. A before and after view of this restoration is shown in Figure 7.

After finalizing the geometry, the reconstructed low-polygon model was imported into specialized texturing software. Both the extracted albedo textures from the high-polygon scans, the vector graffiti, and the newly created seamless material were imported into the software. The first step involved baking normal, ambient occlusion (AO), curvature, and height maps from the high-polygon models onto the digitally reconstructed version of the wall. This process allowed accurate mapping of surface relief and graffiti engravings. Next, the seamless material was applied across the entire wall surface to unify its appearance. Damaged areas on the original surface were carefully masked and cleaned up by blending in the new texture. Following this, planar projection of the original albedo textures was performed on each individual block, enabling precise alignment of the reconstructed graffiti. The previously prepared vector ship graffiti were then carefully placed and projected as planar decals in their original positions. Only ships of a confidence Level 2 or higher were included in this reconstruction. To simulate the engraved look of the graffiti, normal and height maps were used to generate depth and shading effects that mimic carved stone (Figure 8). Further detailing included the addition of subtle imperfections and variations to avoid visual repetition and enhance realism. The final textures were then exported in high-resolution (8K) formats suitable for Unreal Engine. A landscape terrain matching the geographical context was added, using both Unreal library materials and custom shaders for blending textures and procedural vegetation. A VR rig was configured for free movement with teleportation.

4. Challenges and Limitations

The sensory affordances of virtual reconstruction are crucial for accessing intangible dimensions of the past, particularly emotions and affective responses (Izaguirre et al., 2024: 3 referencing Falconer et al., 2020 and Selmanovic et al., 2018: 9). The immersive VR reconstruction of Guitián by Izaguirre et al. (2024), an archaeological site in the Southern Andes, offers a relevant case study in the considerations and challenges of crafting virtual landscapes. Feedback from participant interviews underscored that sound and architecture were insufficient on their own to fully situate users within the ancient virtual environment. Their solution is “to enrich these VR experiences with additional sources of information that provide tools to interpret the virtual world” (Izaguirre et al., 2024: 17), specifically through dialogue with Non-Player Characters to convey aspects of Andean cultural practices.

While our current objective at Kition is not to produce a fully immersive reconstruction of the entire site, we draw on the insights from such solutions to design an ‘annotated’ view of the ship graffiti and different parts of the Temple 1 complex within our VR environment. Users will be able to toggle individual graffiti on or off according to our levels of interpretive confidence and choose between viewing the site in its current state of preservation or in a reconstructed form that includes a non-eroded surface simulating its appearance in the LBA. Audio annotations will function similarly to museum placards, offering didactic content while situating the graffiti within their original architectural context. Such a contextualization is particularly important given current site constraints, since visitors are unable to approach the graffiti due to an elevated footpath. By restoring a physically embodied viewing perspective, our VR model significantly improves accessibility, by not only enabling close interaction with the graffiti, but also by situating them in terms of their original scale and height on the temple. The issue of transparency has also been an important consideration. This relates not only to methodological reproducibility, ensured through clearly documented workflows, but also to transparency concerning interpretive decisions and the degree of authenticity and accuracy in the virtual model (Al shawabkeh and Arar 2024; Fazio et al., 2022; Pietroni and Ferdani 2021). Our VR experience addresses this by allowing users to: (1) explore the graffiti within their reconstructed context, enabling both their experiential and interpretive meaning; and (2) engage critically with the reconstruction process by visualizing the levels of archaeological certainty.

5. Preliminary Results

3D digitalization and virtual restoration tools continue to show great potential for the accurate documentation, analysis, preservation, and dissemination of threatened cultural heritage to diverse audiences, playing an important role in its democratization. In the case of the Kition Kathari complex and its unique assemblage of ship graffiti, our project demonstrates the efficacy of combining a number of complementary digital techniques. First, the 3D recording of the external face of the Temple 1 orthostats has ensured their digital preservation, addressing the pressing issue of their continuous physical degradation due to the lack of on-site conservation measures. 3D models of the graffiti are viewable from the site entry in the open-access database the Ancient Mediterranean Digital Project (Manolova, 2022; https://w3id.org/ancmed/311). Laser scanning has furthermore proven particularly well suited as an analytical tool

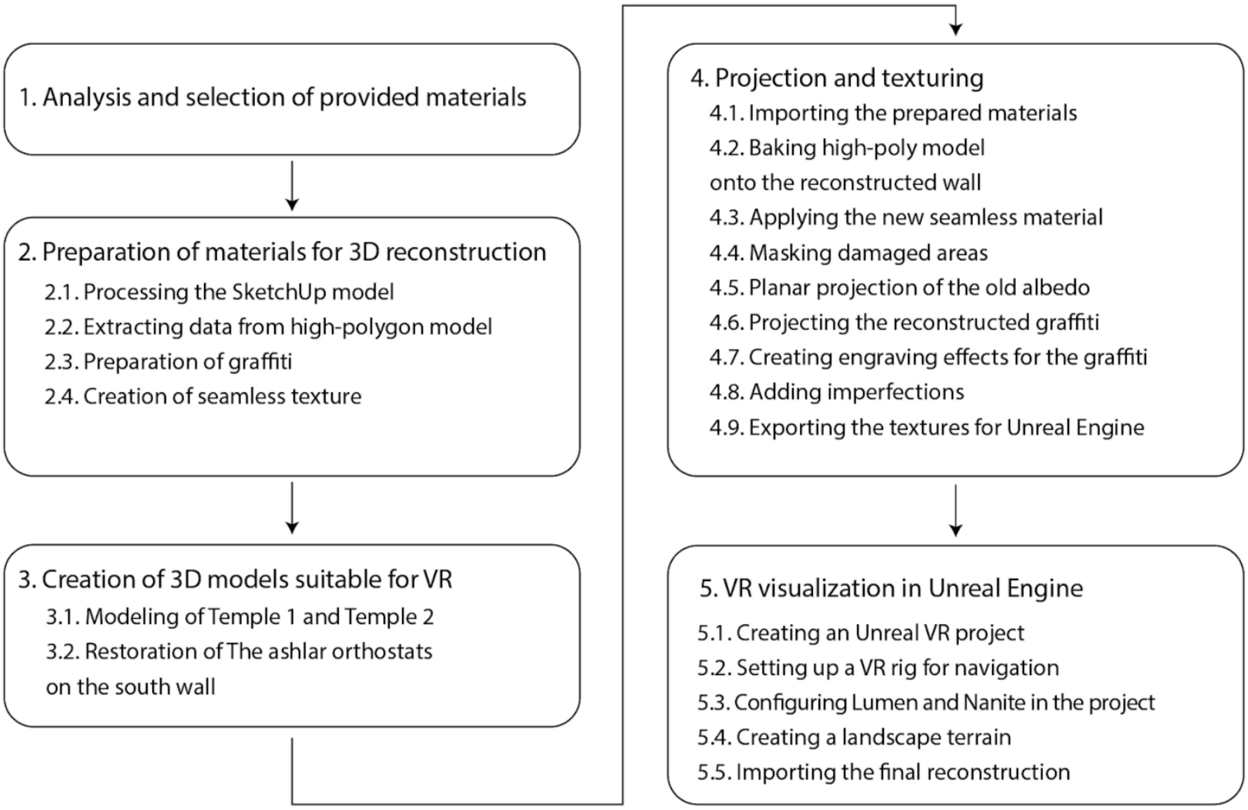

Figure 5. Virtual Reconstruction Workflow

Figure 6. Original section used to create the texture (left) and the final seamless texture after processing (right)

for studying petroglyphs on highly damaged surfaces, allowing us to identify twenty-three additional, previously unnoticed ship graffiti, while also correcting the morphology of others, the full analysis of which will be presented in a forthcoming publication. Finally, the virtual reconstruction of Temple 1 allows us to showcase the graffiti as a whole in their proper monumental context (Figure 9), with an emphasis on viewership as they would have appeared originally. In particular, we consider this to be an integral aspect of the graffiti’s meaning and interpretation given their prominent visual placement within a visitor’s direct line of sight as they approach the temple entrance (Figure 10), a point of emphasis further underlined by the deliberate selection of a specially sourced, white stone which would have stood out amongst the yellow sandstone otherwise used at the site.

Figure 7. Comparison of block T1.8 (bottom) before and after restoration

6. Future directions

Provided the securing of additional funds, the next step of the project is to complete the exterior of the entire temple complex, as well as access to the interior of Temple 4, where the central altar features ashlar blocks engraved with two contemporary ship graffiti. We are currently exploring ways to showcase the VR reconstruction locally in Cyprus, with the hope that it may be suitable either for a museum exhibit, or as an application that allows visitors to the site to experience the temple complex in

Figure 8. Restoration process steps of orthostat T1.5

Figure 9. Preliminary VR reconstruction of Temple 1

Figure 10. View of the Temple 1 orthostats from a user’s perspective walking along the wall towards the entrance

augmented reality. Finally, testing and feedback of the VR experience, as well as interviews with users, is also planned at the LMU Institute for Digital Cultural Heritage Studies at different stages of the project’s completion. The results of this feedback will further inform the next steps of our project.

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