Modeling the Past: Digital Technologies and Excavations in Polis, Cyprus

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Abstract. This research and educational project aimed to create virtual 3-D walkthroughs of four principal buildings from the Princeton University excavations at Polis Chrysochous, Cyprus. The structures date from the Cypro-Archaic period beginning in the 7th century BCE to the Late Antique period of the 7th century CE. The project was conceived together with a special exhibition, a long-term exhibition in Cyprus, and a presentation on the web. In a joint Computer Science and Art and Archaeology seminar in the spring of 2012, students created reconstructions and populated them with 3-D scanned objects. The challenge was to find appropriate visual metaphors for conveying uncertainty and change in these 3-D visualizations as well as to create a computer-animated movie focused on the buildings, their spatial relationships, and possible recon-structions consistent with the excavations.

Keywords: 3-D digital modeling, 3-D scanning, archaeology, Arsinoe, Cyprus, excavation, exhibition, Marion, museum, Polis Chrysochous, public, students.

1 Introduction

Research into 3-D scanning and computer-graphics rendering technologies is beginning to have a significant impact on documenting and understanding material culture for Cultural Heritage projects. With high-resolution digital photographs and 3-D scans we are able to document archaeological artifacts more precisely than through traditional photography alone, and the resulting digital archives can be used for both analysis and exhibition. The project outlined here is part of the larger Princeton University Archaeological Expedition to Polis Chrysochous, Cyprus, usually referred to as the Princeton Cyprus Expedition. While a goal of the Princeton Cyprus Expedition since its inception in 1983 has been to develop digital information storage and imaging technology, usually this has been solely for the scholarly use of archaeologists and art historians. The interdisciplinary project described here, Modeling the Past, also aims to produce images and film for public consumption.

Modeling the Past was first organized during the planning for an exhibition in the Princeton University Art Museum, *City of Gold: Tomb and Temple in Ancient Cyprus* [1]. This exhibition, from October 20, 2012 to January 20, 2013, features the art and

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archaeology of two ancient cities, Marion and Arsinoe, which underlie the modern town of Polis Chrysochous. This project was developed by Smith and Rusinkiewicz in order to model in 3-D four principal buildings that formed community focal points of these ancient cities. It brings together Rusinkiewicz's interests in the digital acquisition and representation of 3-D shape and appearance with Smith's research on the archaeology of the eastern Mediterranean. A film featuring these models will augment the display of artifacts and photographs complemented by texts. The exhibition design is contextualized, with attention to placing objects in relationship to photographs and spaces designed to convey a sense of buildings in which the objects were found. Even so, the film based on the 3-D models provides a greater sense of how one moved inside and around these buildings, as well as how those buildings might have appeared at different times in antiquity within the urban context of the cities.

2 Modeling the Past

The modern town of Polis Chrysochous in northwestern Cyprus lies above the ancient city of Arsinoe (ca. 270 BCE to 1500s CE) and the even older city-kingdom of Marion (founded ca. 800 BCE, destroyed in 312 BCE). From the start of the project, the director, William A. P. Childs, chose to record buildings and artifacts in three-dimensions with the goal of modeling buildings and associated artifacts and soil deposits in 3-D. Early modeling technology in the 1980s led to the development of an innovative but now-outdated VRML system. Since then CAD has been used by the excavation architects, but the larger vision of 3-D modeling remained to be achieved.

The exhibition, *City of Gold*, thus provided an opportunity to explore the po-tential of modern 3-D modeling tools and investigate how digital technologies could augment physical artifacts in "telling the story" of the cultural heritage of Polis. The aim was to highlight the four buildings most featured in the exhibition, two from Marion and two from Arsinoe: a Cypro-Archaic period (ca. 700/650–475 BCE) sanctuary in Princeton grid Area B.D7, a Cypro-Classical period (ca. 475–312 BCE) temple in Area A.H9, a Hellenistic period (ca. 270–58 BCE) porticoed military building in Area E.G0, and a Late Antique (ca. 7th c. CE) basilica in Area E.F2. Each building presented its own challenges for digital modeling. Variables included building material preservation, later phases of reuse, and damage due to later constructions.

With Modeling the Past, we proposed an integrated research and educational project to produce the buildings modeled in 3-D, a computer-animated film for the exhibition, and components for a website that could convey information and uncertainty in a more engaging and flexible way than with images alone. The focus of the project was not research done by a single student or a small group, but rather the first in a series of 12-week, semester-long seminars, offered to undergraduate and graduate students and cross-listed among the Departments of Art and Archaeology and Computer Science and the Program in Hellenic Studies at Princeton University. The final spring 2012 enrollment included twenty undergraduate students and one master's student. Most students were majors in Computer Science. Six students were majors in the fields of Art and Archaeology, Anthropology, History, and the History of Science.

Each three-hour class session was divided into three parts, usually with one or two invited guest-specialists per session. Guest-specialists spoke for 15 minutes and

engaged in class discussion. These specialists included three team members, in addition to Smith, involved in publishing the archaeology of the four buildings. The first hour, led by Smith, focused on topics broadly relevant for understanding how to analyze, interpret, and model the four buildings under study. Readings, short presentations, and discussions addressed the archaeology of Cyprus and Polis Chrysochous, archaeological methods for understanding built space, reading plans and excavation records, Geographic Information Systems, ancient Greek and Near Eastern temples, Hellenistic and Byzantine architecture, building materials, Vitruvian architectural proportions, ritual practices, aesthetics, museum curation, film, and web design.

The second hour, led by Rusinkiewicz, covered topics in computer graphics that were important for understanding approaches for modeling the buildings and levels of certainty in their reconstruction. Short presentations and discussions addressed computer graphics and 3-D scanning, 3-D representations, 3-D meshes, 3-D object scanning, digital imaging and texture mapping, lighting and photorealism, non-photorealism and artistic rendering, computer graphics rendering, and animation. This part of the class also introduced students to custom-written software by Rusinkiewicz that allowed students to manipulate, edit, and mesh 3-D object scans as well as to paste photographs onto 3-D object surfaces.

The third hour was devoted to practical exercises, beginning with how to use Google SketchUp. All underwent training for the software using Lynda.com. Two individual exercises introduced students to modeling the buildings and their geolocation in GoogleEarth. In the fourth class session, students divided into four groups, each focused on one of the four buildings. From that point on, the practical aspect of the class sessions was devoted to progress reports on the models. In the sixth class, students presented midterm reports, showing overall progress on the models and projected plans for the second half of the course. In the eighth week students began working on the storyboard for the short film. In this five-minute film, each building is featured in a one-minute segment. Discussions focused on practical concerns, how to model uncertainty, and the presentation of the models to the public. In the final class session, students presented their final models and film segments.

While the modeling projects were done in the groups, each student was also responsible for writing a final critical assessment of the modeling work, documenting all source materials and other details about the models. These papers as well as the models and associated files form part of the permanent excavation archive. In preparation for this assessment each student wrote a short critical review of a professionally produced 3-D model about which there are publications and short computer-animated films made for university museum exhibitions [2].

Work for the final models and film featured in the exhibition continued during the summer of 2012. One student from the seminar, Nikitas Tampakis, collaborated with Rusinkiewicz and Smith to edit the models, achieve a consistent visual style, and coordinate with the New Media and Broadcast Centers of Princeton University on the final 3-D rendering and lighting for the film with narration in both English and Greek. Not only is the film a feature of the exhibition at Princeton, but also it may be shown in the Local Museum of Marion and Arsinoe in Polis Chrysochous. Animation in the film consists of camera motion, changes in lighting, and switching between models.

Timed with the opening of the exhibition, this film also was made available on the website of the Princeton University Art Museum and the Princeton Cyprus

Expedition. In the long-term we aim to develop a website with flexible hyper-linking and user interaction for scholars and the public. Outstanding questions include how to guide a user's experience of an archaeological site without a linear unifying script on a website and how to integrate this feature into e-Museum exhibitions. Because the seminar, Modeling the Past, is to be offered in years to come, we will take on the challenge of additional buildings, questions of modeling uncertainty, and web design.

3 Scanners and Software

Both standard and custom-written software were used in Modeling the Past. Students had access to digitized primary archaeological information from the Princeton excavations, especially architectural plans and sections of buildings, topographic plans, excavation notebooks, and excavation photographs on the Princeton Cyprus Expedition Sharepoint site, a resource also used by an international team. Students also used the Microsoft Access excavation database. These resources provided descriptive information and x, y, z coordinates for the archaeological data. Based on this information, students used Google SketchUp for modeling buildings and the terrain.

Students also used 3-D scans of objects found in the buildings. These 3-D scans were made in the summer of 2011 by Rusinkiewicz and Smith along with two students, Mali Skotheim, a PhD candidate in the Department of Classics, and Ian McLaughlin, an undergraduate major in Computer Science. The students scanned the objects from the excavations with both a NextEngine HD scanner with roughly 1/8 mm resolution and a Polhemus FastSCAN with roughly 1 mm resolution. Depending on the size of the object, the former was used for small pieces measuring up to 10 cm and the latter for larger pieces, such as a Corinthian column capital (Fig. 1).

The individual scans were aligned with innovative custom-written software implementing the Iterative Closest Points algorithm [3, 4] and merged into a single mesh with Poisson Surface Reconstruction [5]. Finally, custom software was used to align separate DSLR photographs to the merged mesh, and to export a model in Collada format for use by Google SketchUp. High resolution scans are especially useful for the formal study of objects, while lower resolution scans are more appropriate for use within the models. Due to the size and complexity of the 3-D scans of a colossal male statue found inside the temple in Area A.H9, the group modeling that building turned from Google SketchUp to Blender, a switch also made for all the final models in the film. With Blender they were able to animate the statue falling over and breaking into the several pieces as they were originally found during excavation.

These scans and the custom-written software were important for the models, the film, and the objects mounted in the exhibition. A one-meter wide Ionic column capital found in multiple joining and non-joining fragments in the porticoed building in Area E.G0 was mounted using a milled framework based on a composite of 3-D scans of the fragments removed from a complete reconstruction of the capital. All the original pieces were fit and secured into these negative spaces. This framework may be used to display the capital in the Local Museum of Marion and Arsinoe in Polis.

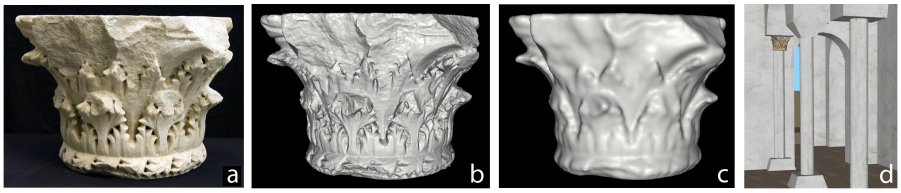

Fig. 1. (a) DSLR photograph of a Corinthian column capital (Princeton Cyprus Expedition R6385/AS123) (b) Polhemus FastSCAN mesh at 0.3 mm resolution, (c) the same mesh at 2 mm resolution, and (d) a lower resolution mesh aligned with DSLR photographs and integrated into the model of the church in Area E.F2

4 Uncertainty and the Future of Modeling the Past

It is important to note that all of the buildings uncovered during Princeton's excavations survive only as foundations and fragmented building materials. Although the structure of a Late Antique basilica may be surmised through comparison with similar existing Byzantine churches and information about the Hellenistic building may be inferred from the geometries of column capitals, shafts, and bases, both present problems due to the mixing of architectural styles and reuse; neither conforms exactly to a type. The Archaic and Classical period buildings are each unique in their specific form. All present challenges due to repeated rebuilding, modification, and destruction.

Taking this preservation into account, from the outset the challenges of Modeling the Past were not only to teach students how to use 3-D modeling tools in archaeology, but also to explore how these tools may be used to convey uncertainty and change, a research question current in both Computer Science and Archaeology. Previous work on 3-D archaeological reconstruction has frequently featured single period models, some highly detailed [2, 6]. Even in complex multi-phase models [7] the transparency of reconstruction can be unclear to users [8]. We sought to create models that may be used to convey different hypotheses of how buildings were constructed or used, to examine relationships between different phases of the same site, and to explore visibility inside and outside of structures. An aim was for lay viewers to learn about the past and how to read a reconstruction, complete with alternate possibilities for buildings that no longer stand. This represents a departure from past research into 3-D scanning and computer-graphics rendering, which is beginning to have a significant impact on documenting and understanding material culture, but has the danger of superseding the authority of the original material.

The earliest structure, a Cypro-Archaic period sanctuary of ca. 700/650–475 BCE in Princeton grid Area B.D7, lies at the heart of the early city of ancient Marion, one km east of the modern town center of Polis. Although its mud-brick architecture is assymetrical and its Cypro-Archaic design was complicated by multiple earlier and later construction phases, the preservation of the foundations, floors, pillar blocks, mud-brick and plaster fragments, and a wall fall that defined the height of the structures all suggested how the sanctuary could be reconstructed. Timber-framed mud-brick architecture provided parallels for the roof. Of particular note are the thousands of votive terracotta figurines and larger sculptures found in place, due to the

destruction of the sanctuary by fire. The model is especially useful for developing hypotheses about movement into and through the sanctuary as well as what could or could not be seen by a person with access to different rooms within buildings (Fig. 2).

The second building modeled from the city of Marion is a large Cypro-Classical period temple with a forecourt and a smaller temple that was destroyed by fire in 312 BCE. Located on a thin spit of land in Princeton grid Area A.H9, this temple was close to the ancient shoreline. It was damaged by the construction of a city wall over its eastern side shortly before its destruction. Even so, the symmetry of the structure, floors, pillar blocks, and roof tiles provided evidence for its reconstruction. While the minimum height of the main temple structure was suggested by the nearly three-meter

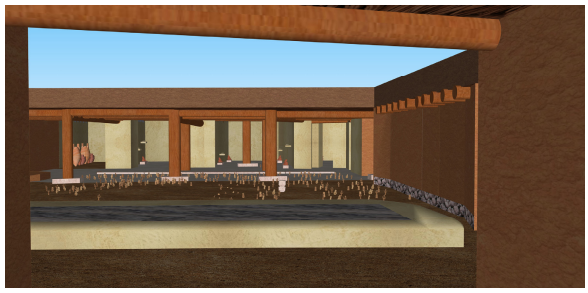

Fig. 2. View from the south entrance looking over the altar and courtyard toward the main temple building of the sanctuary modeled from Area B.D7

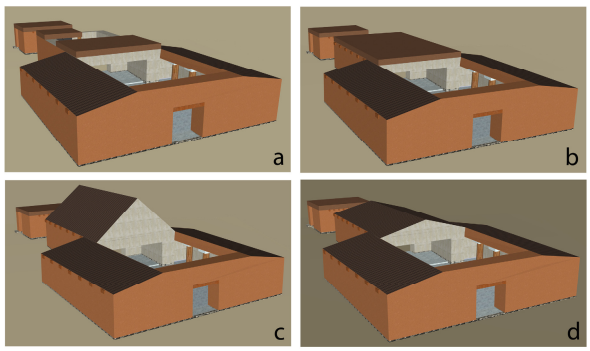

Fig. 3. Different roofs proposed for the temple modeled from Area A.H9, seen from the northeast: (a) flat partial, (b) flat, (c) high pitched, and (d) low pitched. That shown in (d) is thought to be the most plausible

tall colossal statue found inside its interior room, its precise roofing structure was unclear. Based on the presence of a plaster floor only in its porch and a small room inside the temple, the original reconstruction left part of the temple open to the air (Fig. 3a); however, at the midterm this approach was found to be structurally unstable and led to

alternate thoughts about its roof (Fig. 3b), including a high roof pitched at 40 degrees (Fig. 3c) based on the only surviving ancient roof from Cyprus, a stone roof imitating wood found inside a tomb [9]. If the temple's roof was tiled, structural evidence suggests it had a pitch closer to 15 degrees, as in buildings in Classical Greece [10] (Fig. 3d).

From Arsinoe, the earlier structure modeled dates to the Hellenistic period. It was built near the time of the new city's foundation ca. 270 BCE, used into the mid-first century BCE, and possibly reused in the Roman period. It was found just north of the modern town center of Polis in Princeton grid Area E.G0 on a bluff overlooking the ancient shoreline. The destruction of its south end and pillaging of its cut limestone building blocks by those who built a church in the Late Antique period posed considerable challenges for reconstruction. However, the symmetry of the architect-ture, fragments of roof tiles and painted wall plaster, and preserved wall foundations and floors made it possible to model its general design. A study of the proportions of its fragmented Doric and Ionic columns led to calculations of its height. Even its underground cistern and drainage system were modeled. Fortunately the south edge of the southern courtyard was preserved (Fig. 4a), making it possible to suggest a recon-struction of the missing portion of the building (Fig. 4b).

Also from Arsinoe was one of two Late Antique three-aisled basilicas uncovered in the field just north of the modern town center of Polis. The church chosen was not that built over the Hellenistic building, but another more complete example found further south in Princeton grid Area E.F2. Constructed in the 6th c. CE and rebuilt and modified on several occasions until its final collapse in the 11th c., the period chosen for the focus of the model was that of the 7th c., when the basilica was at its height of complexity and design. The clear design of the structure with three aisles, polygonal apses, narthex, and south cloister provided paths to reconstruction. Evidence for floors, frescoed walls, apse mosaics, window transennae, burials, and column capitals all suggested potential reconstructions. The building's multiple phases and coverage with later-period burials were partly incorporated into the model (Fig. 5). It suggests how the presence of burials, not all of which were at floor level as shown here, modified use of the south aisle. The fragmented condition of several details, such as the apse mosaic provided opportunities for experimenting with how to represent projected rather than certain features.

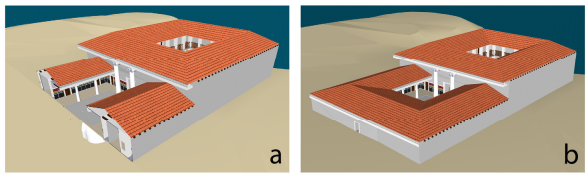

Fig. 4. Reconstruction of the porticoed building overlooking the Chrysochou Bay from the southeast showing (a) a section through the model limiting it to the surface area of the preserved building and (b) the building model with a reconstruction of its southern entrance

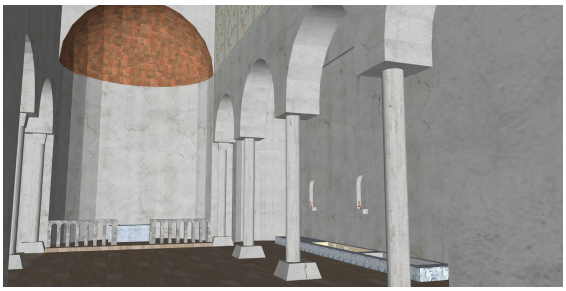

Fig. 5. Modeled interior of the church in Area E.F2 with reconstructed decoration and diachronic features

While Modeling the Past pushed the limits of Google SketchUp, this first stage of the project has promise for the future. The project led us to ask new questions in archaeology and computer graphics that point to new directions for the study and exhibition of cultural heritage through digital technologies. Importantly, it has begun to suggest approaches for representing uncertainty and change. In computer graphics, the fragmentary nature of archaeological remains continues to inspire new ideas about how best to represent and reconstruct them. Archaeologically, the modeling has led to new ideas about these buildings, their urban contexts, and contemporary structures.

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