Online Gaming as Digital Heuristics: The House of the Rhyta at Pseira

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While 3D modeling has only come into widespread archaeological use in recent years, it is hardly a new or untested approach in the study of architecture. Even so, archaeological 3D modeling has largely been limited to use in illustrations, rather than treated as a part of the scientific method. Using the case study of the Minoan House of the Rhyta at Pseira, this article discusses the results of applying 3D modeling as not only a visualization, but also a hypothesis testing tool.

In the summer of 2014, the Minoan Modeling Project undertook a new intensive architectural examination of the Minoan House of the Rhyta at Pseira. The project produced both state and reconstructed 3D models. The 3D reconstruction became the basis of an educational video game designed as a scientific tool to test architectural theories about the use of space. As gamers interact with and circulate through the various rooms in the House of the Rhyta, their movements are tracked and statistically compared with the results of more traditional methods of access and circulation pattern analysis. This article presents preliminary results of this crowdsourced online game study, in addition to discussing strengths and weaknesses of the technique as learned through the process of building the model and game.

1. INTRODUCTION

In the past ten years, archaeologists have seen 3D modeling and, in particular, photogrammetry move from an outlying technology used primarily by specialists to a mainstream tool in the archaeological kit, albeit one that is still often limited to illustration or outreach and frequently published as static images rather than interactive models [Bentkowska-Kafel 2012; Champion 2011; Favro 2012; Forte 2008; Forte and Pietroni 2009; Frischer 2008; Gill 2009; Goodrick and Gillings 2000]. Like any tool, 3D modeling has great utility as well as its own unique set of limitations, which are all too often still murky to non-specialist adopters. Bernard Frischer, as one of the pioneers of 3D modeling in classical archaeology, has also helped to define the next frontier for mainstream 3D modeling: digital

heuristics, direct experimentation using 3D models to verify archaeological hypotheses [2008]. Using the case study of the House of the Rhyta at Pseira, this article highlights one application of 3D modeling and online gaming as scientific tools for research that cannot be accomplished in other ways. It expands on previously published work [Clinton 2020] to present a more finished modeling product as well as the first results of the study. The preliminary results of this project show both the promise of digital heuristics in the study of ancient architecture and some lingering concerns.

Since 2014, I have directed the Minoan Modeling Project, with the aim of creating 3D models related to Bronze Age Crete for scientific research. Beginning with the island of Pseira, I re-studied Building AF North, known as the House of the Rhyta. As an architecture specialist versed in GIS and photogrammetry technologies as well as survey equipment, I combined traditional and digital methodologies in order to reinterpret an enigmatic structure. By 2015, I had built a 3D state model and GIS map of the building, and I next worked with a team of students from Rhodes College to reconstruct the architecture in what I consider to be its most probable original state, although other interpretations are of course possible. The purpose of the reconstruction is not to be the final word on the original House of the Rhyta, but rather to serve as a vehicle for digital heuristics: to use a virtual environment, first, to test whether this reconstruction is plausible; second, to determine how real people might interact with the ancient space; and third, to use those interactions to consider broader implications in the field of Minoan architecture. The reconstruction is now the basis for an experiment to test some of these theories, specifically questions about how people moved through the ancient space of the House of the Rhyta. Thus, this reconstruction should be seen as part of a larger experiment, currently deployed to test my own theories about access and circulation patterns in Minoan architecture, but which could in the future be used to check additional hypotheses, particularly those of other archaeologists who might find the methodology promising. Specifically, the reconstructed 3D model has been uploaded into Unity 3D WebGL, an online gaming engine (albeit without the task-based interactions typically associated with the term "game"). This game can be viewed at rhytahouse.com. The game itself generates the basic data for a crowdsourced research study on access and circulation patterns as real people move through the virtual structure.

2. 3D MODELING METHODOLOGY

The 2014 study of the architecture of the House of the Rhyta at Pseira included traditional drawing and measurement, dGPS, GIS, and high-quality digital photography. The first outputs were a stone-by-stone comparison of the published plans with the preserved architecture, a new block plan, and a 3D state model based on close-range structure-from-motion (SfM) photogrammetry [Koch and Kaehler 2010; Lo Brutto and Meli 2012; Olson et al. 2013; Opitz and Limp 2015; Pollefeys et al. 2000; Santagati et al. 2013; Wulf et al. 2012]. The photos were shot using a 36.3-megapixel Nikon D800 with a 50 mm fixed focal length lens. The photographs were taken at an average distance of 3 m with approximately 53% overlap and processed in Agisoft PhotoScan Professional Edition. The theoretical accuracy of each photograph calculated according to pixel size and distance is 0.3 mm on average. The final state model (Fig. 1) was built from 840 selected photos, out of 7629 photos captured in total. Measurement both for scaling the model and for creation of the GIS plan was completed with a Topcon Hiper Lite Green Label Differential GPS (dGPS), with the resulting measurements imported into ESRI ArcMap for analysis.

Figure 1. 3D photogrammetric state model of the House of the Rhyta at Pseira. View the interactive 3D model on Sketchfab (*https://skfb.ly/6ZyDS*):

After the field research, the team began to build a preliminary reconstructed 3D model in SketchUp (Fig. 2). This preliminary model was created from the GIS-generated block plan, imported as a .jpg file, and supplemented by the state model, imported as a .obj file. The reconstructed walls were modeled directly over the photogrammetric state model, using the ground plan as necessary for clarity and adjusting the floor heights based on excavation records that included the elevations of the multiple succeeding floors, which had been removed during excavations to reveal the foundations of the walls. To import it into SketchUp, the team had to reduce the quality of the state model, which reduced the ultimate accuracy of the reconstructed model. SketchUp's texturing and rendering capacity was also insufficient to create a visually satisfactory gaming experience. Thus, while SketchUp was a useful tool for the team to visualize the reconstruction hypothesis quickly and relatively easily, it lacked sufficient power to create the desired final product.
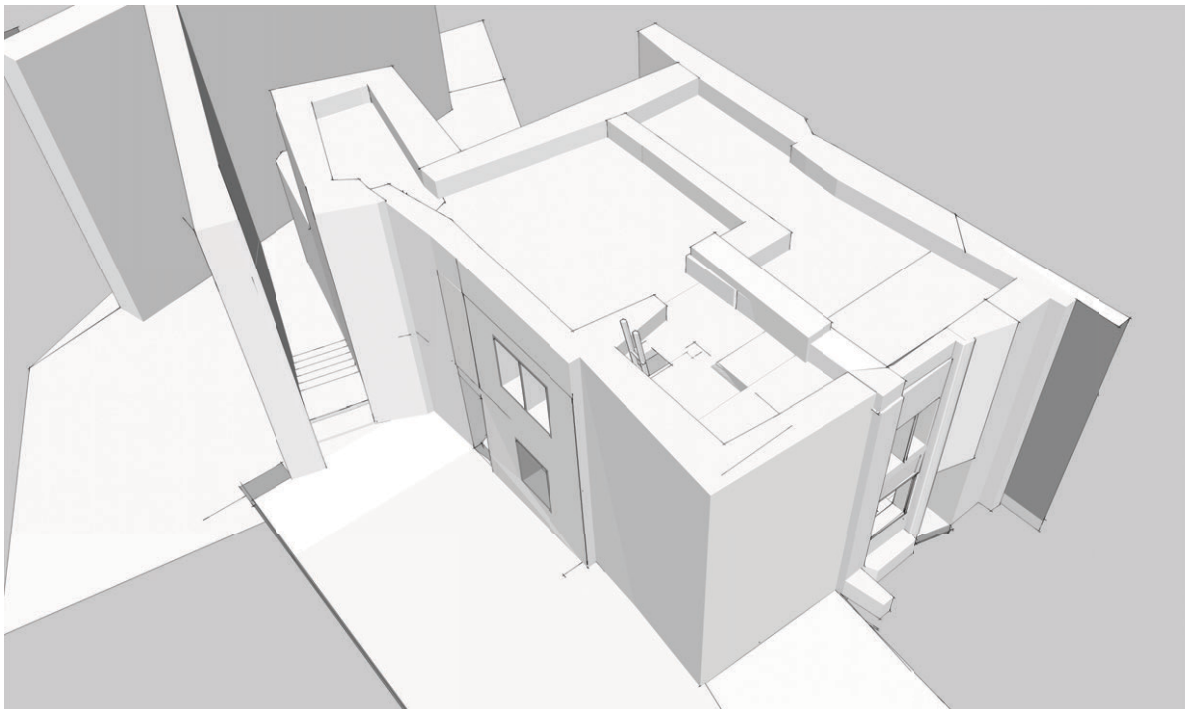

Figure 2. Preliminary reconstructed 3D model built in SketchUp. View the interactive 3D model on Sketchfab (https://skfb.ly/onsRH).

Therefore, the reconstructed model was rebuilt using AutoDesk Maya (Fig. 3) on the basis of both the original SketchUp model and the imported (as a .fbx file) state model. Maya proved robust enough to allow the team to create a more visually appealing and realistic (though not fully photorealistic) reconstructed model, suitable for an online experience. In accord with established standards in 3D modeling research [Bentkowska-Kafel 2012; Champion 2011; Eiteljorg 1998; Favro 2012; Goodrick and Gillings 2000; Johanson 2009; Mosaker 2001], the team sees no need to create a photorealistic rendering for this study, as the processing power required for display would slow the online game substantially without contributing important information either to the front-end users or to the research questions.

Figure 3. Final reconstructed model built in Autodesk Maya. View the interactive 3D model on Sketchfab (https://skfb.ly/onsUW).

3. THE HOUSE OF THE RHYTA AT PSEIRA

The island of Pseira lies approximately 3 km from the northeastern coast of Crete in the Mirabello Bay [Betancourt 2001; Betancourt 2009; Betancourt et al. 1997; Betancourt and Davaras 1993; Dierckx 1995; Floyd 1995; Floyd 1997; Floyd et al. 1995; McEnroe 2001; Pariente 1992]. It is currently uninhabited, but it housed communities of varying sizes and types from the Neolithic through the Byzantine periods. In the Minoan period, a settlement lay on the Katsouni peninsula on the southeastern coast of the island, and, as a seaport, took advantage of its position as a potential harbor for those undertaking voyages to and from the larger island of Crete.

Block AF (Fig. 4), which includes the House of the Rhyta, stands at the southern tip of the Katsouni peninsula. It was excavated in 1990–91 under the direction of Philip P. Betancourt and Costis Davaras. Stratigraphic evidence indicates that Block AF was inhabited from at least Middle Minoan I or II to Late Minoan (LM) IIIA, or roughly 1800–1350 B.C.E. Block AF includes two structures that partially overlap spatially but not chronologically: AF North (Fig. 5), the House of the Rhyta, is the later of the two, having been constructed in LM IB, ca. 1450 B.C.E. It reused two rooms, AF 5A and 5B, that were originally built as part of the earlier construction. AF North was damaged by fire and largely collapsed at the end of LM IB (ca. 1400 B.C.E.). The ground floor of the building was partially reoccupied in LM IIIA (ca. 1400–1350 B.C.E.), but it was never fully reconstructed and fell out of use at the end of the period.
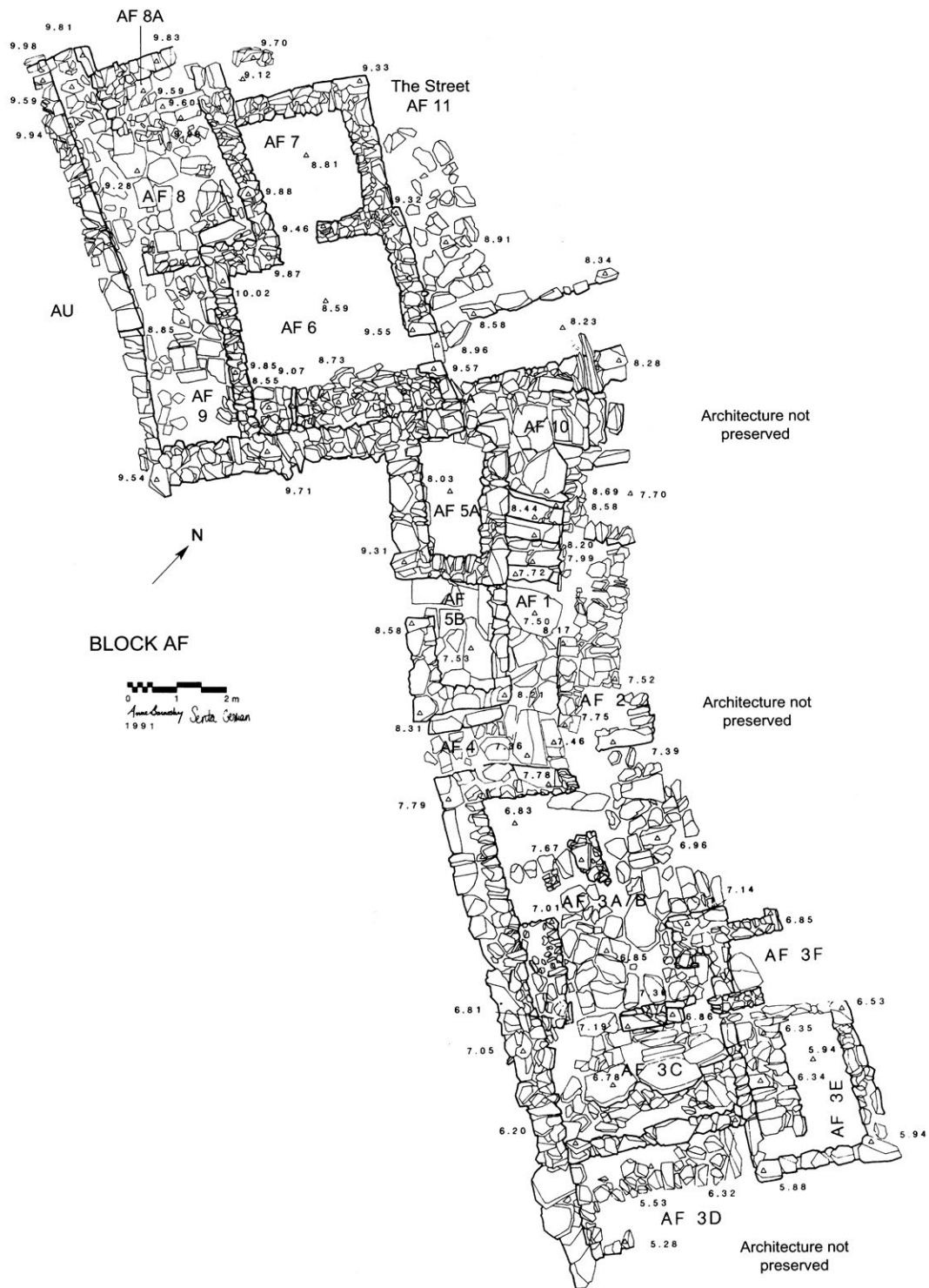
Figure 4. Plan of Block AF at Pseira [after Betancourt 2009].

Figure 5. Plan of AF North, the House of the Rhyta at Pseira [after Betancourt 2009].

Though all of Block AF was studied in the field, and state models for both structures were produced as part of the Minoan Modeling Project, the reconstruction and online gaming study includes only the LM IB building, the House of the Rhyta. This structure falls into McEnroe's Type 2b, signifying a large structure that nonetheless did not display the refinements typical of the palatial or most elite architecture and also contained service areas for activities such as food preparation [1982]. The most notable architectural refinement was the paved flooring set in painted plaster in the upper story. Though it was almost certainly a domestic structure, on the basis of the loom weights; pottery for food preparation, storage, and serving; and installations such as a quern in the service areas, it, like many other Minoan buildings, was multi-functional. Its relative importance in the town is

highlighted by finds, if not architecture, that are more typically associated with elite structures and palaces: far more storage pithoi than would be needed for the inhabitants of the structure alone, pithoi with Linear A inscriptions, pottery in the Knossian Special Palatial Tradition, a marble chalice, and painted and unpainted plaster from both walls and floors. That it also served as a ritual space is indicated by the presence of a large number of rhyta, which are libation vessels with holes in the bottom – including several in the shapes of bulls (whose ritual associations can be confirmed through the evidence of seals and wall paintings, while these particular examples also included molded garlands and painted net decorations, indicating their roles as sacrificial animals), as well as a triton shell of a type found in many sanctuaries, both in domestic and public spaces [Åström and Reese 1990; Karali 1999; Shaw and Shaw 2012]. While many Minoan buildings were multi-functional, the evidence of cult activity is relatively rare, especially on Pseira, which had few ritual structures [Betancourt and Davaras 1998; Davaras 2001; Floyd 1998]. Thus, the House of the Rhyta merits close study not just for its architectural enigmas, but also because of its potential to contribute to a greater understanding of the town of Pseira and its role in the Minoan world. It is also representative of non-elite Minoan architecture, and it can add to the still-developing body of knowledge about Minoan domestic ritual.

The House of the Rhyta (Fig. 5) consisted of six rooms on three terrace levels: the upper terrace, the lower terrace, and the south rooms (by site convention, "north" refers to approximately 315°, though the plans indicate the direction of true north). Rooms AF 8 and 9, which comprised the upper terrace, lay at the northwest. Their only possible entrance must have been in the north wall of room AF 8, but after its collapse the wall was modified by the later LM IIIA inhabitants, who likely blocked the original doorway with a new wall and created a short entrance corridor to its west. The space between the original LM IB north wall of the house and the later LM IIIA wall is visible on the stone-by-stone plans as room AF 8A, but it should not be seen as part of the House of the Rhyta. An opening at the west of the mudbrick partition wall between rooms AF 8 and 9 (still indicated by a jog in the stone socle for the mudbrick), with a step down in floor levels, allowed circulation between the two rooms of the upper terrace. The lower terrace, rooms AF 6 and AF 7, lay at the northeastern corner of the building. Its doorway is still visible in the southeastern corner of room AF 6. As in the upper terrace, a doorway from room AF 6 led to room AF 7, but the terrace had no other access points on the ground floor. Finally, the southern-most rooms, AF 5A and 5B, were also the lowest in elevation. These rooms were not accessible from one another, and only room AF 5B had an outside access point, a doorway in its west wall. In all, the picture of the House of the Rhyta's ground floor is of a house sharply divided. Part of the explanation for the unusual degree of division may be the topography: both the ground level and the structure slope steeply downwards toward the south and less steeply towards the east.

As in many Minoan structures, the more elaborate rooms of the House of the Rhyta were situated on the upper story. The stratigraphy of the debris in rooms AF 5A, 6, 8, and 9 indicates that an upper floor existed, but the architecture itself was destroyed in the LM IB fire and never rebuilt. The LM IIIA inhabitants do not appear to have cleared the collapse debris for the most part, let alone attempted to reconstruct anything other than the ground floor walls. Nonetheless, the finds indicate that the upper story served as the cult space, leaving the ground floor for domestic and work activities. Though few houses on Crete have upper floors any longer, the better-preserved houses of Akrotiri,

which seem to reflect Minoan architecture in many ways, suggest that such an "upstairs-downstairs" arrangement may have been typical of Crete, as well [Palyvou 2005]. Based on the distribution of ritual finds in the collapse debris across rooms AF 5A, 5B, 6, 8, and 9, including some joining sherds found in the debris above different ground floor rooms, the cult space lay somewhere above the upper and lower terraces.

The House of the Rhyta must have been a unified structure, at the very least on the upper story, based on the similar object types and joining sherds found across the collapse levels. Thus, the unusual lack of circulation between the ground floor rooms either indicates a unique zone arrangement without close architectural parallels or suggests that the ground floor terraces were inter-accessible in some way that is no longer preserved, presumably via the upper story. Were it not virtually unknown in Minoan architecture, it would be tempting to conclude that the House of the Rhyta's three terraces were completely separated, perhaps in apartment or townhouse-style construction. Yet, the finds strongly indicate that each was connected to a common upper floor. Exactly how that connection was accomplished is unclear, as no staircase or other obvious access to the upper story has been preserved.

4. RECONSTRUCTION OF THE HOUSE OF THE RHYTA

The ground floor architecture of the House of the Rhyta is relatively clear, though not straightforward. The upper story and the relationship between the ground floor and upper floor rooms, however, remain a mystery. This discussion focuses only on the ground floor and the access points to the upper story, since the online game is designed to test access and circulation patterns. The reasoning behind the full reconstruction visible in the online game will be published in my book in preparation on the House of the Rhyta.

There must have been one or more staircases in the House of the Rhyta. Although a Minoan structure without evidence of staircases, even if those staircases have been destroyed, can occasionally be found (e.g., the Chalinomouri Farmhouse [Soles 2003]), it is unusual. The houses at Akrotiri, the most complete record of domestic architecture available in the Late Bronze Age Aegean, almost all have staircases [Palyvou 2005]. There are 26 preserved staircases at Pseira, likely only a fraction of the total [McEnroe 2001], and some structures on Pseira, such as AD Center [Betancourt and Davaras 1995], even have multiple staircases. Since the House of the Rhyta spans multiple terrace levels, staircases would have been essential. What is more, each zone of the House of the Rhyta must have had its own staircase, since no ground floor access between the zones exists. That is, each ground floor zone must have been accessible from the upper floor. Most important, the presence of the cult facility on the upper floor all but demands an access staircase. While it is true that Minoan structures often contain rooms that are accessible only by ladder, these spaces are almost always doorless storage rooms on the ground floors or basement levels. I know of no examples of ritual spaces on upper floors that were reached solely by ladders; generally, staircases are considered imperative in multi-story Minoan structures [Palyvou 2005].

As can be observed in the model (Fig. 3), I suggest that there were three access points between the ground floor and the upper story of the House of the Rhyta, one in each zone of the structure [Clinton

2016]. Specifically, I place staircases in rooms AF 6/9 and 7/8, while room AF 5A, as a doorless storage room, was most likely accessed only via a ladder [Betancourt 2009] (Fig. 6).
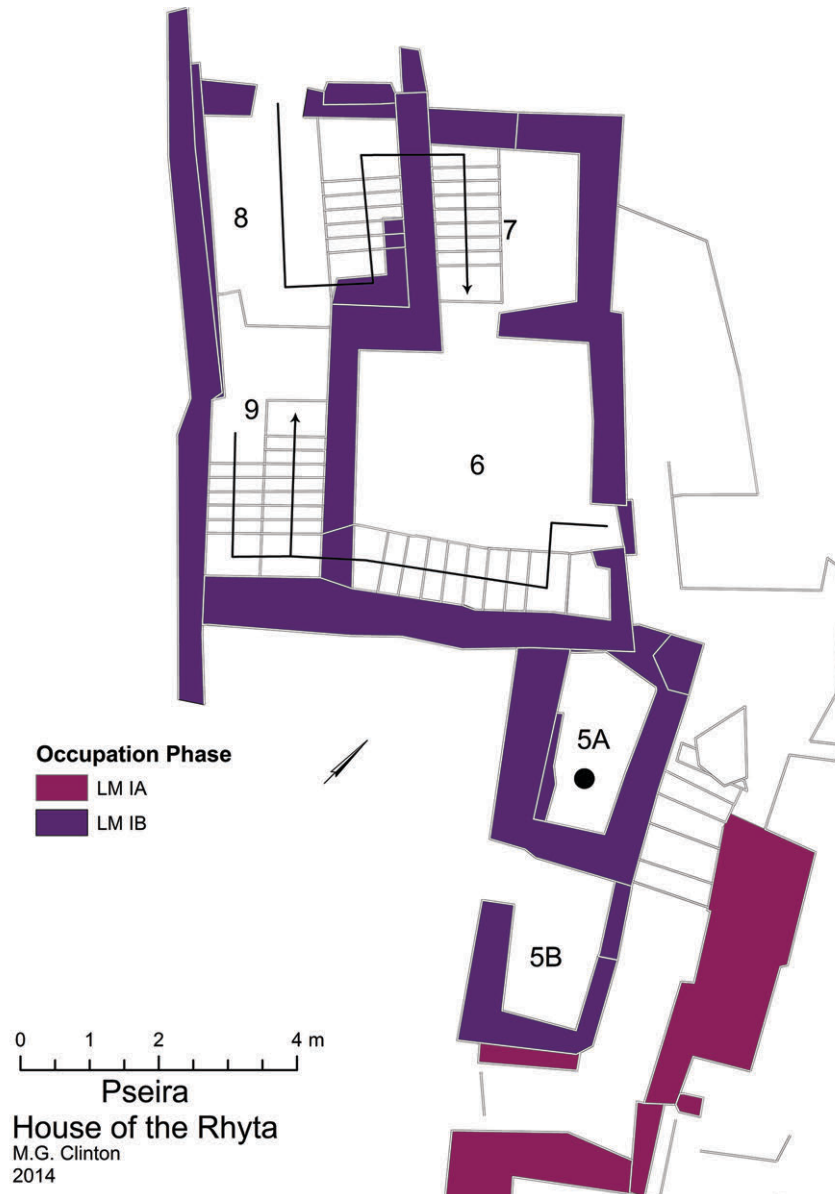

Figure 6. Reconstructed block plan of LM IB House of the Rhyta generated in Esri ArcGIS, showing suggested locations of staircases (outlined without fill) and ladder (black circle). The LM III modification of the north wall has been expunged to allow reconstruction of the LM IB entrance to room AF 8. The L-shaped bench with grinding installation at its foot is visible in the north wall, next to the reconstructed entrance. Arrows indicate paths visitors to the structure could have used to access the upper story.

I suggest that the staircase in rooms AF 6/9 also connected the upper and lower terraces. Room AF 5B's relationship to the rest of the structure is unclear. It may have been accessed by a ladder like room AF 5A, but I have tentatively reconstructed it as a public space entered only from the exterior with no access to the upper floor, similar to rooms sometimes known as "shops" in other Minoan buildings (e.g., The Plateia Building at Pseira [Floyd 1998]).

In addition, I suggest that the primary "public" entrance, or formal visitors' entrance for cult access, was located in the north wall of room AF 8. Two primary clues lead to this identification. First, the L-shaped bench on the north side of this wall is a strong indicator of a main entrance in Minoan architecture (Fig. 7). Vestibules, particularly on Pseira, were often marked by L-shaped benches, including at least two others (Buildings AC 10 and AM 1) that protruded at right angles from an exterior wall [McEnroe 2001]. In addition, the Minoan Modeling Project team's study revealed that the paving slab immediately in front of the bench was an installation for pressing or grinding with one round and three oblong cupules, the oblong ones of which were joined by a shallow channel (Fig. 8). At Akrotiri, it is not uncommon to find installations to manage water and/or perform mill work in or near structures' entrance lobbies [Palyvou 2005]. Second, the finds in room AF 6, the other ground floor room with an exterior doorway, mark it as a space for food preparation, especially the quern built into the floor. At Akrotiri, service areas, including those for food preparation, are usually placed away from the main entrance to a structure [Palyvou 2005].

Figure 7. Still image, detail of Figure 1, showing the L-shaped bench on the north wall of room AF 8.

Figure 8. Photograph of pressing or grinding installation north of room AF 8. Arrows indicate shallow depressions in the flat stone. Water could flow between the three oblong depressions at the south end of the stone, which are longer and shallower than the one at the north.

5.   ACCESS AND CIRCULATION PATTERNS IN THE HOUSE OF THE RHYTA

The variety of access points and staircases that I have reconstructed in the House of the Rhyta can be explained, if not by the topography alone, by the ritual practices on the upper floor, which likely took place in the room above room AF 5. Palyvou has suggested that architectural control over the varying degrees of participation in ritual activities is a hallmark of Minoan religion [1987]. It is likely that the structure's residents, perhaps in an official capacity as has been suggested at Nirou Chani [Hutchinson 1962; Marinatos 1960; Xanthoudides 1922], exercised some control over who could participate in the ritual and how fully. For any ritual participant who entered through room AF 8, the most natural path would be to proceed in a bent axis or almost spiral pattern to reach the cult space, as is seen in Building AC (the "Shrine") at Pseira and elsewhere in Minoan cult spaces [Betancourt and Davaras 1988]. To make the typical elaborate bent axis pattern possible, visitors would have had to climb the staircase on the eastern side of room AF 8, with the second flight rising above the western half of room AF 7. That staircase offered the first internal control point to prevent unwanted access (the entrance itself offered the first over all control point). That is, inhabitants could have stopped visitors in room AF 8 at the foot of the staircase, or again at the head of the stairs before they could enter the cult space above room AF 6. Visitors without the most privileged level of access need

not have been shut out entirely: they could instead have been diverted onto the landing above room AF 9 and even into the room above room AF 8. Presumably the most privileged would have actually entered the cult room above room AF 6.

If the stairway in rooms AF 7/8 can be seen as the public staircase, that in rooms AF 6/9 must have been a more private one (with the caveat that "private" and "public" are terms that probably do not apply in the same way to the Minoan world, which likely had few, if any, fully public or fully private spaces, but are here used for clarity [Altman 1975; Ashcraft and Scheflen 1976; Clinton 2013; Maxwell 1983; Pfeiffer 1980; Scheflen 1976]). By its very presence in a room used for food preparation, the staircase marks itself as a part of the service areas of the house. It likely would not have provided the primary access to the cult space, though it may have had a doorway to the room above room AF 6 on its upper landing, but it would have allowed indirect participation in the ritual through giving access to the room above room AF 8.

My conclusions about the relative privacy of the rooms in the House of the Rhyta spring from my own qualitative typology of access and circulation patterns [Clinton 2013]. For this study, I have focused on privacy from visitors, rather than from other inhabitants. The typology includes a number of circulation patterns, most notably the matrix (or zone), in which certain portions of a structure were more or less isolated from one another, or, rather, limited in their inter-accessibility. Each formed its own area with distinct circulation patterns. The ground floor of the House of the Rhyta is an obvious example of distinct matrices. The upper and lower terraces, each its own matrix, both internally utilize the room-to-room circulation pattern, meaning there are no corridors to guide circulation. Not only is the room-to-room pattern fairly obvious, but in both cases (though to varying degrees) the pattern is also bent axis, requiring the visitor to turn to move from one room to another. AF 5A and AF 5B in the south are each independent. Room AF 5A is a doorless room. In fact, as a doorless space, which would have been accessed only by ladder from the upper story, room AF 5A is the most private room in the structure. Room AF 5B, as a room that opens only to the exterior, seems to be the most public room in the structure. I suggest that rooms AF 8 and AF 6 follow room AF 5B on the spectrum of public to private. Though access and circulation alone, for example as interpreted through strict graphical or Gamma analysis, would indicate that room AF 8 and room AF 6 were equally public, the bench marks room AF 8 as a formal entrance and therefore increases its public-facing appeal over the service area, room AF 6. Rooms AF 6 and AF 7 are also on a more extreme bent axis than rooms AF 8 and AF 9, which helps to support the conclusion that the matrix of rooms AF 8/9 was more public. The upper floor rooms, too, should be considered more private than those on the lower floors (except for room AF 5A) because of the extreme bent axis and room-to-room patterns required to reach them. Thus, if one were to list the rooms of the structure from most public to most private, they might be ranked rooms AF 5B, AF 8, AF 6, AF 9, AF 7 upper, AF 9 upper, AF 8 upper, AF 7, AF 6 upper, AF 5A upper, and AF 5A lower (the doorless room). One could quibble about the particular order in which to rank some of those middle rooms, given that a qualitative typology is not an exact science, but the general ranking is clear, especially the idea that the upper terrace and the rooms above it are more public than the lower terrace and the rooms above it, respectively. Since the room above room AF 6 was the cult space (based on the marble chalice, bull rhyton, wall plaster, and floor slabs fallen from the room, as well as the size of room AF 6), and since room AF 5A was likely a storage room for the cult materials (based on the presence of the triton shell, conical cups, and rhyta and by

analogy with the accepted standard function of doorless spaces), the pattern of increasingly private spaces associated both with ritual and storage of valuable materials accords well with the pattern seen in other Minoan structures.

This qualitative analysis based on architectural observations from other Minoan structures [Clinton 2013] suggests that more Minoans, especially those of higher status, would have entered the House of the Rhyta through room AF 8 than through room AF 6. I additionally suggest that even the people of relative privilege who were allowed to enter room AF 8 would have been further subdivided according to social group: into the more privileged who would have been allowed to climb the staircase at the east of room AF 8 and access the cult space above room AF 6 directly, as opposed to the less privileged, who would have climbed the staircase in room AF 9 to access the cult space indirectly, through hearing but not seeing the rituals from the vantage point of the space above room AF 8. That is not to say that the route up the stairs in AF 8 was the most public route; some and perhaps a majority of Minoan people, after entering through the door into room AF 8, would have proceeded through the doorway to room AF 9, since very likely they were acculturated to know that only privileged people had direct access to the cult area, whereas hoi polloi had only indirect access. Of course, a precise understanding of Minoan class structure is impossible, but analogy with the Cycladic houses of Akrotiri at least suggests that the people of the ancient Aegean in general would have recognized the main staircase near the formal entrance as an elite space.

6. DIGITAL HEURISTICS THROUGH ONLINE 3D GAMING

The majority of methods for access and circulation pattern analysis [e.g., Chermayeff and Alexander 1965; Floyd 1998; Kent 1990a; Kent 1990b; Palyvou 1987; Palyvou 2004; Sanders 1990; Wallace-Hadrill 1988; Wallace-Hadrill 1994], especially those designed to analyze ancient architecture, are qualitative, as is my typology. Even graphical analysis or Gamma analysis [Blanton 1994; Hanson 1998; Hillier 1996; Hillier and Hanson 1984; Letesson 2009], although quantitative, is also limited in its capacity to offer direct proof or incorporate empirical evidence of how ancient people moved through architectural space. The method also has other weaknesses, primarily due to its origins as a means to study modern architecture. Namely, it discards a great deal of contextual information about the ancient structure that would likely be culturally relevant, including the plan [Clinton 2013]. Therefore, this study represents an attempt to create a method by which quantitative data and something approximating direct proof of access and circulation patterns can be provided for ancient architecture. The solution I suggest is to employ a reconstructed 3D model as a tool for digital heuristics, that is, to put the model online and determine what people do in it. The interactive capabilities of 3D modeling provide an opportunity to test how real people move, at least virtually, within ancient space. Since direct observation of ancient inhabitants is impossible, modern proxies are as close as one can get to direct data on the use of space in the ancient world. Such digital heuristics have already been used successfully to test complex social questions in classical archaeology, including specifically to test decision-making in spatial environments (e.g., [Blakely 2015; Clarke 2014a; Clarke 2014b; Clarke 2015; Clarke and Muntasser 2014; Favro 2012; Forte and Siliotti 1997; Frischer 2014; Frischer and Fillwalk 2012; Frischer and Fillwalk 2013; Johanson 2009; Paliou 2011a; Paliou 2011b]).

3D modeling facilitates increasingly realistic interaction with ancient architecture in ways that were impossible in the past, which means that a reconstructed model of an ancient structure provides opportunities for testing access and circulation hypotheses empirically. A 3D reconstruction in a virtual environment allows modern people to immerse themselves in a structure that appears to be complete, with walls that reach above their heads, realistic floors, windows, doors, and even ceilings and a roof. It is as close as a modern visitor can come to experiencing the original building without a physical reconstruction. It stands to reason that those visitors will act and move at least more similarly to how they would in a complete ancient structure, because their virtual bodies will be constrained by the architecture in ways that ruins or plans simply cannot constrain their physical bodies. Therefore, their access and circulation patterns are more likely to be similar to those they would have employed in the original structure than consideration of plans or ruins alone would allow. Their movements, therefore, provide the closest approximation of empirical evidence that current science allows. They can be test subjects to indicate, though never entirely prove, whether architectural theories hold true in the real world. For example, I suggest that the lower floor of the House of the Rhyta is more public than the upper (which, to be fair, is obvious, given that the entrances are on the ground floor) and that, on the ground floor, room AF 7 is less public than room AF 9. If my theories are correct, more online visitors should enter the lower floor of the model than they do the upper; even though it seems obvious that this pattern will hold true in the online game, it is worth quantifying as a check on other results. On the other hand, my hypothesis concerning the relative privacy of rooms AF 7 and 9 on the lower floor is less certain and is based on my own potentially biased experience through years of study and fieldwork. Data on how online visitors move through the structure, however, can be used to test that hypothesis and, hopefully, confirm or deny it.

In the case of the House of the Rhyta, an online game built in Unity 3D and published via WebGL enables the digital heuristics to test my hypotheses regarding access and circulation patterns [Clinton 2020]. The Minoan Modeling Project team imported the reconstructed model into Unity, added a simulated urban environment and sounds, and released it online (Fig. 9) as an educational game. It has been available and collecting data for more than a year. By creating custom colliders and "events," a built-in feature of the software, the team could identify and tag individual rooms within the structure. Although Unity analytics include a position tracker that generates a tabular record of each user's trail, the team built more flexible custom code to record which room (collider) each user entered, how long they spent in that room, and which room they next moved into (an event). All of these data are exported to a SQL database and can then be analyzed with a variety of programs. Most usefully, these data can be used to create a linear and temporal version of access and circulation patterns which can be compared to the access and circulation pattern typology's predictions. They could, in the future, be used to generate heat maps and graphical, as well as statistical, comparisons. Once the game is accessed online, the data are collected automatically. This ease of data collection means that such an online game has the potential to provide "big data" useful for statistical analysis; the team is currently in the process of statistically analyzing the results of interactions with the initial model and producing an improved new game version for more accurate tracking.

Figure 9. Psearching in Pseira, the online game based on the reconstructed House of the Rhyta at Pseira (http://rhytahouse.com).

7. PRELIMINARY RESULTS OF THE ONLINE GAMING STUDY

Although the results of the online gaming study are not final, and true statistical analysis has not yet begun, so far the tracking data have largely supported the hypothesis about access and circulation patterns, based on initial, "back-of-the-envelope," calculations. With the caveat that, without formal statistical analysis, significance and confidence intervals are not yet calculated, the raw numbers are promising. As of May 15, 2020, 341 people had visited the online game, and, after eliminating visitors that were part of the team performing checks or who did not remain long enough to provide valid data (those who visited two or fewer rooms or who stayed fewer than ten seconds), the team was left with 182 hits. People remained in the game for approximately a minute and a half, on average. Most important, the sequence in which they visited different rooms mostly matched the predictions of the access and circulation pattern typology. The hypothesis was that more Minoans would enter via room AF 8, and in fact more modern people in the online game did, too: 112 out of the 182 visitors. One odd note that we are working to understand through the statistical analysis is that if a higher threshold for length of stay, 30 seconds rather than ten seconds, is applied, the percentage of people who enter through room AF 8 seems to drop, as well. The reasons for this correlation are still unclear. Visitors who entered room AF 8 would then have needed to split, entering either room AF 7 or room AF 9. According to the access and circulation pattern hypothesis, more people should have continued straight to room AF 9, and in fact 100 of 112 people did so, rather than climbing the bent axis stairs to reach the ritual space. Once people went into room AF 9 and began climbing the stairs, they were faced with a number of choices: turn back down the stairs and return to room AF 8; continue down the staircase into room AF 6; finish climbing the stairs and continue straight into the space above room AF 8; or turn at the top of the stairs to enter the space above room AF 6. The hypothesis

predicted that more would go straight into the space above room AF 8, but in fact more turned to enter the space above room AF 6, although the split was close to even (39 to 30). No alternative achieved a majority. Without final statistical analysis, it is unwise to draw firm conclusions from these results, but, if they do not relate to some error in the Unity programming, they likely reflect a difference in cultural conditioning between Minoans and modern (primarily) Americans. Thus, the preliminary information seems mostly to support my theories of access and circulation patterns, but even more important for this article, it also shows real success at using 3D modeling as way to test a qualitative theory that is not susceptible to direct proof.

8. LIMITATIONS OF THE METHODOLOGY

The preliminary results of the online gaming study are promising. They suggest that the method of crowdsourcing through an online game is generally useful for addressing questions about ancient architecture. We should not declare victory too quickly, however. A number of factors affect the study's results, and not all can be remedied. On the whole, the crowdsourcing method is an improvement over purely qualitative analysis of access and circulation patterns, but it still does not fully replicate the ancient experience of architecture and therefore cannot be a fully accurate proxy for direct observation. Likely, nothing can.

8.1   Reconstructed Models

Given that the model on which the online game is based is a hypothetical reconstruction, the results of the gaming study are automatically skewed towards my interpretation of the architecture. That is, visitors only have the option to interact with the architecture that the Minoan Modeling Project team reconstructed, which means that they are not moving through other possible versions of the House of the Rhyta. Best 3D modeling practices would suggest that all researchers should produce multiple different reconstructions, separately use each model to analyze the hypothesis to be tested, and include all possible results. Unfortunately, limitations on time and computation precluded the production of multiple models for this particular study, but I encourage future researchers to build on this preliminary work.

In addition, an ideal model would reflect the lived condition of the space, including artifacts, surrounding buildings, crowding conditions, and ambient light and noise, among others, but in archaeological study such accuracy may not always be feasible. For example, many of the surrounding structures on Pseira are either unexcavated or have collapsed into the sea, and the finds have often been scattered by later reuse of the structure, so the team attempted a middle ground that replicated a hilly landscape, included images of surrounding buildings that did not necessarily replicate their original architecture, and built actual finds into the model. We recognize, however, that even our best efforts do not fully recreate the true conditions of the House of the Rhyta in the Minoan world. Such inaccuracies, minimized though they may be, have an unknown effect on the results of the study.

8.2   Ancient Acculturation

The flaw in any theory about access and circulation patterns, including the one presented in this article, is that it is essentially positivist. That is, the theory must be based on an attempt to apply some universal truths about human perception, rather than on a fundamental understanding of the Minoan psyche and perceptual interpretation. For example, science suggests that human vision is more drawn to light areas and to things in front of them rather than to one side, principles long known to artists [Getlein 2020]. Thus, a human, on entering room AF 8, would naturally first be attracted to the doorway to room AF 9 in the far wall, almost directly within line of sight. Unfortunately, real human behavior is not always so simple; natural tendencies are frequently altered by circumstances. That is, humans live in cultural contexts, which can be more influential than their natural instincts. Based on the frequent association of bent axis patterns with cult spaces [Betancourt 2007; Marinatos and Hägg 1986], Minoans were likely acculturated to understand that a bent axis signified something important, usually something ritual. Modern Americans are more acculturated to an axial orientation for both important and sacred spaces. Therefore, Minoans entering room AF 8 might have had a greater tendency than vision science alone suggests to look to their peripheral vision and thus contradict what would otherwise be their natural inclinations. Modern online visitors, however, would more likely follow the patterns indicated by vision science. I suggest that the wide and visible staircase in room AF 8 on the left of Fig. 10, for example, might be a deliberate signal to Minoans entering the doorway that marks the most important pathway, guiding attention away from the noticeably narrow and slightly offset door leading down a step to room AF 9.

Figure 10. The view from the formal entrance to the House of the Rhyta, looking into room AF 8.

I suggest the Minoans were signaling that guidance with their architecture; they routinely arranged sight lines and used visual boundaries to mark zones within structures and to manipulate visitors [Betancourt 2007; Letesson 2009; Marinatos and Hägg 1986; Preziosi 1983; Preziosi and Hitchcock 1999; Sanders 1990].

While a digital model can attempt to recreate the original structure, it cannot simply generate the acculturation a Minoan would have acquired naturally. This flaw is inherent in a modern model of any ancient structure, even a purely analog plan, and it is naturally compounded in the act of interpreting archaeological data. As post-processualist theory suggests, this barrier in inescapable in all archaeological interpretation [Bourdieu 1970; Hodder 1986; Hodder 1999]. Nonetheless, good game designers will attempt to incorporate some degree of ancient cultural knowledge (ideally in a subtle manner). The goal should be to encourage the modern visitor to behave more closely to an ancient visitor without overtly or covertly directing them toward pre-determined ends. This goal might be accomplished through explanatory texts that prepare the visitor before they enter the virtual space. In addition, the format of an educational game, where textual explanations might be expected by users, allows hints including cultural context to be built into the game itself, such as, in the House of the Rhyta, telling visitors that the main entrance to a structure might be marked with a bench. That hint is already incorporated into the game, though in the splash pages before users actually enter the reconstruction, and it may explain modern visitors' preferences for entering room AF 8 rather than room AF 6. On the other hand, "hints" of this sort may cross the line into directions and potentially bias the data by embedding the conscious and unconscious preferences of the archaeologist into what should be free choices by participants. Ultimately, the Minoan Modeling Project team decided to provide explanatory texts at the introduction to the game but not to provide hints once visitors entered the space.

Another way to simulate cultural knowledge is to create groups who have some prior familiarity with the structure and therefore some degree of knowledge about where to go. To accomplish that, a game would need to include multiple levels. Though feasible in the gaming world, there is no reason to believe that such familiarity would form the equivalent of ancient acculturation, unless visitors were inspired to spend significant time within the virtual world. It would also present the problem of maintaining interest among repeat visitors without in other ways biasing their free movement, such as through tasks that constrain their choices of rooms. In turn, such competitive tasks make the interaction more game-like and encourage visitors to move in the unnatural patterns of video gaming [Basu 2018; Basu and Johnsen 2018]. Ultimately, the team decided not to encourage visitors to interact multiple times with the game. Instead, each visitor can choose whether to open a menu that gives educational information about the spaces and artifacts that are visible and, in some cases, offers tasks that the visitor may choose to perform. Not opening the menu and not performing the tasks does not prevent a visitor from moving freely throughout the structure. Instead, the research team concluded that tasks that replicate the Minoan use of the space and require interaction with replicas of the artifacts found in each room best balanced the need for stimulating activities with the requirements of access and circulation pattern research, while simultaneously providing the opportunity for some visitors to gain acculturation. Even this modest level of interference has the potential to introduce some bias, it should be noted, but the team felt that it provided the lowest level

of bias for the desirable goal of providing some minimal acculturation. Other game designers may feel differently.

Ultimately, despite these inherent limitations, the data generated by tracking users through an online model of the sort represented by the House of the Rhyta game is still valuable, simply because it offers the first possibility of direct data on movement through ancient architecture. The study represents a first step; without such new methodologies, it is impossible to know how anyone, ancient or modern, moves through now-destroyed ancient architecture.

9. CONCLUSIONS

This study has presented the continuation of one attempt to use 3D modeling as a tool for digital heuristics. It shows that it is possible, with caveats, to use 3D models for direct experimentation, even to address complex questions involving ancient architecture. Specifically, an online game incorporating position tracking can provide crowd-sourced data to test the hypothesis of whether a dialogic social relationship exists between a structure and its inhabitants and of what nature that relationship might be. While the specific tracking methods used in this study may not be able to answer to every question about ancient architecture, they offer a new tool for the archaeological kit. Archaeologists cannot afford to neglect new sources of data and hypothesis testing. Certainly, 3D modeling as a science and art is continuing to develop, but it has already demonstrated the potential to become a mainstay of the field. As computing capabilities continue to improve and analytical methods are further refined, I anticipate that ever more archaeologists will exploit 3D models for building and testing social hypotheses. It is time well-spent to use such tools to research the lives of non-elites, which are often under-represented in the archaeological record, making new technologies invaluable in providing insights that would otherwise not be available.

10. ACKNOWLEDGEMENTS

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