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Applications of Photogrammetric Modeling to Roman Wall Painting: A Case Study in the House of Marcus Lucretius

Kelly E. McClinton

Department of Informatics, Indiana University at Bloomington, Bloomington, IN 47405, USA; mcclinton.k@gmail.com

Received: 25 March 2019; Accepted: 5 June 2019; Published: 10 July 2019

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Abstract: Across many sites in Italy today, wall paintings face particular dangers of damage and destruction. In Pompeii, many extant fragments are open to the air and accessible to tourists. While efforts are underway to preserve the precious few examples that have come down to us today, after excavation even new finds begin to decay from the moment they are exposed to the air. Digital photogrammetry has been used for the documentation, preservation, and reconstruction of archaeological sites, small objects, and sculpture. Photogrammetry is also well-suited to the illustration and reconstruction of Roman wall painting and Roman domestic interiors. Unlike traditional photography, photogrammetry can offer three-dimensional (3D) documentation that captures the seams, cracks, and warps in the structure of the wall. In the case of an entire room, it can also preserve the orientation and visual impression of multiple walls in situ. This paper discusses the results of several photogrammetric campaigns recently undertaken to document the material record in the House of Marcus Lucretius at Pompeii (IX, 3, 5.24). In the process, it explores the combination of visual analysis with digital tools, and the use of 3D models to represent complex relationships between spaces and objects. To conclude, future avenues for research will be discussed, including the creation of an online database that would facilitate visualizing further connections within the material record.

Keywords: digital humanities; photogrammetry; roman wall painting; roman archaeology; 3D modeling; digital visual analysis

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1. Introduction

This contribution presents a discussion of 3D data capture, modeling, restoration, and publication of Roman wall paintings with special reference to projects involving domestic space. It is possible to view a 3D digital model of wall paintings, or an entire room, as the twenty-first-century equivalent of more traditional illustration methods (such as watercolors, engravings, and 3D physical models) which have been used by archaeologists for centuries (Piggott 1978, pp. 27–35). From these older forms of documentation, 3D models have inherited many of their principal functions, along with several new functions that are advantageous to the study of Roman wall painting, as will be demonstrated here.[1]

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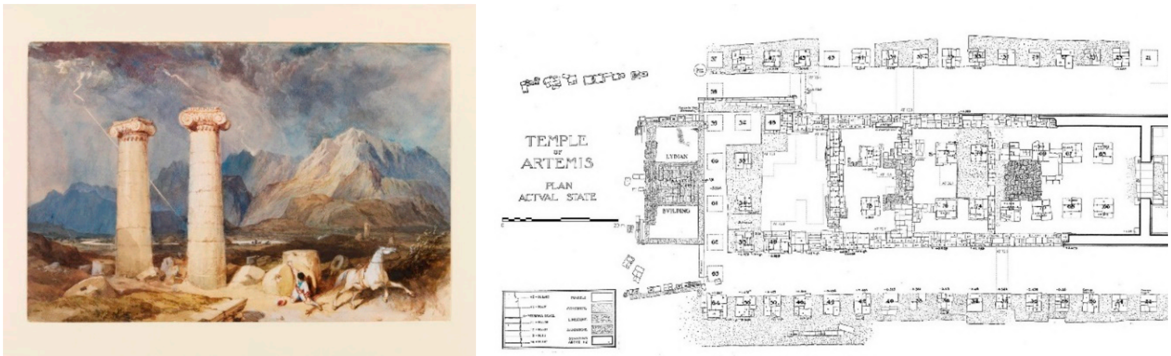
[1] This project represents a collaborative effort of the Virtual World Heritage Lab at Indiana University. Please see the acknowledgements at the end of the article.

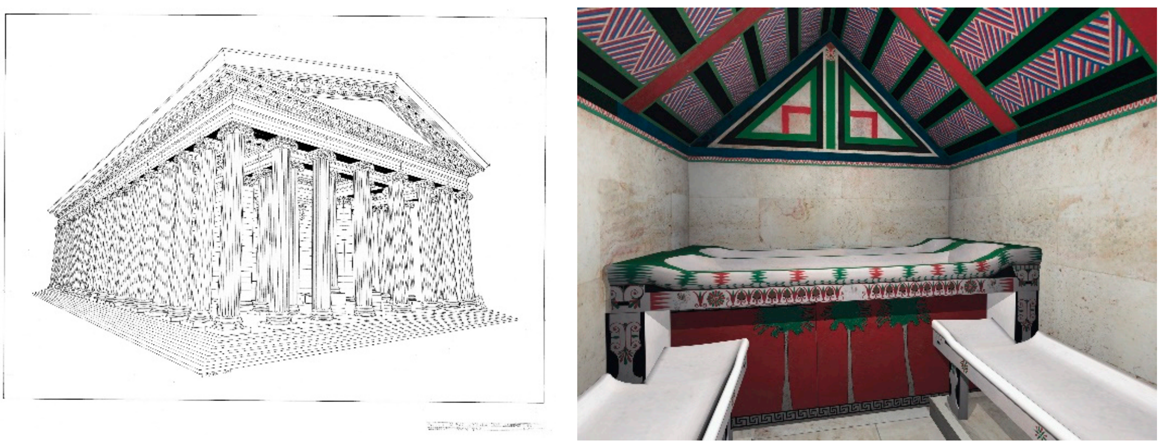
1.1. Brief History of Archaeological Illustration

The important role of illustration in archaeology was recognized early in the history of the field. From the fifteenth century onward, much of the graphic recording of excavation sites was accomplished through drawings and paintings by artists and architects (Figure 1a). In the first minute-book of the Society of Antiquaries of London in 1717, William Stuckley argued for the importance of illustration in the study of ancient objects (Piggott 1978, p. 28). When modern archaeological publication and illustration arrived in the nineteenth century, systematic and scientific documentation methods were adopted quickly (Figure 1b), and schematic plans and line drawings became a standard component of modern excavation (Bowden 1991, pp. 57–94; Piggott 1978, pp. 53–55; Pitt-Rivers 1887). Reconstructive and interpretive drawings were also used to examine possible architectural arrangements and designs. (Figure 2a).



(**a**) (**b**)

Figure 1. Illustrations of Sardis. (**a**) Title: Sardis. One of the Seven Churches (Watercolour), Date: 1834–1835, Place: Turkey, Artist/maker: Stanfield, Clarkson, Current Location: the Victoria and Albert Museum (used by permission); (**b**) Image Courtesy: Plan of the Temple of Artemis showing Church M. The Archaeological Exploration of Sardis/President and Fellows of Harvard College (used by permission).



(**a**) (**b**)

Figure 2. Illustrations of Sardis. (**a**) Reconstruction of fully restored Roman phase of the Temple of Artemis, view from southeast, by Fikret Yegül. Image Courtesy: The Archaeological Exploration of Sardis/President and Fellows of Harvard College (used by permission); (**b**) Reconstruction of tumulus chamber at Lale Tepe (Stinson). Image Courtesy: The Archaeological Exploration of Sardis/President and Fellows of Harvard College. Appeared in (Stinson 2003, p. 141; used by permission).

One of the most famous sites to be illustrated using the techniques noted above is Pompeii. Virtually from the moment excavations began, detailed plans of the uncovered buildings were created to document the site (Guzzo 2018, pp. 21–29; Kockel 2016, pp. 10–15). These documents served not only to illustrate scholarly publications, but also to preserve the arrangement of wall painting panels that had been selected for display in the *Real Museo Borbonico* (Pagano 1992, p. 170). A recent exhibit in the *Museo Archeologico Nazionale di Napoli* highlighted the use of engraving, watercolor reconstructions, and plastic and cork models in the early phases of excavation to preserve and organize information on Pompeii (Guzzo et al. 2018). The *Plastico di Pompei*, now located in the *Museo Archeologico Nazionale di Napoli*, depicts at a scale of 1:100 the state of the excavated area up to 1908. It thus preserves a great deal of information about the rooms and walls that in the meantime have suffered damage or even destruction (Figure 3).

Figure 3. Plastico Pompeii. Image Courtesy: Prisma Archivo (used by permission).

In the 1990s, new digital documentation methods began to be used in conjunction with more traditional illustrational techniques (Figure 2b). These newer forms of documentation, such as 3D models, were not meant to replace photographs and two-dimensional drawings (Stinson 2003, p. 121). Instead, digital 3D illustrations quickly became excellent supplements to these more traditional methods of documentation. Similar to the advantages of cast and digital reproductions over 2D images of sculpture, 3D representations of Roman houses can augment photographs and drawings by preserving their three-dimensional aspects (Borbein and Schuchhardt 1962, pp. 519–21; Frischer 2015, p. 78). In addition, 3D models can quickly document and convey the current state of preservation. They also allow a viewer to virtually experience both scale and space through hypothetical reconstructions.

In comparison to more traditional methods of physical modeling and detailed line-drawing, 3D data capture techniques such as photogrammetry are particularly well-suited to quickly capturing a record of the site as it appears and require no direct contact with the original material. Once 3D models of a single wall painting, or an entire room are created, the results can be compiled into a comprehensive record for an entire house. The photogrammetric 3D model can also serve as a basis for the reconstruction of the original space. In brief, photogrammetric models can be a powerful aid to both documentation and visualization in art history and archaeology.

1.2. Pioneering Projects

The history of digital 3D illustration in cultural heritage began shortly after 3D scanning instruments began to be commercialized in the 1990s. Devices such as laser scanners could be transported to an archaeological site and used for on-site, 3D data collection. Their potential use for documentation of monuments in the field of cultural heritage was quickly realized (Godin et al. 2002, pp. 27–33; Guidi et al. 2004, p. 370; Guidi et al. 2009, pp. 8–9; Levoy 1999, pp. 2–11; Remondino 2011, p. 1105).

Ancient spaces in the Bay of Naples, in particular, have been investigated through a digital approach to visual analysis (Bergmann 2010, pp. 16–31; Fredrick 2014, pp. 464–65; Landeschi 2018, pp. 2–4; Opitz 2017, pp. 1206–7). A notable use of digital modeling within perception studies is the facilitation of a comparison between the preserved remains and an overlaid, hypothetical reconstruction. This can be done by combining both the model of the current state of the structure in an application along with the restoration model. Software allows the user to toggle quickly from one model to the other, thereby facilitating a visual comparison between the hypothetical reconstruction model, and the extant material record.

The Swedish Pompeii Project included in the model of the House of Caecilius Iucundus both a model of the house as it appeared at the time of excavation and a reconstruction of the house as it might have appeared in antiquity (Dell'Unto et al. 2013, pp. 626–27). All this was accomplished in the 3D geographic information system (3D GIS). These models were then used as a basis to perform a line-of-sight analysis on a set of defined targets in the space (Landeschi et al. 2016, pp. 108–11).

The Oplontis Project has likewise created a model of Villa A that allows a viewer to simply press the "R" key to toggle between the actual and restored state of the villa in Unity3D (John and Muntasser 2014, pp. 1–5, pp. 27–35, pp. 36–48; John R. Clarke et al. 2016, pp. 72–73). Another advantage of digital 3D illustration is that it allows for experimentation with visual elements such as such as lighting. Frischer and Stinson digitally reconstructed Room 16 in the Villa of the Mysteries and then considered the effects of lighting within the space (Frischer and Stinson 2007, p. 76). By visualizing the amount of light allowed into the room via doorways and windows over the course of a day, it was possible to conclude that oil lamps would have been necessary in most rooms beginning in the late afternoon. Such an experiment is feasible onsite, but considerably more difficult. A digital 3D illustration also easily allows for experimentation with multiple hypothetical scenarios with differing variables such as furniture layout, window covering types, and viewer position.

Studies utilizing 3D illustration have also leveraged digital tools to carefully document individual wall paintings. Philip Stinson, for example, utilized 3D models in conducting a perspectival analysis on second style wall paintings (Stinson 2011, pp. 413–16). Second style wall paintings typically include painted blocks or panels with a *dado* projecting forward, and realistic architectural elements such as columns, buildings, and stoas (Mau 1902, pp. 462–64). Based on a digital analysis of the orthogonal lines within these second style paintings versus more traditional documentation methods, Stinson found that such perspectival lines can be more accurately illustrated on the computer.

Digital 3D illustration can also be used to visualize complex, quantitative datasets within an ancient architectural setting. In a study of several Theran murals in Late Bronze Age Akrotiri, multiple viewsheds were calculated in GIS using a technique called isovist analysis (Paliou et al. 2011, p. 381; Paliou 2011, pp. 253–56; Paliou and Wheatley 2005, pp. 309–12). Within the model, all potential viewer locations were identified by sampling the edges of the model outside the room at equal intervals. A script was then used to animate a light source over each viewer location in succession at eye level (1.55 m). Information on the visibility of the fresco surface at each viewing location was then extracted and mapped. This method resulted in individual graphs which showed how much of the frescoed area could be seen from each viewing location. Important spatial relationships and the visual experience of someone moving through the space were thus systematically. This approach not only provided a thorough record of the individual visual experience of moving through a space, but also potentially brought to light aspects of the viewing experience which would not have been immediately perceivable by simply walking through the digital reconstruction (Paliou 2011, p. 252).

1.3. Validity and Utility of Using Models for Visual Analysis

All of these projects in some sense address the question of how digital 3D illustrations can be used as research tools. Although the use of 3D models as a component of archaeological illustration is a relatively recent development, there is already a long tradition of using analog 2D models in the study of Roman domestic space. Post-excavation, investigators have often only been able to visit the empty shell of a Pompeiian house (Allison 1999, p. 40). As a result, illustrations have been used on a number of occasions to consider the interaction of wall paintings and even entire visual programs (Bartman 1988, p. 215; Bartman 2010, pp. 71–88; Bergmann 1994, pp. 239–44; Gazda 2015, pp. 380–87). Such models can be used for a variety of research purposes:

- Facilitating greater understanding of visual interactions between architecture and objects.[2]
- Promoting the perception of unanticipated emergent properties.
- Highlighting areas where sources conflict (if multiple sources were used in the creation of the 3D model).
- Elucidating the relationship of large- and small-scale features.
- Helping us to formulate hypotheses.

While all these potential applications are pertinent to the fields of art history and archaeology, for studies concerned with viewing, interpretation, and perception, a digital 3D illustration can be especially beneficial when considering an ancient domestic display (Bergmann 2010, pp. 16–31). It is generally assumed that certain aspects of social significance are embedded in Roman domestic space and that it is possible to understand certain aspects of Roman daily life through the careful observation of these interactions (Clarke 1991, pp. 1–2; Dwyer 2010, pp. 25–28; Elsner 1995, pp. 49–51; Gazda 2010, pp. 1–6; Wallace-Hadrill 1994, pp. 14–16). Depending on the project, it may be useful to consider the space at various points in time, for example, as it appeared at the time of excavation in contrast to how it may have appeared in antiquity. The use of visual analysis tools, such as photogrammetric models, allows a researcher to not only digitally consider a space at many different points in time, but also to organize the symbolic information that has been observed onsite. Digital models also allow a researcher to revisit the space as needed to test a certain hypothesis, explore how areas in the space relate to one another, and consider interactions between objects in a three-dimensional, albeit virtual, context.

2. Methods

While the discussion thus far has centered on the more historical and theoretical aspects of illustration, it is perhaps useful to also describe the practical components of digital 3D modeling. The methods and instruments used for 3D data capture primarily depend on the 3D model's intended application. For the purposes of this case study, the photogrammetric modeling team created high-resolution state models. The state model (Frischer and Stinson 2007, p. 51) displays the object in its current condition, which may well include changes, modifications, and (in the case of a Pompeian house) modern restorations. To create a photogrammetric state model, the first step is a photographic campaign. For the case study described below, the modeling team used a Canon 5DSR digital camera with a ZEISS Otus 28 mm f/1.4 ZF.2 Lens. In the darker rooms, a Nikon D850 was used with a Nikon AF-S NIKKOR 28 mm f/1.4E ED Lens, which is well-suited to low-lighting conditions.

For each room, a set of laminated photogrammetric targets were set down and the distance between each target was measured, giving the model a relative scale.[3] A robust tripod was useful on the uneven flooring which so often characterizes an excavated area. In addition to the tripod, a monopod was used to photograph the higher areas of the wall painting panels. For each room, the

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2 Pariticularly in the study of an entire archaeological site, visual program, or domestic structure, it can often be difficult to mentally hold an image of all the small finds, paintings, and architecutre. 3D models can thus be a useful way to "cognitively offload" this information. Once the objects are externalized, it is possible for a researcher to consider interactions that may only occur when observing the entire area wholistically. For a full discussion of the benefits of thinking with visalizations, see (Ware 2012, pp. 1–27). On the benefits for the fields of archaeology and art history in particular, see (Frischer 2008, pp. v–vi; . Münster et al. 2016, pp. 7–8).

3 On the creation of a scale within RealityCapture, see (RealityCapture: Scale Projection n.d.). To ensure that the individual room models align accurately for this case study, the photogrammetric modeling team will collect a geo-referenced laser scan dataset in 2019 and then globally align the state model to this secondary dataset.

camera and tripod were placed in the center of the space, and three rounds of photos were captured: one aimed at the lower portion of the wall (at the lowest height on the tripod), one at the center (at the median height of the tripod), and one at the upper region (either at the highest point on the tripod, or on the monopod).

Depending on the width and height of the room, the tripod and/or monopod was then moved into the four corners of the room and the same process was repeated. For this project, the photogrammetric modeling team used a Benro TMA38CL Long Series 3 Mach3 Carbon Fiber Tripod and a Manfrotto Element Aluminum Monopod. After these initial rounds were complete, the camera was positioned closer to the wall (approximately 0.3 m) to capture areas of detail, such as cracks and flaking pigment (Forte et al. 2001a, p. 31). For a high-resolution model, it was necessary to collect between 600 photographs for a small ala (5 m^2) and as many as 1500 photos for the larger rooms such as the atrium and garden (15 m^2).

Once the photographic campaign was complete, the photos were edited for consistent exposure in software such as Adobe Lightroom. Daily organization of the resulting photos was essential as, in the course of a day, the team collected enough photos to easily fill a 2 TB hard drive.[4] At the end of the day, the files were thus labeled, tagged with the appropriate metadata, and uploaded to a remote server. A photogrammetric software package was then used to register the location of the camera for each photo and then calculate the relative position of the camera within the room being photographed.[5] The resulting models averaged below a 0.7 median pixel error for all of the individual room models.[6]

Less successful was the team's attempt to capture all the rooms simultaneously via a lengthy photo campaign. The model resulting from this experiment had several significant gaps that were visible even in the alignment phase of model creation (see Appendix A). Instead, the 3D modeling team recommends capturing data on a room by room basis, and then combining the individual models into a single model.[7] For this process, it is critical to take a large number of photos at transition points such as doorways, where tie points are more likely to be created between individual room models. Once the data were aligned, RealityCapture was used to convert the point cloud generated in the alignment stage of the project into a draft mesh model. This draft was then edited in (ZBrush n.d.) to prepare the final version. Copies of the photos and the 3D models were then delivered to the pertinent cultural heritage organization, in this case the *Soprintendenza Archeologica di Pompei.*

3. Results

3.1. A Case Study in the House of Marcus Lucretius

The results of the 3D data capture campaign and postprocessing described above yielded a state model of the garden, its surrounding rooms, and the extant, affixed wall paintings. The primary goal of the art historical project was to explore the visual impact of the central garden on an ancient visitor.[8] It was therefore beneficial to also re-insert artifacts and paintings that had been removed from the site during the initial excavations into the digital illustration, and experiment with various viewsheds into the central garden.

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4 The Canon 5DSR averages 60.5 MP per photo and the Nikon D850 averages 45.4 MP per photo.

5 There are many proprietary software options: (Photoscan n.d.); (RealityCapture n.d.); and (Autodesk ReCap n.d.). For this project, RealityCapture was selected because it easily allows for the alignment of laser scan data and photogrammetric data.

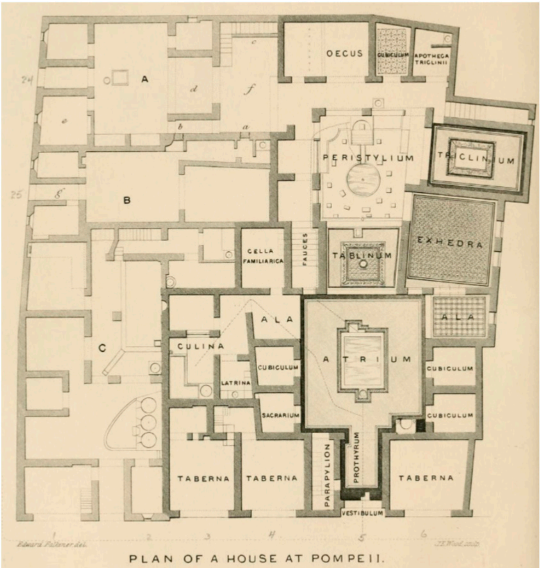
6 This is an acceptable range for a visualization model (RealityCapture: Error Measurement n.d.).

7 This is possible through the "component merge" feature of RealityCapture (RealityCapture: Merging Components n.d.), or the "merge chunks" feature of (Photoscan: Merging Chunks n.d.).

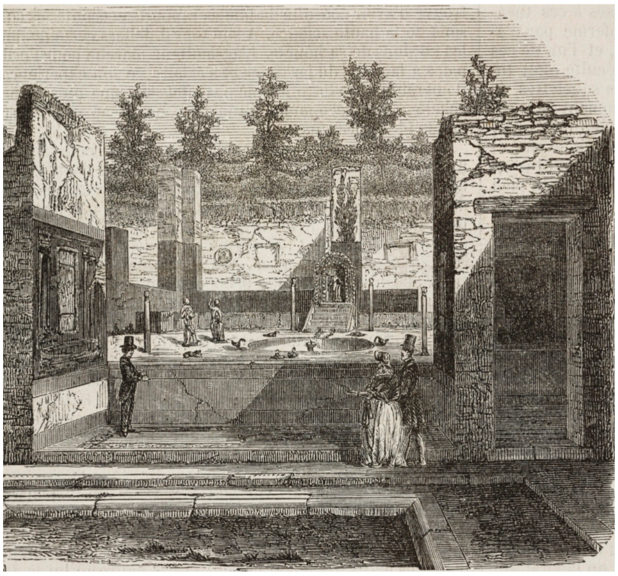
8 This was the subject of a recent MA essay (McClinton 2019). While this was the primary goal for the project, it is worth noting that the Eskenazi Museum of Art, the campus art museum of Indiana University, also wanted to use the resulting visualization as part of a museum exhibit on Roman housing (Gabellone 2009, p. e113) and create a record of the house as it appears today (Forte et al. 2001b, pp. 7–8).

3.2. The Garden Sculpture in Room 18

Prior to digital experimenting with the 3D model, the team explored the existing literature on the house and how the garden had been interpreted, illustrated (Figure 4a,b), and understood both by the initial excavators and by subsequent scholars. In 1847, the English architect and antiquarian Edward Falkener was granted special permission to oversee the excavation of the House of Marcus Lucretius (Falkener 1860, pp. 35–38). Falkener compared the overall visual effect of the garden in the House of Marcus Lucretius to a theatrical display (Falkener 1860, p. 55). Over a century later, Eugene Dwyer, following in Falkener's footsteps, similarly described the garden display as a marionette theater (Dwyer 1982, pp. 40–41). Paul Zanker followed in this interpretation, likening the sculpture display to a stage set (Zanker 1998, p. 174). Eve D'Ambra proposed a slightly modified reading of the garden area as a *tableau vivante* or living picture (D'Ambra 1998, p. 132). Kim Hartswick has most recently pointed out that the sculptural arrangement in the central garden was likely designed to enhance the view of the central fountain and make a relatively small space feel a bit larger (Hartswick 2017, p. 365).



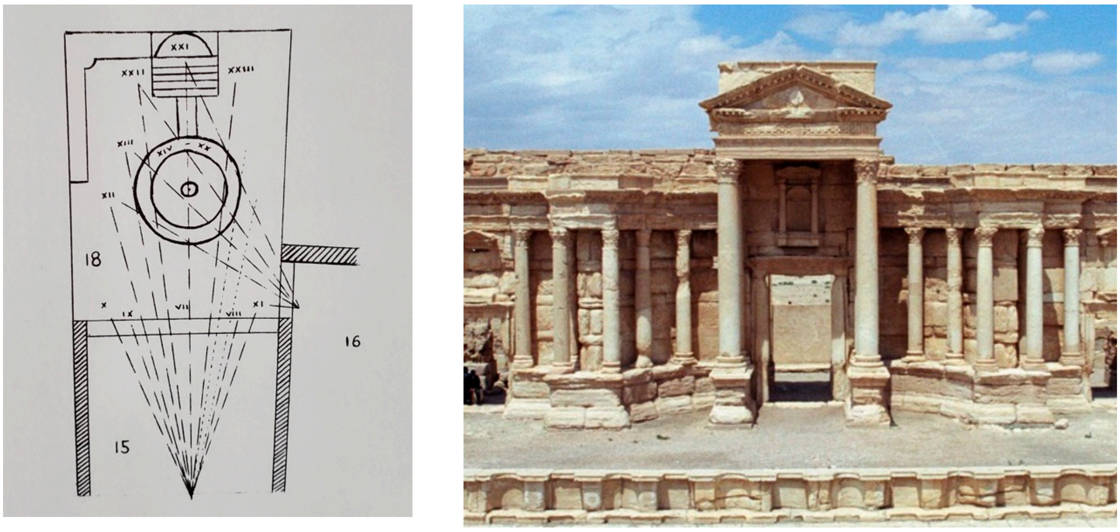
(**a**)



(**b**)

Figure 4. Floor plans of the House of Marcus Lucretius in Pompeii. Room 18 is marked as the "peristylum" in Falkener's plan (**a**) Plan of a house at Pompeii: The House of Marcus Lucretius (IX, 3, 5.24). Illustration Courtesy: E. Falkener (used by permission); (**b**) Marcus Lucretius' house, Pompeii, Italy. Illustration Courtesy: E. Breton (used by permission).

While varying in the analogies used, all of these interpretations center their arguments on the idea that the raised garden and the resulting sightlines (which place the viewer in either Room 15 or in Room 16) imitate a miniature stage (Figure 5a). From these angles, (as well as when seen from the street, the *Via Stabiana*), the garden does, indeed, resemble an area for performance. If a viewer stands directly in front of Room 15, then the series of visual planes created by the garden, recessed tablinum, and surrounding tripartite frame recalls the complex visual effect created by the typical *scaenae frons* (Figure 5b) of a Roman theater (Sear 2006, pp. 83–95). The digital 3D illustration, however, allowed us to also explore the sightlines into the garden from Room 25 and Room 19 (Figure 6), and consider these interpretations further, with several of the removed paintings reinserted.



(**a**) (**b**)

Figure 5. (**a**) Floorplan of the garden, with sightlines. The sculpture locations are indicated by Roman numerals. Illustration Courtesy: (Dwyer 1974, p. 68; used by permission); (**b**) Roman theatre at Palmyra, before the recent destruction by ISIL. Image Courtesy: J. Strzelecki, Wikipedia Commons.

Figure 6. Floor plan showing the House of Marcus Lucretius. Illustration Courtesy: *the Expeditio Pompeiana Universitatis Helsingiensis* (used by permission).

3.3. The Wall Paintings in Room 16

During the initial excavations, many of the paintings in Room 16, which looks out onto the garden, had been moved to the *Museo Archeologico Nazionale di Napoli* and many of the garden statuettes to storage in the *Deposito di Pompei*. As a result, it was difficult to get a sense of how the sculpture in the garden might have interacted with the wall paintings in the surrounding rooms based purely on onsite visual analyses. The digital 3D illustration also allowed us to question the sculptural arrangement in the garden. Falkener shows sixteen sculptures in his ground plan, and contemporary drawings appear to verify this count (Figure 4). The exact arrangement and orientation of each is statue, however, is uncertain. The 2004-5 excavations in the garden did not uncover any ancient supports for the sculpture (Castrén et al. 2008, p. 335; McClinton 2019, pp. 7–8; Viitanen and Andrews 2008, pp. 51–72; Ynnilä 2012, pp. 47–48).[9]

Although it is not possible to know exactly how the sculpture was place in antiquity, it is likely the that arrangement interacted thematically with other areas of the house.[10] Around Room 16 in particular, which opens onto the central garden (Figure 6), there are several images of Bacchus, who is also reflected thematically in the garden. The central panel on the south wall depicts a young satyr leading a procession in an ox-drawn cart (Figure 7). Silenus, sitting in the cart, presents the infant Bacchus in his lap, in triumph. To his left, a man plays a set of pipes and a large container of liquid is lifted onto the wagon. On the north wall, Bacchus is depicted in triumph over a prisoner seated on a pile of weapons in front of him, while Victory writes a triumphal announcement on his shield (Figure 8a). On the east wall, the strength of Bacchus is celebrated by showing his ability to conquer even the mighty, but drunken, Hercules (Figure 8b). To his left, a young woman (likely Omphale) looks on, and around the scene, musicians and cherubim play drums and flutes.

Figure 7. Victory of Bacchus. Image Courtesy: Kelly McClinton, 2017, on concession of the *Ministero dei Beni e delle Attività Culturali e del Turismo, Parco Archeologico di Pompei* (used by permission).

9 Discussed at length with Viitanen, Eeva-Maria. in Email Correspondence, January, March, and April 2019.

10 The primary iconographic theme in the garden is Bacchus and his retinue (Falkener 1860, pp. 71–78; Jashemski 1979, pp. 42–43). See (Dwyer 1982, pp. 38–52; Kuivalainen 2008, pp. 127–37) for a complete catalouge of the sculpture. In brief: four oscilla were suspended between the intercolumniations: one square; two resembling an Amazonian pelta; the fourth circular with a sacrifice of a calf on one side, and on the other a bearded man. At the rear of the garden, Silenus inside the fountain niche. On each side of the mosaic niche: two herms: one depicting Bacchus and Ariadne and the other, a male and female Faun. At the front of the garden: two herms of Bacchus and Ariadne and a statue of a Faun attempting to extract a thorn from the foot of a Pan. On the left of the central pool: a Faun with two short horns was found with a pedestal behind. On the left of the fountain: a half herm, half satyr holding a baby goat. Around the central pool, a series of sculptures are arranged in a circle: a panther eating grapes, two identical cupids riding on dolphins, two toads, two birds, a cow, a hind on right, and a goose on the left.

(**a**) (**b**)

Figure 8. Wall Paintings from Room 16 (used by permission). (**a**) Procession of Bacchus. Image Courtesy: Kelly McClinton, 2017, on concession of the *Ministero dei Beni e delle Attività Culturali e del Turismo, Parco Archeologico di Pompei*; (**b**) Drunken Hercules. *Museo Archeologico Nazionale di Napoli*, 8992. Accessed via the *Expeditio Pompeiana Universitatis Helsingiensis* on concession of the *Ministero dei Beni e delle Attività Culturali e del Turismo, Parco Archeologico di Pompei*.

These paintings seem to relate to the Bacchic iconography in the garden and emphasize themes of performance and ritual. The central iconographic themes which unite the images, and the garden, are Bacchus, and his respective domains: theatre, wine, and agriculture. It was difficult, however, to visualize how the sculpture in the garden, the gazes of the figures, the iconographic themes, and the overall design of the panels in Room 16 might have been orchestrated in the space. The digital 3D illustration allowed us to easily annotate which paintings were located on which wall, and then consider how they interacted as an ensemble beside the garden.

One of the key results of this digital viewshed analysis was the recognition of how the gazes of the painted figures interact inside the room. While onsite, it was clear that the figures in the northern central panel (Figure 9) look out to the garden. In the 3D model, it was possible to also consider how the other two central panels interact. On the south wall (Procession of Bacchus), the wall most clearly visible from the atrium, many figures gaze out towards the central area of the house (Figure 10). As visitors enter Room 16, they encounter the panels on both the north wall and the east wall, where Hercules seems to look out through the window and into the garden, towards the Silenus in the fountain niche (Figures 10–12). This interplay of gazes might have both welcomed the visitor and directed their gaze out towards the garden and it was easier to visualize this interaction once all the elements were digitally reinserted into a single, albeit virtual, visual plane.

Figure 9. Room 16, north wall. Image Courtesy: Kelly McClinton 2017, on concession of the *Ministero dei Beni e delle Attività Culturali e del Turismo, Parco Archeologico di Pompei* (used by permission).

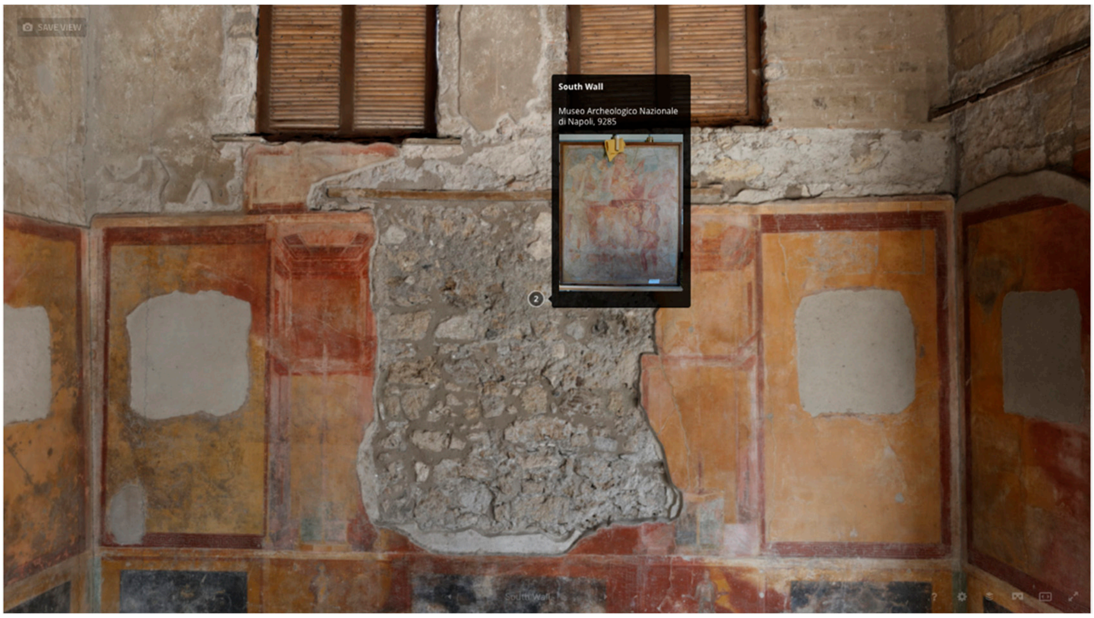


Figure 10. Room 16, south wall. Screenshot showing the interactive 3D model in SketchFab, with the embedded wall paintings from the *Museo Archeologico Nazionale di Napoli* on concession of the *Ministero dei Beni e delle Attività Culturali e del Turismo, Parco Archeologico di Pompei*. Model Courtesy: Kelly McClinton. Image Courtesy: photos for the 3D model on concession of the *Ministero dei Beni e delle Attività Culturali e del Turismo, Parco Archeologico di Pompei* (used by permission).

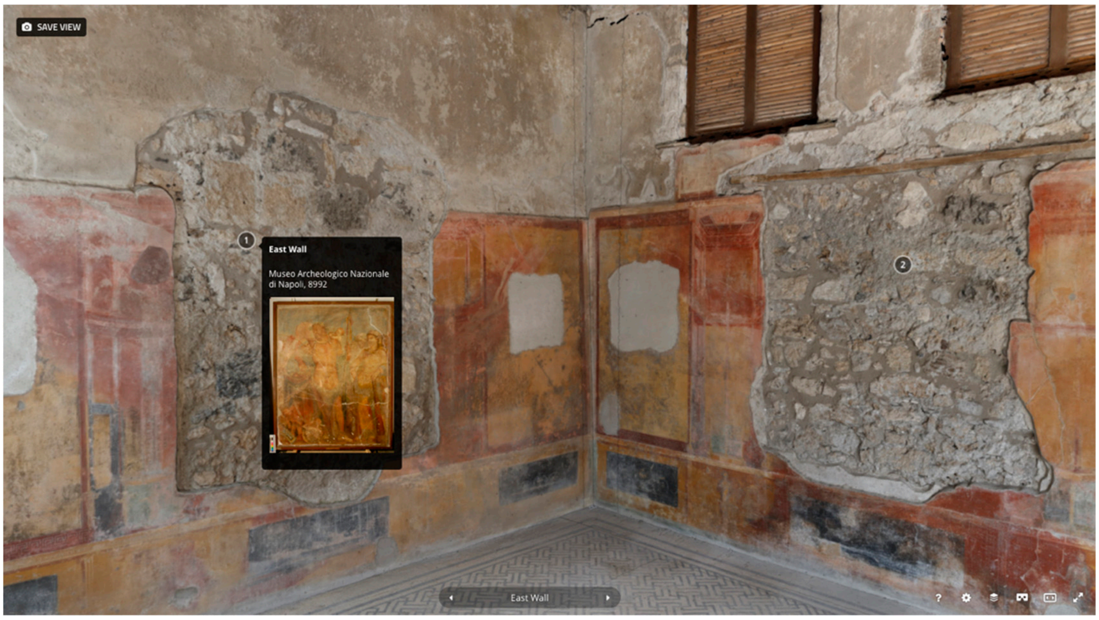


Figure 11. Room 16, east wall. Screenshot showing the interactive 3D model in SketchFab, with the embedded wall paintings from the *Museo Archeologico Nazionale di Napoli*. Model Courtesy: Kelly McClinton. Image Courtesy: photos for the 3D model on concession of the Ministero dei Beni e delle Attività Culturali e del Turismo, Parco Archeologico di Pompei (used by permission).

Figure 12. Room 16, east wall and west wall. Edited screenshot showing the detail of the embedded wall paintings from the *Museo Archeologico Nazionale di Napoli*. Model Courtesy: Kelly McClinton. Image Courtesy: photos for the 3D model on concession of the Ministero dei Beni e delle Attività Culturali e del Turismo, Parco Archeologico di Pompei (used by permission).

The garden in the House of Marcus Lucretius thus created a Bacchic spectacle that would have been particularly appropriate in proximity to the primary areas of the house devoted to dining and entertainment, such as Room 16. To a viewer arriving and staying for dinner, such themes would have been appropriate to welcome guests into an area of *convivium* and the overall ensemble would have been an ideal backdrop panel for an evening's entertainment (Beacham 1992, pp. 23–25; D'Arms 1999, pp. 302–3; Clarke 2006, pp. 223–27, 233, 239; Zanker 1998, pp. 146–48, 174–81).

The digital 3D illustration was also an excellent tool for experimenting with viewsheds in the house, including those from Room 19 and 25 (Figure 13a,b). The conclusions from this digital viewshed analysis were similar to those arrived at onsite: while the views from Rooms 15 and 16 have been emphasized to date, in the last phase of the house, multiple vantage points from various rooms (Room

25, or the *triclinium*, and Room 19) opened onto the central garden and visually interacted with the space (Bergmann 2017, p. 295). While the garden sculpture would likely have primarily been arranged to face the front area of the house, several of the figures might have been positioned to complement Room 19 and Room 25 as well.[11]

(**a**) (**b**)

Figure 13. Screenshots from the State Model of the House of Marcus Lucretius (**a**) View into the garden from Room 19; (**b**) View into the garden from Room 25. Model Courtesy: Kelly McClinton. Image Courtesy: photos for the 3D model on concession of the Ministero dei Beni e delle Attività Culturali e del Turismo, Parco Archeologico di Pompei (used by permission).

4. Discussion

The Use of 3D Models for Visual Analyses

The photogrammetric state model of the House of Marcus Lucretius thus was useful at several stages in the art historical project. First, it made it possible to digitally revisit the space even after the team had left and returned to the United States, some 5000 miles away. It was also possible to use the 3D model as a framework to visually re-contextualize several paintings within the house that had been removed to the nearby *Museo Archeologico Nazionale di Napoli*. The 3D model allowed us to digitally notate which paintings were located on which wall, and then consider how they interacted as an ensemble beside the garden. Finally, the 3D model allowed us to explore several different viewsheds into the garden.

The case study of the House of Marcus Lucretius, in particular, illustrates how a photogrammetric state model has the potential to further research aims in perception and viewshed studies. The reinsertion of removed materials, in particular, was helpful in considering the gazes of the figures in the large wall paintings in Room 16, both as they relate to one another, and to the garden. Once the material record was reconstructed digitally, it was then possible to consider subtle interactions between objects, simply because all the information was visible in a single plane.

Moving forward, the 3D modeling team plans to create a reconstruction model on the basis of the state model and experiment with the positions of the sculpture and architectural arrangement surrounding the garden. The House of Marcus Lucretius originally had a second story (Falkener 1860, pp. 69–71), and future research will also reconsider the visual impact of the garden, after this

[11] Alternative sculptural arrangements will be further explored in a subsequent reconstruction model.

architectural feature has been digitally reconstructed. It will likewise be valuable to experiment with how lighting conditions changed throughout the day once this second story is added back into the space digitally. Finally, it will be useful to reconstruct the house at several phases in antiquity and consider how the space was maintained and altered over time (Guidi et al. 2014, pp. 59–60; Jacobs 2013, pp. 7–17).

5. Materials and Methods

5.1. Digital Publication

Notwithstanding the benefits of digital illustrations for research that have been explored thus far, it is an open question how these illustrations can then be effectively rendered into traditional forms of publication. It is a relatively simple process to generate whatever views may be required using rendering software, as has been done in the study presented above. In the process of such a reduction, however, much of the pertinent three-dimensional information is lost.

There are advantages and disadvantages to other forms of publication as well. 3D models can remain in digital format and be published alongside accompanying texts, such as the new journal founded by the Virtual World Heritage Lab, *Studies in Digital Heritage* (www.studiesdh.org, Studies in Digital Heritage 2019). Once in print, however, it is difficult to update these models as new information comes to light. Digital illustrations can likewise be published online through a web service such as SketchFab (www.sketchfab.com) or the Unity Web Viewer (https://unity3d.com/webplayer). Placing 3D models of entire wall painting panels into a game engine has the advantage of architectural recontextualization and interactive viewing, but it has the disadvantage that the resolution of the model must often be reduced to run in the software. Web services such as SketchFab support medium-resolution models (up to three million polygons), but they do not currently support high-resolution models without a paid subscription. Once the individual 3D models of this case study were complete, the 3D models were uploaded to SketchFab. This allowed us to not only access the model easily as needed for research purposes, but also share the results of the project easily online.

Another output option is a "fly through" which can be exported to services such as YouTube (https://www.youtube.com/watch?v=yf5r8U6J9jM). Videos can be produced and made freely available through web services such as Vimeo and YouTube, but they can only offer one, fixed point of view. Such outputs generally lead the viewer through a guided tour of the space, but areas of interest may be occluded. For research purposes, as we saw above, both the state model and the reconstruction model can be inserted into 3D GIS (Dell'Unto et al. 2016, p. 74). Although a fantastic research tool, the downside of this publication method is that it generally requires specialized software to view the visualization, such as ArcScene.

5.2. Metadata and Paradata

As in the creation of any illustration, human processes of understanding and interpretation enter into the method. When a 3D model is published, a metadata and paradata report should be included, which lists the sources of information and explains any hypothetically restored or reconstructed elements.[12] These data might be compared to footnotes and bibliography, and they primarily contain information about how each model is produced. The inclusion of such reports along with the publication of a digital model also addresses one of the major criticisms of digital 3D illustrations: they can create a false impression (Miller and Richards 1995, pp. 19–22; Maschek et al. 2010, p. 3).

12 An excellent model for cultural heritage data is the (Carare Metadata Scheme n.d.). The (London Charter n.d.) provides an excellent example of paradata standards.

Particularly in a public setting, the presentation of a 3D reconstruction model can often be viewed not as one hypothetical possibility within many, but as a statement of fact. Though this a common occurrence, it is unhelpful because it causes a viewer to cement one image of an ancient space in their minds. Such challenges become especially difficult when 3D models are presented in a museum context, to a more general audience. New information about the ancient world is constantly coming to light, and one of the strengths of digital models is the ability to revise them as such additional data becomes available. Therefore, whenever possible, digital illustrations should be presented as visual interpretations rather than visual facts. An important component of communicating this is emphasizing the role of interpretation, either subtly or explicitly, in any illustration through the inclusion of data about how the study was conducted (Frischer 2015, pp. 76–84). Even in the creation of a state model, choices are made about which areas of detail are important. For the House of Marcus Lucretius, many such choices were made throughout the data capture and model editing process (see Appendix A).

6. Conclusions

Looking Beyond Illustration: A Federated Database for 3D Models of Roman Wall Paintings

As has been demonstrated here, 3D models of ancient Roman houses are still a relatively new form of archaeological illustration and pose several unique advantages to researchers. The digital model of the House of Marcus Lucretius was useful for both spatially organization the complex set of information collected during the research process, and maintaining the three-dimensional relationships between the central garden, along with the surrounding rooms, throughout the project. Digital models also have the unique advantage of allowing a researcher to revisit a space as needed to test hypotheses and reconsider how areas in the space relate to one another. The photogrammetric model, for example, allowed us to re-embed removed material and then examine the visual program digitally *in-situ*. In particular, it was useful to visualize three-dimensional interactions between the paintings in Room 16 and the garden space with the aid of a 3D model. Such advantages can be useful to a researcher when considering a complex visual program.

Looking to future research, digital 3D illustration is likely to become an even larger part of art historical and archaeological study. In response to this trend, companies, such as ESRI, are already working on incorporating 3D models into traditional software packages (Beacham et al.). As a result, it is important that researchers develop rigorous best practices for the creation of this new form of illustration. Scholars have already begun to make strides towards such standards (Beacham et al. 2006, p. 1; Berry and Fagerjord 2017, pp. 114–50; Campanaro et al. 2016, pp. 323–30; Guidi et al. 2013, pp. 307–10; Koller et al. 2009, pp. 1–17; Lingua et al. 2003, pp. 210–15; Nocerino et al. 2014, pp. 466–68).

Nevertheless, one of the potential issues that may arise as the production of 3D data increases is the isolation of project datasets into institutional or project-based silos. Since every project is different, the datasets are often treated as unique entities. Scholarship has recently begun to explore the potential for intra-site digital documentation (Katsianis et al. 2008, pp. 655–67; Dell'Unto 2014, pp. 151–58). In this section of the paper, the Virtual World Heritage Lab at Indiana University would like to propose taking this idea a step further to the development of a federated online database where fragments, and even entire wall painting panels, could be digitally available for viewing and study.

This open-access, online platform for viewing and organizing extant ancient Roman wall paintings would be institutionally neutral. In a federated database, data are still stored in the contributor's home institution (should they so wish). At the same time, any scholar would be able to both contribute to and use the common resource. The federated database would contain not only 3D data, but would also feature photographs of the spaces, and other forms of documentation (e.g., watercolor reconstructions, line drawings, plastic models). Authors and users could thus access and work with common data. Such work would be further supported via queries to navigate the entire scope of the database. The database would at first focus on Pompeii and would eventually expand to other sites as well. Publishing such a vast amount of material online would benefit scholars worldwide, as well as students of archaeology, preservation, and conservation.

What the long-term role of digital illustration will be in art historical and archaeological research is still an open question. Throughout this discussion, the author has called for an increasing level of critical reflection in the creation of 3D assets. The importance of methodological clarity has likewise been emphasized, so that both creators and viewers understand the nature and intent of the model, as well as the way in which it was created. The importance of best-practice guidelines, such as those published in the London Charter, have also been highlighted. Finally, as 3D models become increasingly used by researchers, this article has explored the possibility of hosting 3D models of cultural heritage objects, such as Roman wall paintings, in an institutionally neutral online archive. As sites such as Pompeii continue to face the dangers of degradation, digital illustration may be one of the best options at the moment for scholars to document such sites and consider the impact of the spaces on the ancient viewer.

Funding: This project received support from the National Science Foundation, the Schrader Foundation, and the Department of Informatics at Indiana University.

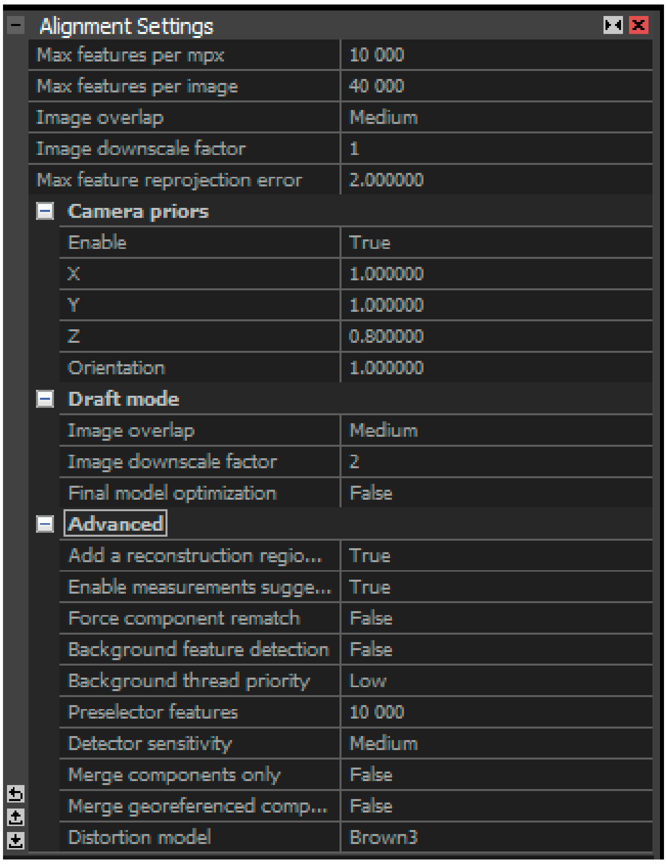
Acknowledgments: First, my gratitude to Regina Gee and Vanessa Rousseau, for inviting me to contribute to this volume. Sincere thanks also to Bernie Frischer for his continued, generous support of my work. His guidance and encouragement have been crucial elements in the success of this project. At Indiana University, thank you to Julie Van Voorhis, for supervising my MA thesis on the garden in the House of Marcus Lucretius and encouraging me to think carefully about the nature of interdisciplinary word, and Luis Rocha, for helping me develop ideas for future research. In addition, thank you to Eleanor Leach, Elaine Gazda, and John Clarke for helping me conduct the needed fieldwork and acquire a permesso to work in Pompeii. A warm thank you as well to the Soprintendenza archeologica di Pompei for allowing me to carry out my research over the past two summers, especially Professor of Classical Archaeology at the University of Napoli Federico II. *Direttore Generale Soprintendenza Pompei*, Massimo Osanna, Dott.essa Annamaria Sodo, *Direttore of the Office for the Archaeological Site and Antiquarium of Boscoreale*, and Dott.essa Grete Stefani, *Direttore of the Excavations of the Pompeii Office*, for granting me the permissions needed. Custodians and people in the Direzione have likewise been very helpful, and this case study would not have been possible without their generous assistance and support. Thanks to Gabriele Guidi, who provided bibliography and gracious guidance in the history of photogrammetry, as well as Eeva-Maria Viitanen, for her guidance in the sections concerning excavations in the House of Marcus Lucretius. My gratitude to the Swedish Pompeii Project, for their execution of the critical fieldwork needed as a foundation for this project, and especially Heini Ynnilä for her superb thesis, which was crucial in the formation of this work. For their generous access and support, thanks to the American Academy in Rome Library, in particular, Denise Gavio and Sebastian Hierl. For her fantastic copy-editing, Jane Crawford. For her assistance and ideas onsite, research assistant Meghan McCullough. For his gracious aid in the final stages of this manuscript, David M. Terner. For their generous support of my research and fieldwork, thank you to the National Science Foundation, the Schrader Foundation, and the Department of Informatics at Indiana University.

Conflicts of Interest: The author declares no conflict of interest.

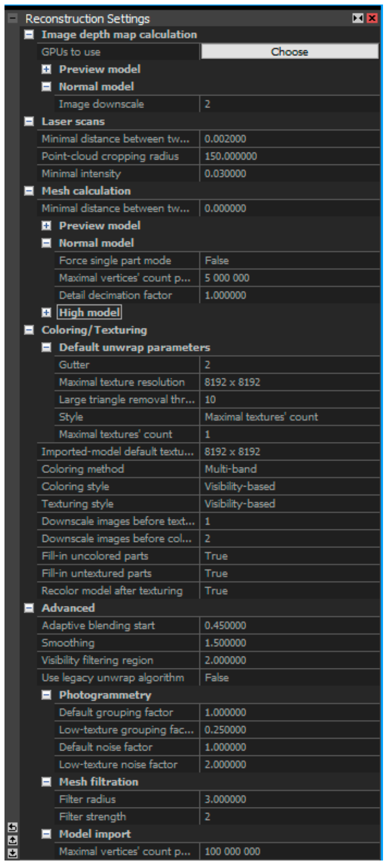
Appendix A. Paradata for the House of Marcus Lucretius

Table A1. Photogrammetry Parameters.

Orientation	No absolute orientation; photos aligned using internal camera GPS + onsite targets.
Software	RealityCapture Version 1.0.3.5681
Mesh Quality	Normal
Color Control	Photos Color Balanced Using Adobe Lightroom and X-Rite Digital Colorchecker Passport, Balance System



(a)



(b)

Figure A1. (**a**) Alignment Settings and (**b**) Reconstruction Settings.

State Model: Room 16
Identifiers

Title/Name: Room 16 in the House of Marcus Lucretius

Characteristics

Format: Room
Artist: N/A
Date: 1st century CE
Materials: mosaic, fresco.
Inscription: n/a
Dimensions: 34.7 m^2

Paradata

Camera: Nikon D850 with a Nikon AF-S NIKKOR 28mm f/1.4E ED Lens
Photographers: Kelly E. McClinton & Meghan McCullough.
Reconstruction Software: RealityCapture, ZBrush
Modeler: Kelly E. McClinton

Alignment report	
Total projections	6 288 676
Average track length	3.578794
Maximal error [pixels]	1.999995
Median error [pixels]	0.635704
Mean error [pixels]	0.730561
Geo-referenced	false
Metric	false
Alignment time	00h:17m:15s

Figure A2. Screenshot of Alignment Report for Room 16.

State Model: Rooms 18
Identifiers

Title/Name: Room 16 in the House of Marcus Lucretius

Characteristics

Format: Room
Artist: N/A
Date: 1st century CE
Materials: mosaic, fresco.
Inscription: n/a
Dimensions: 46.1 m^2

Paradata

Camera: Nikon D850 with a Nikon AF-S NIKKOR 28mm f/1.4E ED Lens
Photographer: Kelly E. McClinton
Reconstruction Software: RealityCapture, ZBrush
Modeler: Kelly E. McClinton

Alignment report	
Total projections	13 688 010
Average track length	3.021174
Maximal error [pixels]	1.999997
Median error [pixels]	0.640806
Mean error [pixels]	0.735445
Geo-referenced	false
Metric	false
Alignment time	01h:06m:36s

Figure A3. Alignment Report for Room 18.

State Model: Room 19
Identifiers

Title/Name: Room 19 in the House of Marcus Lucretius

Characteristics

Format: Room
Artist: N/A
Date: 1st century CE

Materials: mosaic, fresco.
Inscription: n/a
Dimensions: 7.0 m^2

Paradata

Camera: Nikon D850 with a Nikon AF-S NIKKOR 28mm f/1.4E ED Lens
Photographer: Kelly E. McClinton
Reconstruction Software: RealityCapture, ZBrush
Modeler: Kelly E. McClinton

Alignment report	
Total projections	13 688 010
Average track length	3.021174
Maximal error [pixels]	1.999997
Median error [pixels]	0.640806
Mean error [pixels]	0.735445
Geo-referenced	false
Metric	false
Alignment time	01h:06m:36s

Figure A4. Alignment Report for Room 19.

State Model: Room 25
Identifiers

Title/Name: Room 25 in the House of Marcus Lucretius

Characteristics

Format: Room
Artist: N/A
Date: 1st century CE
Materials: mosaic, fresco.
Inscription: n/a
Dimensions: 26.3 m^2

Paradata

Camera: Nikon D850 with a Nikon AF-S NIKKOR 28mm f/1.4E ED Lens
Photographer: Kelly E. McClinton
Reconstruction Software: RealityCapture, ZBrush
Modeler: Kelly E. McClinton

Alignment report	
Total projections	4 333 393
Average track length	3.258694
Maximal error [pixels]	1.999993
Median error [pixels]	0.549219
Mean error [pixels]	0.661877
Geo-referenced	false
Metric	false
Alignment time	00h:07m:49s

Figure A5. Alignment Report for Room 25.

State Model: Rooms 16, 18, 19, 20, and 25
Identifiers

Title/Name: Rooms 16, 18, 19, 20, and 25 in the House of Marcus Lucretius

Characteristics

Format: Room
Artist: N/A
Date: 1st century CE
Materials: mosaic, fresco.
Inscription: n/a
Dimensions: 34.7 m^2

Paradata

Camera: Nikon D850 with a Nikon AF-S NIKKOR 28mm f/1.4E ED Lens
Photographer: Kelly E. McClinton
Reconstruction Software: RealityCapture, ZBrush
Modeler: Kelly E. McClinton

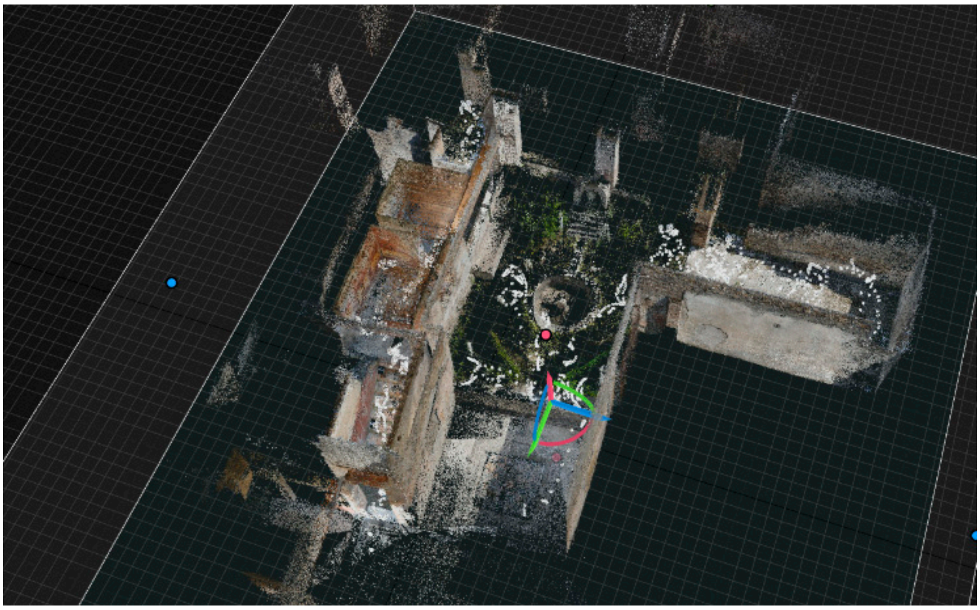


Figure A6. Alignment Results for Rooms 16, 18, 19, 20, and 25.

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